ABS

Review Article

A review of methodology for grassland restoration with practical examples

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Abstract

Currently, the majority of high nature value Slovenian grasslands have an unfavourable conservation status. Based on the available data from habitat type mappings, the surface of high nature value grasslands (6210(*) – semi-natural dry grasslands and scrubland facies on calcareous substrates, 6410 – *Molinia* meadows, and 6510 – lowland hay meadows) at Natura 2000 sites is decreasing. The existing agri-environment measures have been only partly effective in promoting grassland biodiversity. The main threats to biodiversity are driven by various anthropogenic activities, which result in a continuous change in landscape identity, habitat fragmentation, and ecosystem degradation. Therefore, biodiversity restoration became an urgent step in the conservation of high nature value grasslands. Multiple pathways may lead to the ecological restoration of grasslands with an altered, uncharacteristic floristic composition, or grasslands with an unfavourable conservation status. In this paper, we present an overview of the methods used in the restoration of grasslands from different parts of Europe. In an adapted form, these methods could also be used for the restoration of Slovenian grasslands. Grasslands may be left to spontaneous succession, which is mainly suitable for small-scale areas located in the proximity of grasslands with well-preserved biodiversity. However, to re-establish plant communities with specialist species, a more proactive approach is usually required, such as sowing of regional or commercial seed preservation mixtures, transfer of mature plant material, or topsoil transfer from donor sites with appropriate botanical composition. Grassland restoration methods should be carefully thought-out and carried out before the habitat or species is endangered. We conclude that optimally chosen post-restoration management may have an impact that is comparable to or even greater than the impact of a suitable restoration method. Nevertheless, the maintenance of well-preserved grasslands is still much more cost-effective than the restoration of degraded grasslands.

Keywords

grassland restoration, management, methodology, Natura 2000 grassland habitat types, agri-environment measures

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Pregled metodologije obnove travišč s primeri iz prakse

Izvleček

Večina slovenskih travišč z visoko naravno vrednostjo ima trenutno neugoden ohranitveni status. Glede na razpoložljive podatke s kartiranj habitatnih tipov se površine travinja z visoko naravno vrednostjo (6210(*) – polnaravna suha travišča in grmiščne faze, 6410 – travniki s prevladujočo modro stožko in 6510 – nižinski gojeni travniki) na območjih Natura 2000 zmanjšujejo. Predlagani ukrepi v preteklih kmetijsko-okoljskih programskih obdobjih so bili le delno učinkoviti pri ohranjanju biotske raznovrstnosti travišč. Glavno grožnjo biotski raznovrstnosti predstavljajo različne antropogene aktivnosti, ki vodijo v stalno spreminjanje krajine, razdrobljenost habitatov in degradacijo ekosistemov. Obnova biotske raznovrstnosti je zato postala nujen ukrep za ohranjanje travišč z visoko naravno vrednostjo. Do ekološke obnove travišč s spremenjeno, neznačilno floristično sestavo, ali pa travišč v neugodnem naravovarstvenem stanju, vodi več poti. V tem prispevku predstavljamo pregled metod, uporabljenih pri obnovi travišč iz različnih predelov Evrope, ki bi jih lahko ustrezno prilagojene uporabili tudi za obnovo slovenskih travišč. Travnike lahko prepustimo spontani sukcesiji, ki je primerna predvsem za manjše degradirane površine v bližini travišč z dobro ohranjeno biotsko raznovrstnostjo. Praviloma pa vnovična vzpostavitev rastlinskih združb z značilnimi vrstami zahteva bolj proaktiven pristop, kot je setev regionalnih ali komercialnih ohranjevalnih semenskih mešanic, prenos dozorelega rastlinskega materiala ali prenos vrhnje plasti tal z donorske površine z ustrezno vrstno sestavo. Metode obnove travinja je potrebno natančno pretehtati in z obnovo vrstne pestrosti začeti še preden je habitat ali določena vrsta ogrožena. Ugotavljamo, da ima lahko optimalen način upravljanja travinja po obnovi primerljiv ali celo večji učinek glede na tistega, ki ga lahko dosežemo z ustrezno metodo obnove. Kljub vsemu pa še vedno velja, da je vzdrževanje dobro ohranjenih travišč z ustreznim načinom rabe cenejše od obnove degradiranih travišč.

Ključne besede

obnova travišč, upravljanje, metodologija, Natura 2000 travniški habitatni tipi, kmetijsko-okoljski ukrepi

Introduction

Grasslands are areas dominated by naturally occurring grasses and other herbaceous species, used mainly for grazing by livestock and wildlife (Allen et al. 2011). They comprise approximately 40.5% of the Earth's surface (excluding Greenland and Antarctica), making them one of the world's largest ecosystems (Suttie et al. 2005).

In general, grasslands can be divided into two types: primary (natural) and secondary (semi-natural). The first type is represented by sites that are unfavourable for the establishment of trees, while the second type is of anthropogenic origin, sustained by regular mowing and/or livestock grazing. Despite their anthropogenic origin, secondary grasslands represent some of the most species-rich and also some of the most vulnerable habitats in Europe since they have been extensively managed for several hundred years (Török et al. 2020). In contrast to intensively managed systems with high productivity and thus high input requirements per unit area, extensively managed systems use small amounts of labour and capital per unit area and primarily rely on natural soil fertility, water availability, and climate (Ashton et al. 2012). Therefore, extensively managed grasslands have higher biodiversity value (Lesschen et al. 2014). The most species-rich secondary grasslands are dry and semi-dry grasslands. They are found on shallow to deep soils and are predominantly formed on calcareous or volcanic bedrocks from lowlands to mountains. Calcareous grassland types are especially species-rich. However, they are increasingly threatened by woody encroachment (Elias et al. 2018).

Grasslands may also be divided according to their age, namely into temporary and permanent grasslands. According to the European Commission, permanent grasslands are defined as "land used to grow grasses or other herbaceous forage naturally (self-seeded) or through cultivation (sown), and that is not included in the crop rotation of the holding for five years or longer" (Commission Regulation (EC) No 796/2004). Grasslands that are less than five years of age (including in a crop rotation) are therefore defined as temporary grasslands (Reheul et al. 2007).

Natural and semi-natural grasslands are usually defined by climatic, pedological, or topological factors. However, in natural grasslands, plant species richness is further increased by fires and grazing, which also prevent litter accumulation and thus limit woody encroachment in addition to climate and extreme habitat conditions (Kuzemko et al. 2016, Török et al. 2020). Both natural and semi-natural grasslands depend on microclimatic, soil, and bedrock gradients (Sutcliffe et al. 2016). Among these, the main drivers of species composition are soil depth, soil texture, and soil pH. The relationship between pH and plant diversity of a certain region is generally hump-shaped, as the highest plant species richness is found under neutral or slightly basic conditions (Palpurina et al. 2017). A hump-shaped relationship can also be found between plant species richness and primary productivity (Fraser et al. 2015). The productivity of grassland communities is mostly driven by the availability of water and nutrients, which affects the biodiversity of these communities. The amount of moisture and its seasonal variation influences the productivity of natural grasslands, whereas the productivity of semi-natural grasslands is controlled by the fertility gradient (Török et al. 2020). Limiting nutrients play an important role in shaping the richness-productivity pattern (Palpurina et al. 2017) since various species are adapted to nitrogen (N) and phosphorus (P) limitation (Roeling et al. 2018). Generally, grasslands rich in N, P, and potassium (K) have low biodiversity (Merunková and Chytrý 2012). Although fire is not as crucial for the formation of grassland plant communities as climate, its contribution to this process in terms of seasonality, intensity, and return rate is still significant (Ewing and Engle 1988, Biondini et al. 1989). Moreover, areas that have recently undergone fires are usually richer in nutrients, attracting large ungulates that may further change species composition (Milchunas et al. 1988, Hartnett et al. 1996).

Natural and semi-natural extensively managed grasslands provide many ecosystem services that cannot be provided by other land uses. Their ecosystem services are of higher value compared to those of sown and intensively managed grasslands (Wick et al. 2016). For example, natural and semi-natural extensively managed grasslands harbour rich and unique flora and fauna, they produce biomass, serve as forage for herbivores, provide natural medicines, present habitat for pollinators and birds, ensure resources for water infiltration, flood reduction, purification, and storage, they prevent erosion, balance local climate, and play an important role in nutrient cycling and nutrient retention (Wick et al. 2016, Török et al. 2020). They also act as carbon dioxide (CO_2) sinks and thus have a great carbon (C) sequestration potential (Ammann et al. 2007) since they contain up to 12% of the soil organic C global pool (Schlesinger 1997). Converting grasslands into arable land leads to a decline in soil C due to C loss by tillage and lower C input from litter (Jones and Donnelly 2004). Grasslands also offer a variety of intangible aesthetic, cultural, and recreational services (Török et al. 2017) and also have a good potential for biogas and biofuel production (Heinsoo et al. 2010).

Despite their ecological, cultural, and agricultural importance, grasslands are threatened globally due to numerous anthropogenic factors and climate change. Their degradation results in a reduced provision of ecosystem goods and services (Wick et al. 2016). The most common reasons for grassland degradation include, on the one hand, their fragmentation and isolation caused by the intensification of agriculture and increased development of the secondary and tertiary economic sector, especially in lowlands, along with the abandonment of extensive management by mowing or grazing in less accessible areas, resulting in overgrowth and encroachment by trees and shrubs. Other frequently mentioned causes include the absence of naturally occurring fires, biological invasions caused by introductions of non-native species, overgrazing, eutrophication, and the already mentioned climate change (Wick et al. 2016, Török et al. 2020).

In Slovenia, permanent grasslands cover 58% of the total agricultural land (Factsheet on the 2014-2022 Rural Development Programme for Slovenia 2022). About 20% of the Slovenian Natura 2000 network is represented by utilised agricultural land, among which extensive meadows are the most important (Prioritised action framework (PAF) for Natura 2000 in Slovenia 2019). The latest report by the European Environment Agency on the state of nature in the European Union from the year 2020 claims that 50% of the assessments for grasslands in Slovenia under the Habitats Directive are showing a bad conservation status (U2) and about 22% are showing an inadequate (U1) conservation status. Therefore, altogether, no less than 72% of Slovenian grassland areas have an unfavourable conservation status (EEA 2020). Among grassland areas, semi-natural dry grasslands and scrubland facies on calcareous substrates (Natura 2000 habitat type 6210(*)) are particularly affected. The main reason for such a negative trend is their dependency on particular sustainable management measures (EEA 2020). Kaligarič et al. (2019) studied four grassland-specific agri-environment measures (AEM) in Slovenia in the period from 2007 to 2013 and found that these failed to preserve high nature value (HNV) grasslands in Slovenia since AEM did not reach most of the HNV grasslands in Slovenia and since this limited interest in the AEM targeted any permanent grassland, irrespective of its conservation value. As a result, many grasslands included in the AEM were not HNV grasslands. The authors concluded that this was due to the lack of pre-selection criteria for grasslands and the lack of monitoring of the efficiency of the measures, and due to low interest of farmers in the subsidies (Kaligarič et al. 2019). Ivajnšič et al. (2019) also reported negligible integration of agricultural holdings in the AEM in Slovenia. Unfortunately, the AEM in the period from 2014 to 2020 retained more or less the same concept as in the previous period (Kaligarič et al. 2019). Therefore, Kaligarič et al. (2019) suggested that future schemes should be prepared on a completely different basis, wherein HNV grasslands should be prioritised, and monitoring of biodiversity should be the most important requirement. The proposed Common Agricultural Policy (CAP) for the period from 2021 to 2027 was said to be more flexible and effective (Lovec et al. 2020). However, Lovec et al. (2020) argue that the actual long-term impact was not thoroughly considered in the new CAP. Therefore, no significant improvements in biodiversity conservation can be expected (Lovec et al. 2020). Šumrada et al. (2021) conducted a study where they explored the potential of a payment-by-results approach as an alternative to management-based schemes (MBS) in Slovenia. MBSs are schemes that provide payments for farming practices, which are believed to secure certain services instead of being tied to their actual provision (Burton and Schwarz 2013). Alternatively, result-based schemes (RBS) remunerate farmers for ecological results, demonstrated by certain indicators (e.g., presence of certain plant species, breeding success of farmland birds, etc.) (Herzon et al. 2018). Šumrada et al. (2021, 2022) found that most farmers and experts were in favour of the introduction of such RBSs for grassland conservation. Farmers knew the selected plant indicators and preferred monitoring of their presence over the current system (Šumrada et al. 2021). However, for the successful conservation of HNV grasslands, institutional capacity is also needed to implement RBSs on a larger scale (Šumrada et al. 2021). In addition, regardless of their many advantages in comparison to MBSs (Pe'er et al. 2022), RBSs do not seem to be better suited than the current schemes in addressing the specific needs of small and (semi-)subsistence farmers (Davidova 2011) and in the cases where land ownership is highly fragmented (Hartvigsen 2014). For this reason, older farmers and those who manage semi-subsistent and small farms are mostly not in favour of RBSs (Šumrada et al. 2022). The findings of Šumrada et al. (2021) indicate that there is an institutional gap in the understanding of agroecology and of the importance of integration of biodiversity policy, which needs to be bridged to be able to enforce changes into the current system and achieve better conservation outcomes. Pe'er et al. (2022) argue that a combination of both result-based and action-oriented payments might be optimal.

According to the various ecosystem services that grasslands provide, it is vital to prevent their further degradation in the future. In this review article, we present an overview of the techniques for grassland restoration used in experiments carried out in various European countries (but not in Slovenia), evaluate their practical use in the past, and form recommendations for their future application. All findings and recommendations are drawn from these studies.

Grassland restoration in general

The best way to maintain the biodiversity of grasslands is to prevent both their abandonment and overexploitation by using extensive traditional agricultural practices, mainly grazing and/or mowing. These two practices have been shown to exert many positive effects on grassland biodiversity and are often recommended as tools for both the restoration and maintenance of grasslands (Galvánek and Lepš 2008, Török et al. 2016). Among these, wild herbivore grazing on open areas (by wild horses and cattle) and low-intensity grazing by herded livestock (local breeds) are often suggested (Török et al. 2016, Tóth et al. 2018).

