10
TEMPERATE GRASSLANDS

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Temperate grasslands are generally dominated by graminoid vegetation and have less than 10 per cent cover of trees and shrubs. These ecosystems occur around the world, provide important ecological functions, and often have high biodiversity. We review the types of temperate grasslands, consider why they have been lost or degraded and why they are being restored, summarize common restoration methods, and end with several examples of such restoration efforts.

Types, origin and present distribution of temperate grasslands

We distinguish primary and secondary temperate grasslands on the basis of the factors that conditioned their existence and maintain them. Among the secondary grasslands we distinguish pastures and hay meadows.

Primary grasslands

Primary grasslands occur where the establishment of woody plants is restricted by natural processes. These restrictions may be climatic (e.g. duration of the dry season), edaphic (low water holding capacity and/or high salt content of substrates), or disturbance-related (fire, avalanches, grazing) or combinations thereof. Extensive primary grasslands whose existence is conditioned by the macroclimate represent zonal biomes. For detailed descriptions see Archibold (1995) or Gibson (2009). Below we highlight a few key types:

- *Euro-Asia*: Steppes stretch from central Europe to central Asia and vary from forest-steppes to very short-grass steppes with some transitions to semi-desert formations. They often exhibit high species diversity especially at scales up to several square meters. Key genera are *Stipa* and *Festuca*; *Artemisia* are also typical in short-grass steppes. Many steppes have been ploughed, particularly where they occurred on fertile chernozem soils; some spontaneously recovered after ploughing ceased but rarely reached their original species composition (Dengler *et al.* 2014). Nowadays, undisturbed steppe vegetation mostly occurs on extreme sites such as south-facing hillsides, in transitional areas towards semi-deserts, or at man-made ancient cultural and burial monuments such as kurgans.

- *North America*: Prairies occur primarily in the centre of North America. Several types of prairie are distinguished, ranging from tallgrass prairie in the south and east to shortgrass prairie in the north and west. Warm-season grasses increasingly dominate as humidity and temperature increase (Gibson 2009). Key genera include *Andropogon*, *Hesperostipa* and *Bouteloua*. The historical influence of Native Americans is difficult to ascertain but it was likely significant. The arrival of European immigrants in the 1800s resulted in the conversion of many prairies to intensive agriculture, especially in the tall-grass prairie region, and introduced many alien plants. Nowadays, there are many programs and projects to restore prairies. The world's first intentional restoration project was established in 1936 to restore a tall-grass prairie near Madison, Wisconsin.
- *South America*: The Southern Cone of South America contains large expanses of temperate grasslands, including pampas, campos and steppe (Zuleta *et al.* 2015). Compared to North American prairies, there is little historical evidence of disturbances such as fire or grazing that would have maintained them. However, livestock were introduced several centuries ago, and have been a dominant aspect of the ecology of these systems since then: Zuleta *et al.* (*ibid.*) estimate three-quarters of the grasslands in Argentina are subject to livestock ranching. Intensive grazing is practiced in some areas, and other areas are being lost to afforestation (Six *et al.* 2014).

Secondary grasslands

Secondary grasslands are maintained and/or created by cultural practices such as mowing, burning, hay harvesting, and grazing by domestic livestock.

European secondary grasslands are described in Veen *et al.* (2009) and briefly also in Dengler *et al.* (2014). They started to develop during the Neolithic period, beginning there approximately 7500 years before present (BP). They had precursors in earlier primary grasslands and in treeless openings within forests that were probably maintained predominantly by free grazing of wild animals (Vera 2000). Hay meadows appeared in temperate Europe during the Bronze Age, some 4000 years BP. Over the millennia since then, changes in management have altered the composition of these pastures and meadows, though these changes pale compared to the degradation they experienced in the second half of the twentieth century (see below).

In North America, the relative importance of natural factors and the cultural practices of Native Americans before European settlement are difficult to ascertain, though there is evidence that some grasslands were strongly shaped by cultural practices. In the Pacific Northwest, for example, edaphic conditions are highly suitable for forests yet there were estimated to be ~100,000 ha of prairies, with unique flora and fauna, when European settlers arrived around 1850. These areas were maintained by Native American practices such as burning and the harvesting of foods such as *Camassia* bulbs (Dunwiddie and Bakker 2011). In some cases, the ecotone between grassland and forest has been stable enough that it can be detected by examining soil properties (Hegarty *et al.* 2011). Some of the temperate grasslands in the Midwestern and eastern United States were created by anthropogenic clearing and grazing that began several hundred years ago (Gibson 2009).

