THE INFLUENCE OF VEGETATION ON EROSION FOLLOWING RESTORATION IN HIGH ZONES

DER EINFLUSS DER VEGETATION AUF DAS EROSIONS-GESCHEHEN IN HOCHLAGEN NACH REKULTIVIERUNGEN

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SUMMARY

The areas from the montane to the sub-alpine and alpine vegetation belts are among the most sensitive parts of the Alps. Nevertheless, a great many interventions are undertaken in these regions every year that engender the need for subsequent recultivation. Vegetation taken from a site is generally not available in sufficient amounts. Seed mixtures used for the restoration of such areas should therefore combine different economic and ecological characteristics, such as a low nutrient demand, the capacity to foster a closed sward as well as endurance and good adaptation to climate and soil.
Conventional restoration seed mixtures and those containing useful site-specific species were compared at six different locations in Austria, Germany and Italy. The results obtained generally showed an increase of positive ecological effects together with a higher vegetation cover and corresponding erosion stability on plots where site-specific seed mixtures were used. With increased altitude, restoration becomes increasingly more difficult due to a rapidly worsening climate and more extreme soil conditions. Only sufficient vegetation development through sufficient ground cover stabilises topsoil in the long term and reduces erosion to an acceptable degree. The choice of recultivation technique is alone decisive for the degree of erosion control in the restoration area in the short term. In the long term, a stable, sufficient plant-stock cover of the topsoil in high zones can be achieved only through the establishment of site-specific vegetation with the use of site-specific restoration seed mixtures.

Keywords: seed mixture, site-specific vegetation, erosion control, high zones

ZUSAMMENFASSUNG

Bereiche von der montanen über die subalpine bis zur alpinen Vegetationsstufe gehören zu den sensibelsten Teile der Alpen. Trotzdem werden in diesen Regionen jedes Jahr sehr viele Eingriffe vorgenommen, die eine Rekultivierung nach sich ziehen. Vegetation vom Standort steht im Regelfall nicht in ausreichender Menge zur Verfügung. Die zur Wiederbegrünung solcher Flächen vorhandenen Saatgutmischungen sollten unterschiedliche ökonomische und ökologische Eigenschaften aufweisen, wie geringen Nährstoffbedarf, die Fähigkeit eine geschlossen Grasnarbe zu bilden, Ausdauer und gute Anpassung an Klima und Boden.
Auf sechs unterschiedlichen Standorten in Österreich, Italien und Deutschland wurden konventionelle Begrünungsmischungen und Begrünungsmischungen mit standortgerechten Arten verglichen. Die Ergebnisse zeigen generell einen höheren ökologischen Effekt neben einer höheren Vegetationsdeckung und damit verbundenen Erosionsstabilität auf den Flächen mit standortgerechten Saatgutmischungen. Mit zunehmender Höhenlage wird die

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Rekultivierung durch das rauere Klima und die extremeren Bodenverhältnissen immer schwieriger. Nur eine zufriedenstellende Vegetationsentwicklung mit einer damit verbundenen projektiven Deckung von 70 bis 80 % stabilisiert den Oberboden langfristig und reduziert die Erosion auf ein akzeptables Niveau. In den ersten Monaten nach der Rekultivierung ist die Wahl der richtigen Technik wichtig für die Vermeidung von Erosion. Langfristig können in Hochlagen erosionsstabile Verhältnisse nur durch einen ausreichend deckenden Pflanzenbestand erreicht werden. Dies ist nur bei Verwendung von standortgerechten Saatgutmischungen und sich daraus entwickelnder standortgerechter Vegetation möglich.

Keywords: Saatgutmischungen, standortgerechte Vegetation, Erosionskontrolle, Hochlagen

INTRODUCTION

As before, thousands of hectares of ground are levelled annually as a part of opening up areas for tourism and the corresponding infrastructural adaptations, and are now in need of restoration. A significant part of the need for recultivation is made necessary by the construction and adaptation of ski runs and lifts. But many of the technical measures required for the protection of facilities, which are mainly within the sphere of responsibility of the torrent- and avalanche barrier authorities, also take up large areas. All of the measures described lead to intensive construction activity each year, which subsequently engender the need for restoration of the areas subjected to intervention. Especially infrastructural measures undertąken for winter tourism also engender the need for restoration or reseeding in the sub-alpine and alpine-vegetation belts. The main aim of restoration is the creation of areas that ensure stability against erosion with low nutrient demand and sustainability (Krautzer et al. 2003).

