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Near-natural restoration methods for high nature value areas

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1. Introduction

In Central Europe, several studies have highlighted the extremely high biodiversity potential of High Nature Value Farmland (HNVF) and, particularly of extensively or less intensively managed semi-natural grasslands. Their biodiversity can be protected by specific conservation measures but also by the use of their seed potential for restoration of degraded or destroyed semi-natural grasslands or the creation of new semi-natural grasslands within the scope of infrastructural interventions or compensation measures.

Restoration of species-rich grasslands is limited by abiotic and biotic constraints. The success of restoration measures depends on abiotic factors such as nutrient status, pH, and hydrology as well as the availability of appropriate seed sources. Restoration success is impeded by depleted seed bank of restoration sites, limited dispersal in fragmented landscapes and decrease or loss of target species in the surroundings.

Early restoration efforts in the 70s and 80s were mostly focused on the removal of nutrients, re-wetting and the re-introduction of an adequate management. In many cases such measures alone were frustratingly unsuccessful and did not lead to the re-establishment of target communities even after successful lowering of nutrient levels and productivity (BAKKER & BERENDSE 1999). Therefore, introduction of target species is of decisive importance for restoration success. In the UK, pioneer work on grassland restoration via sowing was done by WELLS et al. (1986). Since the 1990s, different methods for ecological restoration have been tested by several working groups all over Europe (Reviews see WALKER et al. 2004, KIRMER & TISCHEW 2006, KLIMKOWSKA et al. 2007, KIEHL et al. submitted).

2. State of the art in restoration: sowing of commercial seed mixtures

Commercially produced mixtures comprising genetically uniform and optimised seeds for agriculture or gardening are commonly used for the restoration or re-creation of grasslands across Europe. As these seeds are mostly propagated abroad (e.g. East Asia, Balkan peninsula, New Zealand) they often contain foreign ecotypes, sub-species and even species (MARZINI 2004, FRANK & JOHN 2007), which may threaten local and regional genetic diversity. Several studies indicated that the introduction of foreign ecotypes can lead to higher failure rates in recruitment compared to seeds of local provenance (HUFFORD & MAZER 2003, BISCHOFF & MÜLLER-SCHÄRER 2005). In addition, hybridisation between local and non-native genotypes may dilute native gene-pools and reduce the fitness of subsequent hybrid populations (Keller & Kollmann 2000, McKay et al. 2005). Therefore, it is essential in ecological restoration to use local genotypes to preserve the genetic integrity of local populations (e.g. Sackville Hamilton 2001, Walker et al. 2004). One way to reach this goal is to define "seed zones" for collection and propagation as well as for harvesting of seeds and plant material based on geographical and climatic conditions.

3. Near-natural restoration methods

Compared to the use of commercial seed mixtures, near-natural restoration methods show many advantages. Utilisation of plant material or seeds of local provenance preserve local ecotypes. Harvesting of seeds or plant material in local vegetation communities led to seed mixtures that contained species typical for the region and optimally adapted to local climatic and edaphic conditions. On extreme sites (e.g. nutrient-poor, dry, acid) native species from sites with similar site conditions proved to be more successful than species from commercial seed mixtures. Since commercially bred species are more nutrient-demanding, amelioration of nutrient-deficient sites is necessary to ensure establishment. Especially in cultural landscapes that are characterised by an ongoing eutrophication (e.g. Pearson & Dawson 2005) nutrient-poor site conditions should be preserved since they are most important for nature conservation.

In general, near-natural restoration methods showed a better cost-benefit ratio if follow-up cost and ecological efficiency are included in cost calculations. Especially for ecological compensation after infrastructural interventions, ecological efficiency of the measure is most important (Tischew et al. 2008). Conrad (2006) showed that if total costs of commercial seed mixtures including realisation, maintenance and rework are calculated, the costs are similar or even higher than the total costs for near-natural restoration with (green) hay, transfer of seed-rich chaff and transfer of topsoil with vegetation (sod dumping). This is supported by Marzini and Vollrath (2003) who compared total costs for planting of shrubs of local and foreign provenance on raw soil. They found that in the long run, planting of foreign ecotypes was more expensive because of maladaptation to winter cold. If replacement costs were included into the total calculation, costs for planting of foreign ecotypes was 15 % higher than planting of local ecotypes.