Reasons why temperate grasslands have been lost or degraded

Loss of grasslands

Besides direct destruction by building and other construction activities, there are three widespread reasons grasslands have been lost:

- *Ploughing*. With increasing crop production, especially of cereal grains, many grasslands were converted to arable land. Large-scale ploughing of primary steppes in the former Soviet Union happened during the communist era. Secondary grasslands were ploughed in some parts of Europe between 1950 and 1980, reducing their original area by up to a third. Compared to unploughed grasslands, arable land exhibits lower water retention capacity, lower water filtering effects and is more susceptible to erosion. Moreover, many grasslands were ploughed and then re-seeded by species-poor commercial seed mixtures containing a few productive grasses and legumes.
- *Spontaneous forest succession*. Forests may spontaneously develop when grasslands no longer experience the disturbances that hinder tree seedling establishment. Wind or animal dispersed woody plants (e.g. *Betula*, *Populus*, *Pinus*, *Picea*) are often the first to colonize these areas.
- *Technical afforestation*. In some regions, grasslands have been intentionally planted with trees, usually fast-growing species that provide pulp or timber.

Grassland degradation

We usually define degradation when there is undesirable changes in species composition, especially decrease of diversity, increase of unwanted competitors and/or weeds, and deterioration of ecosystem functioning. Grasslands can be degraded in many ways:

- *Cessation of management*. If the cultural practices, such as cutting, grazing or burning, that maintain a secondary grassland cease, the area can rapidly undergo succession towards woodland. Changes can occur in a few decades. In some cases, competitive herb or grass dominants may expand and preclude establishment of woody species for a long time, but diversity of grassland species also decreases.
- *Fragmentation*. Fragmentation reduces the size of remnant patches and increases their isolation, thus limiting landscape-scale dispersal. As fragmentation increases, the areas around the patches can increasingly alter the patches by, for example, serving as sources of weeds.
- *Altered water regime*. Many wet grasslands were drained to increase the amount and quality of fodder production. Draining alters the species composition of the grassland and can decrease ecosystem functions such as water filtration.
- *Eutrophication*. Nutrients may be added to grasslands directly by mineral or organic fertilizers or indirectly by aerial deposition, mostly of nitrogen, or fertilizer run-off from cropland areas. Species diversity usually declines due to the expansion of competitive, nutrient-demanding species.
- *Altered frequency and intensity of management*. Grasslands that are overgrazed or cut too frequently have reduced biodiversity as they support only a few resistant species. Conversely, however, diversity also decreases if management is not intensive enough. Management should be heterogeneous in kind, space, and time; cutting or grazing large areas at once may drastically reduce insect populations and cause large-scale homogenization of the vegetation.

Why restore grasslands? Possibilities and limitations

Grasslands provide many ecosystem services, so their restoration can be profitable for humans.[1] However, grassland restoration is also a moral challenge or obligation. Reasons to restore temperate grasslands include:

- *To increase local biodiversity*. Biodiversity is a multi-faceted term, encompassing variation within species, the wide range of living organisms (plants, birds, microbes, etc.), and communities. Grasslands with higher biodiversity usually exhibit better ecosystem functioning. Moreover, many people agree that there are ethical reasons to preserve and restore biodiversity (Lanzerath and Friele 2014).
- *To enhance connectivity*. When conducted on sites between extant grasslands, restoration can create corridors and increase landscape-scale connectivity. This connectivity is necessary to facilitate the migration of species for which the matrix vegetation is a barrier.
- *To increase productivity*. In areas where grasslands have been lost to desertification, for example, grassland restoration can increase the availability of fodder for livestock.
- *To decrease erosion*. Grasslands are generally dominated by perennial species whose roots hold the soil in place and reduce erosion compared to arable lands.
- *To increase water quality and quantity*. Water that drains into grassland soils rather than running off via surface flow can recharge aquifers and decrease the flood risk in lower parts of a watershed. Grassland soils can also immobilize pollutants and nutrients held in solution in the water.
- *To sequester carbon and counteract climate change*. Chernozem and other soils, which develop beneath grasslands, accumulate high amounts of carbon, hence act as carbon sinks that can ‘lock up’ what otherwise would be mass releases of greenhouse gases.
- *To restore the aesthetic and cultural values of landscapes*. Grasslands have a subtle beauty, and also have important cultural connections. This is most notable for secondary grasslands that have developed from long-term human activities.