In 1999 an international EU project was started under the direction of the HBLFA Raumberg-Gumpenstein with the participation of further research groups and firms from Austria (office of the Provincial Government of Tyrol, Kärntner Saatbau), Italy (provinces of Pordenone and Vicenza), Germany (University of Kassel) and Switzerland (Association for High Zone Restoration). The aim was to make possible for the first time an exact scientific comparison of the standard state of technology, high-quality application techniques and site-specific seed. The development of the vegetation from site-specific seed mixtures and a common conventional mixture was compared over a period of four years at six different sites. The aim of the work was to make a scientifically exact comparison of site-specific and conventional restoration seed mixtures and their influence on sustainable restoration in high zones.

MATERIALS AND METHODS

Exact trials arranged as two factorial split-plot designs were carried out on $21m^2$ plots between 1999 and 2002 (Table 1) and replicated three times on six different sites. The seed mixture and its development will be presented in detail for two sites (Hochwurzen and Gerlos) and an overview of all six sites will then be given as an average.

Tab1: Beschreibung der Versuchsflächen, mittlere Temperatur (MAT) während der Vegetationsperiode (Juni bis August, Durchschnitt der Jahre) und Bodenkennwerte der Versuchsanlage (Krautzer et al. 2003, Graiss 2004, Peratoner et al. 2004)

Tab1: Description of experimental sites, mean air temperature (MAT) during the vegetation period (June to August, average of the years) and soil chemical properties at the trial site (Krautzer et al. 2003, Graiss 2004, Peratoner et al. 2004)

Site	Location	Examination period	Altitude (m) exposure	MAT °C	Chemical soil properties				
					pH_{CaCl2}	Humus g kg^{-1}	N_{tot} g kg^{-1}	P (CAL) mg kg^{-1}	K (CAL) mg kg^{-1}
Bayrischzell	Bav., G	2000-2002	1,230; N	14.0	6.9	82	4.4	<13	55
Piancavallo	Porden., I	2000-2002	1,435; SE	12.7	7.1	11	2.7	<13	64
Val Zoldana	Vicenza, I	2000-2001	1,660; NNE	12.5	6.2	43	1.7	<13	80
Hochwurzen	Styria, A	2000-2002	1,830; SE	10.5	6.6	40	2.1	<13	47
Gerlos	Tyrol, A	2000-2002	2,280; S	8.1	4.9	57	2.7	21	25
St. Anton	Tyrol, A	2000-2002	2,350; SSE	7.3	6.9	47	2.5	16	70

Two different seed mixtures (SM 1 = common conventional restoration seed mixture; SM 2 = site-specific restoration seed mixture containing sub-alpine and alpine grasses, leguminosae and herbs) were established at the Hochwurzen site (Table 2) using the hydro-seeding application technique (15g m^{-2} mineral fertiliser (15N:15P:15K), 5g m^{-2} Rekuform®, 15g m^{-2} synthetic binder, 15g m^{-2} seeds).

Tab2: Zusammensetzung der Mischungen (in Gew. %), Hochwurzen (SM 1 und SM 2) und Gerlos (SM 1 und SM 3)

Tab2: Composition of the seed mixtures (weight in %), Hochwurzen (SM 1 and SM 2) and Gerlos (SM 1 and SM 3)

