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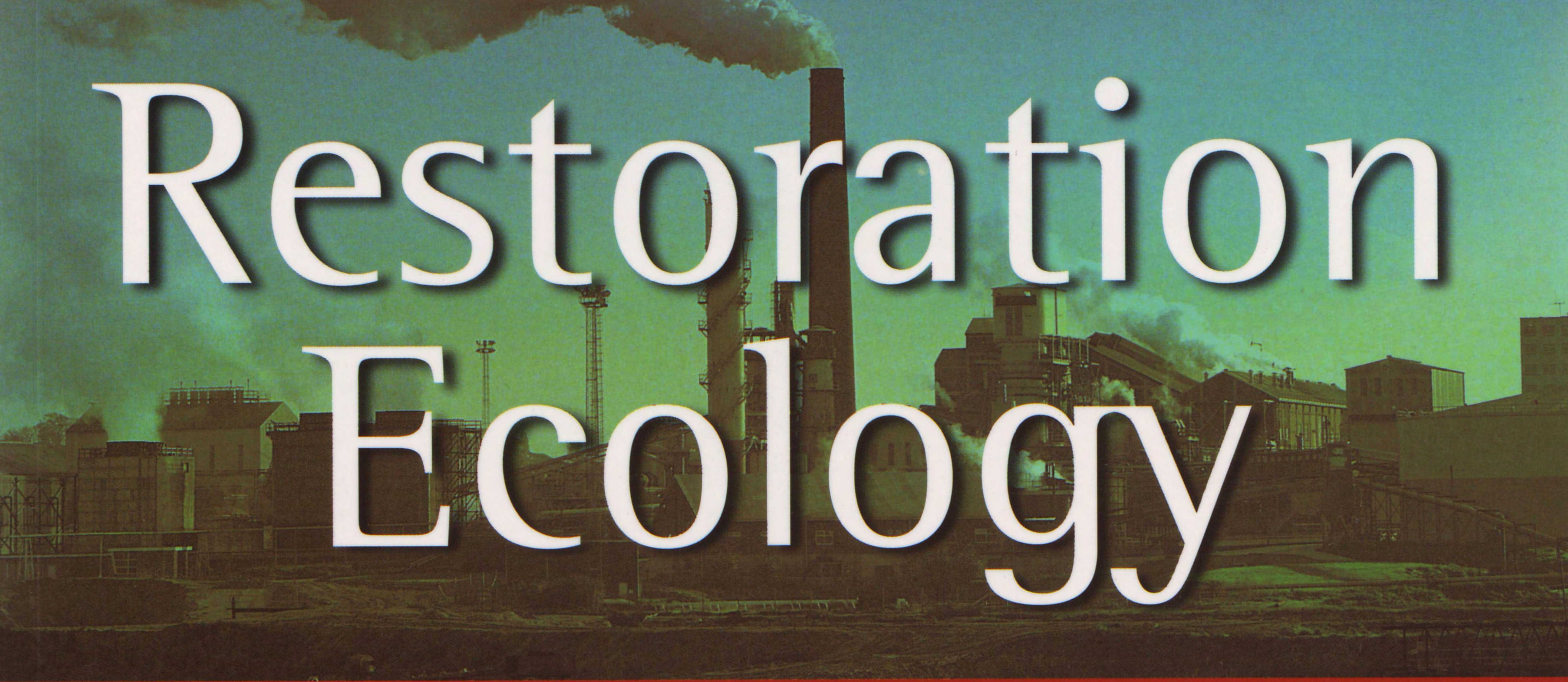

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Restoration of alpine ecosystems

Bernhard Krautzer and Helmut Wittmann

15.1 Introduction

15.1.1 Historical overview, state of the art

Mass movement and erosion in a young high mountain range, such as the Alps, are utterly natural processes. A decisive regulating mechanism to counteract this natural instability is intact vegetation (Tappeiner 1996). Humans have interceded in this sequence of events for around 7000 years. Overgrazing, deforestation and technical interception over hundreds of years have repeatedly provoked erosion, resulting in slight to catastrophic effects (Stone 1992). Nevertheless, many alpine regions would have been beyond settlement had people not undertaken protective measures at a very early date against the results of erosion. Thus, a more or less stable balance was achieved in which agrarian use and mining were in the foreground of human interest.

With the conclusion of the Alpine Convention in 1991, the region of the Alps was defined for the first time and borders were established at a community level. According to this definition the Alps cover an area of 191,287 km^2 and the number of inhabitants is 13 million (CIPRA 1998). It was the aim of this convention on the protection of the Alps to pursue a comprehensive policy for the preservation and protection of the Alps by applying the principles of prevention, payment by the polluter and cooperation between member states, concerned regions and the European Community, concisely to balance ecology and economy (EC 1991).

Permanent changes have taken place in the entire region of the Alps during the course of the last 50 years. Wide areas used for agrarian purposes have been reduced or abandoned. On the other hand, there has been widespread opening of power stations and intensive road building, torrent and avalanche barriers, as well as extensive infrastructural measures especially for winter tourism. Some 40,000 ski runs, amounting to 120,000 km in length, have been built in recent decades in the Alps and are used annually by 20 million tourists (Veit 2002).

All of the measures described lead to intensive building each year, which then requires the restoration of the areas burdened by the intrusion. But at increasing altitudes restoration becomes increasingly more difficult due to the rapidly worsening climatic conditions. Due to cost, restoration continues to be relinquished in some areas of the Alps, but a combination of usually cheap restoration procedures and cheap and alien seed mixtures are relied upon. The resulting ecological and often economic damage is comprehensive: soil erosion, increased surface drainage, inadequate vegetation cover, the high costs of ecologically dubious fertilization measures and management, and flora falsification are some of the effects that follow.

