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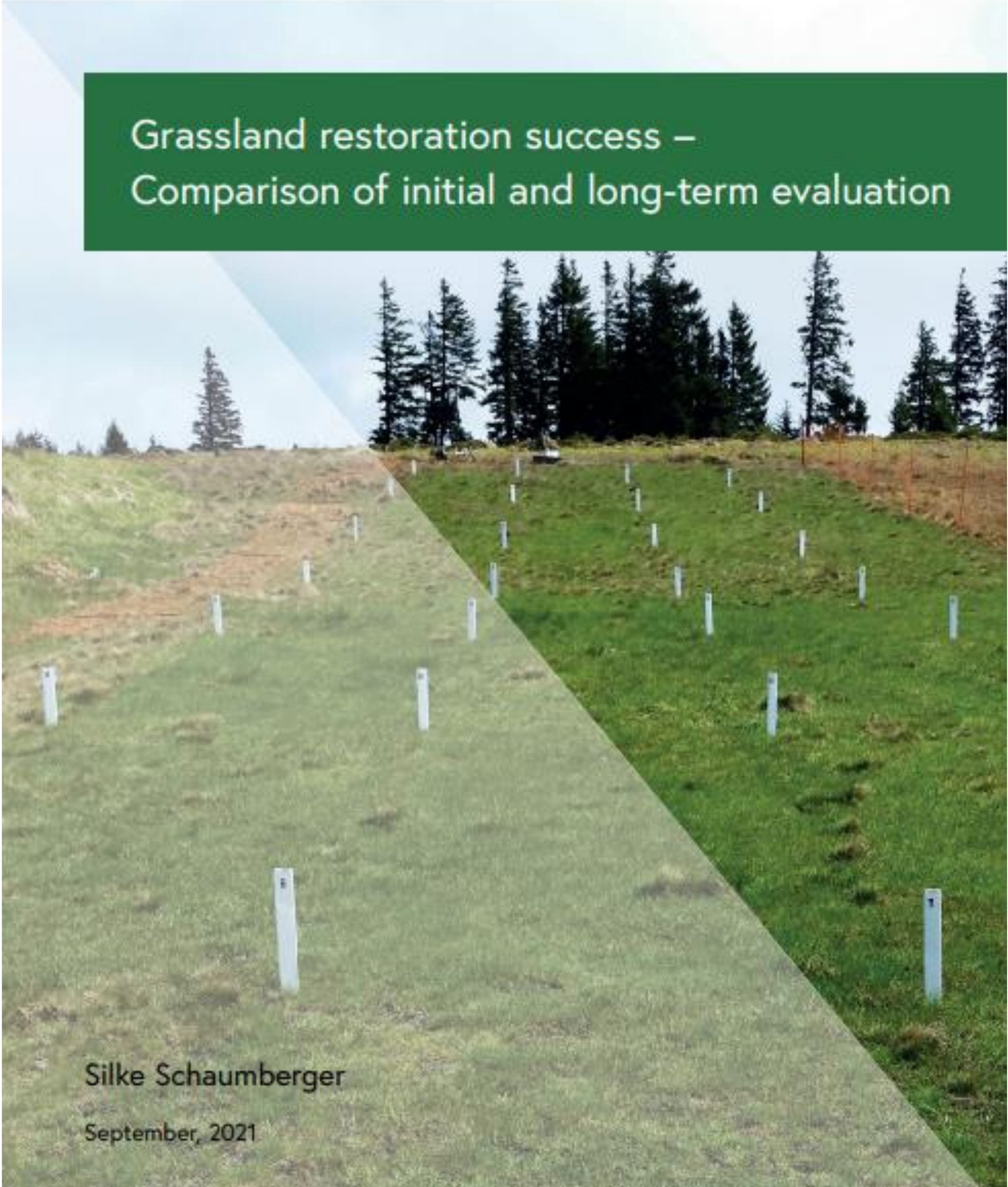

Grassland restoration success – Comparison of initial and long-term evaluation

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Universität für Bodenkultur Wien
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Doctoral Dissertation

Grassland restoration success –
Comparison of initial and long-term evaluation

submitted by

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Wien, am 14. September 2021 ....

Silke Schaumberger

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Silke Schaumberger

Abstract

Grassland comprises a very diverse ecosystem, that can be found in different variations all over the world. It plays an important role, as it provides forage and pasture fields for agricultural use and belongs to the cultural heritage. Apart from that, grassland provides numerous crucial ecosystem services like water cycle regulation, CO_2-fixation and erosion protection. But grassland is also of utmost importance for biodiversity, as especially marginal lands are hosting a lot of different floristic and faunistic species.

Restoration of grasslands is often necessary and can follow a wide variety of objectives, but one aspect is almost the same: projects concerning grassland restoration usually have a similar funding and working period of approx. 3-5 years. At the end of these periods, an evaluation is usually conducted in order to evaluate the respective success of the project. As grassland and its vegetation is very dynamic, it is questionable if a valid evaluation is always possible after such a short time. Therefore, the following research questions were addressed: (I) Are there differences between short-term and long-term evaluation of grassland restoration success? (II) Which aspects support the recommendation for long-term evaluation of grassland restoration success (III) Is there a benefit on an extended observation period beyond the usual project observation time span?