Grasses	SM 1	SM 2	SM 3		SM 1	SM 2	SM 3
Agrostis capillaris	4.6	4	6	**Leguminosae**			
Avenella flexuosa			6	*Anthyllis vulneraria*		5	
Cynosurus cristatus				*Lotus corniculatus*	5	3	6
Dactylis glomerata				*Trifolium badium*		5	2
Festuca nigrescens		35	22	*Trifolium hybridum*	2.4		6
Festuca ovina	2.5			*Trifolium nivale*		7	
Festuca pratensis				*Trifolium repens*	4.2		6
Festuca supina			5				
Festuca rubra agg.	31			**Herbs**			
Lolium perenne	15.7	3		*Achillea millefolium*	0.7	1	2
Phleum alpinum		10	6	*Campanula barbata*		0.22	
Phleum pratense	19.9			*Crepis aurea*		0.5	
Poa alpina		15	27	*Leontodon hispidus*		1	1
Poa pratensis	10.6			*Silene dioica*		0.03	
Poa supina		5	4	*Silene vulgaris*		0.25	1
Poa violacea		5		*Vicia sativa*	3.4		

Two different seed mixtures (SM 1 = common conventional restoration seed mixture; SM 3 = site-specific restoration seed mixture) were established at the Gerlos site using the hydro-seeding application technique with an additional straw mulch layer (500g m^{-2}) for protection against surface erosion in the first year after the intervention (Krautzer and Wittmann 2006). Due to the normally limited possibilities for reaching and utilising such areas, the plots were fertilised only once during initial establishment. ANOVA was carried out for all comparisons.

An F-ratio of $P<0.05$ was regarded as significant. Since no significant differences were seen between the application techniques in 2001 and 2002, no results were reported.

Classification of the assessed species was made in respect of their overall value in order to measure their ecological value and sustainability, and thus the capacity of the different plots for maintaining long-term protection against erosion, (Krautzer et al. 2006, Graiss et al. 2005).

Group 1: site-specific species, growing naturally under site conditions.
Site-specific species are mixtures of ecological materials with a high genetic biodiversity that have been collected at several sites in montane, subalpine and alpine zones in the Austrian Alps (Krautzer et al. 2004). This group shows the greatest endurance and best suitability for long-term protection against erosion in high zones.
Group 2: site-adapted species, not site-specific but sustainable under comparable site conditions.
Site-adapted species are mostly cultivated varieties that are well adapted to respective site conditions. This group showed satisfactory erosion protection in high zones in the long term.
Group 3: non-site-adapted species that do not occur naturally under specific climatic and site conditions.
Non-site-adapted species of seed mixtures generally comprise agriculturally cultivated varieties of lowland species. The decline and eventual absence of these species over the years leads to sparse vegetation cover and thus to erosion.

The projective vegetation cover and botanical composition (the share of protective cover given by each single species) were assessed each year. The share of all single species according to one overall (ecological viability and capacity for long-term protection against erosion) group was summarised. For the seed mixture, the total value of each group is expressed as a weight percentage and the results of the field assessments are expressed as a percentage of projective cover.

RESULTS AND DISCUSSION

The higher the altitude and the steeper the reseeded areas, the more important is sufficient protection against erosion. The results of several assessments indicate that a minimum vegetation cover of at least 70% is required to avoid erosion (Tasser et al. 2003) at altitudes between 1,200-2,400 metres. The achievement of a sufficient vegetation cover of more than 70% was therefore an important aim on all assessed sites. Greatly differing approaches can be found in the literature for describing indicators for the ecological value of stocks, e.g. balanced scores of the Landolt (1977) ecological indicators or an efficiency index (Parente et al. 2002). The presented method of grouping species according to their overall value permits a simple comparison of different sites and different seed mixtures.