To retain grassland biodiversity in (near) optimum conditions, not only one single type but a whole scheme of traditional management practices is required (Babai and Molnár 2014). In addition, mosaic management should also be taken into account to ensure the highest biodiversity (i.e., temporally and spatially dynamic combination of abandoned and mown grassland patches) (Török et al. 2017). Nonetheless, it is often the case that traditional practices are not possible or economically sustainable. For this reason, conservation authorities and site managers are looking for alternative practices, such as prescribed burning during the dormant season. Prescribed burning with long fire-return periods could be a suitable and economically feasible way of eliminating accumulated litter and sustaining grassland biodiversity (Valkó et al. 2014). However, in some cases, soil biota may be negatively affected by fires (McLeod and Gates 1998, Vasconcelos et al. 2017, Zaitsev et al. 2017). Annual prescribed fires were found to be inappropriate for maintaining the desired species richness and structure, whereas periodic prescribed fires every two to six years may have a positive impact even in terms of soil biological properties (Valkó et al. 2014).

For partly degraded grasslands, a decrease in management intensity is often sufficient for their recovery, while for fully degraded grasslands that have been converted into other land uses, spontaneous succession or technical reclamation is required for a successful restoration (Prach and Hobbs 2008). Spontaneous succession has been reported to be a promising restoration tool in several different Central European grassland habitats, especially where the proportion of target grassland communities is high (Albert et al. 2014, Prach et al. 2015). However, for large-scale restoration projects to be successful, well-preserved donor grasslands acting as spontaneous sources of propagules must be available nearby (Török et al. 2020). Regarding technical reclamation, the most common methods that have been successfully used in some extensive grassland restoration projects (Lengyel et al. 2012, Prach et al. 2015) are sowing of regional seed mixtures and transfer of plant material (Török et al. 2011).

The main goal of many restoration actions is not to directly increase biodiversity on chosen plots per se, but rather to (re-)establish and maintain the presence of characteristic indicator species of target grassland communities, with an additional aim of reducing cover and impact of non-target weeds (Lepš et al. 2007).

Restoration of species-rich grasslands can be time-consuming, and additionally, it usually requires plot preparation (Kiehl et al. 2010, Krautzer et al. 2011) and appropriate post-restoration management (Kiehl et al. 2010, Török et al. 2011). Many sources claim that seeding on bare soil improves the chances of vegetation establishment (Kiehl et al. 2010, Krautzer et al. 2011, Török et al. 2011). Soil preparation is mostly done by ploughing or disking, followed by raking for seedbed preparation. After sowing, the covering of seeds is carried out by raking or ring rolling (Török et al. 2011). If an existing sward is present, it should be cut to the height of 3-5 cm, when necessary, and then opened (Krautzer et al. 2011). Grassland restoration should first be carefully thought-out and then carried out according to the plan shown in Fig. 1.

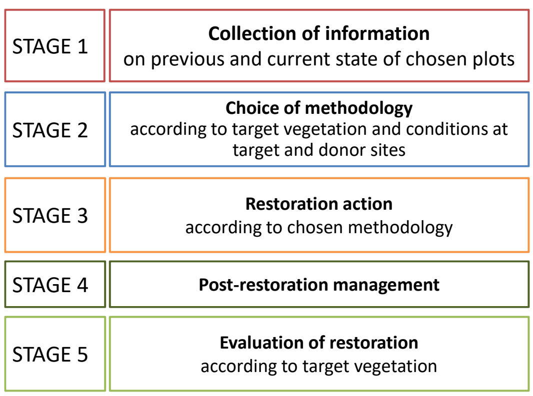

Figure 1. The stages of grassland restoration.

Slika 1. Zaporedje korakov pri obnovi travnikov.

Most commonly used methods in grassland restoration with practical examples

When restoring degraded permanent grasslands, we can choose between different methods. Each of them has its advantages and disadvantages, which are described below and summarised in Tab. 1.

Decrease in management intensity

Grassland management (especially traditional) is a crucial tool in the maintenance of semi-natural grasslands (Bischoff et al. 2009, Milberg et al. 2017, Goret et al. 2021). Cessation of management intensity (extensification) on previously intensively used grasslands has recently been discussed as a useful grassland restoration tool in many conservation policies and attempts. It might, theoretically,

Table 1. A summary of grassland restoration techniques used in different European countries.

Tabela 1. Povzetek tehnik obnove travnikov, ki so bile uporabljene v različnih evropskih državah.

Grassland restoration technique			Suitable for	Advantages	Limitations	Reference / An example of use
A decrease in management intensity			degraded grasslands of various habitat types (mesophilic, calcareous, and acidic grasslands)	reduction and prevention of further nutrient accumulation in the soil; general improvement of soil properties; an increase of taxonomical and functional biodiversity; increased landscape heterogeneity	drastic decrease in management intensity can lead to abandonment and biodiversity loss, causing overgrowth of weeds, forbs, and shrub encroachment; positive impacts of fertilisation reduction are not noticeable immediately; might negatively impact grass coverage in mesic grasslands and pastures	Marriott et al. 2004, Milberg et al. 2017, Mayel et al. 2021, Resch et al. 2021
Spontaneous succession			ruined grasslands; small-scale areas located in the proximity of well-preserved grasslands (mesic *Arrhenatherion* grasslands, dry *Festuco-Brometea* grasslands)	natural process; no action is needed	requires a high proportion of target grassland communities; high probability for an increased presence of weeds; long-term method; most suitable for recently degraded grasslands	Bossuyt and Honay 2008, Fagan et al. 2008, Lencová and Prach 2011, Knappová et al. 2012, Albert et al. 2014, Prach et al. 2014, Sojneková and Chytrý 2015, Prach et al. 2021a
Sowing of regional seed mixtures	low-diversity seed mixtures	manual collection vacuum harvesting combine harvesting	degraded grasslands; ruined grasslands; plots that are at risk of erosion; larger plots (mesic *Arrhenatherion* grasslands, dry *Festuco-Brometea* grasslands)	quick results	requires well-preserved donor grasslands; manual collection is time-consuming, requires good seed recognition; proper harvesting time	Lepš et al. 2007, Kiehl et al. 2010, Hofmann et al. 2020
	high-diversity seed mixtures	manual collection vacuum harvesting combine harvesting	ruined grasslands; smaller plots (mesic *Arrhenatherion* grasslands, dry *Festuco-Brometea* grasslands)	greater restoration success; a useful first step towards revegetation	requires well-preserved donor grasslands; limited availability; larger collecting effort; manual collection is time-consuming, requires good seed recognition; proper harvesting time	Jongepierová et al. 2007, Lepš et al. 2007, Kiehl et al. 2010, Török et al. 2011, Mitchley et al. 2012, Haslgrübler et al. 2013, Prach et al. 2013, 2014, Baasch et al. 2016, Hofmann et al. 2020, Prach et al. 2021a

Grassland restoration technique			Suitable for	Advantages	Limitations	Reference / An example of use
Transfer of plant material	hay threshing	plant clipping or green hay	ruined grasslands; all types of habitats	greater restoration success; genetic diversity preserved; low-cost; applicable on a larger scale	requires well-preserved donor grasslands; lower seed content	Kiehl et al. 2006, Donath et al. 2007, Edwards et al. 2007, Galvánek and Janák 2008, Kiehl et al. 2010, Rydgren et al. 2010, Krautzer et al. 2011, Albert et al. 2019, Hofmann et al. 2020
		dry hay/ 'hay sensu stricto'				
	seed stripping			does not require vegetation cutting	requires well-preserved donor grasslands	
	brush harvester (most common)		ruined grasslands; tall meadows (*Molinion, Cnidion*)	successful and widely used restoration method; does not require vegetation cutting; greater restoration success	requires well-preserved donor grasslands; seeds of shorter species underrepresented; specific equipment	
Topsoil transfer			ruined grasslands	greater restoration success	destructive for donor site; laborious; costly	Kiehl and Pfidenhauer 2007, Török et al. 2011
Mechanical disturbance, applied prior to restoration techniques			variously managed temperate grasslands; severely degraded grasslands; wet meadows; *Nardus* grasslands	increased soil seed bank potential and seedling recruitment	low specificity and selectivity; might improve the development of weeds	Hofmann and Isselstein 2004, Donath et al. 2007, Edwards et al. 2007, Mitchell et al. 2009, Krautzer et al. 2011, Klaus et al. 2018
Planting of entire plant individuals			degraded grasslands; individual/specific species; for stimulating succession to later stages	better establishment of endangered species	laborious; costly	Török et al. 2011
Cessation of fertilisation			grasslands degraded by over-fertilisation (mesic semi-natural grasslands containing *Molinio-Arrhenatherea* and *Festuco-Brometea* species; *Nardus* grasslands)	low-cost; no active measurements needed	unpredictable species shift; depends on abiotic parameters (climate); highly dependent on initial state; time-consuming	Marriott et al. 2004, Hejcman et al. 2007, Královec et al. 2009, Korzeniak 2016, Van Daele et al. 2017, Prach et al. 2021b

increase biodiversity on chosen plots by reducing work intensity, but at the same time increasing work effectiveness on larger grassland areas (Marriott et al. 2004, Milberg et al. 2017). However, results are context-dependent and differ according to the methodology used and the initial state at chosen sites. A study on the impact of grassland extensification by Marriott et al. (2004) showed that management cessation had a moderately negative impact on the diversity of calcareous and mesic grasslands, wherein changes were primarily visible in the long term. On the other hand, management abandonment had a significant negative impact primarily on mesic grasslands, which were showing signs of succession to forest vegetation in a 13-year period and were overgrown by shrubs and forest species in 30 years. Acidic grasslands were overgrown by non-palatable grasses (such as *Molinia caerulea* and *Deschampsia flexuosa*) and ericoid shrubs, whereas calcareous grasslands were overgrown by *Brachypodium pinnatum* (Marriott et al. 2004). Milberg et al. (2017) found that cessation of mowing intensity (from annually to once every three years) had a weak impact on diversity of wet grasslands, whereas the diversity of dry grasslands decreased significantly. Significant biodiversity loss was noticeable one decade into the experiment, more specifically after 11-14 years, which is somehow similar to the results of the study by Marriott et al. (2004). Rare mowing has a particularly negative impact on short-growing species, which can be impaired by higher and/or woody species that out-compete them and benefit from sporadic management. A combination of annual mowing of grasses and forbs in swards and occasional (once every few years) mowing of shrubby, overgrown parts of vegetation might be a solution that would combine the benefits of the aforementioned policy of reduced, but more efficient work, and conservation of grassland habitats (Milberg et al. 2017). The benefits of grassland management are discussed in more detail in the chapter Post-restoration management with grazing and mowing.

Spontaneous succession

Spontaneous secondary succession is a natural process of changes in species' structure and interaction dynamics in an already established ecosystem following natural or anthropogenic disturbance events. Particularly in the case of grassland restoration actions, secondary succession often occurs following the abandonment of previously used arable land. It is the most natural way of grassland restoration, relying on naturally (spontaneously) occurring processes in an ecosystem (Török et al. 2011). It is strongly dependent on the local availability of seeds (propagules) of the target grassland species and their efficient dispersal by different vectors, deriving from natural vegetation near the restoration target sites (Hölzel and Otte 2003, Donath et al. 2007, Kardol et al. 2008, Kiehl et al. 2010, Krautzer et al. 2011, Török et al. 2011, Hofmann et al. 2020). Natural succession of ex-arable fields usually begins with the establishment of annual and perennial ruderal plants, followed by perennial grasses and forbs – species of later successional stages, which are better adapted to specific grassland conditions (such as resource limitation). However, the transition to more complex plant communities during later stages of ecological succession rarely occurs. The structure of these plant communities stagnates with an increased presence of weeds, ruderals, and grasses, due to the low germination potential of grassland species' seeds in the seed banks and their limited dispersal potential (Kleijn 2003, Lawson et al. 2004). As stable ecosystems, grasslands do not typically rely on soil seed banks since characteristic grassland species do not produce long-lived or numerous seeds (Bossuyt and Honnay 2008). They rather rely on the dispersal of seeds (Edwards et al. 2007, Bossuyt and Honnay 2008). A study by Knappová et al. (2012) reported on the ability of dry grassland species (*Festuco-Brometea*) to colonise grasslands in their proximity as an alternative to restoration actions of a particular grassland type. While about 68% of the species present showed dispersal potential, some of the 'grassland specialists', such as *Helianthemum nummularium* subsp. *grandiflorum*, *Carex humilis*, *Anthericum ramosum*, *Filipendula vulgaris*, *Melampyrum nemorosum*, *Gymnadenia conopsea*, and *Campanula glomerata*, did not colonise proximal area. Overall, the authors defined the distance of 0.5 kilometres as the limit for successful propagule spreading, pointing out that in addition to distance and plot area, biotic and abiotic factors of the selected grasslands also need to be considered when discussing this topic (Knappová et al. 2012).

A review study by Bossuyt and Honnay (2008) showed that grassland soil seed banks were amongst the ones with the highest diversity, richness, and evenness, in comparison to those of forests, marshes, and heathlands. However, their generally low seed density and common absence of target species' seeds (especially in calcareous grasslands) made them an unreliable source for restoration. Exceptionally, seed banks might be useful at sites that were recently degraded (up to 5 years ago) (Bossuyt and Honnay 2008). Intensive use of agricultural fields and increased soil fertility negatively impact grassland soil seed banks (Edwards et al. 2007), favouring the development of weeds as remnants of previous successional stages (Török et al. 2011), along with invasive and non-target species that are commonly found at earlier stages of succession (Bossuyt and Honnay 2008). Another common issue with spontaneous succession is landscape fragmentation, resulting in the isolation of grassland plots and the absence of suitable propagule sources (Kleijn 2003, Kiehl et al. 2010, Lawson et al. 2004, Török et al. 2011), along with their dispersal limitation (Donath et al. 2007). All these issues generally cause delayed restoration (Kleijn 2003, Török et al. 2011). In addition, natural regeneration is often limited by inadequate germination conditions found on plots where vegetation is already established (mainly regarding light availability and soil). These differ between species of early and later successional stages. Species of early successional stages are usually taller and are consequently better competitors for light. Furthermore, they have a better capability for vegetative reproduction and thus out-compete species of later successional stages (Kleijn 2003).