Two restoration projects were re-surveyed about one resp. two decades after experimental set-up and the results were compared with the initial evaluation. The Eschwald wood pasture separation project focused on creating new pasture grounds for cattle grazing on an acidic site. Different seed mixtures were applied and a single liming treatment during experimental set-up was also analyzed. The site was re-surveyed 16 and 18 years later and the results of vegetation surveys and laboratory forage analyses were compared. The second restoration experiment belonged to a set of experiments within the Central-Europe-Project SALVERE: species-rich grassland was transferred by green hay or by on-site-threshing from a donor site to a receptor site. The restoration success of both methods was re-surveyed 10 years after the set-up again with vegetation surveys and these results were also related with the first evaluation results.

The re-surveys of both restoration projects showed differences between initial and long-term evaluation (research question I). During the first evaluations, the vegetation had not finally reached a balanced stadium. This may be caused by too less time or by ongoing changes of soil, climate or management conditions. If such developments are identified or known, it is recommendable or even necessary to extend the observation period (research question II). Several potential benefits of long-term observations were identified within the present work (research question III): The re-survey of the wood pasture separation revealed that a single lime fertilization during trial set-up still leads to significantly better cover and yield parameters, even after nearly 20 years. The SALVERE experiment showed, that even under differing site conditions, species-rich grassland can successfully be transferred and established in the long term. Additionally, the long-term observation of both restoration projects helped to detect the invasion of unwanted species.

All these aspects can be considered for practical advice and activities in the future. Therefore, the relevance of long-term studies is often not known in the beginning, but they can reveal unexpected findings and raise new questions. And in any way, long-term experiments will become even more important in the future, especially for analyzing and understanding the global changes we are facing.

Keywords:

grassland, recultivation, long-term observation, vegetation dynamics, restoration success

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1 Introduction

1.1 Definition and short history of grassland

A common definition of grassland seems to be difficult, as this term comprises a huge variety of different lands and their vegetation. According to Gibson (2009) and Allen *et al.* (2011), grassland vegetation is often dominated by grasses and also contains legumes and forbs with different shares, woody species are usually missing. Many further distinctions are possible, mainly depending on origin (natural, anthropogenic), utilisation (meadows or pastures), intensity of use (moderate or intensive/improved) and duration of vegetation (permanent, temporary) (Allen *et al.*, 2011, Gibson, 2009, Hejcman *et al.*, 2013).

Grassland naturally occurs where site conditions prevent tree growth by e.g. shallow soils and rocky ground (mountains), changing (ground) water levels (boggy areas, marshland and often flooded land), dryness (steppe), temperatures (high altitudes), etc. (Dierschke und Briemle, 2002, Hejcman *et al.*, 2013). On forested sites, grassland developed mostly due to biotic and anthropogenic influences (Hejcman *et al.*, 2013).

Before the Neolithic, the development and maintenance of Central European grassland at potential forest sites was induced by animals like beavers, due to their (flooding) activities, but especially by herbivores like wild horses, red and roe deer, aurochs and bison. From the Neolithic until the Iron Ages, the share of anthropogenic grasslands (pastures as well as wood pastures for domesticated animals) and arable fields still was relatively low. In Central Europe, appropriate scythes for grass cutting can be dated back to 500-600 BC – meadows then became a possible kind of agricultural use (Hejcman *et al.*, 2013). Ancient pasture management and hay making led to the development of species-rich extensive pastures, wood pastures and meadows that were widespread throughout Europe, also known as semi-natural grassland (Hopkins, 2009).

Today, grassland still plays a world-wide, essential role for meat and milk production dedicated to human nutrition (FAO, 2005). Within the EU, grassland still covered about 17.4 % of the total area in 2018 (EU, 2018). Concentrates are nowadays usually supplied for highly productive animals in order to secure sufficient energy intake. However, sufficient supply with structural fiber from fresh or conserved grass is also crucial for animal health (Plaizier *et al.*, 2012, Zebeli und Metzler-Zebeli, 2012). Nevertheless, the demands of a lot of live-stock bred for high performance inquire sufficient amounts of high-energy forage. So marginal lands were abandoned or afforested, whereas on more productive sites, fertilization and frequency of use increased (Krautzer *et al.*, 2011b). This enabled the wide-spread establishment of highly nutritive grass species and the harvesting of more biomass. But the intensification of grassland changed the habitat conditions and only few species are able to persist on such sites.