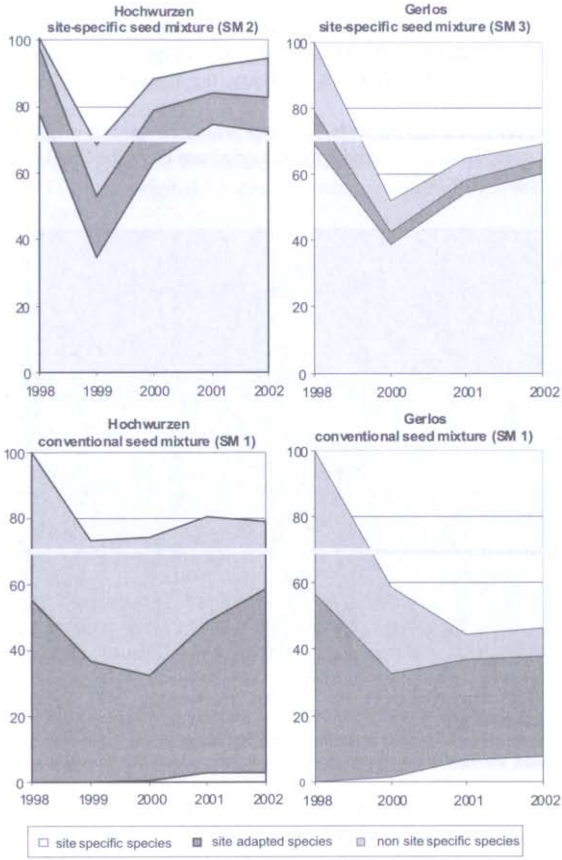

Abb1: Durchschnittliche Deckung der gruppierten Arten im Bezug auf die Standorte Hochwurzen und Gerlos (1998 = Gew.% der Ansaatmischung, 1999-2001 = Artendeckung in %)

Fig1: Average vegetation cover of grouped species in reference to the Hochwurzen and Gerlos sites (1998 = original seed mixture weight in %, 1999-2001 = species cover in %).

The conventional restoration seed mixture (SM 1) at the Hochwurzen site contained no site-specific species but more than 56% of site-adapted species, mainly *Festuca rubra* (Figure 1). The total vegetation cover developed from 73% in 1999 to nearly 80% in 2002. A slow immigration of site-specific species, mainly from neighbouring plots, could be assessed from 2000. The share of site-adapted species decreased in the first two years and again reached 56% in 2002. The non-site-adapted species spread during the first two years, which can be explained by the effect of fertilisation undertaken in 1999. Their share decreased to below 20% from 2000. In all, the share of the valuable groups with expected sustainability and capacity for long-term protection against erosion reached 59%. Considering the share of species in the site-adapted restoration seed mixture (SM 2), it contained only 3% of the non-site-adapted *Lolium perenne* "Guru" variety, as a fast-growing nursery crop. Nearly 78% were allocated by weight to the group of site-specific species; about 20% accounted for the group of site-adapted species. The total vegetation cover increased from 70% in 1999 to 94% in 2002, nearly 15% higher than for SM 3. The ratio of difference in all groups differed little between the years of observation. The share of non-site-

adapted species increased to 11%, of which 7% was the *Lolium perenne* "Guru" variety that showed remarkable winter hardiness. A share of 72% of site-specific species and 10% of site-adapted species could be assessed in 2002. In summary, the share of valuable groups exceeded 82% of the total vegetation cover.
The total number of species reaches 38 with SM 2, of which 12 species originate from the seed mixture (Figure 4). In comparison, only eight species originate from the SM 1 seed mixture, with a total number of 29 species (in 2002).

Abb2: Vergleich von Begrünungsmischungen am Standort Hochwurzen, links Standardmischung, rechts standortgerechte Begrünungsmischung
Fig2: Comparison of different restoration seed mixtures on the Hochwurzen site. Left: conventional seed mixture. Right: site-specific restoration mixture

Most subalpine grassland is used agriculturally in summer in Austria. Nevertheless, rapid and enduring protection against erosion that can only be achieved with the aid of a dense sward is the first and most important aim. This can be assured in the short term with the use of a high-quality application technique (OEAG 2000). A plant stock comprising sustainable, site-specific vegetation that withstands the harsh climatic and soil conditions at such altitudes is necessary in the long term. The results obtained in the field trial at the Hochwurzen site show that the share of non-site-adapted species, and therefore the cover of plots with the SM 1, continuingly decreased. A mid-term evaluation showed that the cover will fall below the critical value of 70% and erosion problems can be expected. It can be assumed in the long term that especially in the subalpine vegetation belt the lack of sustainable site-specific species would require ongoing cultivation and corresponding expenditure.