For 15 years, intensive research has been carried out by various institutes to break this negative circle of events. In various research projects (e.g. Urbanska 1986, 1997, Wild & Florineth 1999, Wittmann & Rücker 1999, Florineth 2000, Krautzer *et al.* 2003) it has been proved that a combination of high-quality application techniques and site-specific vegetation or seed has led to stable, sustainable and ecologically adapted populations of high value for the protection of nature. Fertilization and management measures can be clearly reduced, which makes these methods useful in the medium term, as well as being economical.

The following depictions should offer a brief overview of the restoration problems in alpine environments as well as the possibilities with and necessity for site-specific restoration measures, and also the limits of what is possible.

15.1.2 Concepts and terms

Appropriate to the climatic changes at specific altitudes, vegetation in the Alps and many other landscape elements and processes are divided into altitudinal zones (Veit 2002). The change of these factors, according to altitude, leads to a vertical sequence in various climatic areas (Ozenda 1988). The high zones are separated by borders that are fairly easily recognizable: the montane zone is separated from the subalpine zone by the forest line, the subalpine zone from the alpine zone by the tree line, the alpine zone from the subnival zone by the grassland border.

The following depictions of the restoration of alpine ecosystems relate to the subalpine and alpine zones and are thus limited to the zones between altitudes of 1300 and 2400 m (Ellenberg 1996). In lower zones, overcoming the power of erosion is easier by degrees. At extreme altitudes, over 2400 m, satisfactory restoration is no longer possible according to the current state of technical awareness.

In the *Richtlinie für standortgerechte Begrünungen* (which translates to *Guidelines for Site-Specific Restoration*; ÖAG 2000) the important terms with respect to restoration measures are defined exactly: vegetation is site-specific when after generally extensive agricultural use or non-use it is enduringly self-stabilizing, and when the manufacturing of agricultural products is not a prime target for this plant society. This site-specific vegetation, with the exception of finishing and development management, or possible intensive agricultural use, requires no further management measures.

Vegetation created by humans is then site-specific when the following three criteria are fulfilled.

1 **Site-adapted**: the ecological amplitudes (the demands) of the applied plant species should be in accord with the characteristics of the site.
2 **Indigenous**: the plant varieties used are to be seen as indigenous when they are found in the geographical region (e.g. Val d'Aosta, Hohe Tauern), at least in the same region in which restoration takes place, and are evident, or have been evident, at appropriate natural sites.
3 **Regional**: the seed or plant material used should originate from the immediate surroundings of the project area and from the habitats which with respect to essential site factors are appropriate to the type of vegetation to be produced. Due to a lack of availability of regional seed, the regional criterion should be aimed at, but is not obligatory.

15.2 Consequences of a change in land use

15.2.1 Change of agricultural use

Comprehensive deforestation measures undertaken in the high zones of the Alps – especially after the beginning of the Middle Ages – to create grazing areas on the one hand and to supply the enormous timber needs for salt mines and mining operations on the other, have repeatedly caused ecological crises in the Alps, which were counteracted partly by restrictive forestry laws (e.g. in Austria, Bavaria and Switzerland). In the last 150 years, agrarian usage in high zones and other less-productive areas has clearly receded, which has led to a corresponding expansion of forested areas (Cernusca *et al.* 1996). As a result, the exploitation of alpine meadows intensified or was, on occasion, completely abandoned. In the subalpine zone, during the transition process from the lavish and intensively cultivated alpine meadow areas to the original forest vegetation, a creeping destabilization of the ecological systems of high alpine-meadow regions can arise. Summer precipitation flows increasingly on the surface and erosion that cannot be restored immediately – as in alpine-meadow cultivation – leads to extensive landslides and the formation of shell-shaped erosion scarp (Stahr 1996, Tasser *et al.* 2003). Up to the time at which the original vegetation – forests – is re-established there is a clear increase of natural erosion processes, which requires repeatedly more restoration and preventative measures (Gray & Sotir 1996).

15.2.2 *Opening for tourism*

Contrary to agricultural use, summer and winter tourism in the last few decades has led to extensive opening of high locations. There are already more than 13,000 lifts, cable cars and other transport facilities throughout the Alps, which are used mostly for tourism. Taking the calculations made in the middle of the 1990s as a starting point, the actual area of ski runs and lift facilities is more than 110,000 ha, of which 10,000 ha are already covered by artificial snow (CIPRA 1998). Even if an exact estimation is not possible, at least half of these areas are in high zones. As before, thousands of hectares are levelled annually as part of the opening for tourism and infrastructural improvements, and these areas now require restoration. Necessary measures for the protection of the facilities (above all, torrent and avalanche barriers) also require large areas each year.

15.3 Specific alpine characteristics

15.3.1 *Alpine climate*

Plants at high altitudes are often subject to frequent and often rough change of climatic factors. The transition of the seasons takes place very quickly. With increasing altitude, the vegetation period is around 1 week less per 100 m of altitude (Reisigl & Keller 1987). The differentiation of the macroclimate from the microclimate, dependent on altitude and broad location is important. The most important difference from sites in valley locations can be briefly characterized by the following factors (see Fig. 15.1).