Proactive measures of grassland restoration are usually needed since restoration by spontaneous succession is mainly suitable for small-scale areas located in the proximity of well-preserved grasslands, which serve as an adequate source of propagules. It is a good restoration method where no urgent results are expected due to slow and often unpredictable development of vegetation (Török et al. 2011). For example, Fagan et al. (2008) showed that they preferred the regeneration of dry grasslands by natural succession, combined with moderate management, defined by local agro-environmental schemes, rather than regeneration by sowing seed mixtures. Another study favouring natural succession over sowing of seed mixtures as a form of dry grassland restoration was conducted by Lencová and Prach (2011). They claim that if target sites are in the proximity of adequate propagule sources, properly managed, and not (extremely) loaded with nutrients, no sowing is required unless urgent results for grassland production are needed.

Sowing of seed mixtures

Many grassland restoration attempts rely on different methods of plant material introduction (Hofmann et al. 2020). One of the most commonly used methods is seed addition by sowing seed mixtures (Török et al. 2011, Hofmann et al. 2020). Seed mixture composition depends on numerous factors, such as target vegetation, conditions at the target site, and seed availability (Török et al. 2011).

Török et al. (2011) mention two main types of seed mixtures used in restoration: (1) low-diversity (LD) seed mixtures, usually consisting of seeds of 2-8 species, mostly dominant grasses and/or forbs of the target vegetation, and (2) high-diversity (HD) seed mixtures, which contain seeds of 10 or more target species. LD seed mixtures are often applied in restoration experiments that aim for quicker results – for instance, on plots that are at high risk of erosion. On larger plots, where HD seed mixtures might not be quantitatively sufficient due to their limited availability and greater collection effort, mixtures may be combined and/or applied in patches. Seeds can be either commercially sourced or locally harvested. Commercial seed mixtures are acceptable if they contain seeds of target species from local populations. It is, however, highly suggested to use seeds of plants grown or harvested locally, as this way the chances of successful restoration are higher. Non-native ecotypes in commercial seed mixtures namely have lower genetic and ecological compatibility with local conditions (Kiehl et al. 2010, Török et al. 2011). Additionally, foreign ecotypes may hybridise with local ecotypes, causing genetic biodiversity loss and reduced fitness in new hybrid populations (Kiehl et al. 2010). Seed collection, as opposed to the application of commercially sourced propagules, may help in the reintroduction of certain rare species, whose seeds are not readily available (Kiehl et al. 2010). Seeds can be collected manually or by using specific equipment, such as vacuum or combine harvesters (Edwards et al. 2007), which require special attention in the choice of proper harvesting time (Krautzer et al. 2011). An exception is vacuum harvesting, which can be easily carried out with machines used for leaf vacuuming and blowing even after seed shedding. Due to its complexity, this method should be carried out primarily at locations where other methods are not readily applicable (Kiehl et al. 2010). Application of different seed densities results in varying success rates of grassland restoration. Generally, the application of a larger number of seeds results in greater restoration success. However, it could also cause greater resource competition among sown species, which might result in decreased diversity of target species (Lepš et al. 2007, Török et al. 2011). As a potentially good alternative to spontaneous succession, Török et al. (2011) recommend sowing densities from 4000 to 13000 seeds/m^2 on areas of up to a few hundred square meters, whereas larger areas (measured in hectares) might require between 20 and 45 kg of seeds per hectare (for more details, see Török et al. 2011). Sowing of regional seed mixtures has been repeatedly proven as a successful restoration method for dry grasslands (Lepš et al. 2007, Jongepierová et al. 2007, Mitchley et al. 2012, Johanidesová et al. 2014, Prach et al. 2021a). Jongepierová et al. (2007) reported that sowing of regional seed mixtures is a very good method for the restoration of *Bromion* grasslands, indicating the use of a specific methodology in the form of strip sowing. Regional seed mixtures may be expensive and not readily accessible. In this case, strips of regional seed mixtures could be applied inside fields designated for natural regeneration, which should theoretically be colonised by previously sown target species. Mitchley et al. (2012) studied vegetation at the same plots in 2009, following the first part of the survey by Jongepierová et al. (2007), further confirming the positive effects of sowing regional seed mixtures, with the highest success achieved by sowing regional grasses, which covered around 50% of the studied plots. All experimental plots showed divergence towards ancient grasslands in the 10-year period, but donor and recipient sites still showed significant differences in species composition, suggesting that the 10-year period might not be sufficient to achieve the intended results and prove the importance of time dimension in grassland restoration experiments. Regarding different types of seed mixtures, Lepš et al. (2007) confirmed the positive impact of sowing both HD and LD seed mixtures on grassland vegetation succession. Both LD and HD seed mixtures were proven as suitable, even though HD seed mixtures were generally more successful and had higher productivity. An additional benefit that they provided was a higher probability of compensation in the case of species establishment failure, expressing the 'insurance effect' on diversity. Grasses were generally more successful than forbs. However, non-sown control plots subjected to natural succession had higher species richness and diversity, which did not result from dispersal from sown plots. Namely, sown species never achieved dominance on control plots, even though they spread relatively successfully over short distances into adjacent plots. Sowing of species is therefore defined as better suited for species introduction and not necessarily for biodiversity increase. An ideal combination might be planned to sow seed mixtures in strips, with some space left for natural colonisation between the strips. When seed mixtures are used in restoration actions, the species composition of both applied mixtures and recipient sites should be taken into consideration, focusing on the colonisation potential and competitiveness of present species. The presence of highly competitive species in mixtures might negatively impact the development and survival of other species, which were either previously sown or initially present at the site. Due to the competitiveness or invasiveness of various plant species (particularly weeds), the presence of those species in plant communities that are located near the restored grasslands should also be taken into account. By doing that, we might prevent their spreading into newly sown sites, where they might cause negative shifts in target species composition. Johanidesová et al. (2014) additionally reported that restoration by seed addition could be a successful first step towards revegetation and that its continuation in the form of natural succession depends on the vicinity of appropriate grasslands that would serve as a natural source of propagules. The latter is important due to limitations in the sowing of some grassland species' seeds for many reasons, either biological or technical. If natural spreading does not fulfil expectations in the set time frame, repeated sowing of selected target species may be required. Prach et al. (2014) studied the differences between restoration attempts of two grassland types of the *Arrhenatherion* and *Bromion* alliances in the White Carpathian Mountains, pointing out that spontaneous succession and use of commercially prepared mixtures led to the establishment of mesic vegetation, whereas local mixtures favoured dry grasslands. A study by Prach et al. (2013) on the same area gave the same results, favouring the use of local seed mixtures. 98% of sown species grew successfully, along with unsown species that spread from nearby reference ancient grasslands.

Transfer of plant material

Other commonly used seed collection techniques include threshing, seed stripping, and the use of a brush harvester. Brush harvesting is a generally successful and widely used restoration method that does not require vegetation cutting. It is overall better suited for tall meadows since seeds of shorter species are often underrepresented in the harvested material. Shortgrass meadows could therefore benefit from collecting plant material by cutting or even raking, followed by transfer of raked material, which would additionally help transfer propagules of bryophytes and lichens. Hay threshing and brush harvesting are more expensive methods due to the use of specific equipment (Kiehl et al. 2010).

Restoration of species-rich grasslands usually requires transplantation of plant material from donor sites since the collection of adequate HD seed mixtures demands a lot of time and resources (Török et al. 2011). The application of plant material containing seeds is a cost-effective method that is applicable on a large scale and in a wide range of habitats. In addition, this method might be beneficial due to the introduction of an entire gene pool of the donor community, which might also include some rare or endangered species that cannot be sown. Therefore, the genetic diversity of locally-adapted ecotypes is preserved, along with the provision of microsites required for seed germination. Like other restoration methods, it is highly context-dependent, and it requires the proper selection of quality donor plant material applied at corresponding, ecologically compatible sites. Although the seed content of the transferred plant material is an important variable in the evaluation of restoration success, colonisation ability is also very important (Hölzel and Otte 2003).

When plant material with propagules is collected by mowing (cutting), it can be applied either as fresh or dry hay (Kiehl et al. 2010, Krautzer et al. 2011). Application of fresh hay is known as 'plant clippings' or 'green hay', whereas dry hay is known as 'hay *sensu stricto*' (Kiehl et al. 2010). Application of fresh plant material increases the chances of species establishment (Kiehl et al. 2010, Török et al. 2011), while dry hay requires additional manipulation of the material and therefore increases the costs of the process (Krautzer et al. 2011), with a limited restoration potential due to lower seed content. Low-productivity grasslands, such as calcareous grasslands, typically require around 300-600 g/m^2 of freshly cut hay with a 2:1 to 3:1 donor-to-recipient plot ratio, whereas other habitat types, such as fens, require a 1:1 to 2:1 plot ratio (Kiehl et al. 2010). Immediate transfer of freshly cut plant material with ripe seeds is known as hay strewing (Edwards et al. 2007). Plant material can be applied in a 5-15 cm layer, which is advised for mesotrophic to eutrophic grasslands (Kiehl et al. 2010). Thicker layers are not recommended since they can suppress the colonisation of target species (Kiehl et al. 2010, Török et al. 2011). Transfer of plant material containing seeds is best combined with prior preparation of recipient sites with various soil disturbance methods, which are chosen according to the grassland type and its nutrient status. The importance of mechanical disturbance for grassland restoration based on seed bank potential was studied by Klaus et al. (2018). Results showed that mechanical disturbance could potentially increase the diversity of severely degraded grasslands. The sole impact of seed banks on partly developed grasslands is, however, questionable. The similarity between seed banks and vegetation stands did not increase with disturbance frequency. Thus, other measures of propagule introduction, such as sowing, were required (Klaus et al. 2018). Apart from the quality of applied seed mixtures, another crucial factor is the availability of microsites that would provide adequate conditions for seedling germination and development, preventing seed desiccation. This can be achieved by providing an additional mulch layer that also prevents soil erosion (Kiehl et al. 2010).

Diaspore transfer was proved as a successful method in the restoration of wet meadows of the *Molinion* and *Cnidion* alliances (Hölzel and Otte 2003, Donath et al. 2007). Previous disturbance of existing grass swards in the form of rotavating before the application of seed-containing plant material was proved beneficial for the establishment of target vegetation of wet grasslands, although the authors noted that competitive relationships within the stand (with a specific focus on grasses) severely dictated the dynamics of restoration. They also noted that heavier disturbance (such as ploughing of existing sward) might be needed to expand niches for introduced species (Donath et al. 2007). Both studies reported low establishment rates for sedges (*Carex* spp.) (Hölzel and Otte 2003, Donath et al. 2007). This can be explained by their specific phenology and ecology. Namely, their seeds ripen early in the vegetation season and are absent at the time of seed collection in late summer or autumn. They also have specific germination requirements, such as prolonged incubation in warm and moist conditions, and due to their successful vegetative reproduction, they are better suited for other methods of propagule introduction, such as turf transfer (Donath et al. 2007). Donath et al. (2007) do not recommend simultaneous sowing of grasses when applying seed mixtures due to the potential of grasses to out-compete target vegetation and their ability to successfully colonise sites of stands in the proximity, even though simultaneously sown grasses do not disturb the development of newly introduced vegetation (Donath et al. 2006, 2007). Already established grass stands presented a bigger obstacle to the recruitment of new vegetation (Donath et al. 2007).

Green hay transfer was proved by Kiehl et al. (2006) to be a successful method of restoration of ancient grasslands, although it is also not suitable for the reintroduction of sedges (*Carex* spp.). Albert et al. (2019) found that green hay transfer was the most efficient restoration method for *Bromion erecti* grasslands, followed by triple brush harvesting and single brush harvesting. Donor sites were located in the Protected Landscape Area and Biosphere Reserve of the White Carpathian Mountains in the Czech Republic. Thirty-five species were recorded at the recipient site, on which green hay consisting of 112 species collected at donor plots was applied, whereas triple harvesting showed a similar success rate with 33 newly established species. The success of this method may be due to the fact that plants were transferred as specimens, providing a possibility for the seeds to ripen on parent plants, whereas harvesting methods require effort to remove fruits and seeds from plants. Harvesting proved to be more successful when repeated during the season. However, all of the tested options had a relatively low success rate, with minimal differences between green hay and triple harvesting. Albert et al. (2019) noted that, due to the higher practicality of seed mixtures collected by harvesting, which can be stored and transferred, brush harvesting has a significant potential for restoration, whereas hay transfer needs to be applied as soon as possible after mowing and is usually limited to smaller areas. Hofmann et al. (2020) tested different methods of grassland restoration on various vegetation types (*Festuco-Brometea*, *Nardo-Callunetea*, *Sedo-Scleranthetea*, and *Trifolio-Geranietea*). Their results confirmed the efficiency of hay transfer. However, they noted the importance of choosing the right time for the application of this method, which should be before the seeds are ripe, and should be repeated if necessary.

Edwards et al. (2007) studied the influence of preparatory disturbance practices (power harrowing and turf stripping) on the efficiency of two commonly used grassland restoration methods (brush harvesting and green hay strewing) applied to lowland hay meadows and chalk grasslands as two target vegetation types. Both methods of seed addition proved successful. Hay strewing was more efficient for seed collection of low-growing plant species due to the greater height at which the brush harvester collected seeds. In addition, it sampled a wider phenological range of different plants, a trait specific to mesic chalk grasslands. Early cutting might favour perennial grasses, whereas later hay cut includes a wider range of different forbs, of which many have a conservation value. This confirms the importance of phenology knowledge in choosing the adequate restoration method. Disturbance generally had a positive impact on grassland establishment, except for power harrowing in chalk grasslands. They did, however, benefit from turf stripping, even though the positive impact might have been related to a decrease in nutrients in the soil caused by the given disturbance. This study confirmed the importance of background knowledge and context dependence. The choice should be in line with phenology, and management techniques should be considered.