Efforts to restore grasslands face various obstacles and limitations. We group these broadly into natural and societal obstacles.

Natural obstacles include:

- *Spontaneous succession* has proceeded to such an advanced stage, such as a former grassland that is now forested, that restoration back to a grassland would be prohibitively expensive.
- *Seed bank depletion*. Seeds of desirable grassland species are not preserved in the soil seed bank. Many grassland species do not form persistent seed banks.
- *Limited species pool*. Target grassland species are not present in the surrounding landscape. Instead, weedy species that disperse from the matrix vegetation are a threat to the grassland community.
- *Species are unable to colonize the site*. Dispersal opportunities may be limited or blocked. Examples include altered floodplains where flooding does not occur to transport seeds, systems in which seeds are animal-dispersed but those animals are extirpated, or areas where the landscape includes barriers to movement such as woodlands that some grassland insect species cannot move through.
- *Establishment is limited*. Seeds or other propagules can reach a site, but species are unable to establish because of adverse abiotic or biotic site conditions.
- *Abiotic site conditions are so deeply changed* (e.g. the site is heavily eutrophied or the water regime is deeply altered or there has been extensive soil erosion) that restoration to a desirable stage is not possible without significant effort.

Societal obstacles include:

- Financial or physical limitations such as insufficient personnel or equipment.
- Unwillingness or inability of stakeholders to agree on restoration approaches and targets.
- Legislative obstacles.
- Insufficient knowledge about how to do restoration.

Methods of grassland restoration

We distinguish between restoration of extant degraded grasslands and restoration of grasslands on sites where they do not currently exist. Effective restoration efforts often integrate several of the listed methods. The efforts should be based on knowledge of the autecology of the species potentially forming the community, as they may also create conditions where undesirable species can establish.

Restoration of degraded grasslands

Restoration of degraded grasslands may include the following:

- *Removal of undesirable woody species.* Woody species are often undesirable in grasslands as they alter the physical structure and microenvironment. On the other hand, scattered woody species in grasslands usually increase heterogeneity and thus increase the diversity of grasslands. Their removal can be appropriate, especially where conservation strategies require enlarged spaces for grassland species or to increase connectivity between grassland patches. Removal can be accomplished by many different methods, including cutting, pulling, prescribed fires, and herbicide application. Appropriate techniques vary among systems and with the life history characteristics of the species, such as whether they resprout. Once woody species are removed, a regular grassland management regime should be initiated to prevent their re-establishment (see later text).
- *Control of invasive non-native species*. Especially in North American grasslands, invasive non-native species are a common challenge in restoration. Restoration often occurs at scales that are too large for effective manual control of these species, so managers rely on herbicides (Tu *et al*. 2001). Careful consideration of ancillary effects of herbicides is important. Herbicides that target particular types of plants can minimize off-target effects. For example, invasive grasses can be controlled in forb-dominated grasslands using grass-specific herbicides. When possible, the timing or spatial pattern of application is adjusted to capitalize on life history differences among undesirable invasive species and desirable native species. For example, the application of broad-spectrum herbicides soon after prescribed fires can be very effective at controlling invasive species that rapidly resprout without hindering native species which resprout more slowly (Stanley *et al*. 2011).
- *Adjustment or re-introduction of former/traditional management*. The re-introduction of former management regimes such as grazing or mowing is important for restoring many grasslands. Management regimes should not be uniform, but should be allowed to vary spatially and temporally to allow the survival and dispersal of plants and insects with varied life cycles. Abandoned grasslands are usually dominated by competitive plant species which suppress diversity. When appropriate management is re-established, these species usually decrease in cover, enabling the establishment of other species.
- *Manipulation of the water regime*. Former wet grasslands that have been drained may benefit

from an increase of water table by blocking ditches or removing drainage tubes. On the other hand, we also know examples where the diversity of species-rich managed grasslands decreased when drainage ditches were not regularly cleaned.