Due to extreme conditions on the Gerlos site, both seed mixtures were not able to establish to a satisfactory vegetation cover (Figure 1). The conventional restoration seed mixture (SM 1) showed continuous decrease for the first three years and achieved a cover of 46% in 2002. The non-site-adapted species reduced from 43% to 8%, while the site-adapted species reduced from a 56% share of the original seed mixture to 31% projective cover. Site-specific species were able to fill emergent gaps by more than 7%. In comparison, the site-adapted restoration seed mixture (SM 3) showed a decreasing vegetation cover during the first year of assessment. The vegetation cover in the two following years showed an increase from 52% to 69%, more or less achieving

the threshold for sufficient stability against erosion. Of interest on this site was that the group of site-adapted species showed a strong decrease from 10% to 4%, whereby the site-specific species remained stable. As on all assessed sites, the non-site-adapted species also showed a strong decrease of cover from 20% to 4%.
In comparison to the subalpine Hochwurzen site, with the SM 1 mixture, the number of species decreased to 22 on the alpine site in Gerlos, of which only six of the surviving species originated from the mixture. 11 of the original 14 species sown were found with the SM 3 mixture, with a total count of 25 (Figure 4).

Abb3: Vergleich von Begrünungsmischungen am Standort Gerlos, links Standardmischung, rechts standortgerechte Begrünungsmischung
Fig3: Comparison of different restoration seed mixtures on the Gerlos site. Left: standard mixture. Right: site-specific restoration mixture

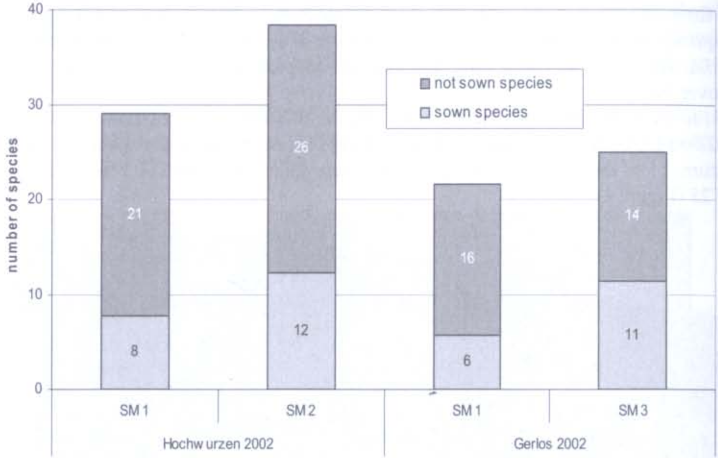

Abb4: Anzahl eingewanderter und von der Saatgutmischung verbliebener Arten im Vergleich der verwendeten Mischungen

Fig4: Number of migrated species and the remaining seed-mixture species compared to the mixtures used on the Hochwurzen and Gerlos sites

Most of the non-site-adapted species in the alpine vegetation belt that are suitable for grassland at low elevations disappear after a few years. Only a few species, such as *Festuca rubra, Phleum pratense* and *Trifolium repens,* are able to survive for a longer period. Only seed mixtures with a preferably high share of site-specific and site-adapted species can therefore be recommended for reseeding or restoration at such altitudes. The results taken at the Gerlos site additionally showed that in some cases it is necessary to continue such measures as fertilisation or reseeding until the time that sufficient vegetation cover is achieved.