For restoration or creation of high nature value areas, several near-natural restoration methods are available:

- site-specific seed mixtures with seeds from local provenance,
- seed-rich chaff,
- seed-rich hay or green hay,
- hay threshing, on-site threshing, brush-harvesting, vacuum harvesting, raking,
- transfer of turfs and seed-containing soil.

Site-specific seed mixtures with seeds from local provenance

These mixtures comprise seeds that are multiplied by local seed producers using basic seed material hand collected within defined seed zones. The composition of the seed mixtures essentially depend on local preconditions (e.g. climate, exposition, soil, water and nutrient availability). Usually, the mixtures should be based on surveys of the vegetation of natural or near-natural sites which resemble the site to be restored as closely as possible. In comparison, high diversity mixtures of at least 15 species had been more successful than low diversity mixtures of four species (Lepš et al. 2007). As minimum standard, the mixture should comprise of 6-10 grasses and 10-15 herbs. If specific species are required in the mixture, a timely multiplication must be ensured. Dependent on species and availability of basic seed material, seed multiplication needs at least 1-3 years for production.

On ex-arable fields or species-poor grasslands it is decisive to reduce both nutrient status and competition (e.g. perennial weeds, grass sward) before sowing. Since commercial grasses are more competitive than herbs of local provenance it is not recommendable to sow wildflower seeds into swards established from commercial grass mixtures (Jongepierová et al. 2007). To create safe sites for germination and establishment and to enhance water supply, surface forming can be favourable (e.g. caterpillar trucks).

In Germany, for commercial seed mixtures a seeding quantity of 20 g per m² is recommended (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. 2007) that resulted in more than 20,000 grass seeds per m² (Stolle 2006). This produces high competitive pressure regarding space, water and nutrients, especially on nutrient-limited raw soils. In several practical studies a seeding quantity of 1-5 g per m² of site-adapted plant species has been proven to be the optimum seeding quantity (e.g. Jongepierová et al. 2007, Pywell et al. 2007). Under difficult soil or substrate conditions, 200-400 plants per m² will establish quickly, developing optimal root systems which ensure protection against erosion.

On extreme sites, a (seed-poor) mulch layer is favourable to create safe sites for germination and establishment. Material with a tight C/N ratio (e.g. hay, green hay) is more favourable than straw, since during the decomposition of straw a part of the nitrogen resources which are usually restricted on raw soils is used and is hence not available for the developing vegetation (Stolle 1998). In addition, the decomposition of straw can inhibit the germination of seeds from the seed mixture.

The costs are highly variable and depend on the composition of seed mixtures (20-160 € per kg) and on the method used for sowing: drilling machinery 25-100 € per ha; by hand c. 1000 € per ha; hydroseeding 2500-15,000 € per ha (Mann 2006 and M. Stolle, pers. comm.).

Example: target vegetation mesic grassland

Mined site Roßbach, Saxony-Anhalt/Germany, raw soil, disturbed loess, pH value ($CaCl_2$) 7-7.5
Sowing of 6 grasses and 15 herbs (2 g /m², 890 seeds /m²) on 0.3 ha in September 2000
Mulching with green hay from second cut of Saale dikes with very low seed content (thickness c. 5-10 cm) to prevent erosion
Contact person: Anita Kirmer, a.kirmer@loel.hs-anhalt.de
Results (after 7 years):

Mulch sowing plots:	fast vegetation development, no erosion, final establishing rate of sown species: 81 %; cumulative coverage of herb layer 131 %, percentage of target species on total coverage 96 %
Control plots:	slow vegetation development, partly with deep erosion channels, cumulative coverage of herb layer 76 %, percentage of target species on total coverage 65 %

Seed-rich chaff

One of the oldest methods for species introduction that dates back to Roman times is the transfer of seed-enriched chaff, harvested on hay-barn floors due to hay storage. Since the Middle Ages, farmers used the seed-rich material to establish new grasslands. In general, the quality of the chaff depends on the meadow quality and on the time of hay making (Losvik & Austad 2002). In Central Europe, species-rich hay meadows are becoming rare and traditional hay making and storage in barns is on the decline. In Germany, the material is often difficult to obtain.