- *Manipulation of nutrient levels*. Many grasslands are overloaded by nutrients; reducing their nutrient levels can increase species diversity. Regular cutting and removal of biomass can gradually reduce nutrient levels, especially for nitrogen and available phosphorus. Grazing tends to redistribute rather than remove nutrients. Adding carbon can increase soil C:N ratios and reduce N uptake by plants (Török *et al.* 2011). Frequently used carbon sources are wood mulch, hay, and even sucrose. However, the effect of carbon addition on nutrient availability may be temporary as high microbial turn-over in the soil enables rapid mineralization.
- *Topsoil removal* can be very effective and immediately reduce nutrient levels in heavily eutrophied grasslands, but requires heavy machinery. In addition, this approach leads to problems about disposal of the removed material.
- *Creation of artificial gaps*. Some plants establish best in bare soil, which can be exposed by raking or harrowing.
- *Sowing seeds of desirable plants*. Many typical grassland species are seed limited (Seabloom *et al.* 2003). Seeds of desirable species may be obtained from wild populations or from seed production beds. A variety of seeding techniques are possible, including broadcasting, drilling, or hydroseeding. Species vary greatly in establishment rate and in the degree to which their establishment is affected by site preparation, though this information is often not known or at least not published. Where suitable reference sites exist, particularly those that do not contain undesirable non-native species, hay can be collected there and spread on the restoration site, thereby dispersing seeds of diverse species simultaneously. Decisions about which species to include in the seed mix can have long-term ramifications for how the grassland develops.
- *Planting desirable plants*. Species richness in grasslands can be rapidly increased by planting individual plants or perennial belowground structures (e.g. rhizomes, bulbs). By avoiding the germination and establishment phases of a plant's life, planting can greatly accelerate grassland recovery, particularly for species with good clonal growth. Planting is a cost- and manpower-intensive method, and therefore is most effective at small scales. Plants can be grown as plugs from seed in the nursery. In special cases, such as when a site is slated for destruction, it is possible to salvage established plants and move them to restoration sites.
- *Transfer of topsoil or turf*. When grasslands are slated for destruction another alternative is to salvage topsoil and spread it onto restoration sites. In specific cases we can also transfer turf or whole compact blocks, i.e. intact topsoil together with above- and belowground biomass, from a donor to a restored site. In addition to plant propagules, the turf or blocks may contain microbes and soil biota that are thus transferred to the restoration site. These benefits may ensure a much quicker recovery process. The expectation is that target species will spread from these blocks (used as stepping stones) across the restored site. However, it must be stressed that these methods are only appropriate in very specific circumstances as they strongly damage or destroy the donor site. In addition, they are costly and require considerable manpower and machinery. Even with careful planning and care during implementation, transplantation often heavily damages the transferred biota and often results in high mortality.
- *Transfer of desirable animals*. Insects are important for pollination and other processes in grasslands. Desirable insects or other invertebrates can be collected when at appropriate life stages and transferred to restoration sites, though this too can be thwarted by limited

species and genetic pools and possible mismatches of genotypes and phenotypes to a restored environment.

Establishment of new grasslands

New grasslands are often created on arable lands but also in disturbed sites such as mining sites, road banks, ski runs, and brownfields. These areas may or may not have been grassland historically. Many of the restoration methods discussed previously are also appropriate here, but other methods may also be required.

- *Spontaneous succession*. There is potential for grasslands to recover spontaneously, without subsequent management, in sites with environmental conditions corresponding to those of primary grasslands (Hölzel *et al.* 2002). However, the respective species must occur in the surroundings and be able to colonize the sites.
- *Spontaneous succession and subsequent management*. In sites where woodland is the potential vegetation, it is more common that spontaneous succession must be accompanied by management such as regular cutting or grazing to prevent the establishment and spread of woody species and support establishment of grassland species. Generally, successful spontaneous grassland recovery can be expected in sites where (i) agricultural production (i.e. crop production) only lasted for a short time, (ii) adjacent grasslands can act as effective seed sources of target species, and (iii) the risk of infestation by weeds is low.
- *Site preparation*. The conditions at the time restoration begins will inform the type of site preparation required. Arable fields may require control of existing vegetation and the seed bank, but more impoverished sites such as mining sites and landfills may also require the installation of allochthonous topsoil. Methods of controlling the existing vegetation include prescribed fires, herbicides, tilling, and topsoil removal; these methods differ in their effects on the seedbank. It is important to take the time to ensure that good site preparation has been conducted before seeding occurs, as it is much more difficult to deal with weeds or to modify environmental conditions once desired species are established.
- *Seeding*. Seeding is the most commonly restoration method when establishing new grasslands. As noted previously, species selection is a very important restoration decision. Sowing a few productive grasses and legumes, as is common in some commercial seed mixes, is unlikely to be an effective restoration, though desired grassland species may eventually colonize the site (Török *et al.* 2011; Prach *et al.* 2015). The best option is to use a regional seed mix containing as many species as possible (Jongepierová 2008; Kiehl *et al.* 2014). Local propagules are likely to be better adapted to the local environmental conditions and may increase restoration success. Seeds can be collected in nearby reference sites or the constituent species can be cultivated. Seeds can be harvested by hand or by special harvesters (Kiehl *et al.* 2014).
- *Plant material transfer*. This includes harvested raw plant material or hay, raked litter, threshed material or hay-chaff containing the seeds of target species. This may be cheaper than seeding, though effectiveness can vary. A common issue is finding sufficiently large donor sites. Two factors to consider are the areas of the targeted and the donor sites, and when to collect and apply the plant material. The ratio between target and donor sites ranges from 1:2 to 1:10, depending on the species and seed richness of the vegetation in the donor site at the time of harvest (Kiehl *et al.* 2014). These methods can also be used to improve degraded grasslands (see previous section).
- *Topsoil removal*. Most former croplands are characterized by high residual nutrient levels in