- Temperature decreases in the air and in the deeper levels of the Earth by an average of 0.6°C per 100 m of altitude. Frost is a possibility at all times of the year in high zones; at the beginning and end of the vegetation period an interchanging frost climate generally predominates (Arenson 2002). The climatic vegetation period with average daily temperatures of over 10°C is around 67 days at an altitude of 2000 m, which is one-third of the vegetation period in valley areas (Krautzer *et al.* 2003).
- The deep-ground temperatures in the mountains strongly reduce the activity of micro-organisms. Reduction of dead organic mass and thus the provision of basic mineral nutrition is inhibited. The subterranean habitat is thus limited – contrary to the grasses in warmer, lower zones – to the most strongly warmed, humus-rich, generally acidic and intensively rooted upper layers of the ground.
- Precipitation increases with altitude; in addition, on the fringes of the Alps, where clouds from adverse weather fronts – coming mainly from the Atlantic but

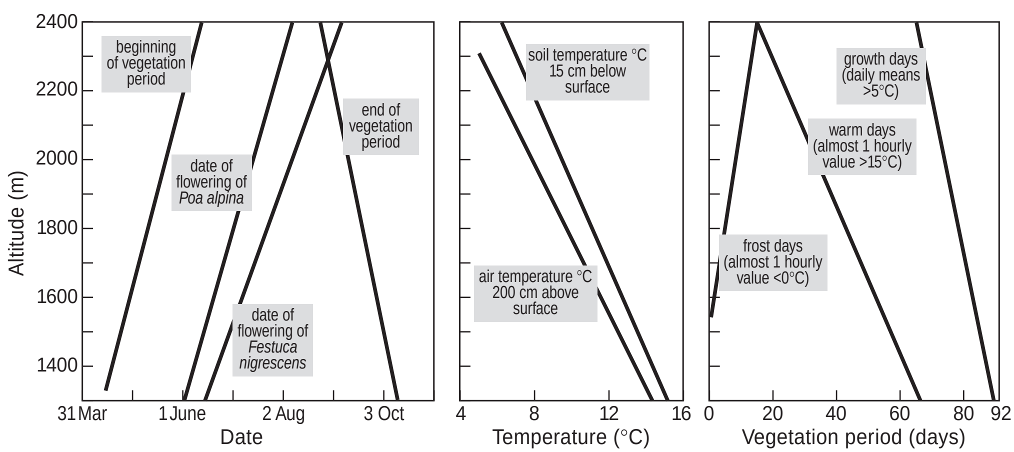

Fig. 15.1 Average changes of important phenological and climatic parameters according to altitude. After Krautzer *et al.* (2003).

partly also from the Mediterranean Sea – accumulate, precipitation is 800–1000 mm more than in the heart of the Alps. Evaporation rises. Critical situations in the water balance of plants, however, are rare, other than in special locations (those of strong radiation, high temperature and high wind).

- Wind increases in frequency and strength with altitude. This strongly influences the distribution of snow in winter and thus the length of the snow-free period and the water balance, which makes a strong erosion effect possible in exposed locations. Various inclinations of the sun's radiation create differing degrees of heat.
- The difference between a north and south aspect is increasingly greater with altitude. The microclimate, however, can surpass the influence of the macroclimate and altitude.

15.3.2 Loss of the mother soil, loss of the established species, and erosion

Removal of the topsoil, as is common in technical interception, means the destruction of the mother soil specific to a site. Without this, ecologically adapted grassland can no longer thrive. Only pioneer communities can develop on stony ground lacking fine soil, which is usually created within the sphere of re-cultivation.

The species in the high zones of naturally present grassland communities are adapted to an optimum degree to the soil and weather conditions of their habitat (short vegetation period, low provision of nutrition). Insofar as they were previously available, these species as well as the natural seed bank and the vegetative organs of renewal contained in the mother soil are generally lost during building activities.

The mastering of erosion, with all of its resulting effects, such as increased surface drainage and loss of topsoil, and up to the formation of karst, is one of the main problems in re-cultivation work in alpine environments. Average slope gradients of 30–45% in the area of ski runs, and far above in the area of natural erosion zones and avalanche barriers, make adequate erosion protection a prerequisite for successful restoration. Only sufficient vegetation cover stabilizes the topsoil and reduces soil erosion to an acceptable degree (Markart *et al.* 1997). Results of several assessments indicate that at altitudes of between 1800 and 2400 m a minimum vegetation cover of 70–80% is required to avoid erosion (Stocking & Elwell 1976, Mosimann 1984, Tasser *et al.* 1999, Peratoner 2003). Therefore, a sufficient combination of application technique and adapted seed mixture, or plant material, reaching the minimum requirement of sustainable vegetation with 70–80% cover within the first two vegetation periods, must be the main target for restoration at high altitudes. Assessments of the vegetation cover of the sites showed that, under average conditions at high altitudes, the necessary minimum demand of cover can be achieved in the second vegetation period at the earliest. This requires application techniques with sufficient protection for topsoil for the first two vegetation periods.

15.3.3 Ski runs and agricultural utilization

No resulting burden normally occurs in the recultivated areas in the course of building protective measures (torrent and avalanche barriers). But areas used as ski runs in winter and/or alpine pasture in summer are subject to very special site factors, such as extended snow cover that is generally longer than usual at the given altitude. The generally dense snow cover on ski runs, often with deposits of ice layers, hinders the exchange of oxygen between the plant cover, the ground and the atmosphere in winter. Mechanical disturbance factors, such as the effect of the steel edges and chains on ski-run preparation machinery, can have a destructive influence on vegetation on rounded hills and steep slopes.

Low herbal vegetation growing on ski slopes also decisively increases the influence of surface runoff following large volumes of precipitation in high zones. In contrast to forests and areas stocked with dwarf shrubs, only technical measures (diagonally running and open drainage channels) can effect a safe disposal of the surface water.