1.2 Problems and challenges

Grassland habitats are very important for biodiversity: 18% of Europe´s endemic vascular plants are associated with grassland (Hobohm und Bruchmann, 2009, Isselstein, 2018). Especially for insects like butterflies, wild and honey bees as well as other pollinators, flower-rich semi-natural grassland is essential (Biesmeijer *et al.*, 2006, Wallis De Vries und Van Swaay, 2009). The ongoing decline of butterflies and pollinating insects and the following loss of insectivorous animals like birds emphasizes the crucial role of grassland habitats. The disappearance of species-rich marginal lands like dry grasslands or litter meadows led to a strong decline of floristic and faunistic diversity (Habel *et al.*, 2013, Poschlod und Wallis De Vries, 2002). Only small patches of the mentioned originally species-rich grasslands are left until today. And they are not only threatened by management changes, there is also a general loss of (grass)land due to soil sealing (Nestroy, 2006, Virto *et al.*, 2015).

Additionally, reseeding is often necessary on intensively used pastures and meadows and the applied commercial seed material mainly contains only a few cultivars of high-performance grasses – this leads to a constant loss of genetic diversity regarding original grassland species. Genetic diversity of the ‘crop-wild relatives’ of agriculturally used plants is very valuable, as they form the source for breeding activities for cultivation, which is getting more important in consideration of climate change and connected challenges for plants (Meilleur und Hodgkin, 2004). Unfortunately, there is hardly any awareness of this problem with regard to forage-producing species.

But grassland is not only important for agriculture, human nutrition and as a habitat, its cultivation has a long tradition and meadows and pastures are an important part of cultural landscapes. They are also contributing to the attractiveness of the landscape and therefore support tourism and recreation in general (Parente und Bovolenta, 2012).

In summary, grassland provides a lot of important ecosystem services like provisioning (food, water, genetic diversity), regulating (climate, air and water quality, avoiding soil erosion and water run-off), supporting (soil formation, carbon fixation, nutrient and water cycling) and cultural services (health, well-being, aesthetics, recreation) (Millenium Ecosystem Assessment, 2005, Schellberg und Pötsch, 2014).

Especially in regard to climate change, the functionality of grassland like water and CO_2 retention is very important, but the changing climate conditions will influence grassland and its species composition itself– increasing drought periods and CO_2-concentration within the atmosphere are also upcoming challenges for grassland species, their impact is already an issue of research (Deléglise *et al.*, 2015, Meeran *et al.*, 2021, Pötsch *et al.*, 2019a, Pötsch *et al.*, 2019b, Schaumberger *et al.*, 2019).

1.3 Grassland restoration

Grassland restoration in general aims at (re-)establishing grassland for many different purposes: apart from the main purpose of producing forage, wide-spread goals are maintaining or re-establishing cultural landscapes or creating precious habitats either for specific floristic or faunistic species or groups (like *Crex crex*, *Iris sibirica*, pollinators, etc.) or 'just' establishing habitats with high biodiversity (Isselstein, 2018). Seed material is usually spread onto prepared soil – the seeds can be pure like seed mixtures, but especially during restoration processes for nature conservation or biodiversity issues, plant or soil material is also transferred. Different techniques are known and applied, depending on restoration aims and circumstances like costs and logistics of the respective restoration activity (Kiehl *et al.*, 2010, Rydgren *et al.*, 2010, Török *et al.*, 2011).

Natural regeneration seems the easiest way to restore grassy vegetation, just waiting for plants to conquer back the restoration site. No costs occur in the first time (but usually later when removing unwanted species, management like cutting, etc.), but, as Rydgren *et al.* (2010) and Prach *et al.* (2014) reported, the desired vegetation development is slow in comparison with other restoration methods. Additionally, the invasion of unwanted species from soil seed bank or other seed vessels (wind, animal fur, etc.) is possible and may happen very quickly. Nevertheless, it may be an appropriate possibility if it is used interspersed with e.g. hay or vegetation sods, but only if soil erosion is no issue (Rydgren *et al.*, 2010).

The transfer of vegetation sods and seed-containing soil is also reported in literature (Kiehl *et al.*, 2010, Rydgren *et al.*, 2010, Sengl *et al.*, 2017) and may be appropriate in some cases, e.g. for small restoration sites and used as triggers for invasion from the sod vegetation. But it often goes along with heavy damage at the donor sites and therefore it is not advisable for wide-spread application.

The procedure of (light or hard) raking is recommendable especially for low growing species as well as bryophyte and lichen transfer. Raking material is sometimes gathered due to management activities like creating gaps on grasslands of high conservation value (Kiehl *et al.*, 2010).

The most frequently used method for establishing grassland in agriculture and nature protection usually is the application of different seed mixtures, according to the specific purpose. Harvesting seed material with machines for grassland transfer is also part of restoration practice: the necessary equipment for cutting hay (mowers) or gaining threshed material (threshers) is more easily available than seed-strippers or vacuum machines (Kiehl *et al.*, 2010), so the latter ones are less wide-spread. In the present work, the applied restoration methods were based on seed mixtures, green hay and on-site-threshing. These methods are explained in more detail below.