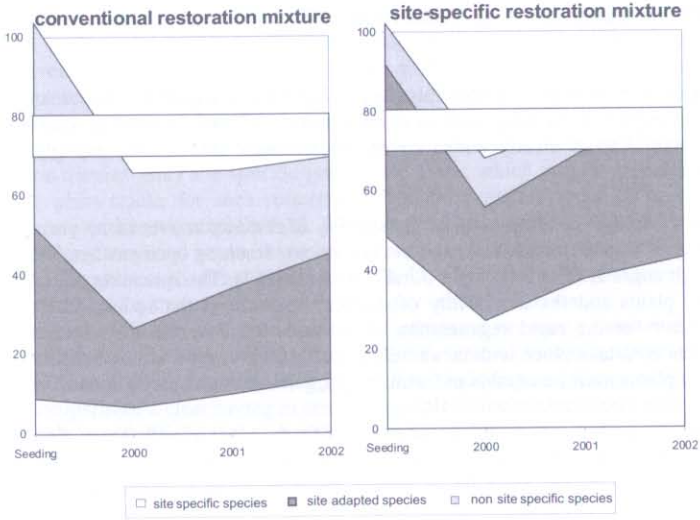

Abb5: Vergleich der durchschnittlichen Gesamtdeckung in Prozent der herkömmlichen und standortspezifischen Wiederbegrünungsmischung (Saatgutmischung = Mischungszusammensetzung in %) auf sechs Versuchsflächen zwischen 1.245 und 2.350 Meter Seehöhe, Durchschnitt aller Standorte (Krautzer et al. 2006)
Fig5: Comparison of the overall average cover as a percentage of the conventional and site-specific restoration mixtures (seed mixture = mixture composition weight in %) on six trial sites at altitudes between 1,245 to 2,350 metres, average of all sites (Krautzer et al. 2006)

If one assesses the development of the entire ground cover on average on all trial sites, the conventional restoration mixture achieved somewhat more than a 60% overall cover in the fourth year of vegetation, thus still not achieving the target value of a 70% vegetation cover to stabilise erosion conditions (Figure 5).
Only about 24% of the total measured cover comprised non-site-specific species in 2002, the loss of which must be assumed in the short- and mid-term; 31% were site-adapted and 14% were site-specific species.

Compared to the conventional restoration mixture, the entire cover comprising the site-specific restoration mixtures achieved a significantly higher share of 79%.
The share of site-specific species remained stable at about 50% compared to the share in the initial mixture. The site-adapted species showed a cover of 25% in 2002, the non-site-specific species showed a cover of below 10% (Figure 5).

Conventional restoration mixtures available on the market comprise mainly high-growth, alien lowland plants that were originally bred for grassland economy in valley areas or for sport grass. These types are adapted to lower, warmer locations and are generally unsuitable for restoration in high zones (Florineth 1992). The high need for the nutrition of these species requires long-term, costly fertilisation measures to acquire the necessary complete cover. A high production of biomass is connected to this, and again requires regular cutting, grazing or removal of the material arising, because in the short vegetation period no sufficient decomposition of the increased biomass takes place and a stifling of the vegetation stigma would be the result. In many cases further use or care of the restored areas are also no longer desired or possible. Moreover, if the plants from conventional mixtures show no reproduction, meaning after the dying off of the initial restoration, a total loss of the vegetation sown occurs.

The site-specific restoration mixtures therefore achieved a comparably clearer and more stable turf. In respect of the adaptation to climate and site of the observed species, the last named mixtures showed clearly better cover, sustainability and correspondingly lasting erosion protection.

A significant factor for the assessment of the stability of restoration over many years is seen in the capacity of stigma to regenerate and to close up any resulting open patches. Vegetative growth in high zones is relatively slight (Grabherr et al. 1987). The spreading of seeds from neighbouring plants and the availability of diaspore material in the soil are therefore an important factor for the rapid regeneration of a vegetation cover in the case of stigma damage. If this is to take place without additional cultivation in the form of fertilisation and reseeding, the plants must be capable of forming ripe, germination-capacity seeds (Figure 6).

The assessments carried out at various sites and altitude zones clearly show that lowland species, and thus non-site-specific species, are practically incapable of reproducing at altitudes above 1,800 metres. Most alpine species, however, could form germination-capacity seeds at altitudes of up to 2,400 metres.