The costs for this methods are calculated with 1200 € per ha if sown by hand (R. SCHUBERT, pers. comm.).

Example: target vegetation dry mesic grassland
City of Chemnitz, raw soil, sandy loam
Collection of seed-rich chaff in a barn between June and September 2005
Application of the seed-rich chaff by hand in November 2005 with 250 g/m²
Contact person: René Schubert, DVL-Saatgut@gmx.de
Results (after 2 years):
43 plant species in second vegetation period, low growth forms, very attractive because of many flowers, low management effort (one cut per year)

Seed-rich hay and green hay

In most studies, the plant material was mown at the time of maximal seed set of target species and immediately transported to the receptor sites (e.g. PYWELL et al. 1995, KIRMER & MAHN 2001, HÖLZEL & OTTE 2003, KIEHL et al. 2006, DONATH et al. 2007). Commonly, only one cut is used. Some studies harvested seed-rich hay (e.g. SCOTTON et al. 2009) that is easier to transport and can be stored for later use. Different harvest times can be mixed and applied together. Dependent on the hay-making process the amount of seeds is lower than in green hay. If donor sites are lacking important target species or if the harvesting time is not optimal for seed set, additional sowing of missing species is recommended.

Donor and receptor sites must have similar site conditions. The appropriate amount of applied plant material depends on plant community type, productivity and site conditions. Fine material should be spread in thinner, coarse material in thicker layers. Mostly, a layer of 5-10 cm thickness (0.5-1 kg per m²) is useful. At restoration sites with steep slopes and mobile substrate, e.g. in mined areas, the mulch layer provides an effective erosion control (KIRMER & MAHN 2001). On bare soils, the mulch layer provides safe sites for germination and establishment by improving moisture conditions. In addition, the decomposition of the material released a low amount of nutrients.

The use of green hay prevents that the material is blown away because the drying process adhered the material to the soil surface. If hay is used, the material must stay on the site for at least one night: dew building during the night and subsequent drying also led to adhesion of the material to the surface.

The costs for harvest and application range between 500-3000 € per ha dependent on properties and conditions of donor sites (MANN 2006).

Example: target vegetation calcareous grassland
Restoration of calcareous grassland on ex-arable fields north of Munich/Germany; with and without removal of 40 cm nutrient-rich topsoil, substrate: calcareous gravel, pH 7.2
Mowing of donor site on 27th August 1993
Application of seed-rich green hay on 27th August 1993 with 0.23 kg dry weight per m² (c. 5 cm)
Contact person: Kathrin Kiehl, k.kiehl@fh-osnabrueck.de
Results (after 13 years):

Without topsoil removal:	final establishing rate of all transferred species 67 %, of transferred target species 55 %; cumulative coverage of herb layer 127 %, percentage of target species on total coverage 73 %
With 40 cm topsoil removal:	final establishing rate of all transferred species 70 %, of transferred target species 66 %; cumulative coverage of herb layer 51 %, percentage of target species on total coverage 95 %

Hay threshing, on-site threshing, brush harvesting, vacuum harvesting, raking

All these methods have in common that mainly seeds are harvested (exception: raking). The harvested material can be transported, stored (after drying) and applied more easily than (green) hay. Just like the other methods, the site conditions on donor and receptor sites must be quite similar. Harvesting of seeds is required when target species have ripe seeds. Different harvest dates can be mixed and sown together.

Difference between methods:

- hay threshing (ENGELHARDT 2000): harvesting of green hay, controlled drying in barns and subsequent threshing of the dried material; often several harvests are mixed together; in Germany, the method is patent-protected with guaranteed success and liability by the owner of the trademark (www.heudrusch.de),
- on-site threshing : cutting off the sward and threshing the fresh material on the site with a harvester,
- seed brushing (EDWARDS et al. 2007) or seed stripping (SCOTTON et al. 2009): seeds are brushed off with a special machine (brush harvester) without cutting the vegetation; seed content is lower and low-growing species are underrepresented; more than one harvest can be necessary,
- vacuum harvesting (STEVENSON et al. 1997, THORMANN et al. 2003): seeds are sucked up with a special machine (vacuum harvester) without cutting the vegetation; seed content is rather high and even early flowering or low-growing species can be transferred; usually one harvest is sufficient,
- raking (STROH et al. 2002, JESCHKE 2008): harvesting of mosses, lichens and low growing vascular plants by hand with a rake (optimal in low productive grasslands); one harvest is sufficient.