1.3.1 Application of seed mixtures

Grassland restoration by soil preparation and seeding of seed mixtures is widely used in agricultural practice. The choice of seed mixtures always depends on the planned use (grazing, cutting, site conditions, etc.). For regular agricultural use, the application of commercially produced seed mixtures is widespread. Its seed material is based on only a few high-performance species cultivars and is genetically limited. Additionally, the cultivars are often based on foreign ecotypes or subtypes and sometimes even on foreign species, and the seeds are propagated in different countries and different climatic zones (Kirmer und Tischew, 2006). The widespread use of this kind of seed mixtures may endanger local and regional genetic diversity and additionally, they often fail under suboptimal conditions like rougher climate or more acidic soil, as they are ‘designed’ for conventional grassland farming in favourable regions (Krautzer *et al.*, 2011a). Site-specific and autochthonic seed material is the best choice for establishing grassland, at least for ecological restoration and under challenging site conditions – especially if it comprises regional high genetic diversity (Bucharova *et al.*, 2019). This is due to its better adaption regarding regional climate conditions than in comparison with common commercial seeds that have been bred and propagated in other climatic regions (Hancock *et al.*, 2013, Vander Mijnsbrugge *et al.*, 2010).

Nowadays, it is possible to purchase certified wild plant seeds with traceable place of origin and propagation in Austria. Austria as well as some other European countries already successfully defined biogeographical regions and established certificates for regulating, propagating, distributing and using wild plant seeds (Bucharova *et al.*, 2019, Durka *et al.*, 2017, Krautzer *et al.*, 2018, Rometsch, 2009).

1.3.2 Hay transfer

The transfer of green (or also dried) hay is a quite simple but effective method and is already known for successful restoration of species-rich grasslands (Kiehl *et al.*, 2010, Rydgren *et al.*, 2010, Török *et al.*, 2011). Fresh plant material is cut, transported and then spread at the restoration site. The harvesting date depends on the ripening status of the desired species' seeds (if target species are involved) or is related to the seed ripening of most species (e.g. for establishing species-rich grassland). The advantages of hay transfer are low costs as only a mower and a transport vehicle are necessary. The mulching layer may have positive impact on microsite-climate and therefore can support germination processes. Additionally, the material may prevent soil erosion and water loss. Challenges are the identification of a suitable donor site, the optimal harvesting date and a quick transport to the receptor site (Kirmer und Tischew, 2006, Török *et al.*, 2011, Wagner *et al.*, 2021). An appropriate area ratio (biomass of x m^2 of donor site is spread on y m^2 of receptor site) is also important – too few material often does not contain enough material and too much material prevents proper germination and may inhibit the restoration process (Kiehl *et al.*, 2010).

1.3.3 Transfer of threshed material

Threshing of species-rich grasslands is also a good possibility to gain seed-rich material for restoration purposes (Kiehl *et al.*, 2010), even if Scotton und Ševčíková (2017) claimed green hay transfer as more efficient. Donor site vegetation is harvested with a threshing machine and the gained material then needs to be processed. Once the threshed material is correctly cleaned and dried, it can be stored for quite some time and may be used for more than one site, if appropriate. The necessary use of machines is not possible on all sites (e.g. if too wet or too steep) and usually this kind of machine needs to be borrowed and driven by an experienced person – this makes it a more expensive method than e.g. the transfer of fresh material.

1.3.4 Restoration success and challenges of evaluation

The success of restoration activities always needs to be connected to the individual restoration goals, that, according to Waldén und Lindborg (2016) and Prach *et al.* (2019), need to be clear and concise and should also be (easily) measurable by suitable indicators. Such goals could be e.g. production of forage (Schaumberger *et al.*, 2020), the establishment of specific 'target' species, the establishment of general species-rich grassland (Kiehl *et al.*, 2010), improving landscape structures, ecosystem services, desired community species composition and many more (Prach *et al.*, 2019). This wide range of goals results in the necessity to choose an appropriate evaluation method for the respective goal. Prach *et al.* (2019) recommend to focus on a few well-selected indicators that are easily measureable, clearly interpretable and which are mechanistically related to the structure or process they are supposed to indicate.

A lot of different possibilities to evaluate restoration success of species-rich grassland are already mentioned in literature: Indicators used for restoration success evaluation are for example the Shannon diversity index for comparison with reference or donor sites (Sengl *et al.*, 2017) and similarity coefficients (Conrad und Tischew, 2011). Further possible indices are different vegetation cover data like cover of seeded/transferred species or species groups. Especially for forage grassland, yield and forage quality parameters like biomass and nutrient content values may also be applied for evaluating the gained forage quality (Pötsch *et al.*, 1998). The assessment and measurement of some of these indicators are based on specific knowledge (e.g. species identification during vegetation survey) or equipment (e.g. laboratory analyses of content), these requirements need to be taken into account when planning the evaluation process.

Kiehl *et al.* (2010) focused on vegetation data from donor and receptor sites for their review of restoration techniques and calculated ratios in form of transfer rates. Different rates were used: absolute transfer rates show "*the percentage of transferred species in relation to the total number*" of donor site species, whereas the relative transfer rate provides "*the percentage of transferred species in relation to the number of potentially transferable species*", based on viable seeds within the plant material (Kiehl *et al.*, 2010). Within this context the transfer rate of the final evaluation is addressed as final establishment rate (Kiehl *et al.*, 2010).