Large areas used for agriculture are mostly burdened by grazing in summer. This burdening can lead to a multiplicity of damage (trampling and pressure damage by animals, humans and machines, soil density, etc.), which cause erosion and then require expensive restoration measures. Nevertheless, the task of the work-intensive management of alpine meadows in high zones, with regular measures taken, such as the removal of stones and bushes and the rapid restoration of points where erosion has begun in the course of a possibly long process of reforesting, can also lead to the massive formation of shell-shaped erosion scarp. Mostly affected are pastures below the potential forest line with deeply crevassed soil and a slope gradient of over 30°. Those areas showing shell-shaped erosion scarp are mainly those that have not been utilized (i.e. mowed or grazed) for many years (Bernhaupt 1980). Plant communities, in which the formation of shell-shaped erosion scarp appears, are marked by a high share of biomass-rich grasses and high-growing herbs. The root horizon is relatively low and uniform. The formation of a sliding horizon is fostered in this way. Stable plant communities, in comparison, comprise somewhat loose swards and low growth. They form relatively small amounts of biomass above the surface, but relatively high amounts of root biomass.

15.3.4 Plant growth and vegetation

In most cases, above all in the alpine zone, natural development back to the original vegetation units within human planning periods is not to be expected. With respect to sufficient protection against erosion, the first target function of restoration in high zones is usually the achievement of stable grassland. Previous damage mostly leads to the destruction of the vegetated earth or affects the eroded areas with a lack of humus groundcover. The results are mostly more or less a lack of fine soil, stony restoration bases with slight water-storage capacity and a high tendency to erode (Chambers 1997). To achieve sufficient protection against erosion restoration measures must take place as quickly as possible.

15.4 Approaches for sustainable restoration in alpine environments

15.4.1 General

Restoration at high altitudes is subject to limits. With increasing altitude, restoration following building measures always becomes more difficult. Irrespective of whether terrain corrections have been made in the course of constructing ski runs, or forest and alpine-meadow trails, measures for the improvement of tourism infrastructure or torrent and avalanche barriers, only a combination of high-quality plant material or seed adapted to the site with the optimum restoration technique will bring permanent success. The use of seed mixtures is only sensible in high zones within which the species can reproduce. This border is generally achieved at altitudes of 2300–2400 m. The planning of restoration at extremely high altitudes (over 2000 m) is to be carried out by appropriately trained experts with sufficient experience. The methods used are suitable for the climatic and geobotanical conditions and are principally for the restoration of alpine ecological systems. For the production of vegetation cover that is similar or identical to nature in areas with no primary agricultural use, the methods given here can be recommended for all altitudes in the subalpine–alpine zones.

Natural re-vegetation

Currently to be seen as site-specific and restorable according to the latest advances in the field are areas subject to human influence, somewhat nutrition-rich plant communities as the basis for various grazing lands, former cattle resting places and fields of high perennials and shrub communities. The recultivation of areas not subject to human influence, exposed alpine grasslands (curved sedge, cushion sedge, high-altitude formations of horst sedge grasslands, etc.) is currently hardly possible, as is that of windy ridge communities (the community of the three-leaved rush, etc.). There is no commercial seed available of the characteristic species of these types of vegetation (some are also beyond production). Moreover, the majority of these natural grasslands cannot be planted; many of them die shortly after transplantation.

In principle, it is possible in high zones to permit natural successive procedures. Due to specialized considerations for nature protection, this strategy is sometimes (with appropriately favourable conditions and awareness of the danger of erosion) favoured over other restoration methods, or at least combined with them. The substratum and site conditions will define the development of the vegetation. The spreading of mulch materials or geological textiles, facilitating so-called safe sites (Urbanska 1997), can foster the habitat and the germination of wind-blown seed.

Above all, on lime-rich restoration sites with sufficient fine soil and diaspora material, vegetation development is relatively rapid and richly blossomed pioneer stages can occur. On silicate sites in high zones the redevelopment of the vegetation takes place extremely slowly, for which reason this method is not to be used at such sites.

In some areas in the subalpine–alpine zones it is utterly legitimate to re-cultivate with rubble, meaning rock material of various granular sizes containing no vegetation. Such habitats are a part of the natural surroundings and it is possible to gain similarity to the areas to be re-naturalized. Such procedures have proved especially useful where, through the combination of restored areas and open-rubble areas in the course of site restoration, the mosaic of restored sections typical of the high zone and vegetation-free sites can be obtained.

The opportunities for natural re-vegetation are very limited in alpine environments, which necessitates the application of other methods.

Demands on the application technique

The available topsoil should be carefully collected and left at the site at the beginning of building activities. The diaspora material it contains and the remaining parts of vegetation make resettlement possible with vegetation from the original site. This is important for an enrichment of indigenous plants deriving from restoration, because their seed cannot be obtained on the market or is very expensive. Even after a partial mixing of the top soil with mineral layers, which are devoid of a seed bank, seed densities can be considerable (Diemer & Prock 1993). Therefore, conservation and redistribution of the topsoil should be considered a very important task when planning restoration. Discarding the topsoil represents a waste of valuable autochthonous plant material, which is available, on-site, for site-specific, low-impact restoration (Peratoner 2003).

On inclined areas, a sufficient cover of the topsoil with mulch or geo-textiles is a prerequisite for minimizing surface drainage and soil erosion. With the exception of intentionally initiated successive areas, recultivation techniques are to be used exclusively, which guarantee sufficient protection for the topsoil. This includes seeding processes combined with a cover of the topsoil with a layer of mulch, netting or matting, as well as hay-mulch seeding. With the use of hay-flower seeding, the necessity for additional cover is to be decided on by an expert.