Other methods of grassland restoration

Other, not commonly used methods of grassland restoration include topsoil transfer, turf transplantation, and community translocation directly from donor sites to recipient plots (Török et al. 2011). Potential advantages of chosen methods include the transfer of diaspores with their associated soil fauna and microbiota, which could increase the chances of vegetation establishment in its original form and dynamics (as close as possible) (Török et al. 2011). Kiehl and Pfidenhauer (2007) confirmed a positive impact of topsoil removal on the re-establishment of dry *Bromus* grasslands by an increased cover of various target species, such as *Thymus praecox*, *Hippocrepis comosa*, and *Dorycnium germanicum*, following the experiment. However, transplantation methods are still not widely used due to their destructive nature, the high effort that they require, and the costs they cause (Török et al. 2011). This was also noted by the authors of the original research (Kiehl and Pfidenhauer 2007). In addition to sowing or hay transfer, planting of entire plant individuals or their belowground parts is sometimes carried out in restored areas. Due to higher costs, it is only recommended in specific cases, for example, for a better establishment of endangered species or for stimulating succession to later stages (Török et al. 2011). Other potential issues in soil transfer are eutrophication, caused by increased nutrient mineralisation in the applied soil, and ruderalisation, which require additional management measures afterwards (Kiehl et al. 2010).

As an option for the restoration of grasslands dominated by *N. stricta*, Mitchell et al. (2009) suggested the creation of gaps in turf for other plant seedlings by rotavation. Nonetheless, regular cutting and chopping of biomass using a flail or rotary mower is not advised since it may cause changes in species composition and dominance of some grasses (Krahulec et al. 2007, Galvánek and Janák 2008). Too regular burning is also not recommended, as it can promote the spreading of invasive species (Bensettiti et al. 2005).

For long-term maintenance of *Nardus* grasslands in Serbia, Dajić Stevanović et al. (2008) recommend practices such as juniper burning or roller chopping, or the introduction of horse grazing to control the spreading of some undesired low-quality grasses, and mechanical clearance of woody species, along with the reintroduction of cattle and sheep grazing.

Parolo et al. (2011) defined a few management practices necessary for the preservation of *Nardus* grasslands. They suggested mechanical removal of woody pioneer species to prevent encroachment at pasture edges, establishing electric paddocks for more intensive grazing at the periphery of pastures, and using electric fences on lower pastures that are grazed twice to ensure the concentration of cows at pasture edges. It is advisable to distribute animals along the peripheral parts of pastures so that nitrophilous species have less potential for spreading (Bensettiti et al.

2005). Moreover, Parolo et al. (2011) recommended turf stripping in the centre and fertilisation at the periphery of pastures, and combining cattle with small herbivores, such as sheep and goats, for a more efficient limitation of woody encroachment following restoration. However, fertilisation in these habitats is usually forbidden or at least very restricted, as it can lead to eutrophication (Galvánek and Janák 2008). Some countries encourage liming for the improvement of *Nardus* grasslands, as higher calcium (Ca) levels may positively affect species diversity (Common et al. 1991). Nevertheless, a thorough assessment is required before application since liming, like P, has a long-term effect on species composition (Hejcman et al. 2007). Turf stripping is otherwise mainly used in the case of eutrophication of the upper soil horizons. This technique removes nutrients from the upper soil layers, and thus restoration of such oligotrophic habitats is possible (Galvánek and Janák 2008).

Sometimes it is necessary to apply several restoration techniques at once. However, this correspondingly also requires more effort. Since grasslands that are to be restored are often abandoned and, therefore, densely overgrown, a technique that is often used is the removal of trees and shrubs by hand or with machinery. If a habitat is not densely overgrown, cutting and chopping of biomass with a flail or rotary mower may be used. When, however, trees and shrubs are too lush, a cultivator has to be used. Another possible, but costly method is also manual cutting with a brush cutter (Galvánek and Janák 2008). All these methods for scrub cutting are effective, but only if regular management is assured afterwards (Bensettiti et al. 2005), as scrub encroachment could turn out to be even more intense after cutting (Galvánek and Janák 2008).

Restoration of completely destroyed habitats is very expensive, yet feasible. There were some attempts of restoration of severely damaged habitats in Belgium by turf transplantation using sod-cutting techniques and by utilisation of hay or mulch from species-rich donor grasslands (Galvánek and Janák 2008). The turf should be placed on open land in a chessboard layout. Such an arrangement prompts seed dispersal and recruitment, and thus enables faster rehabilitation of disturbed habitats. In addition, turf also prevents soil erosion (Stanová et al. 2007). If farmers are not interested in maintaining these habitats, or when these habitats are threatened by various economic activities, land acquisition is of great importance in order to ensure their proper management. In any case, no matter which restoration measure is used, regular active management of these habitats is still much more cost-effective than their restoration (Galvánek and Janák 2008).

Timeline of grassland restoration

When designing restoration studies, it is important to take into account the conditions and area of both donor and recipient grassland plots, along with the phenology of the community and target grassland species (Edwards et al. 2007, Török et al. 2011). Seed collection should take place when most of the seeds in the donor plant community are ripe (Edwards et al. 2007, Török et al. 2011). The most appropriate times for seed collection in different habitat types are shown in Tab. 2. Nevertheless, it should be noted that these data were collected in different parts of Europe and, therefore, cannot be directly applied to the conditions in Slovenia.

For example, to maximise the yield of grass seeds, mowing of European dry grasslands should be carried out in June, whereas mesic grasslands should be mown later during the vegetation season (between June and July) (Török et al. 2011). To promote better biomass decomposition at the recipient sites in *Nardus* grasslands, propagule collection for restoration purposes in these grasslands should be carried out as early as May (Van Daele et al. 2017), in the period from June to July (Rūsiņa et al. 2017), in mid-July (Galvánek and Janák 2008, Kurtogullari et al. 2020), or by the end of July at the latest (Háková et al. 2004). Actions taken later in the vegetation season are generally more suitable for *Nardus* grasslands and pastures at higher altitudes (Kurtogullari et al. 2020). Wet grasslands are usually mown in late summer, only in August (Török et al. 2011). Generally, earlier cuts of grasslands favour grasses, whilst later or repeated cuts favour forbs (Krautzer et al. 2011, Haslgrübler et al. 2013). Late propagule collection can severely decrease the chances of successful grassland restoration. To avoid this, it is recommended to carry out multiple collections throughout the vegetation season (Török et al. 2011). The area ratio between recipient and donor site size varies between 1:2 and 1:10, and mostly depends on the state of vegetation at donor sites (Edwards et al. 2007, Török et al. 2011).

Table 2. An approximate timeline of plant material collection (primarily by mowing), which is used for the restoration of different European grassland habitat types. Differently coloured cells in the following table indicate theoretically defined optimal timing for mowing at different grassland habitat types. Individual restoration actions should, however, consider climate conditions and the state of donor grassland vegetation at a given time. Following works by Háková et al. (2004), Galvánek and Janák (2008), Krautzer et al. (2011),Török et al. (2011), Haslgrübler et al. (2013), Rūsiņa et al. (2017), Van Daele et al. (2017), Kurtogullari et al. (2020).

Tabela 2. Časovni okvir nabiranja rastlinskega materiala (predvsem s košnjo) za obnovo različnih evropskih habitatnih tipov travišč. Različno obarvana polja v spodnji preglednici označujejo teoretično optimalen čas za košnjo in nabiranje rastlinskega materiala v različnih travniških habitatnih tipih. Kljub temu pa je pri akcijah obnavljanja travnikov vedno potrebno upoštevati klimatske razmere in stanje vegetacije območja izbranih donorskih površin. Prirejeno po Háková in sod. (2004), Galvánek in Janák (2008), Krautzer in sod. (2011), Török in sod. (2011), Haslgrübler in sod. (2013), Rūsiņa in sod. (2017), Van Daele in sod. (2017), Kurtogullari in sod. (2020).

	January	February	March	April	May	June	July	August	September	October	November	December
Dry calcareous grasslands (habitat type 6210(*))												
Mesic grasslands (habitat types 6510, 6520)												
Oligotrophic *Nardus* grasslands (habitat type 6230)					Dependent on area							
Wet grasslands (habitat type 6410)												

Choice of donor sites for grassland restoration

When choosing adequate donor sites for grassland restoration, one should opt for donor sites that fulfil specific criteria. Primarily, we should choose donor sites that are biogeographically and phytocoenologically suitable for recipient sites, with representative target plant community structure and low presence of neophytes. Some databases for grassland sites in Germany also cite the need for adequate management status and naturalness of the site (not sown with commercial seeds), without incoming/planned changes in land use (Krautzer et al. 2011). Additionally, donor sites must be compatible with recipient plots regarding their nutrient status, hydrology, and substrate, with special attention paid to differences in water and nutrient status of dry, nutrient-poor grasslands (*Bromion*), mesic and mesotrophic grasslands (*Arrhenatherion*), and wet grasslands (*Molinion* and *Deschampsion*) (Krautzer et al. 2011).

Soil fertility as a crucial factor in grassland restoration

On land formerly used for cropland, the establishment of target grassland species can be limited by increased nutrient levels in topsoil, which stimulate the growth of highly competitive annuals and weeds (Kardol et al. 2008). The removal of the topsoil layer might be applied to lower nutrient concentrations (Hölzel and Otte 2003, Kardol et al. 2008, Kiehl et al. 2010, Török et al. 2011) and to remove propagules of weeds (Hölzel and Otte 2003, Kiehl et al. 2010, Török et al. 2011). To prevent soil erosion, the removal of 25-50 cm of soil is recommended, whereas soil removal on a larger scale is not advised. Soils of ex-arable fields are often saturated with inorganic N, which stimulates the development of non-target species in the initial phases of vegetation succession. To prevent overgrowth by non-target species (namely weeds), a decrease in soil fertility is required and carried out by different actions: topsoil removal, offtake optimisation, or the currently popular C addition (for more details, see Török et al. 2011).

Two different studies, one from Switzerland and one from the Czech Republic, reported a long-term impact of fertilisation on *Nardus* grasslands. In the latter study, the impact of fertilisation was evident even 37 years after the last nutrient application, especially on behalf of P and Ca (Hegg et al. 1992, Hejcman et al. 2007). Therefore, due to their preference for oligotrophic soils, restoration of extensive *Nardus* grasslands where fertilisers were applied in the past is difficult (Dähler 1992, Hejcman et al. 2007). Van Daele et al. (2017) claim that to restore species-rich *Nardus* grasslands, it is crucial to reduce bioavailable

P below 10 mg/kg or to select sites with bioavailable P contents below this threshold. Similarly, Korzeniak (2016) found that, especially for mesic *Nardus* grasslands in the lower montane zone, nutrient levels should be kept low to successfully control the expansion of nitrophilous species. For the restoration of species-rich *Nardus* grasslands, Van Daele et al. (2017) suggest inoculation of soil with a native soil community since native soil communities are known to promote restoration management (Middleton and Bever 2012, Wubs et al. 2016). Another criterion for selecting suitable sites for restoration could be a pH of approximately 4.5 to lift seed limitation. Last but not least, they recommend mowing in May, as this measure could reduce the competitive disadvantage of the slower-germinating *Nardus* species. They emphasised that to increase the success of restoration management, knowledge about establishment limitation should be considered (Van Daele et al. 2017).

According to Schelfhout et al. (2017), a prerequisite for successful restoration is that the requirements regarding the abiotic conditions are met. These authors conducted a study where they tried to restore *Nardus* grasslands on formerly intensively managed agricultural land. They discovered that traditional mowing and grazing did not change community composition in such a way that it would resemble *Nardus* grasslands. They concluded that when threshold values for abiotic conditions are exceeded, abiotic restoration should be performed before biotic restoration. Therefore, it is crucial to perform measurements of important initial soil characteristics (e.g., pH, nutrients, etc.) before restoration. For abiotic restoration, the authors suggest P-mining or topsoil removal. Nevertheless, topsoil removal is a costly procedure from both the perspectives of time and money. Topsoil removal is, therefore, more feasible in larger restoration projects with more funding. Restoration projects with less funding should focus on sites that were previously managed less intensively (Schelfhout et al. 2017).

Post-restoration management with grazing and mowing

The most commonly applied methods in post-restoration management, used in the studies analysed, are listed in Tab. 3. It is very important to use an appropriate type of post-restoration management since optimally chosen post-restoration management may have an impact that is comparable to or even greater than the impact of a suitable restoration method (Paolinelli Reis et al. 2022).

Grasslands in Europe are semi-natural ecosystems that greatly depend on how they are managed (Butaye et al. 2005). This fact confirms the importance of disturbance in grasslands (Edwards et al. 2007), primarily mowing and/or grazing in restored grasslands, once basic vegetation is established (Butaye et al. 2005, Kiehl et al. 2010, Török et al. 2011). Disturbance in the form of grazing and mowing enhances the colonisation of target species by creating better germination and establishment conditions at microsites by reducing the cover of highly competitive species (Edwards et al. 2007). Cutting taller plants is especially effective, as it stimulates the establishment of sown forbs (Lawson et al. 2004) and improves plot diversity (Török et al. 2011). One of the many positive impacts that grazing and mowing as forms of management also have on grasslands is the reduction of accumulated aboveground plant (litter) biomass since they open space and offer new niches for new plants to emerge and establish in the community (Török et al. 2011). This is a specificity of mesic grasslands due to their higher biomass production in comparison to xeric grasslands, which do not benefit from grazing and/or mowing as much (Hayes and Holl 2003). Huhta et al. (2001) indicated that different mowing timeline has a different impact on grasslands: late mowing as a form of grassland upkeep and litter removal, whereas early mowing might shift species structure due to disturbed seed production.