Time itself is directly addressed as an evaluation tool by Auestad *et al.* (2020), who have developed an ordination-regression-based approach in order to predict time to recovery

(Rydgren *et al.*, 2019, Rydgren *et al.*, 2020). But this approach may not be suitable for all restoration sites, e.g. if receptor site and donor/reference site may not provide identical (site) conditions for the vegetation (Schaumberger *et al.*, 2021, Sullivan *et al.*, 2020).

Nevertheless, a deficiency of restoration success evaluation approaches seems to be that there is no clarity regarding the optimal timing for final evaluation.

1.3.5 Duration of restoration observation

Most (grassland) restoration projects are limited in costs – and this also necessarily results in limitations of monitoring and evaluation time. Project results and success usually need to be assessed before money and time are running out, which is usually the case after 3-5 years at the latest (Lengyel *et al.*, 2012, Rydgren *et al.*, 2010). But as grassland vegetation is highly dynamic – is it possible to really give answers about restoration success after such a short period? In regard to grassland restoration, the necessity of longer monitoring periods is already discussed (Bischoff *et al.*, 2018, Mudrák *et al.*, 2017, Rydgren *et al.*, 2010).

Ellenberg und Leuschner (2010) mention 3-4 years as sufficient for e.g. the establishment of a *Salvia-Arrhenatheretum*-like vegetation under suitable conditions. Nevertheless, even if a grassland vegetation has reached a kind of equilibrium after some years (Ellenberg und Leuschner, 2010), occurring changes of environmental conditions may change vegetation in regard to species composition (Pötsch *et al.*, 2015). This in turn influences the long term success of grassland restoration, if e.g. unwanted species are invading or target species disappear.

So time obviously is a very important issue for evaluating restoration success: Grassland vegetation is subject to strong dynamics, as the establishment and persistence of species is influenced by e.g. climate, biotic and abiotic soil conditions, management aspects (frequency of mowing/grazing) and inter- and intraspecific competition. The achievement of an equilibrium needs time and additionally, all these aspects may change over time. This makes it quite difficult to find the optimal time to evaluate restoration success.

2 Frame and objectives

2.1 Hypothesis and research questions

The Agricultural Research and Education Centre (AREC) Raumberg-Gumpenstein in Austria regularly conducts applied research experiments considering a wide range of topics with agricultural background. As common in science, most experiments do not exceed the typical project period of approx. 3-5 years. Nevertheless, we were able to extent two different restoration projects. The results of an additional long-term evaluation was compared with the evaluation at the end of the original project period – this was the basis for the two published manuscripts.

The following research questions were addressed:

(1) Are there differences between short-term and long-term evaluation of grassland restoration success?
(2) Which aspects support the recommendation for long-term evaluation of grassland restoration success?
(3) Is there a benefit of an extended observation period beyond the usual project observation time span?

2.2 Eschwald wood pasture separation process

In 1998, AREC Raumberg-Gumpenstein scientifically accompanied grassland restoration activities within the wood-pasture separation process at the acidic site of Eschwald (Graiss, 2004). Woodland was clear-cut in order to create a cattle pasture in compensation for the relinquishment of grazing rights within the wood. Different seed mixtures (commercial, site-adapted, site-specific and unseeded control plots) were applied and firstly scientifically monitored for 3-4 years after establishment in regard to vegetation and yield parameters. As the site was very acidic, the impact of a single lime application at trial setup was also tested within the experiment. Afterwards, the new pasture was used according to its purpose as a montane cattle pasture in summer time. No changes or manipulations were conducted, so 16 and 18 years after the establishment, a long-term evaluation with vegetation surveys and laboratory analyses of forage was conducted (Schaumberger *et al.*, 2020) in order to compare the results with the former ones of the initial monitoring (Graiss, 2004).

2.3 Central-Europe project SALVERE: semi-natural grassland as a source of biodiversity improvement

AREC Raumberg-Gumpenstein was one of eight partners from six countries that worked together within the EU-project SALVERE (2009-2011). The main issue was to stop decline of biodiversity and to contribute to semi-natural grassland biodiversity protection by using propagules of potential donor sites for restoring species-rich grassland on different sites like former arable land, ski slopes, opencast mining areas and road embankments (Haslgrübler *et al.*, 2011). Different aspects were analysed like seed production (Scotton, 2020), seed harvesting (Scotton und Ševčíková, 2017), seed quality (Haslgrübler *et al.*, 2013), influence of different restoration management tools like donor site harvesting time and sowing density (Scotton, 2016) and a practical handbook was elaborated (Scotton *et al.*, 2012). Among other things, different methods for harvesting seed material from species-rich grasslands were compared with each other. Schaumberger *et al.* (2021) conducted a long-term comparison of the two harvesting methods green hay and threshing regarding their restoration success at a receptor site. Seed material was harvested at a species-rich donor site, analysed and transferred to a receptor site at the trial field at Gumpenstein. Vegetation surveys were conducted quite regularly (seven out of ten years) and the development of vegetation parameters like species composition, cover of transferred species, species groups, and transfer rates were analysed over a ten-year period.