The costs of hay threshing (harvest, drying, threshing, application via hydroseeder, germination tests) range between 6000 and 16,000 € per ha. Within the SALVERE project, the costs for on-site threshing and brush harvesting will be calculated.

Transfer of turfs and seed-containing soil

The translocation of species assemblages by transfer of abiotic and biotic components can be accomplished by different means (BULLOCK 1998): (1) hand turfing involving cutting and lifting of small turfs using spades, (2) machine turfing with earth-moving machinery, (3) macroturfing with specially designed equipment to cut and lift very large turfs, (4) spreading of excavated soil and vegetation (= sod dumping). In England, there is a long tradition of habitat transfer covering a wide variety of plant communities (BYRNE 1990, BULLOCK 1998). SCHWICKERT (1992) gives an overview about different transplantation projects in Germany and Switzerland.

With the exception of heathlands, the donor community will be destroyed by harvesting of turfs or overburden. Therefore, only vegetation communities threatened to be destroyed by infrastructural interventions (e.g. road/railway construction, mining activities) should be considered as donor sites.

The sod dumping technique can be used as a method for introduction of hospitable soil, soil micro-organism, soil seed bank and vegetation fragments in order to enable the development of a similar plant community on the receptor site. By contrast, turf transplantation is aiming to transfer a complete vegetation community and maintain it unaltered on its new locality (BRYNE 1990). In every case, the donor and receptor site must have similar site conditions regarding hydrology, substrate, and nutrient status. Turfs can be stored for some time with a maximum base area of 1 m² and a height of 0.6 m - in winter without problems, in summer maximal for four weeks (SCHIECHTL & STERN 1992).

The costs can be rather high and vary between 2500 and 30,000 € per ha dependent on properties and conditions of donor sites and depth of soil removal (MANN 2006).

Example: target vegetation psammophytic grassland

Mined area Goitzsche, Saxony-Anhalt/Germany, substrate: silty-loamy sand, raw soil, pH 3-4, nutrient-deficient
Removal of topsoil in a species-rich psammophytic grassland by hand with spades
Application of topsoil by hand in June 1995, amount c. 10 kg per m²
contact person: Anita Kirmer, a.kirmer@loel.hs-anhalt.de
Results (after 10 years):

Sod dumping plots:	microrelief prevented erosion, cumulative coverage of herbs and bryophytes/lichens 83 %, percentage of target species on total coverage 93 %, final establishing rate of transferred species 69 %
Control plots:	deep channel erosion, cumulative coverage of herbs and bryophytes/lichens 70 %, percentage of target species on total coverage 33 %

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Summary

For restoration and creation of high nature value areas several near-natural restoration methods are available. Seeds and plant material of local provenance enables the development to vegetation communities typical for the region, thereby contributing to the preservation of regional biodiversity as requested in the Convention on Biological Diversity. Material from management measures in nature protection areas is the best choice and guarantees a high quality. With transfer of seed-rich material from suitable donor sites, dispersal limitation can be overcome. It is decisive to chose donor and receptor site with similar site conditions (hydrology, substrate, nutrient status) because abiotic conditions will determine long-term restoration success.

In general, knowledge transfer into practice must be increased to deal with prejudices regarding success, effort and costs of these methods. Anyway, sustainability and ecological efficiency must be included into discussions about costs because near-natural methods have a better cost-benefit-ratio. For a broader implementation it is necessary to reform legal and organisational frameworks:

- the demands of the Convention on Biological Diversity must be met more strictly and should be effectively embedded in national laws,
- public procurements must request the use of local provenance in restoration activities (e.g. compensation measures, re-vegetation after infrastructural interventions),
- information platforms and donor site registers must be developed because they are effective tools to facilitate the applicability of near-natural restoration methods.