the upper soil layers arising from the use of fertilizers. High nutrient loads favor weedy species after cultivation ceases, and can reduce the establishment of less-competitive grassland species adapted to nutrient-limited and stressed conditions. Under these conditions, it can be helpful to remove the upper 10-50 cm of soil. This also removes many of the weed seeds (Klimkowska *et al.* 2007). The method is very costly because it requires heavy machinery, though sometimes the removed topsoil can be sold for other agricultural purposes, thus offsetting the costs.

Examples of restoration of main grassland types

Eurasian steppes

Nearly all original zonal steppes in the Ukraine, Kazakhstan and Russia have been ploughed. In the 1990s, after communist rule fell, large portions of arable land in these countries were abandoned and underwent spontaneous succession. In the past decade, however, the intensity of agriculture has increased again (Hölzel *et al.* 2002). Kamp *et al.* (2011) reported from Kazakhstan that spontaneously developed and then extensively grazed habitats on ex-arable land resemble natural steppe and are convenient for biome-restricted bird species. An assessment of spontaneous recovery there is in progress (N. Hölzel, pers. comm.). In the Ukraine, there have been attempts to restore steppe by seeding abandoned land with native species (Charles 2010), though the future of these efforts is unclear given current Russian military attacks.

North American prairies

The general restoration strategy for North American prairies is to control invasive species, add seed of desired species, and identify the disturbance regime that will enable the community to persist. There is no single restoration treatment that can achieve all of these elements: treatment combinations are required, and often have to be applied repeatedly (Stanley *et al.* 2011). A case study illustrates these ideas.

The Pacific Northwest contained significant prairies at the time of European settlement in around 1850. Many of these areas were ploughed by European settlers to grow agricultural crops. Areas that were not cultivated often were subject to fire suppression; many of these are now forested. Around 2000, it was estimated that only 2–3 per cent of these grasslands were still dominated by native species (Dunwiddie and Bakker 2011). Prairie remnants are owned by numerous land managers, thus necessitating collaborative working relationships. Restoration and management of this ecosystem has been stimulated in large part by the listing of rare species by the federal government and associated support for the recovery of these species. Listed species include a plant (*Castilleja levisecta*), butterfly (*Euphydryas editha taylori*), bird (*Eremophila alpestris strigata*) and mammal (*Thomomys mazama pugetensis*).

Restoration efforts began in the 1990s and focused initially on the control of non-native species. During the first decade or two, a primary task was mowing to control *Cytisus scoparius*, a non-native leguminous shrub. That species is now largely under control, though some mowing and manual removal continue. Current control efforts include the use of grass-specific herbicides to control non-native invasive grasses such as *Arrhenatherum elatius* and of broad spectrum herbicides to control non-native invasive forbs such as *Potentilla recta* and *Senecio jacobaea* (N. Johnson, pers. comm.).

A key restoration goal in this system is to increase the quantity and diversity of native species. Initially, seed was collected by hand from wild populations and, because it was so laborious to collect, sown in the nursery to produce plugs that were then outplanted into degraded prairies. In recent years, wild-collected seed was used to establish seed increase beds that produce large quantities of seed. In 2014, for example, one conservation nursery produced about 1000 kg of seed and 344,000 plants of more than 100 prairie species (S. Smith, pers. comm.). The production of large quantities of seed enables restoration across larger areas and with more diverse species. Research in recent years demonstrated that abandoned agricultural lands can be effectively restored to prairie and examined the sensitivity of restoration success to variability among sites and seeding years (E. Delvin, pers. comm.; Figure 10.1). This work has also led to successful establishment of the rare *Castilleja levisecta*; the global population of this species increased by almost an order of magnitude from 20,000 plants in 2004–2010 to 186,000 in 2014 (J. Arnett, pers. comm.). Another focus in recent years has been the enhancement of butterfly habitat (M. Linders, pers. comm.).