3 Publications

3.1 Publication 1: Long-term sustainability of wood pasture separation processes – A matter of seed mixtures and management

Schaumberger, S., Krautzer B., Graiss W. and Pötsch E.M. (2020): Long-term sustainability of wood-pasture separation processes – A matter of seed mixtures and management. *Grass and Forage Science* 75 (3), 303-315. https://doi.org/10.1111/gfs.12477

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ORIGINAL ARTICLE

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Long-term sustainability of wood-pasture separation processes—A matter of seed mixtures and management

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Abstract

We studied the performance of different seed mixtures and the influence of liming on the establishment of a montane pasture under acidic site conditions during a wood-pasture separation process from 1998 to 2001 in Styria, Austria. Two treatments (with and without liming) were established, each with four seeding treatments (without seeding, commercial, site-adapted and site-specific mixtures), and all plots were regularly fertilized from 1998 to 2002. Vegetation surveys and forage analyses regarding development of vegetation cover, seeded species persistence, quality and yield parameters were conducted again in 2014 and 2016; soil samples were taken in 2015. After cessation of regular fertilization, the analysed soil parameters declined to levels that were sufficient or low for grasslands. pH decreased again over time, but still was significantly higher (p = .0034) in the liming treatment. The single liming during experimental set-up also caused better long-term performance for nearly all vegetation, quality and yield parameters. The site-specific seed mixture performed best regarding most analysed parameters, under both liming treatments. Concerning seeded species, the habitat-typical species *Agrostis capillaris*, *Festuca rubra* agg. and *Trifolium repens* persisted best with and without liming. All analysed vegetation and yield parameters stayed far behind their results of 2001 and their potential. The use of site-specific seed mixtures supports the establishment of productive grassland on specific locations. The long-term results also illustrated that even low-input management like liming in multi-annual intervals can help to improve acidic site and growing conditions significantly and thereby increases the sustainability of cost-intensive wood-pasture separation processes under similar conditions.

KEYWORDS
forage quality, liming, pasture restoration, seeded species, site-specific, vegetation cover

1 | INTRODUCTION

Wood pastures are a type of agroforestry, which was widespread in Europe back until the Neolithic time (Hartel, Plieninger, & Varga, 2015; Mosquera-Losada et al., 2012). In South-East and Central Europe, wood pastures can be traced back 7,500 years (Bergmeier, Petermann, & Schröder, 2010). Due to changes in agricultural management, wood pastures experienced a strong decline in the last century (Buttler, Kohler, & Gillet, 2009), but they are still practised in some regions, e.g. in the Alps (Buttler et al., 2009; Plieninger et al., 2015). Servitudes in Austrian forests were introduced when the common use of forestland was banned in the 11th century, repeatedly restructured and in the late 19th century a lot of servitudes were discharged. In 1992,

3.2 Publication 2: Succesful transfer of species-rich grassland by means of green hay or threshing material – does the method matter in the long term?

Schaumberger, S., Blaschka A., Krautzer B., Graiss W., Klingler A. and Pötsch E.M. (2021): Successful transfer of species-rich grassland by means of green hay or threshing material – does the method matter in the long term? *Applied Vegetation Science* 24 (3), 24:e12606. https://doi.org/10.1111/avsc.12606

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RESEARCH ARTICLE

Applied Vegetation Science IAVS

Successful transfer of species-rich grassland by means of green hay or threshing material: Does the method matter in the long term?

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Abstract

Questions: We investigated the transfer of seeds from species-rich grassland using green hay and seed material from on-site threshing to answer the following questions: do these two methods differ in terms of restoration success; and how do the two methods behave in their long-term effect concerning species composition and species presence?

Location: Styria, Austria.

Methods: We harvested seed material of a species-rich *Arrhenatherion* meadow by green hay and on-site threshing and transferred it to a receptor site. Transferable species were identified by vegetation survey and seed sample analyses. We analysed transfer rates and vegetation cover for the donor site species pool and *Arrhenatherion* target species, covering a 10-year observation period. Species composition and presence were derived from plant surveys.

Results: The restoration success of both methods was similar within the observation period. Although donor site species declined, the establishment of target species was satisfactory and species-rich grassland was successfully established, despite different site conditions between donor and receptor sites and strong dynamics in species composition over time.

Conclusions: Both harvesting methods are well suited for restoring species-rich grassland, and the actual choice ultimately depends on the costs and the given circumstances. Even if donor and receptor site differ in their site conditions, species-rich grassland can be established successfully. The prerequisite for this is that: (a) a high proportion of transferred species is able to establish; and (b) specific restoration goals do not exclude vegetation development according to specific receptor site conditions.

KEYWORDS
Arrhenatherion, grassland, green hay, high-nature-value farmland, long-term effect, on-site threshing, restoration success, species-richness, vegetation transfer

4 Discussion

In comparison with their initial evaluation results, the long-term observations of both restoration projects revealed differences and showed developments that were not able to be foreseen during the first evaluation (Schaumberger *et al.*, 2020, Schaumberger *et al.*, 2021).