Turtureanu et al. (2014) claim that the highest plant species richness in semi-natural grasslands is provided by mowing. However, grazing and minor disturbance by animals may also be important for a higher diversity of plant species in semi-natural grasslands (Enyedi et al. 2008). Mowing may affect species composition since, for example, early mowing facilitates early-flowering species. As opposed to mowing, grazing usually inhibits graminoids and promotes the development and replenishment of forb species. However, grazing has a positive impact on the development and germination of many important grassland species, primarily by providing open soil surfaces and niches by livestock trampling while grazing (Török et al. 2020). Nevertheless, grazing animals may exert a large force on the soil surface due to their heavy weight and, at the same time, relatively small hoof area (Bilotta et al. 2007). As a result, trampling may reduce both biodiversity and vegetation cover at grazed sites (Matches 1992). Thus, the load imposed on the soil by grazing animals should always be taken into account. The amount of pressure exerted on the soil differs according to the species and age of grazing animals (Bilotta et al. 2007). Furthermore, there are differences regarding grazing preference according to the type of grazing livestock. Cattle and horses feed on taller grasses, whereas sheep prefer short grasses and forbs (Tóth et al. 2018). Moreover, browsers, such as goats, can reduce shrub encroachment into grasslands (Elias et al. 2018). On *Nardus* grasslands, late onset of grazing, badly organised grazing, or too low grazing intensity might lead to the spreading of small shrubs, such as *Vaccinium myrtillus* or *V. uliginosum*, which results in a lower pasturing value of these habitats (Bensettiti et al. 2005).

Table 3. A list of post-restoration grassland management techniques used in the studies reviewed.

Tabela 3. Seznam tehnik vzdrževanja travnikov po njihovi obnovi, ki so bile uporabljene v pregledanih raziskavah.

Grassland management technique	Suitable for	Advantages	Limitations	Reference / An example of use
Grazing	mesic and semi-dry semi-natural grasslands, e.g., habitat types 6210(*) and 6230*; not optimal for hay meadows and xeric grasslands	relatively frequent, but low-intensity disturbance; when carried out adequately (in line with species phenology), it can prevent shrub overgrowth and encroachment; enhancement of target species colonisation; removal of accumulated biomass and litter; grazing animals might serve as vectors for propagule transfer; decreases fire hazard; provision of open areas (niches) for the development of grassland species by animal trampling; increase and maintenance of microhabitat heterogeneity	selective (might cause an overgrowth of woody and thorny species, not palatable for certain types of livestock – primarily cows, so grazing by goats is recommended in this case); favours grasses over forbs due to their biology; dependent on species phenology; not suitable for xeric grasslands	Halada et al. 2001, Muller 2002, Hayes and Holl 2003, Pykälä 2004, Edwards et al. 2007, Galvánek and Lepš 2008, Török et al. 2011, Turtureanu et al. 2014, Török et al. 2016, Bonari et al. 2017, Tóth et al. 2018, Silva et al. 2019, Köhler et al. 2020, Kurtogullari et al. 2020, Mrázková-Štýbnarová et al. 2020, Török et al. 2020, Tölgyesi et al. 2022, Zarzycki et al. 2022
Mowing	various semi-natural grasslands, including habitat types 6210(*), 6230*, 6410, 6510, 6520	generally more accessible than grazing; early mowing facilitates the development of early-flowering species; enhancement of target species colonisation; improvement of the development of sown forbs by increasing competitiveness of higher plants; elimination of accumulated biomass and litter	beneficial only if carried out at an appropriate time in the season (when most diagnostic grassland forb species are ripe) and not too frequently (regime dependent on grassland type); when carried out with machinery, it is a non-selective and high-intensity disturbance single event (compared to grazing) – hand mowing has more advantages that are similar to grazing, but it is costly and time-consuming; might cause vegetation homogenisation; heavy machinery threatens invertebrate diversity	Halada et al. 2001, Muller 2002, Lawson et al. 2004, Edwards et al. 2007, Enyedi et al. 2008, Galvánek and Lepš 2008, Královec et al. 2009, Halada et al. 2011, Török et al. 2011, Valkó et al. 2012, Török et al. 2016, Bonari et al. 2017, Milberg et al. 2017, Van Daele et al. 2017, Tälle et al. 2018, Török et al. 2020, Zarzycki et al. 2022
Prescribed burning (with long fire-return periods)	various types of grasslands	elimination of accumulated biomass and litter	might cause drastic species shift; might increase chances of biological invasions	Bensettiti et al. 2005, Galvánek and Janák 2008, Valkó et al. 2014
Mulching	nutrient-poor grasslands	prevents overgrowth by woody species; promotes the development of target species found at nutrient-poor sites		Moog et al. 2002

Grassland management technique	Suitable for	Advantages	Limitations	Reference / An example of use
Cessation of fertilisation	suitable for oligotrophic grasslands (such as *Nardus* grasslands); previously used arable fields	retains naturally occurring nutrient status of oligotrophic habitats	revegetation might be time-consuming	Critchley et al. 2007, Galvánek and Janák 2008, Královec et al. 2009, Korzeniak 2016, Van Daele et al. 2017, Kurtogullari et al. 2020
Mechanical elimination of woody vegetation	*Nardus* grasslands	prevention of overgrowth at pasture edges	if not followed by regular management, it might cause worse shrub overgrowth compared to initial conditions	Galvánek and Janák 2008, Parolo et al. 2011
Mixed management	various semi-natural (including restored) grassland types	favours plant and butterfly diversity; takes into consideration the fact that different habitats require different approaches and that there is no ultimate solution that could be applied to all habitats	time- and resource-challenging	Bonari et al. 2017

Grazing is a more selective form of management that favours rosette and prostrate plant life forms, so its abandonment favours the development of taller plant stands. Pykälä (2004) also found that grazing improves the diversity of different plant functional types and life forms in mesic grasslands more than in wet or arid habitats. The latter are additionally limited by natural limiting factors, such as drought or flooding. In this study, grazing particularly benefitted annual, biennial, and perennial plants, whereas geophytes had a negative response to grazing. Cattle grazing might increase the coexistence of different species with different life strategies and functional types, if given species are not under selective pressure by cows as a food source. Apart from species' traits and habitat type, impacts of this specific disturbance are also geographically defined and, therefore, context-dependent. Török et al. (2011) noted that grazing could potentially have more positive impacts on grasslands in comparison to mowing since grazing animals can serve as vectors for propagule transfer. Furthermore, through their selective grazing, they can form more heterogeneous landscapes with different microclimatic and microstructural conditions. However, selective grazing can negatively affect the diversity and establishment of target species since grazers (especially cows) usually avoid woody and thorny species. Consequently, these can overgrow the target area. Such common field weeds should be avoided in forage production and may be suppressed with occasional clean cuts. Otherwise, goat grazing is also recommended in areas under pressure by shrub vegetation (Török et al. 2011). This was confirmed by Köhler et al. (2020), whose study showed that grazing by goats (browsing) had a positive effect on orchid-rich dry calcareous grasslands in Germany at a Natura 2000 site classified as habitat type 6210(*), due to the presence of *Gymnadenia conopsea*, *Orchis purpurea*, *O. militaris*, *Ophrys sphegodes*, *O. apifera*, and *O. insectifera*. Browsing should be conducted in early spring in accordance with the phenology of orchids and the onset of shrub development, when young shrub plants are still palatable. The results of this study are promising. However, they should be further researched since this study was conducted on a relatively small scale and with orchid cover varying throughout the eight-year study. Grazing and trampling probably enhance light availability in pastures, promoting the annual recruitment of orchids (Köhler et al. 2020). The positive effects of grazing are also reflected in epizoochory (Tölgyesi et al. 2022).

Mowing is a more accessible form of management. However, it does not offer the same probability of possible improvement in grassland and landscape diversity as grazing does, often causing homogenisation of vegetation and negatively impacting invertebrate diversity in grasslands, particularly when carried out by heavy machinery. When possible, mowing by hand is recommended, although this method itself is not very useful at a larger scale (Török et al. 2011).

Muller (2002) compared different management practices between different Natura 2000 grassland habitat types and denoted mowing without fertilisation as an adequate form of management for dry grasslands (6210(*))

since fertilisation led to structurally- and diversity-degraded forms of habitats dominated by grasses. On the other hand, abandonment led to overgrowth by shrubs. Low-intensity mowing without fertilisation is also recommended for *Molinia* grasslands (6410), which are very sensitive to eutrophication. Grazing without fertilisation turned out to be the best method for species-rich *Nardus* grasslands (6230*) since grazing prevents regressive succession to the previous form (heathlands), whereas fertilisation would disturb the oligotrophic nature of this habitat. Hay meadows (Natura 2000 habitat types 6510 and 6520) require extensive management with low fertilisation and late cutting. Moog et al. (2002) noted that for *Arrhenatherum elatius* and *Bromus erectus* grasslands, the best management regimes for grassland conservation include regular grazing, mowing, and mulching since these practices promote the development of species that are typical of nutrient-poor habitats. On the other hand, irregular mulching was proved to have a very similar impact as natural succession. Succession favoured the development of seedlings of woody species, such as *Fraxinus excelsior*, *Acer platanoides*, *A. pseudoplatanus*, and species of nutrient-rich habitats. Therefore, to prevent grassland degradation, it is highly discouraged to cease their management. Královec et al. (2009) reported on the possibility of natural regeneration of agriculturally used fields following cessation of fertilisation and regular management in the form of multiple cuttings per year. However, this experiment was relatively small-scale and was probably highly dependent on the colonisation of target species in the proximity and regular management rather than on the seed bank itself. A positive impact of post-restoration management on dry grasslands, evident from the suppression of ruderal perennial vegetation, was experimentally proved by Kiehl and Pfidenhauer (2007), particularly in the later phases of experiments.

The importance of regular management of grassland habitat types 6210(*), 6410, and 6510 was confirmed by Milberg et al. (2017), whose results showed that in comparison to annual mowing, mowing every three years had a negative impact on plant diversity after 11-14 years from cessation of management. Cessation of management had the highest impact on short plants, so the authors recommended extensive management (for example, mowing once every two years) on taller grasslands, whereas short-grown swards are suited for annual mowing. Even though irregular mowing might not be the ideal solution for the conservation of all grassland plants, it is still more reasonable and sustainable regarding diversity in comparison to abandonment, with additional benefits for pollinators.

One of the largest attempts at grassland restoration was carried out as part of the project LIFE04 NAT/HU/119 titled 'Grassland restoration and marsh protection in Egyek-Pusztakócs' in the Hortobágy National Park in the Great Hungarian Plain (Valkó et al. 2021). Following restoration actions in the form of seed mixture sowing, the authors studied the importance of post-restoration management and the impact of seed bank on grassland development. Their results showed that cessation of management had a negative impact on both seed bank and vegetation stands, favouring weed development. Furthermore, seed bank itself had limited potential in grassland restoration since it mainly consisted of weed species and not target species. The similarity between vegetation stands and seed bank was low (Valkó et al. 2021).

When trying to reduce *N. stricta* cover in the case of *N. stricta* dominance on *Nardus* grasslands, it is generally better to choose cattle than sheep, as sheep usually avoid *N. stricta* (Grant et al. 1996), and plant species diversity increases under cattle grazing (Armstrong et al. 1997). Similarly, in a study in the Hrubý Jeseník Mountains in the Czech Republic, overall species richness increased on a previously long-term unmanaged pasture after six years of revived cattle grazing. In addition, rare and endangered species became more dominant. The authors concluded that this was probably the result of cattle trampling, which formed small open habitats that enabled the germination and survival of new species (Mrázková-Štýbnarová et al. 2020). However, according to Hejcman et al. (2008), sheep grazing proved to be a suitable management practice for degraded meadows in the Giant Mts. in the Czech Republic, as it reduced the extent of undesirable species typical of long-term abandoned swards. Crawley (1983) even promotes mixed stocking with sheep and cattle (or goats), as one species improves the environment for the other, and thus facilitation is enabled. Accordingly, Holland et al. (2008) observed that the combined use of cattle and sheep was more effective in creating structural change on *N. stricta* grasslands compared to when sheep alone were used. Next, Kurtogullari et al. (2020) believe that pastures at lower altitudes should have a lower grazing intensity. Velev and Apostolova (2008) also found in their study in Bulgaria that the abundance of *N. stricta* was lower at lower grazing intensity. This could be achieved by moving cattle to higher altitudes earlier during the season. At higher altitudes, cattle should first be sent and enclosed in areas where *N. stricta* is dominant in order to reduce its cover as long as it is still palatable (Kurtogullari et al. 2020).