Ski runs

Ski runs are emphasized as an independent focus because above all the re-cultivation of bare terrain following the erection of skiing facilities has been, and is often, insufficiently carried out. Owing to this situation, the important economic and tourism policies have acquired a somewhat negative image. Numerous terrain corrections at high altitudes are recognizable as extensive vegetation-free areas with a high erosion potential after decades of operation and, despite some restoration attempts, are seen as wounds in the landscape. Above all, in relation to the re-cultivation of such skiing areas the latest advances in the field are not being utilized, and the lack of contractual and realizable legal nature-protection criteria and guidelines is especially flagrant. In numerous cases, permanent site-specific restoration was agreed upon in decisions supporting legal nature protection as well as in tenders, but was never realized. In this respect, it is to be maintained that where sites are beyond restoration, according to the latest advances in the field, terrain-changing measures are to be used.

Fertilization

Restoration in the area of ski runs is generally only successful with the use of seeds or plants interacting with proper fertilization. A poor volume of minerals available to plants is mostly found in areas following levelling. Rapid development of the seeding to a full grass cover is also necessary in site-specific restoration for rapid erosion protection at such sites. A single fertilization of such areas with a suitable fertilizer is generally sufficient to achieve establishment (Krautzer *et al.* 2003). If there is insufficient cover in the second year of vegetation, further fertilization measures to achieve a sufficient grass density is necessary (Holaus & Partl 1996). These measures can also be combined with seeding-over with a site-specific seed mixture. With the achievement of a relatively dense

Table 15.1 Main and secondary components for site-specific seed mixtures for restoration of alpine ecosystems (ÖAG 2000, Krautzer *et al.* 2003).

Species	*Distribution*	*Vegetation belt*			*Parent rock*		*Moisture*		*Against fertilization*	*Tolerance*	
		Montane	*Subalpine*	*Alpine*	*Silicious*	*Calcareous*	*Dry*	*Wet*		*Against cutting*	*Against trampling*
Main components (≥ 60% of weight)											
Grasses											
Avenella flexuosa	Worldwide	+	+	+	+	–	+	(–)	(–)	–	(–)
Bellardiochloa variegata	Middle/south Europe	–	+	+	+	(–)	(+)	(+)	(+)	(+)	(+)
Deschampsia cespitosa	Worldwide	+	+	+	+	+	(–)	+	+	(+)	+
Festuca nigrescens	Europe	+	+	+	+	+	+	+	+	+	+
Festuca picturata	Middle Europe	–	+	+	+	+	+	(+)	+	+	(+)
Festuca pseudodura	Middle Europe	–	(+)	+	+	(–)	+	(–)	(+)	–	(+)
Festuca supina	North/middle Europe	–	+	+	+	(–)	+	(–)	(+)	(–)	+
Festuca varia s. str.	Europe	(–)	+	+	+	(–)	+	–	(–)	–	–
Phleum hirsutum	Middle/south Europe	(+)	+	+	(–)	+	+	(–)	+	+	+
Phleum rhaeticum	Middle/south Europe	(+)	+	+	+	(+)	(+)	+	+	+	+
Poa alpina	Europe/Siberia/N.Am.	(+)	+	+	(+)	+	+	(+)	+	+	+
Sesleria albicans	Europe	+	+	+	(–)	+	+	–	(–)	(–)	(–)
Leguminosae											
Anthyllis vulneraria ssp. *alpestris*	Europe	+	+	+	(–)	+	+	–	(+)	(–)	(+)
Trifolium alpinum	Middle/south/west Europe	–	(+)	+	+	–	(+)	(+)	+	+	+
Trifolium badium	Europe/Siberia	(+)	+	+	+	+	+	+	(+)	+	+
Trifolium pratense ssp. *nivale*	Middle/south Europe	–	+	+	+	(+)	(+)	+	(+)	+	+
Secondary components (≤ 40% of weight)											
Grasses											
Agrostis capillaris	Euroasia	+	+	(-)	+	(+)	+	+	+	+	+
Agrostis stolonifera	Euroasia/North America	+	(+)	–	+	+	(+)	+	+	+	+
Briza media	Europe	+	(+)	–	+	+	+	(+)	(+)	+	(+)
Cynosurus cristatus	Euroasia	+	+	–	(+)	+	(+)	(+)	+	+	+
Festuca rubra ssp. *rubra*	Euroasia/North America	+	+	(+)	+	+	+	+	+	+	+
Koeleria pyramidata	Europe	+	+	–	(-)	+	+	–	(+)	(+)	(+)
Phleum pratense	Worldwide	+	(+)	(–)	+	+	(+)	+	+	+	+
Poa pratensis	Euroasia/North America	+	(+)	–	+	+	+	+	+	+	+
Leguminosae											
Anthyllis vulneraria	Middle/south Europe	+	(+)	–	(–)	+	+	–	(+)	(-)	(+)
Lotus corniculatus	Worldwide	+	(+)	–	(–)	+	+	–	+	(-)	+
Trifolium hybridum	Europe/Siberia/N.Am.	+	(+)	–	(+)	+	(+)	+	+	+	(+)
Trifolium repens	Europe/Siberia	+	+	(+)	(+)	+	(+)	+	+	+	+
Herbs											
Achillea millefolium s.l.	Europe/Siberia	+	+	(+)	(+)	+	(+)	(+)	+	+	+
Leontodon hispidus s.l.	Europe	+	+	+	(+)	(+)	(+)	(+)	(+)	(+)	+

+, Very good; (+), good; (–), poor; –, very poor; N.Am., North America.

grass cover, the measures can be limited to unsatisfactory patches within the area.

Fertilizer of a slow and permanent effect should be used, which promotes the build-up of humus and has good plant tolerance. Attention should be given to achieving a balanced nutritional relationship (Heer & Körner 2002). The use of roughage-promoting or unhygienic fertilizer should be avoided. Where possible, organic fertilizer such as well-rotted farmyard manure, composted fertilizer or certified biological compost (according to the existing legal regulations) should be used. The use of fluid and semi-solid sewage should be avoided. The use of organic mineral fertilizers with the appropriate characteristics (slow, permanent release of nutrition) is possible. Their use should be limited to the necessary degree in relation to the positive additional effects of the organic fertilizer (multiple effects, deposit effect, herb tolerance, build-up of humus).