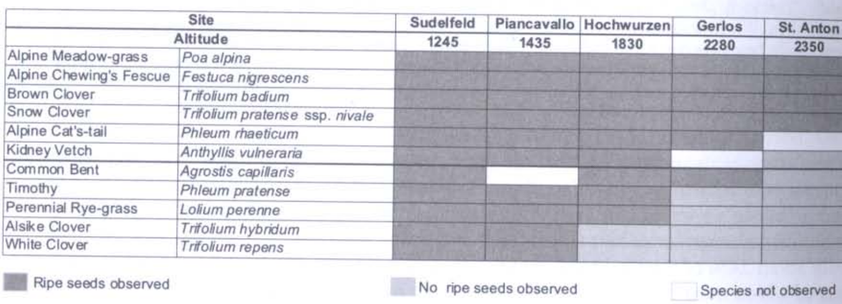

Abb6: Fertilität ausgesuchter Arten in Abhängigkeit von der Seehöhe
Fig6: Fertility of selected species dependent on altitude (Krautzer et al. 2006)

Site-specific subalpine and alpine plants are adapted to an optimum to high-altitude climates and extreme site conditions. They produce little biomass, but with the appropriate selection of species they produce high-quality feed. Seeding with site-specific seeds generally requires only slight amounts of nutrition and short-term cultivation measures, and in the shortest time lead to a natural, and to a great extent, self-maintaining grassland that has high resistance to subsequent use through tourism and agriculture. With the use of site-specific seed mixtures, the required seeding amounts can be reduced from the commonly used 200 to 500 kg per hectare to 80 to 160 kg. Within the sphere of several international research projects, grasses and leguminosae were selected that are suitable for seed production in valley locations and can be used in various site-specific alpine seed mixtures (Krautzer et al. 2003). In the meantime, suitable ecological types and quality restoration mixtures, graded according to altitude zone, basis rock and use are being reproduced over large areas and brought to the market for high-zone restoration. The use of such site-specific seed mixtures, if available, should be binding and obligatory for seeding in high zones (Figure 6).

The essential long-term aim of recultivation in high zones lies in the establishment of resistant, easily maintained and sufficiently dense and enduring vegetation. This aim can only be achieved with the use of a site-specific seed mixture. With the use of such seed mixtures, a single fertilisation measure during sowing is generally sufficient to achieve a stable vegetation cover of more than 70%.
Only in exceptional cases are further fertilisation measures necessary to achieve satisfactory vegetation density. Only site-specific grasses and herbs, which provide an essential basis for enduring plant stocks for such restorations, can form mature seeds in high zones. Turf damage can in this way rapidly heal. Site-specific leguminosae ensure sufficient nitrogen supply to the grasses and are another essential component of sustainable restoration mixtures. Careful restoration with site-specific seed can be made without subsequent maintenance when needed, and without the danger of choking or other limitations.
In practice, this enables a strong decrease of otherwise necessary maintenance measures, which is especially desirable in restoration within the area of torrent- and avalanche barriers. Site-specific seed mixtures are more expensive than seed mixtures of species from low zones. But by comparison, a clear saving in costs is possible in the medium term with the saving of sowing volumes, fertilising, subsequent repair and maintenance.

CONCLUSIONS

According to the limited climatic and soil conditions of most meadows and pastures on the montane- to the alpine-vegetation belts, it becomes more and more important to choose species suitable for the prevailing site conditions. Collaterally, the possibility and feasibility for agricultural use and fertilisation of such sites decreases with altitude. A comparison of the assessments of the six trials in three different vegetation belts clearly showed that due to the worsening conditions and the naturally low intensity of land use, site-adapted and site-specific species become more and more important with increasing altitude.
In the montane vegetation belt, seed mixtures containing site-adapted but agriculturally useful species should be favoured. In the sub-alpine and alpine-vegetation belts, only seed mixtures containing a high share of site-specific and suitable site-adapted species can guarantee sustainable vegetation and sufficient protection against erosion, which is generally the first and most important aim if reseeding or restoration activities are necessary. Only such species are able to withstand the harsh climatic conditions of such sites. They ensure sustainable vegetation that provides sufficient long-term protection against erosion processes.
The suitability of site-adapted and site-specific seed mixtures for agricultural purposes could also be proved in several previous publications (Krautzer et al. 2003, Graiss 2004, Peratoner et al. 2004, Graiss et al. 2005, Krautzer et al. 2005).

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