According to Bedia and Busqué (2013), the most suitable management practice for maintaining species-rich *Nardus* grasslands is grazing by large herbivores, as it reduces not only *N. stricta* dominance through defoliation, but also shrub encroachment through trampling and fertilisation (Hartley and Mitchell 2005). In general, low-intensity management by mowing, grazing, or a combination of both is crucial to retain *Nardus* grasslands (Krahulec et al. 2001, Dullinger et al. 2003). A combination is especially beneficial, as it enables the occurrence of a greater number of different species (Galvánek and Janák 2008). Most of all, a spatially variable disturbance regime is needed (Dullinger et al. 2003). Parolo et al. (2011) showed that heterogeneous grazing management had a positive impact on plant diversity in the alpine species-rich *Nardus* pastures in Italia. Likewise, Zarzycki et al. (2022) claim that to preserve the biodiversity of mountain grasslands, it is vital to preserve a mosaic spatial structure and retain extensive management practices with various forms of human impact, such as mowing and grazing. On the contrary, Vassiliev et al. (2011) suggested the formation of sheep pens for a more spatially uniform grassland management within the mountain in less accessible sites with abandoned pastures in the Western Balkan Mts. in Bulgaria. However, they also advocated extensive management with a zonation regime (Vassiliev et al. 2011). Yearly rotational grazing is also recommended to limit woody encroachment in remote areas on the one hand and also overgrazing near populated areas on the other hand (Başnou et al. 2009). In a study by Lüth et al. (2011), the *Sieversio montanae-Nardetum strictae* grasslands were most species-rich in the case of mowing, slight fertilisation, and grazing in autumn. Thus, they suggested that traditional hay management is the most appropriate practice (Lüth et al. 2011). Some use of manure or leaving cut grass on the ground every now and then is advisable when the only management practice on *Nardus* grasslands is mowing (Háková et al. 2004), as regular removal of biomass might gradually lead to oligotrophisation of these grasslands, especially on very poor soils, which reflects in a lower number of species (Krahulec et al. 1996, Halada et al. 2001). However, several soil parameters have to be considered first to prevent eutrophication (Galvánek and Janák 2008). In the case when *Nardus* grasslands are only mown, it is also highly recommended to introduce artificial disturbance to ensure space for those plant species that are less competitive (Háková et al. 2004). Fischer and Wipf (2002) advised to continue with traditional mowing of subalpine meadows and to switch back to mowing in the case of recently grazed meadows, as grazing negatively affected plant species richness in their study. However, this traditional management practice presents high costs and is, therefore, often no longer feasible (Galvánek and Janák 2008). Considering this, traditional mowing may also be alternated with sheep grazing. In fact, the alternation between mowing and grazing is advisable not only from the perspective of lowering the costs, but also to suppress the spreading of invasive species, as utilisation of only one restoration technique is often not enough to curb the expansion of invasive species (Pecháčková and Krahulec 1995, Krahulec et al. 2001). Pecháčková and Krahulec (1995) reported that by using multiple restoration techniques at once, it is possible to restore species-rich grasslands in three to five years. Nonetheless, Halada et al. (2001) found that the vitality of invasive species was also suppressed by applying regular mowing only. Along with the position of grasslands along the altitudinal gradient, management practices should also always take into consideration the sensitivity of grasslands to isolation and fragmentation (Reitalu et al. 2012, Janišová et al. 2014). Korzeniak (2016) stated that the above-mentioned suggestions are necessary especially for thermophilous grasslands with *Nardus* in the lower montane zone.

Evaluation of grassland restoration techniques

Evaluation of grassland restoration techniques and their comparison is a very demanding task since every restoration action has specific initial conditions at both target and donor sites (Török et al. 2011). Every restoration action depends on interspecies' interactions on the field, particularly competition (Hölzel and Otte 2003), and therefore requires individual approaches (Török et al. 2011). Additionally, technical details differ for each restoration action. Different methods are generally harder to compare. Therefore, only similar actions should be compared (e.g., sowing of seeds and addition of plant material). In general, any restoration planning effort should start with the collection of reliable information regarding the previous and current state of chosen plots. The choice of methodology should be carefully considered and planned according to the target vegetation and conditions at both target and donor sites, which should be ecologically similar (Török et al. 2011). Sengl et al. (2017) noted that commonly used variables, such as similarity and dissimilarity indices, biodiversity indices, number and coverage of chosen functional plant groups, and species number, are applicable only if sites are similar or located nearby, and not when they are distant and/or degraded. For instance, sites with high diversity could be degraded by invasive species and weeds, and thus their ecosystem services could be disrupted. Therefore, Sengl et al. (2017) recommend the evaluation of grassland naturalness, more specifically, the use of ecological indicator values, which explain the state of grasslands through the presence of specific plant species, level of invasiveness, grassland functional diversity, and resilience of grasslands to disturbance and degradation.

The evaluation of success is highly context-dependent. According to Prach et al. (2021a), varying abiotic and biotic factors at chosen sites affect restoration success and are also influenced by the chosen restoration method. Furthermore, soil and landscape characteristics are also highly important. Their experiment showed that the use of regional seed mixtures benefitted the establishment of dry grasslands, whereas methods like natural succession and commercial seed mixtures favoured the establishment of mesic grassland species (Prach et al. 2021a). They also noted that researchers should evaluate measures of post-restoration management, which would primarily help in the establishment of characteristic target species. In addition, restoration must also be thought out from the technical and economic points of view. When possible, the desired restoration actions should be tested. Restoration progress should be monitored and sampled using an appropriate methodology, which should be able to show the differences and results of revegetation attempts. In addition, these should be documented for future reference (Török et al. 2011). The survival of newly established plant populations is often limited by ecosystem services, such as seed production and dispersal, but also by other factors, such as lack of suitable pollinators, limited genetic diversity in sexual mating, vegetative reproduction by dominant species, herbivory, and inadequately planned management (Albert et al. 2021). Albert et al. (2021) found that donor sites provide more ecosystem services in comparison to recipient sites. These show signs of pressure by previous arable use and dominance of ruderals and weeds, supporting mostly herbivory, whereas the presence of late-flowering meadow generalists supports pollination and pollinator diversity on donor grasslands.

Conclusions

Today, grasslands are under threat all over the world, mainly due to human activity and climate change, which is why their ability to provide ecosystem services is rapidly decreasing.

The agri-environment measures for the preservation of high nature value grasslands in Slovenia are not successful for various reasons. Therefore, they should be reconsidered and based on a different basis.

Given the many benefits that grasslands provide, it is vital to prevent their further decline. The best way to maintain grassland biodiversity is to ensure traditional extensive agricultural practices, such as mowing and/or grazing. For this reason, these two practices are also often recommended for grassland restoration. In order to successfully maintain grassland biodiversity, not only one type of appropriate practice but rather the introduction of a wider scheme of traditional management practices is necessary. In addition, mosaic management should also be taken into account.

In the case of partly degraded grasslands, a reduction in management intensity is usually sufficient for their successful restoration. On the other hand, for entirely degraded grasslands, spontaneous succession or technical reclamation (for example, sowing of regional seed mixtures or transfer of plant material) is necessary for their recovery. In any case, the proximity of well-preserved donor grasslands, which serve as a natural source of reproductive units (propagules) for degraded grasslands, is key to the success of larger grassland restoration projects.

Restoration of species-rich grasslands can be a very time-consuming process and usually requires a certain amount of soil preparation on the land that will be subject to restoration, as well as further management after restoration. It was found that optimally chosen post-restoration management may have an impact that is comparable to or even greater than the impact of a suitable restoration method.

When designing restoration studies, it is always necessary to take into account the conditions and area of donor and recipient grassland plots, as well as the phenology of the community and target grassland species.

When selecting donor plots for grassland restoration, attention should be paid to the fact that donor plots should be compatible with recipient plots in terms of nutrient status, hydrological conditions, and substrate. In addition, donor plots must also demonstrate a biogeographically and phytocoenologically representative plant community composition, with as little presence of neophytes as possible.

In any case, active maintenance of well-preserved grasslands that have not yet been degraded is more cost-effective than the restoration of grasslands that have already been degraded.

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References

Albert, Á.-J., Kelemen, A., Valkó, O., Miglécz, T., Csecserits, A., Rédei, T., Deák, B., Tóthmérész, B., Török, P., 2014. Secondary succession in sandy old fields: a promising example of spontaneous grassland recovery. Applied Vegetation Science, 17, 214-224.

Albert, Á.-J., Mudrák, O., Jongepierová, I., Fajmon, K., Frei, I., Ševčíková, M., Klimešová, J., Doležal, J., 2019. Grassland restoration on ex-arable land by transfer of brush-harvested propagules and green hay. Agriculture, Ecosystems and Environment, 272, 74-82.

Albert, Á.-J., Götzenberger, L., Jongepierová, I., Konečná, M., Lőkkösné-Kelbert, B., Májeková, M., Mudrák, O., Klimešová, J., 2021. Restoration of ecosystem functions: seed production in restored and ancient grasslands. Applied Vegetation Science, 24, 202107.

Allen, V.G., Batello, C., Berretta, E.J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., Sanderson, M., 2011. An international terminology for grazing lands and grazing animals. Grass and Forage Science, 66, 2-28.

Ammann, C., Flechard, C.R., Leifeld, J., Neftel, A., Fuhrer, J., 2007. The carbon budget of newly established temperate grassland depends on management intensity. Agriculture, Ecosystems & Environment, 121, 5-20.

Armstrong, R.H., Grant, S.A., Common, T.G., Beattie, M.M., 1997. Controlled grazing studies on *Nardus* grassland: effects of between tussock sward height and species of grazer on diet selection and intake. Grass and Forage Science, 52, 219-231.

Ashton, M.S., Tyrrell, M.L., Spalding, D., Gentry, B. (eds.), 2012. Managing Forest Carbon in a Changing Climate. Springer Science+Business Media B.V., Dordrecht.

Babai, D., Molnár, Z., 2014. Small-scale traditional management of highly species-rich grasslands in the Carpathians. Agriculture, Ecosystems & Environment, 182, 123-130.

Baasch, A., Engst, K., Schmiede, R., May, K., Tischew, S., 2016. Enhancing success in grassland restoration by adding regionally propagated target species. Ecological Engineering, 94, 583-591.

Başnou, C., Pino, J., Šmilauer, P., 2009. Effect of grazing on grasslands in the Western Romanian Carpathians depends on the bedrock type. Preslia, 81, 91-104.

Bedia, J., Busqué, J., 2013. Productivity, grazing utilization, forage quality and primary production controls of species-rich alpine grasslands with *Nardus stricta* in northern Spain. Grass and Forage Science, 68, 297-312.

Bensettiti, F., Boullet, V., Chavaudret-Laborie, C., Deniaud, J. (eds.), 2005. "Habitats manuals" Natura 2000. Knowledge and management of habitats and species of community interest. Tome 4. Agropastoral habitats. Volumes 1 and 2, 445 pp. and 487 pp.

Bilotta, G.S., Brazier, R.E., Haygarth, P.M., 2007. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. Advances in Agronomy, 94, 237-280.

Biondini, M.E., Steuter, A.A., Grygiel, C.E., 1989. Seasonal fire effects on the diversity patterns, spatial distribution and community structure of forbs in the Northern Mixed Prairie, USA. Vegetatio, 85, 21-31.

Bischoff, A., Warthemann, G., Klotz, S., 2009. Succession of floodplain grasslands following reduction in land use intensity: the importance of environmental conditions, management and dispersal. Journal of Applied Ecology, 46, 241-249.

Bonari, G., Fajmon, K., Malenovský, I., Zelený, D., Holuša, J., Jongepierová, I., Kočárek, P., Konvička, O., Uřičár, J., Chytrý, M., 2017. Management of semi-natural grasslands benefiting both plant and insect diversity: the importance of heterogeneity and tradition. Agriculture, Ecosystems and Environment, 246, 243-252.

Bossuyt, B., Honnay, O., 2008. Can the seed bank be used for ecological restoration? An overview of seed bank characteristics in European communities. Journal of Vegetation Science, 19, 875-884.

Burton, R.J.F., Schwarz, G., 2013. Result-oriented agri-environmental schemes in Europe and their potential for promoting behavioural change. Land Use Policy, 30, 628-641.

Butaye, J., Adriaens, D., Honnay, O., 2005. Conservation and restoration of calcareous grasslands: a concise review of the effects of fragmentation and management on plant species. Biotechnologie, Agronomie, Société et Environnement, 9, 111-118.

Common, T.G., Hunter, E.A., Floate, M.J.S., Eadie, J., Hodgson, J., 1991. The long-term effects of a range of pasture treatments applied to three semi-natural hill grassland communities. 1. Pasture production and botanical composition. Grass and Forage Science, 46, 239-251.

Crawley, M.J., 1983. Herbivory: The Dynamics of Animal-Plant Interactions. Studies in Ecology, Volume 10. Blackwell Scientific Publications, Oxford, 437 pp.

Critchley, C.N.R., Fowbert, J.A., Wright, B., 2007. Dynamics of species-rich upland hay meadows over 15 years and their relation with agricultural management practices. Applied Vegetation Science, 10, 307-314.

Dajić Stevanović, Z., Peeters, A., Vrbničanin, S., Šoštarić, I., Aćić, S., 2008. Long term grassland vegetation changes: case study Nature Park Stara Planina (Serbia). Community Ecology, 9, 23-31.

Davidova, S., 2011. Semi-subsistence farming: an elusive concept posing thorny policy questions. Journal of Agricultural Economics, 62, 503-524.Dähler, W., 1992. Long term influence of fertilization in a *Nardetum*. Vegetatio, 103, 141-150.

Donath, T.W., Hölzel, N., Otte, A., 2006. Influence of competition by sown grass, disturbance and litter on recruitment of rare flood-meadow species. Biological Conservation, 130, 315-323.

Donath, T.W., Bissels, S., Hölzel, N., Otte, A., 2007. Large scale application of diaspore transfer with plant material in restoration practice – impact of seed and microsite limitation. Biological Conservation, 138, 224-234.

Dullinger, S., Dirnböck, T., Greimler, J., Grabherr, G., 2003. A resampling approach for evaluating effects of pasture abandonment on subalpine plant species diversity. Journal of Vegetation Science, 14, 243-251.

Edwards, A.R., Mortimer, S.R., Lawson, C.S., Westbury, D.B., Harris, S.J., Woodcock, B.A., Brown, V.K., 2007. Hay strewing, brush harvesting of seed and soil disturbance as tools for the enhancement of botanical diversity in grasslands. Biological Conservation, 134, 372-382.

EEA (European Environment Agency), 2020. State of nature in the EU. Results from reporting under the nature directives 2013–2018. EEA Report No 10/2020.

Elias, D., Hölzel, N., Tischew, S., 2018. Goat paddock grazing improves the conservation status of shrub-encroached dry grasslands. Tuexenia, 38, 215-233.

Enyedi, Z.M., Ruprecht, E., Deák, M., 2008. Long-term effects of the abandonment of grazing on steppe-like grasslands. Applied Vegetation Science, 11, 55-62.

Ewing, A.L., Engle, D.M., 1988. Effects of late summer fire on tallgrass prairie microclimate and community composition. The American Midland Naturalist, 120, 212-223.

Factsheet on the 2014-2022 Rural Development Programme for Slovenia, 2022. European Commission. https://agriculture.ec.europa.eu/system/files/2022-10/rdp-factsheet-slovenia_en.pdf (16. 3. 2023).