15.4.2 *Restoration with seeds*

Seed mixtures

The conventional high-zone mixtures available on the market mainly comprise high-growing, non-site-specific plants originally bred for grassland economy in valley locations or as grasses for sporting events. These species are adapted to lower, warmer locations and are generally not suitable for restoration in high zones (Florineth 1992). The high nutritional needs of these species require long-term, expensive fertilization measures to achieve the necessary grass density. These species also show relatively high biomass production, which again requires regular cutting, grazing or removal of the materials arising. This is because in the short vegetation period that occurs at high altitudes the additional biomass that grows does not decompose sufficiently, with the result that the vegetation's stigmas would be choked. In many cases, further use or management of the restored areas is not wished for or possible.

Site-specific subalpine and alpine plants are adapted to an optimum degree to the high-zone climate. They produce little biomass, but with an appropriate choice of species they do produce high-quality feed. Seeding with site-specific seeds generally requires only small amounts of nutrition, and short-term management measures lead quickly to natural, generally extensive self-maintaining grass, which has high resistance against subsequent uses for tourism and agriculture. With the use of site-specific seed mixtures, the required sowing volumes commonly used in practice can be reduced from 200–500 to 80–160 kg ha^{-1}. Grasses and legumes were selected within the sphere of several international research projects, which are suitable for seed production in valley locations and can be used in various site-specific alpine seed mixtures (Krautzer *et al.* 2003, Peratoner 2003). In the meantime, the ecological species suitable for high-zone restoration will multiply over a broad area and can then be graded according to altitude, original rock and usage, packaged as high-quality restoration mixtures and then marketed. The use of such site-specific seed mixtures should be obligatory when sowing in high zones.

Standards for seed mixtures

Minimum standards for site-specific seed mixtures for high-altitude restoration include the following. First, when faced with a lack of indigenous plant material, seed mixtures need to be used for restoration at high altitudes. To avoid errors when using such mixtures, alternative recipes are used that fulfil the following criteria. Due to their natural area of distribution, site-specific, high-altitude mixtures are divided into main components and secondary components (see Table 15.1). The main components encompass the species currently commercially available. A further series of site-specific species (grasses, legumes and special herbs) are more or less offered commercially and regularly in small amounts, which according to definition may also be used as high-altitude seed. High-altitude seed must comprise at least 60% main-component seed, by weight. The remaining 40% of the weight can be made up with secondary components (Table 15.1). Secondly, mixtures must comprise at least five species. The share of a single species must not exceed 40% of the weight. Leguminosae must comprise at least 10% of the weight of high-altitude mixtures. Thirdly, for high altitudes (> 2000 m) site-specific, ready-made mixtures are generally usable to only a limited extent. A special combination of site-specific mixtures made up by experts is necessary.

Finally, according to the degree of availability, and the choice of restoration method, improvements with the inclusion of further species, and the reduction of cultivation varieties or their use through local ecological types, are possible and desired.

15.4.3 Plant clippings and nets

Mulch seeding

In the mulch-seeding process, soil and seeds are covered and protected with various organic materials. For optimum growth the depth of the layer of mulch should not be more than 3–4 cm and should be pervious to light. The most common mulch materials are hay and straw. To avoid the inclusion of undesired seed, in principle only hay of the second or third cut should be used.

With the simple hay or straw seeding methods, a 3–4 cm straw or hay cover is applied over the seeding. The prerequisite for this restoration method is sites that are protected against the wind and not too steep. The material expenditure is 300–600 g m^{-2} in a dry state.

At steep points, especially above the tree line, the black-green seeding method is suitable. Seeds and fertilizer are applied into the 3–4 cm straw layer and an unstable bitumen emulsion sprayed over it (not to be used in drinking-water-protected areas). Hay is not as suitable for spraying with bitumen because it is compressed; due to thinner stalks and better cohesion, hay-cover seeding alone is more stable than straw. Hay and straw can also acquire sufficient cohesion through light, organic gluten.

Hay-mulch seeding

With the availability of appropriate areas, the seeds can also be won by special mowing in suitable donor areas. The areas to be mown should generally bear site-specific vegetation that is appropriate to the aims of the areas to be restored. Mowing is undertaken at staggered intervals (with two or three mowing dates) to include the broadest possible spectrum of species in a mature state. These mowing dates should be determined by an expert. The plants to be harvested should not be in an overly ripe state because a slight loss of seed can take place. With the intermediate storage of the hay, which often requires the selection of several mowing dates, sufficient drying is necessary to hinder the attack of mould. The ratio of winning to restoration areas is generally 1 : 1 or 1 : 2. The hay won in this way, and the seeds it contains, is to be applied to the restoration area in a uniform layer to a maximum depth of 2 cm. Over-intensive application is to be avoided to prevent anaerobic decomposition processes in the distributed seed.

Geological textiles

A number of geological textiles are available commercially. This netting of jute, coconut fibre, synthetic fibres or wire can be used for all restoration processes described above. When possible, the use of synthetic fibres and wire netting as a planting aid in site-specific restoration should be avoided (galvanized-iron netting and synthetic netting have lifespans of around 30 years and are not biologically degraded). Geological textiles are used predominantly where there is a clear danger of erosion or extreme site conditions (e.g. on very steep, ridged banks). They offer the possibility for stronger surface protection and, according to the materials used, are more or less stable in the face of natural forces such as falling rock, snowdrifts and precipitation. According to the material, site conditions and altitude, the netting rots within 1–4 years, leaving no residue.