4.1 Differences between short-term and long-term evaluation

The Eschwald wood pasture restoration as well as the seed transfer of the two harvesting methods during the SALVERE project have both been evaluated as successful and very satisfying within the first evaluation three years after trial setup. Nevertheless, both re-surveys differed from their original results, especially the wood pasture separation: from the long-term point of view, the results did seem less successful than within the short-term evaluation. Analysing the circumstances of both experiments revealed changes in abiotic and biotic environmental conditions, which weren´t finished before the short-term evaluation. Additionally, differences in donor and receptor site influenced the duration of equilibrium achievement at the SALVERE experiment. According to Sullivan *et al.* (2020), time was already identified as significant effect on species composition of restored meadows, as some transferred species may not be able to persist in the long term and some may establish later – we also observed such time-taking developments that were not able to be pictured within the initial evaluation and are in line with the findings of Mudrák *et al.* (2017).

4.2 Aspects supporting the recommendation of long-term evaluation

Ellenberg und Leuschner (2010) and Pötsch *et al.* (2015) already mentioned the importance of continuous conditions like fertilization and land use management as a precondition for establishing and maintaining a stable grassland community, with an equilibrium regarding nutrient flows, soil conditions and floristic composition. Taking a closer look at the two re-surveyed grassland restoration experiments revealed that this has not been the case at the time of the first evaluation. So obviously, a too early conduction makes a valid evaluation of restoration success more difficult. Within the two re-surveyed experiments, a missing botanical equilibrium as well as changes in environmental conditions were identified as important drivers for alterations of vegetation composition.

4.2.1 Effects of soil and climate conditions

At the Eschwald wood pasture separation, the (unforeseen and unplanned) neglection of any fertilization after the trial period led to a return of soil acidity and hence the growing conditions for the grassland vegetation changed or even worsened. This was followed by a significant reduction of vegetation cover, yield and quality parameters. But even if most of the productive grassland species were not able to persist and the long-term-success of the sown seed mixtures was lower than expected, the additional single lime fertilization at the acidic site caused significantly higher vegetation, quality and yield parameters than without liming. The positive influence of liming is already discussed in literature (Johnson *et al.*, 2005, Kennedy *et al.*, 2004, Poozesh *et al.*, 2010, Schechtner, 1993), but its longevity was impressively shown at the Eschwald experiment and would have not been detected during the evaluation after the first three years. As the fairly positive short-term evaluation was strongly influenced by the regular fertilization activities during the trial period, the subsequent development – due to the unexpected and total neglection of fertilization – could neither be expected nor foreseen.

Taking a look back within the SALVERE experiment, the short-term evaluation highlighted the similar species transfer success of both harvesting methods, but the long-term re-survey showed the strong impact of receptor site conditions on long-term restoration success. In comparison with the donor site (pH 6.9-7), the receptor site was more acidic (pH 5.1), and therefore did not meet the requirements of some transferred species like *Bromus erectus* and *Festuca rupicola* (both having an Ellenberg ‘reaction’ indicator value of 8) in the long-term – they only appeared for a short time. Another potential reason for long-term vegetation shifts was the occurrence of some drought events at the receptor site, which might have weakened the initially dominant group of grasses, especially *Arrhenatherum elatius*, as they are shallow-rooted and suffer more from water stress than deep-rooting forbs (Ellenberg und Leuschner, 2010, Otieno *et al.*, 2012) and additionally, the receptor site is located at the edge of its distribution zone. So obviously the first evaluation of the SALVERE experiment has been conducted while the vegetation obviously has not had reached a stable phase.

4.2.2 Biotic and anthropogenic factors

A very strong biotic driver for vegetation changes at the Eschwald was the uncontrolled grazing of cattle. As the surrounding pasture ground did not contain much attractive forage plants, the grazing pressure was very high and self-seeding of the seeded species was rarely possible. Professionally sound pasture management usually includes grazing steering processes like fencing out strongly grazed or trampled areas (Zhang *et al.*, 2018), site-adapted fertilization and, if necessary, reseeding of appropriate seed material (Hennessy, 2018). None of these management activities was set, so the originally established productive grassland vegetation degraded due to increasing acidity and mechanical stress. We were able to show that habitat-specific species (like *Agrostis capillaris, Festuca rubra agg*. and *Trifolium repens*) persisted best even under rough conditions, but their share was reduced due to invading species like *Nardus stricta*.

Considering the SALVERE experiment, the management stayed similar to the donor site with cutting in June and September (cut plant material staying on the plots for at least one day for dropping seeds), so most species may have had time for self-seeding. The biggest biotic factor responsible for the changes detected within the long-term observation here was interspecific competition. *Rhinanthus minor*, a very strong competitor, that has not been detected during the seed material transfer, invaded the plots three years after the short-term evaluation – and four years later finally showed the highest projective cover at both green hay and threshing plots. This species is known to parasite on grasses and legumes and therefore strongly influences species composition (Cameron *et al.*, 2009, Davies *et al.*, 1997), so it very likely intensified changes in species abundance and composition.