Fagan, K.C., Pywell, R.C., Bullock, J.M., Marrs, R.H., 2008. Do restored calcareous grasslands on former arable fields resemble ancient targets? The effect of time, methods and environment on outcomes. Journal of Applied Ecology, 45, 1293-1303.

Fischer, M., Wipf, S., 2002. Effect of low-intensity grazing on the species-rich vegetation of traditionally mown subalpine meadows. Biological Conservation, 104, 1-11.

Fraser, L.H., Pither, J., Jentsch, A., Sternberg, M., Zobel, M., Askarizadeh, D., ... Zupo, T., 2015. Worldwide evidence of a unimodal relationship between productivity and plant species richness. Science, 349, 302-305.

Galvánek, D., Janák, M., 2008. Management of Natura 2000 habitats. 6230 *Species-rich *Nardus* grasslands. Technical Report 2008 14/24. European Commission, Brussels, 24 pp.

Galvánek, M., Lepš, J., 2008. Changes of species richness pattern in mountain grasslands: abandonment vs. restoration. Biodiversity and Conservation, 17, 3241-3253.

Goret, T., Janssens, X., Godefroid, S., 2021. A decision-making tool for restoring lowland grasslands in Europe. Journal for Nature Conservation, 63, 126046.

Grant, S.A., Torvell, L., Sim, E.M., Small, J.L., Armstrong, R.H., 1996. Controlled grazing studies on *Nardus* grassland: effects of between-tussock sward height and species of grazer on *Nardus* utilization and floristic composition in two fields in Scotland. Journal of Applied Ecology, 33, 1053-1064.

Halada, Ľ., Ružičková, H., David, S., 2001. Monitoring of the grassland communities in the East Carpathians biosphere reserve – basis for the future ILTER site. Ekológia, 20, 107-114.

Halada, Ľ., Evans, D., Romão, C., Petersen, J.-E., 2011. Which habitats of European importance depend on agricultural practices?. Biodiversity Conservation, 20, 2365-2378.

Háková, A., Klaudisová, A., Sádlo, J. (eds.), 2004. Zásady péče o nelesní biotopy v rámci soustavy Natura 2000. Planeta XII, 8/2004, druhá část. Ministerstvo životního prostředí, Praha, 144 pp.

Hartley, S.E., Mitchell, R.J., 2005. Manipulation of nutrients and grazing levels on heather moorland: changes in *Calluna* dominance and consequences for community composition. Journal of Ecology, 93, 990-1004.

Hartnett, D.C., Hickman, K.R., Walter, L.E.F., 1996. Effects of bison grazing, fire, and topography on floristic diversity in tallgrass prairie. Journal of Range Management, 49, 413-420.

Hartvigsen, M., 2014. Land reform and land fragmentation in Central and Eastern Europe. Land Use Policy, 36, 330-341.

Haslgrübler, P., Krautzer, B., Blaschka, A., Graiss, W., Pötsch, E.M., 2013. Quality and germination capacity of seed material harvested from an *Arrhenatherion* meadow. Grass and Forage Science, 69, 454-461.

Hayes, G.F., Holl, K.D., 2003. Cattle grazing impacts on annual forbs and vegetation composition of mesic grasslands in California. Conservation Biology, 17, 1694-1702.

Hegg, O., Feller, U., Dähler, W., Scherrer, C., 1992. Long term influence of fertilization in a *Nardetum*: phytosociology of the pasture and nutrient contents in leaves. Vegetatio, 103, 151-158.

Heinsoo, K., Melts, I., Sammul, M., Holm, B., 2010. The potential of Estonian semi-natural grasslands for bioenergy production. Agriculture, Ecosystems & Environment, 137, 86-92.

Hejcman, M., Klaudisová, M., Štursa, J., Pavlů, V., Schellberg, J., Hejcmanová, P., Hakl, J., Rauch, O., Vacek, S., 2007. Revisiting a 37 years abandoned fertilizer experiment on *Nardus* grassland in the Czech Republic. Agriculture, Ecosystems & Environment, 118, 231-236.

Hejcman, M., Žáková, I., Bílek, M., Bendová, P., Hejcmanová, P., Pavlů, V., Stránská, M., 2008. Sward structure and diet selection after sheep introduction on abandoned grassland in the Giant Mts, Czech Republic. Biologia, 63, 506-514.

Herzon, I., Birge, T., Allen, B., Povellato, A., Vanni, F., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R., Underwood, E., Poux, X., Beaufoy, G., Pražan, J., 2018. Time to look for evidence: results-based approach to biodiversity conservation on farmland in Europe. Land Use Policy, 71, 347-354.

Hofmann, M., Isselstein, J., 2004. Seedling recruitment on agriculturally improved mesic grassland: the influence of disturbance and management schemes. Applied Vegetation Science, 7, 193-200.

Hofmann, S., Conradi, T., Kiehl, K., Albrecht, H., 2020. Effects of different restoration treatments on long-term development of plant diversity and functional trait composition in calcareous grasslands. Tuexenia, 40, 175-200.

Holland, J.P., Waterhouse, A., Robertson, D., Pollock, M.L., 2008. Effect of different grazing management systems on the herbage mass and pasture height of a *Nardus stricta* grassland in western Scotland, United Kingdom. Grass and Forage Science, 63, 48-59.

Hölzel, N., Otte, A., 2003. Restoration of a species-rich flood meadow by topsoil removal and diaspore transfer with plant material. Applied Vegetation Science, 6, 131-140.

Huhta, A.-P., Rautio, P., Tuomi, J., Laine, K., 2001. Restorative mowing on an abandoned semi-natural meadow: short-term and predicted long-term effects. Journal of Vegetation Science, 12, 677-686.

Ivajnšič, D., Pintarič, D., Škornik, S., Kaligarič, M., Pipenbaher, N., 2019. SOSKOPOP Haloze: podporni sistem potencialnim uveljaviteljem ukrepov KOPOP na nivoju travišč. Revija za geografijo, 14, 49-64.

Janišová, M., Michalcová, D., Bacaro, G., Ghisla, A., 2014. Landscape effects on diversity of semi-natural grasslands. Agriculture, Ecosystems & Environment, 182, 47-58.

Johanidesová, E., Fajmon, K., Jongepierová, I., Prach, K., 2014. Spontaneous colonization of restored dry grasslands by target species: restoration proceeds beyond sowing regional seed mixtures. Grass and Forage Science, 70, 631-638.

Jones, M.B., Donnelly, A., 2004. Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO2. New Phytologist, 164, 423-439.

Jongepierová, I., Mitchley, J., Tzanopoulous, J., 2007. A field experiment to recreate species rich hay meadows using regional seed mixtures. Biological Conservation, 139, 297-305.

Kaligarič, M., Čuš, J., Škornik, S., Ivajnšič, D., 2019. The failure of agri-environment measures to promote and conserve grassland biodiversity in Slovenia. Land Use Policy, 80, 127-134.

Kardol, P., Van der Wal, A., Bezemer, T.M., de Boer, W., Duyts, H., Holtkamp, R., Van der Putten, W.H., 2008. Restoration of species-rich grasslands on ex-arable land: seed addition outweighs soil fertility reduction. Biological Conservation, 141, 2208-2217.

Kiehl, K., Thormann, A., Pfadenhauer, J., 2006. Evaluation of initial restoration measures during the restoration of calcareous grasslands on former arable fields. Restoration Ecology, 14, 148-156.

Kiehl, K., Pfidenhauer, J., 2007. Establishment and persistence of target species in newly created calcareous grasslands on former arable fields. Plant Ecology, 189, 31-48.

Kiehl, K., Kirmer, A., Donath, T.W., Rasran, L., Hölzel, N., 2010. Species introduction in restoration projects – evaluation of different techniques for the establishment of semi-natural grasslands in Central and Northwestern Europe. Basic and Applied Ecology, 11, 285-299.

Klaus, V.H., Hoever, C.J., Fischer, M., Hamer, U., Kleinebecker , T., Mertens, D., Schäfer, D., Prati, D., Hölzel, N., 2018. Contribution of the soil seed bank to the restoration of temperate grasslands by mechanical sward disturbance. Restoration Ecology, 26, S114-S122.

Kleijn, D., 2003. Can establishment characteristics explain the poor colonization success of late successional grassland species on ex-arable land?. Restoration Ecology, 11, 131-138.

Klimeš, L., Hájek, M., Mudrák, O., Dančák, M., Preislerová, Z., Hájková, P., Jongepierová, I., Klimešová, J., 2013. Effects of changes in management on resistance and resilience in three grassland communities. Applied Vegetation Science, 16, 640-649.

Knappová, J., Hemrová, L., Münzbergová, Z., 2012. Colonization of central European abandoned fields by dry grassland species depends on the species richness of the source habitats: a new approach for measuring habitat isolation. Landscape Ecology, 27, 97-108.

Korzeniak, J., 2016. Mountain *Nardus stricta* grasslands as a relic of past farming – the effects of grazing abandonment in relation to elevation and spatial scale. Folia Geobotanica, 51, 93-113.

Köhler, M., Elias, D., Hiller, G., Hölzel, N., Tischew, S., 2020. Restoration of orchid-rich dry calcareous grasslands by rotational goat pasturing. Tuexenia, 40, 201-223.

Krahulec, F., Blažková, D., Balátová-Tuláčková, E., Štursa, J., Pecháčková, S., Fabšičová, M., 1996. Louky Krkonoš: rostlinná společenstva a jejich dynamika. Opera Corcontica, 33. Správa Krkonošského národního parku, Vrchlabí, 252 pp.

Krahulec, F., Skálová, H., Herben, T., Hadincová, V., Wildová, R., Pecháčková, S., 2001. Vegetation changes following sheep grazing in abandoned mountain meadows. Applied Vegetation Science, 4, 97-102.

Krahulec, F., Chytrý, M., Härtel, H., 2007. *Nardus* grasslands and heathlands. In: Chytrý, M. (ed.): Vegetation of the Czech Republic. 1. Grassland and Heathland Vegetation. Academia, Prague, pp. 281-306.

Královec, J., Pocová, L., Jonášová, M., Macek, P., Prach, K., 2009. Spontaneous recovery of an intensively used grassland after cessation of fertilizing. Applied Vegetation Science, 12, 391-397.

Krautzer, B., Bartel, A., Kirmer, A., Tischew, S., Feucht, B., Wieden, M., Haslgrübler, P., Rieger, E., Pötsch, E.M., 2011. Establishment and use of high nature value farmland. In: Proceedings of the 16th EGF Symposium on "Grassland farming and land management systems in mountainous regions". Gumpenstein, Austria, August 29-31, pp. 457-469.

Kurtogullari, Y., Rieder, N.S., Arlettaz, R., Humbert, J.-Y., 2020. Conservation and restoration of *Nardus* grasslands in the Swiss northern Alps. Applied Vegetation Science, 23, 26-38.

Kuzemko, A.A., Steinbauer, M.J., Becker, T., Didukh, Y.P., Dolnik, C., Jeschke, M., Naqinezhad, A., Uğurlu, E., Vassilev, K., Dengler, J., 2016. Patterns and drivers of phytodiversity in steppe grasslands of Central Podolia (Ukraine). Biodiversity and Conservation, 25, 2233-2250.

Lawson, C.S., Ford, M.A., Mitchley, J., 2004. The influence of seed addition and cutting regime on the success of grassland restoration on former arable land. Applied Vegetation Science, 7, 259-266.

Lencová, K., Prach, K., 2011. Restoration of hay meadows on ex-arable land: commercial seed mixtures vs. spontaneous succession. Grass and Forage Science, 66, 265-271.

Lengyel, S., Varga, K., Kosztyi, B., Lontay, L., Déri, E., Török, P., Tóthmérész, B., 2012. Grassland restoration to conserve landscape-level biodiversity: a synthesis of early results from a large-scale project. Applied Vegetation Science, 15, 264-276.

Lepš, J., Doležal, J., Bezemer, T.M., Brown, V.K., Hedlund, K., Igual Arroyo, M., Jörgensen, H.B., Lawson, C.S., Mortimer, S.R., Peix Geldart, A., Rodríguez Barrueco, C., Santa Regina, I., Šmilauer, P., van der Putten, W.H., 2007. Long-term effectiveness of sowing high and low diversity seed mixtures to enhance plant community development on ex-arable fields. Applied Vegetation Science, 10, 97-110.

Lesschen, J.P., Elbersen, B., Hazeu, G., van Doorn, A., Mucher, S., Velthof, G., 2014. Defining and Classifying Grasslands in Europe. Wageningen University and Research, Wageningen.

Lovec, M., Šumrada, T., Erjavec, E., 2020. New CAP delivery model, old issues. Intereconomics, 2, 112-119.

Lüth, C., Tasser, E., Niedrist, G., Dalla Via, J., Tappeiner, U., 2011. Classification of the *Sieversio montanae-Nardetum strictae* in a cross-section of the Eastern Alps. Plant Ecology, 212, 105-126.

Marriott, C.A., Fothergill, M., Jeangros, B., Scotton, M., Louault, F., 2004. Long-term impacts of extensification of grassland management on biodiversity and productivity in upland areas. A review. Agronomie, 24, 447-462.

Matches, A.G., 1992. Plant response to grazing: a review. Journal of Production Agriculture, 5, 1-7.

Mayel, S., Jarrah, M., Kuka, K., 2021. How does grassland management affect physical and biochemical properties of temperate grassland soils? A review study. Grass Forage Science, 76, 215-244.

McLeod, R.F., Gates, J.E., 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. The American Midland Naturalist, 139, 164-177.

Merunková, K., Chytrý, M., 2012. Environmental control of species richness and composition in upland grasslands of the southern Czech Republic. Plant Ecology, 213, 591-602.

Middleton, E.L., Bever, J.D., 2012. Inoculation with a native soil community advances succession in a grassland restoration. Restoration Ecology, 20, 218-226.