Hay-flower seeding

Required for this method is the availability of the seed-rich remains from threshing floors in hay barns, which above all at high altitudes is still mostly of sufficient quality. This material should come from hay that is not older than 1 year or maximally 2 years. A further prerequisite is that the hay must be cut sufficiently late, which promotes the forming of mature seeds in many field grasses and herbs. Sieving is often recommended to acquire an appropriately high seed concentration. The hay flowers (0.5–2.0 kg m^{-2}) are sown with their stalks to a maximum depth of 2 cm. An additional layer of mulch is only necessary when sieved material has been used. To hinder loss through scattering by the wind, seeding should only take place on wet soil, or if the hay flowers are watered after seeding. At high altitudes, seeding weighted with steel building grids, wire netting or coconut netting, which can be removed after a few weeks, has proven successful. A certain degree of protection of the soil against mechanical interference is achieved with the mulch layer, and microclimatic conditions are improved. The additional use of a cover crop has proven useful. If the germination capacity of the hay flowers is insufficient, important seed components can be additionally purchased and sown.

15.4.4 Restoration with plant material

Sod clippings

Shoots or rosettes (mostly mechanically separated vegetation turfs) are loosely distributed. Distribution can take place mechanically in areas that can be driven on. In this way, a much larger area can be restored with well-established vegetation than with grass swards. Restoration, however, is significantly more sparse, and the danger of erosion higher.

Grass turfs

Available and natural vegetation is above all the best substance in the alpine zone for enduring restoration identical to nature. Therefore, extreme care should be taken when using such vegetation because destruction or a lack of re-use must be strictly avoided.

Grass turfs (also known as grass swards) or larger pieces of vegetation won during levelling or path construction are grouped together following completion of the work. They are very suitable for the rapid and site-specific restoration of damaged areas. On steeper banks, the grass turfs must be fixed with wooden nails. Wherever possible the planting of grass turfs should take place before shooting or after the start of the autumn vegetation pause, just after the melting of snow or immediately before the coming of snow in winter. At these times the success of planting, even in the extreme high zones, is very good.

Before levelling begins, the available grass or pieces of vegetation are lifted together with the rooted soil and laid again after levelling. Depending on whether the turfs are cut manually, or lifted mechanically, their size is 0.15–0.5 m^2. If required they can be stored in pits or stacked on pallets (maximum of 1 m wide × 0.6 m high) to hinder drying out, stifling and rotting. The storage period should not exceed a maximum of 2–3 weeks in summer. Following the end of levelling the grass turfs or pieces of vegetation are again laid out and pressed in lightly.

With appropriate planning of the building process, the direct use of vegetation turfs is possible without intermediate storage.

Potted plants

The plants and seeds are pre-cultivated in nurseries and planted with a well-developed root stock at the restoration site. Site-specific species with a good vegetative growth are used for this (Grabherr & Hohengartner 1989). One can also turn to mother plants or seeds taken directly at the site by experts. With the appropriate choice of species, excellent results can be achieved at extreme sites in this way. The supporting use of this method as a post-improvement measure against sparseness in the restoration area is favourable.

Ready-made sward (sod rolls)

Sod rolls with site-specific vegetation are already available in small amounts for differing starting substrates. Sod rolls are produced at specialized firms over a period of around 12 months until the sufficient development of site-specific altitude species is ensured. According to need and restoration aims, certain grass mixtures can be produced beforehand. The grass is then harvested to order and transported to the restoration area. Thus a complete cover of restoration areas is possible in the shortest possible time. This method is especially interesting in restorations following small-area interception and in extreme locations.

15.4.5 Combined techniques

Vegetation transplantation: combined seed-sward process

In this special restoration technique, the covering with grass swards, or other pieces of vegetation, is combined with dry or wet seed. The grass swards used must be appropriate to the desired site-specific type of vegetation and are generally acquired from the project area or the immediate vicinity at the beginning of building work. There can therefore be cases of an interception in the vegetation sphere beyond the immediate project area to achieve optimum success through the division of available vegetation. The area to be restored is therefore often larger than the original project sphere.

The grass swards (0.2–0.5 m^2) are placed in groups in dry locations, to prevent them from drying out, or in a grid-like pattern in areas subject to high precipitation. Site-specific seed is applied to sparse patches between the swards. This seed has a stabilizing effect on the vegetation-bearing layer. Due to the short distances between the covered grass swards, it is possible for well-established vegetation to move into the intermediate spaces (Fig. 15.2). In this way, these patches will also be restored and inhabited in a natural way by species that are not available as seeds.

This method has been tested at altitudes of at least 2400 m and according to the latest advances in the field. Especially suitable are moderately nutrition-rich plant communities subject to little human influence, such as those found on grazing land (of the most differing types), high-growing perennials and green alder bushes.

The conception of this restoration technique, and above all the selection of grass-donor areas, is only to be undertaken by appropriate experts. In steeper areas (with a gradient of over 30%), and in terrain endangered by erosion, the use of geological textile matting or similar is planned for securing the covered vegetation or for the protection of the topsoil against erosion.

Fig. 15.2 Seed production of site-specific species (harvest of *Poa alpina*), a precondition for ecological restoration of alpine environments.

15.4.6 Management

Constant cultivation is not obligatory or necessary following the use of site-specific seed mixtures or plant material. With the appropriate composition of the seed mixtures or the use of appropriate plant materials, a restoration area can be left to itself, which is greatly desired for the restoration of areas prone to erosion, and those containing torrent and avalanche barriers.

Management of ski-run restoration is in most cases also necessary in areas not used predominantly for farming. Management takes place in the form of extensive grazing or annual mowing (Persson 1995), with or without the removal of organic material (only small amounts of biomass).