4.3 Benefits of long-term evaluation

Both analysed grassland restoration projects benefitted from the long-term evaluation in regard to a few different aspects: first of all, as time passes, the obtained results are getting more reliable. It is already discussed in literature, that if a target vegetation needs to be established (Auestad *et al.*, 2016) the three (Rydgren *et al.*, 2010) or even four years (Lengyel *et al.*, 2012) of most project periods with final evaluation may be too short for gaining reliable results, especially if changing environmental conditions occur. This is in the line with our findings from the two experiments.

The importance of long-term (grassland) experiments and longer grassland restoration observation periods is mentioned by a lot of authors (Bischoff *et al.*, 2018, Janzen, 2009, Mudrák *et al.*, 2017, Pötsch *et al.*, 2015, Rydgren *et al.*, 2010, Tilman *et al.*, 2001). According to Janzen (2009), some aspects may not be detected and new research questions may never be identified without long-term observations. According to Schaumberger *et al.* (2020) and (Schaumberger *et al.*, 2021), the long-term evaluation revealed new aspects: even after nearly two decades, a single liming during grassland restoration still significantly improved vegetation and yield parameters at the Eschwald. And at the SALVERE grassland transfer experiment, the long-term observation showed that even under differing site conditions it is possible to establish a solid matrix of transferred species by both green hay and threshing. Additionally, the long-term observation helped to detect the strong invasion of *Rhinanthus minor* – as soon as such unwanted and unforeseen developments occur, appropriate management activities can be set in order to sustainably secure restoration goals.

Nevertheless, there are also quite a few critical points to long-term experiments or re-surveys: first of all, as a lot of projects are limited in finances and therefore often restricted to only a duration of a few years (mainly 3-5 years), the funding of extending studies is often tricky (Janzen, 2009, Pötsch *et al.*, 2015).

And one important issue is the definition of the period from which we speak of long-term observation. While Tilman *et al.* (2001) already spoke of long-term experiments at seven years, Rasmussen *et al.* (1998) defined a period of at least 20 years as minimum requirement. Better than holding on to a specific number of years seems to be the approach of Pötsch *et al.* (2015), who see the following criteria as preconditions for the definition of 'long-term' experiments:

- Completed transition phase and achievement of an equilibrium regarding nutrient fluxes, floristic composition and soil life
- Occurring variations of the observed parameters are mainly caused by environmental conditions and not by any ongoing adaptation of the initial plant stock to the new balance
- Originally planned treatments and management activities are regularly conducted (no changes)

These criteria were originally related to long-term grassland experiments (Pötsch *et al.*, 2015) and not specifically for evaluation of restoration sites, but the core issue is identical: restored grassland vegetation should have reached a phase of stability (equilibrium) in regard to vegetation development (due to constant site and management conditions) before a valid evaluation of restoration success seems possible – so long-term observations would probably often be advisable and they definitely were of great benefit in regard to both analysed experiments.

5 Conclusions

Accompanying vegetation development of different restored grasslands over a long-term period helped to emphasize and reveal several issues (Schaumberger et al., 2020; Schaumberger et al., 2021). First of all, it underlined the importance of sufficient time for the restored vegetation to reach a stable stage or equilibrium, before a valid evaluation of restoration success can be conducted. Another valuable aspect was the possibility to show the long-lasting influence of liming on acidic sites. It revealed a low-cost management activity which can help to make grassland restoration for forage use more sustainable if applied in practice under similar conditions. Additionally, as grassland vegetation and its species composition is very dynamic and may alter due to different soil, climate and management conditions, changes can take place that are not suitable for the respective restoration goals. Long-term observation helps to identify unwanted developments like e.g. invasion of undesirable species or disappearance of target species. This gives the possibility to react in time with appropriate activities and helps to secure the maintenance of initial restoration purposes. Accompanying restoration projects over a long term may also help to identify mistakes and weaknesses – this should not be seen as a threat, but as a chance to learn and do things better the next time (Lorenzet *et al.*, 2005, Weinzimmer und Esken, 2017).

Due to related costs and efforts, long-term observation will only be possible in a few cases, but it is highly recommendable for very dynamic systems like restored vegetation, especially if it is obvious, that no equilibrium is reached until the planned end of scientific analysis or that changes are lying ahead. Janzen (2009) makes a passionate plea for long-term experiments, calling them "listening places" for patiently hearing and feeling the pulse of the earth. And he especially assigns them a tremendous importance for the future, as long-term experiments will highly probably help to analyse and understand the global changes lying ahead of us. Due to climate change and atmospheric deposition for instance, vegetation and soil composition already showed slow, but clearly identifiable changes within an observation period of four decades (McGovern *et al.*, 2011). So we have to face the fact that the relevance of long-term studies is not immediately visible in the beginning. Consequently, long-term observations are highly recommendable in vegetation and earth sciences, if anyhow reasonable and feasible.

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