Milberg, P., Tälle, M., Fogelfors, H., Westerberg, L., 2017. The biodiversity cost of reducing management intensity in species-rich grasslands: mowing annually vs. every third year. Basic and Applied Ecology, 22, 61-74.

Milchunas, D.G., Sala, O.E., Lauenroth, W.K., 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. The American Naturalist, 132, 87-106.

Mitchell, R.J., Rose, R.J., Palmer, S.C.F., 2009. The effect of restoration techniques on non-target species: case studies in moorland ecosystems. Applied Vegetation Science, 12, 81-91.

Mitchley, J., Jongepierová, I., Fajmon, K., 2012. Regional seed mixtures for the re-creation of species-rich meadows in the White Carpathian Mountains: result of a 10-yr experiment. Applied Vegetation Science, 15, 253-263.

Moog, D., Poschlod, P., Kahmen, S., Schreiber, K.-F., 2002. Comparison of species composition between different grassland management treatments after 25 years. Applied Vegetation Science, 5, 99-106.

Mrázková-Štýbnarová, M., Holec, J., Štencl, R., Kolářová, M., Tyšer, L., Oldřich, L. 2020., Impact of renewed cattle grazing on floristic composition in the Hrubý Jeseník Mountains. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 68, 335-342.

Muller, S., 2002. Appropriate agricultural management practices required to ensure conservation and biodiversity of environmentally sensitive grassland sites designated under Natura 2000. Agriculture, Ecosystems & Environment, 89, 261-266.

Palpurina, S., Wagner, V., von Wehrden, H., Hájek, M., Horsák, M., Brinkert, A., … Chytrý, M., 2017. The relationship between plant species richness and soil pH vanishes with increasing aridity across Eurasian dry grasslands. Global Ecology and Biogeography, 26, 425-434.

Paolinelli Reis, B., Szitár, K., Kövendi-Jakó, A., Török, K., Sáradi, N., Csákvári, E., Halassy, M., 2022. The long-term effect of initial restoration intervention, landscape composition, and time on the progress of Pannonic sand grassland restoration. Landscape and Ecological Engineering, 18, 429-440.

Parolo, G., Abeli, T., Gusmeroli, F., Rossi, G., 2011. Large-scale heterogeneous cattle grazing affects plant diversity and forage value of Alpine species-rich *Nardus* pastures. Grass and Forage Science, 66, 541-550.

Pecháčková, S., Krahulec, F., 1995. Efficient nitrogen economy: key to the success of *Polygonum bistorta* in an abandoned mountain meadow. Folia Geobotanica et Phytotaxonomica, 30, 211-222.

Pe'er, G., Finn, J.A., Díaz, M., Birkenstock, M., Lakner, S., Röder, N., Kazakova, Y., Šumrada, T., Bezäk, P., Concepción, E.D., Dänhardt, J., Morales, M.B., Rac, I., Špulerová, J., Schindler, S., Stavrinides, M., Targetti, S., Viaggi, D., Vogiatzakis, I.N., Guyomard, H., 2022. How can the European Common Agricultural Policy help halt biodiversity loss? Recommendations by over 300 experts. Conservation Letters, 2022, e12901.

Prach, K., Hobbs, R.J., 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology, 16, 363-366.

Prach, K., Jongepierová, I., Řehounková, K., 2013. Large-scale restoration of dry grasslands on ex-arable land using a regional seed mixture: establishment of target species. Restoration Ecology, 21, 33-39.

Prach, K., Jongepierová, I., Řehounková, K., Fajmon, K., 2014. Restoration of grasslands on ex-arable land using regional and commercial seed mixtures and spontaneous succession: successional trajectories and changes in species richness. Agriculture, Ecosystems and Environment, 182, 131-136.

Prach, K., Fajmon, K., Jongepierová, I., Řehounková, K., 2015. Landscape context in colonization of restored dry grasslands by target species. Applied Vegetation Science, 18, 181-189.

Prach, K., Fajmon, K., Řehounková, K., Jongepierová, I., 2021a. Hierarchy of environmental factors driving restoration of dry grasslands: a multi-site analysis. Applied Vegetation Science, 24, 202104.

Prach, K., Vítovcová, K., Řehounková, K., Královec, J., 2021b. Three decades of vegetation changes in a submontane grassland after the cessation of intensive fertilization. Preslia, 93, 169-179.

Prioritised action framework (PAF) for Natura 2000 in Slovenia pursuant to Article 8 of Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive) for the Multiannual Financial Framework period 2021 – 2027, 2019. Ministry of the Environment and Spatial Planning. https://natura2000.gov.si/fileadmin/user_upload/IP_PAF_Slovenia_final.pdf (17. 10. 2022).

Pykälä, J., 2004. Cattle grazing increases plant species richness of most species trait groups in mesic semi-natural grasslands. Plant Ecology, 175, 217-226.

Reheul, D., De Vliegher, A., Bommelé, L., Carlier, L., 2007. The comparison between temporary and permanent grassland. In: Proceedings of the 14th EGF Symposium on "Permanent and temporary grassland: plant, environment, economy". Ghent, Belgium, September 3-5, pp. 1-13.

Reitalu, T., Purschke, O., Johansson, L.J., Hall, K., Sykes, M.T., Prentice, H.C., 2012. Responses of grassland species richness to local and landscape factors depend on spatial scale and habitat specialization. Journal of Vegetation Science, 23, 41-51.

Resch, M.C., Schütz, M., Buchmann, N., Frey, B., Graf, U., van der Putten, W.H., Zimmerman, S., Risch, A.C., 2021. Evaluating long-term success in grassland restoration: an ecosystem multifunctionality approach. Ecological Applications, 31, e02271.

Roeling, I.S., Ozinga, W.A., van Dijk, J., Eppinga, M.B., Wassen, M.J., 2018. Plant species occurrence patterns in Eurasian grasslands reflect adaptation to nutrient ratios. Oecologia, 186, 1055-1067.

Rūsiņa, S., Auniņš, A., Spuņģis, V., 2017. Chapter 13. 6230* Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas. In: Rūsiņa, S. (ed.): Protected Habitat Management Guidelines for Latvia. Nature Conservation Agency, Sigulda, pp. 155-163.

Rydgren, K., Nordbakken, J.-F., Austad, I., Auestad, I., Heegaad, E., 2010. Recreating semi-natural grasslands: a comparison of four methods. Ecological Engineering, 36, 1672-1679.

Schelfhout, S., Mertens, S., Perring, M.P., Raman, M., Baeten, L., Demey, A., Reubens, B., Oosterlynck, S., Gibson-Roy, P., Verheyen, K., De Schrijver, A., 2017. P-removal for restoration of *Nardus* grasslands on former agricultural land: cutting traditions. Restoration Ecology, 25, S178-S187.

Schlesinger, W.H., 1997. Carbon balance in terrestrial detritus. Annual Review of Ecology and Systematics, 8, 51-81.

Sengl, P., Magnes, M., Erdős, L., Berg, C., 2017. A test of naturalness indicator values to evaluate success in grassland restoration. Community Ecology, 18, 184-192.

Silva, V., Catry, F.X., Fernandes, P.M., Rego, F.C., Paes, P., Nunes, L., Caperta, A.D., Sérgio, C., Bugalho, M.N., 2019. Effects of grazing on plant composition, conservation status and ecosystem services of Natura 2000 shrub-grassland habitat types. Biodiversity and Conservation, 28, 1205-1224.

Sojneková, M., Chytrý, M., 2015. From arable land to species-rich semi-natural grasslands: succession in abandoned fields in a dry region of Central Europe. Ecological Engineering, 77, 373-381.

Stanová, V., Šeffer, J., Ripka, J., 2007. Hodnotenie vegetácie a návrh monitoringu zjazdoviek lyžiarskeho strediska Veľká Rača. Daphne - Inštitút aplikovanej ekológie, Bratislava.

Suttie, J.M., Reynolds, S.G., Batello, C. (eds.), 2005. Grasslands of the World. Plant Production and Protection Series, No. 34. Food and Agricultural Organization of the United Nations, Rome.

Sutcliffe, L.M.E., Germany, M., Becker, U., Becker, T., 2016. How does size and isolation affect patches of steppe-like vegetation on slumping hills in Transylvania, Romania?. Biodiversity and Conservation, 25, 2275-2288.

Šumrada, T., Vreš, B., Čelik, T., Šilc, U., Rac, I., Udovč, A., Erjavec, E., 2021. Are result-based schemes a superior approach to the conservation of High Nature Value grasslands? Evidence from Slovenia. Land Use Policy, 111, 105749.

Šumrada, T., Japelj, A., Verbič, M., Erjavec, E., 2022. Farmers' preferences for result-based schemes for grassland conservation in Slovenia. Journal for Nature Conservation, 66, 126143.

Tälle, M., Deák, B., Poschlod, P., Valkó, O., Westerberg, L., Milberg, P., 2018. Similar effects of different mowing frequencies on the conservation value of semi-natural grasslands in Europe. Biodiversity and Conservation, 27, 2451-2475.

Tóth, E., Deák, B., Valkó, O., Kelemen, A., Miglécz, T., Tóthmérész, B., Török, P., 2018. Livestock type is more crucial than grazing intensity: traditional cattle and sheep grazing in short-grass steppes. Land Degradation & Development, 29, 231-239.

Tölgyesi, C., Vadász, C., Kun, R., Csathó, A.I., Bátori, Z., Hábenczyus, A., Erdős, L., Török, P., 2022. Post-restoration grassland management overrides the effects of restoration methods in propagule-rich landscapes. Ecological Applications, 32, e02463.

Török, P., Vida, E., Deák, B., Lengyel, S., Tóthmérész, B., 2011. Grassland restoration on former croplands in Europe: an assessment of applicability of techniques and costs. Biodiversity and Conservation, 20, 2311-2332.

Török, P., Miglécz, T., Valkó, O., Kelemen, A., Tóth, K., Lengye,l S., Tóthmérész, B., 2012. Fast restoration of grassland vegetation by a combination of seed mixture sowing and low-diversity hay transfer. Ecological Engineering, 44, 133-138.

Török, P., Hölzel, N., van Diggelen, R., Tischew, S., 2016. Grazing in European open landscapes: how to reconcile sustainable land management and biodiversity conservation?. Agriculture, Ecosystems & Environment, 234, 1-4.

Török, P., Janišová, M., Kuzemko, A., Rūsiņa, S., Dajić Stevanovic, Z., 2017. Grasslands, their threats and management in Eastern Europe. In: Squires, V.R., Dengler, J., Hua, L., Feng, H. (eds.): Grasslands of the World: Diversity, Management and Conservation, 1st Edition. CRC Press, Boca Raton, FL, pp. 64-88.

Török, P., Dembicz, I., Dajić-Stevanović, Z., Kuzemko, A., 2020. Grasslands of Eastern Europe. In: Goldstein, M.I., DellaSala, D.A. (eds.): Encyclopedia of the World's Biomes. Elsevier, Amsterdam, pp. 703-713.

Turtureanu, P.D., Palpurina, S., Becker, T., Dolnik, C., Ruprecht, E., Sutcliffe, L.M.E., Szabó, A., Dengler, J., 2014. Scale- and taxon-dependent biodiversity patterns of dry grassland vegetation in Transylvania. Agriculture, Ecosystems & Environment, 182, 15-24.

Valkó, O., Török, P., Matus, G., Tóthmérész, B., 2012. Is regular mowing the most appropriate and cost-effective management maintaining diversity and biomass of target forbs in mountain hay meadows?. Flora, 207, 303-309.

Valkó, O., Török, P., Deák, B., Tóthmérész, B., 2014. Review: prospects and limitations of prescribed burning as a management tool in European grasslands. Basic and Applied Ecology, 15, 26-33.

Valkó, O., Deák, B., Török, P., Tóth, K., Kiss, R., Kelemen, A., Miglécz, T., Sonkoly, J., Tóthmérész, B., 2021. Dynamics in vegetation and seed bank composition highlight the importance of post-restoration management in sown grasslands. Restoration Ecology, 29, e13192.

Van Daele, F., Wasof, S., Demey, A., Schelfhout, S., De Schrivjer, A., Baeten, L., van Ruijven, J., Mertens, J., Verheyen, K., 2017. Quantifying establishment limitations during the ecological restoration of species-rich *Nardus* grassland. Applied Vegetation Science, 20, 594-607.

Vasconcelos, H.L., Maravalhas, J.B., Cornelissen, T., 2017. Effects of fire disturbance on ant abundance and diversity: a global meta-analysis. Biodiversity and Conservation, 26, 177-188.

Vassiliev, K., Pedashenko, H., Nikolov, S.C., Apostolova, I., Dengler, J., 2011. Effect of land abandonment on the vegetation of upland semi-natural grasslands in the Western Balkan Mts., Bulgaria. Plant Biosystems, 145, 654-665.

Velev, N.I., Apostolova, I.I., 2008. Successional changes of *Nardus stricta* communities in the Central Balkan Range (Bulgaria). Phytologia Balcanica, 14, 75-84.

Wick, A.F., Geaumont, B.A., Sedivec, K., Hendrickson, J.R., 2016. Grassland degradation. In: Shroder, J.F., Sivanpillai, R. (eds.): Biological and Environmental Hazards, Risks, and Disasters. Elsevier, Amsterdam, pp. 257-276.

Wubs, E.R.J., van der Putten, W.H., Bosch, M., Bezemer, T.M., 2016. Soil inoculation steers restoration of terrestrial ecosystems. Nature Plants, 2, 16107.

Zaitsev, A.S., Gongalsky, K.B., Korobushkin, D.I., Butenko, K.O., Gorshkova, I.A., Rakhleeva, A.A., Saifutdinov, R.A., Kostina, N.V., Shakhab, S.V., Yazrikova, T.E., 2017. Reduced functionality of soil food webs in burnt boreal forests: a case study in Central Russia. Contemporary Problems of Ecology, 10, 277-285.

Zarzycki, J., Korzeniak, J., Perzanowska, J., 2022. Impact of land use changes on the diversity and conservation status of the vegetation of mountain grasslands (Polish Carpathians). Land, 11, 252.