Above all, in the first years of seeding with fertilization, ski areas must be managed. Until the achievement of sufficient grass density, at least over the first two vegetation periods, no grazing or trampling is to take place (Klug *et al.* 2002). Annual mowing is necessary following the appearance of appropriately lush growth. This mowing removes biomass and thus hinders the stifling of the growth in winter. Tillering of the plants is also stimulated and promotes grass density. If necessary, grazing should be hindered by fencing on steep and footfall-sensitive areas, in favour of mowing.

When cover is less than 50% in the year following restoration, further necessary measures are to be taken, such as reseeding or replanting with a site-specific seed mixture (30–50 kg ha^{-1}) or plant material. When necessary, appropriate improvement work must be undertaken in small areas.

15.5 Concluding remarks

A state of acceptance is normally not given before the site being restored shows signs of development that ensures the achievement of the restoration aims or is appropriate to the same. Confirmation of the work carried out and the achievement of an acceptable state of development is in certain cases to be executed through proper and successful care until completion. Therefore, an exact evaluation of success and failures is an important foundation.

15.5.1 Evaluation of success

Evaluation of the success of restoration requires special criteria in high-altitude sites. The primary aim of every restoration is sufficient protection against erosion following restoration until the vegetation has developed to be able to fulfil the task adequately. This immediate protection against erosion is enabled by the use of recommended application techniques with the covering of the topsoil. As an essential limit for sufficient erosion protection created by the developing vegetation, ground cover of 70–80% is considered appropriate by experts (Stocking & Elwell 1976, Mosimann 1984). With a site-specific choice of species, the vegetation can be considered stable from this point in time. Restoration created by seeding should form vegetation that is as uniform as possible, which when left uncut, unless otherwise agreed, must show at least 70% of the projected ground cover. In justified cases, a divergent ground cover can be agreed upon. Vegetation-free areas of over $20 \times 20\ cm^2$ are not permitted in cases where potted plants are used. Up to 60% of the projected cover should be comprised of the species specified in the seed mixture, or as determined by the restoration aims in terms of vegetation type. The species-specific annual condition of the plants is to be taken into account when defining the degree of cover. Nursery vegetation and alien vegetation should not be a part of the required degree of cover. Divergent degrees of cover or states of decrease, above all in the restoration of difficult sites, are to be agreed upon and taken into account during evaluation.

The sown or planted vegetation in high locations must have survived two rest periods and two frost phases before evaluation can be conclusive. In special cases (e.g. re-introduction projects) individual evaluation criteria are necessary.

15.5.2 Failures

Restoration can easily fail in extreme locations or at extreme altitudes. The most common causes for such a lack of success are listed below.

False restoration methods

The more extreme the conditions, the more specific must be the planning of the restoration or rehabilitation measures. The securing of valuable pieces of vegetation, the gathering, restoration, intermediate storing and expert reapplication of the topsoil, the subsequent prevention against erosion, the use of special restoration methods and the choice of donor areas for the combined seed/sward technique or for hay-mulch seeding, require planning by appropriately experienced experts. Successful high-location restoration at over 2000 m has always been planned and maintained by trained experts.

False seed

A common mistake, even in less than extreme conditions, is the choice of unsuitable seed. Not only the use of lowland seed in the subalpine and alpine zones, but also the lack of attention given to decisive criteria, such as the degree of acidity of the soil, or the availability of nutrition, are causes for insufficient restoration success. Also valid here is the maxim that the more extreme the conditions, the more necessary is the use of trained experts.

False fertilization

As already mentioned, fertilization at the restoration site and the restoration method are to be mutually adapted. Too little as well as too much can hinder success. In this way, with the combined seed/sward technique, heavy fertilization can destroy vegetation of the replaced swards and the natural seed slumbering in the soil. The slightest failure in this respect can be caused by small doses of slowly working and long-term fertilizer.

Inexpert work

Grass swards as well as seeds are living materials and therefore careful handling and expert attention is indispensable. Badly stored grass swards, inexpert fixing of the sward in the soil, a lack of adequate bedding-in and the connected drying-out phenomenon can even destroy restoration undertaken with high expenditure. Above all, under difficult conditions one must call in a competent restoration expert.

Lack of subsequent management

In many cases, a certain degree of subsequent management is required for the success of restoration: when mowing is to be undertaken an exactly dosed post-fertilization, additional seeding or necessary fencing against grazing animals is required for the achievement of the projected level of restoration. All of these measures are essential elements of restoration that must not be forgotten if one wishes to achieve appropriate success.

15.5.3 Prospects for the future

Above all, restoration at extreme altitudes has made great progress in recent years. Whereas the restoration of areas above 2000 m back to a natural state was considered impossible 20 years ago, there are now fine examples of restoration at altitudes up 2400 m. Even when the techniques used are comparably extensive, they nevertheless create at these high altitudes management-free units of vegetation that are identical or almost identical to nature.

The current awareness of technology for the restoration of alpine ecosystems in various neighbouring alpine states is defined very differently and the knowledge of special restoration methods is insufficient. The legal sphere dedicated to extensive restoration methods also lacks uniformity. What is common in some countries is strictly forbidden in others. Above all, due to the manifested prohibitions, mostly given in nature-protection laws, the use of vegetation alien to such sites is in practice often ignored due to a lack of the knowledge about alternatives. Although permission for building projects at high altitudes is obligatory in almost all of the affected states, the protection laws are less than strictly controlled. There is also a lack of information among the authorities concerning what is technically possible. The drawing up of binding guidelines for site-specific restoration at high altitudes within the region of the Alps, which reflect the latest awareness of technological advances, is needed urgently. Specialized experts from within the region of the Alps should participate in the drawing up of such guidelines.