A frequent fire regime has been re-instated on many prairies: in 2014, 90 burns totaling about 1,000 ha were conducted (M. McKinley, pers. comm.). These prairies are generally burnt on a 2–4 year rotation to reduce thatch accumulation and create microsites of bare ground in which species can establish. Frequent fires may also create important habitat for native annual species, which appear to be much less common now than they were historically (Dunwiddie *et al.* 2014). Burning is often followed soon thereafter by a broad-spectrum herbicide to control rapidly resprouting non-native species (Stanley *et al.* 2011).

Figure 10.1 Experimental plots used to test methods of restoring grassland on former agricultural land in the Pacific Northwest. Each plot in the foreground of this image is 40 m^2. Beyond them is a larger area that was restored a few years later and, in the far distance, are *Cytisus scoparius* and *Pseudotsuga menziesii* on the edge of the prairie. The plots were seeded in autumn 2008 and burned in autumn 2014; the photo was taken in spring 2015

Source: Photo by J. D. Bakker

Looking to the future, efforts in this ecosystem are likely to focus on enhancing plant species diversity in degraded prairies, habitat enhancement for rare species, understanding interactions between species and disturbance regimes (e.g. how heterogeneous should prescribed fire effects be to balance general management needs without harming insect larvae), and improving connectivity. Another opportunity is to work with private landowners and explore how livestock grazing could be integrated into grassland management.

European secondary grasslands

In Europe, the first grassland restorations occurred in the countries with the most altered landscapes due to intensive exploitation (i.e. the United Kingdom and the Netherlands). Degraded existing grasslands were the first restoration focus; later efforts examined the restoration of various types of grasslands on ex-arable land or other environments such as spoil heaps.

Early restorations focused on grasslands from the ends of the moisture gradient. Dry grasslands, usually on calcareous soils, support a high diversity of plants and insects and thus were of high conservation interest (Dengler *et al.* 2014). Wet grasslands, often alluvial, were of interest because of efforts to restore degraded river floodplains and decrease flood risk (Joyce and Wade 1998). A similar pattern existed along the nutrient gradient: restoration interest focused primarily on oligotrophic grasslands or highly eutrophied grasslands. The former were of interest because of their fast disappearance due to eutrophication, abandonment and afforestation, while the latter were of interest due to their striking degradation and indication of excessive pollution.

Degraded existing grasslands

A classic and long-term restoration study was conducted in the Netherlands, where abandonment of species-rich chalk grasslands led to an expansion of the competitive grass *Brachypodium pinnatum* and subsequent deep decrease of diversity (Bobbink and Willems 1993). Willems and Bik (1998) conducted an experiment in 1970 and then 20 years later. Experimental sites were more degraded in 1990 than 1970, but restoration of high species richness was significantly faster in 1990 not only due to the lower start but also due to the increase size of the community species pool at the site as a result of appropriate management in the surrounding landscape during intervening decades (Figure 10.2). Their study demonstrates restoration success at the site and landscape scales.

Restoration of degraded wet grasslands in Western Europe was reviewed by Klimkowska *et al.* (2007). The most effective restoration required a combination of techniques such as rewetting, topsoil removal, and seed transfer. In the UK, restoration of grasslands is often connected to restoration of heathlands (Lowday and Marrs 1992). One project restored Estonian alvar grasslands overgrown by woody species (Pärtel *et al.* 1998). The authors emphasized the importance of proximity effects, concluding that species-rich grasslands could recover if the woody species were cut and regular extensive grazing occurred, as long as the local species pool had been maintained. The role of seed sources has also been emphasized in restored dry calcareous grasslands overgrown by shrubs in the French Prealps (Barbaro *et al.* 2001), species-rich grasslands in northern France (Muller *et al.* 1998), and formerly abandoned grasslands restored by grazing in Sweden (Lindborg and Eriksson 2004). It seems that the character of the surrounding landscape is a key factor determining restoration success.

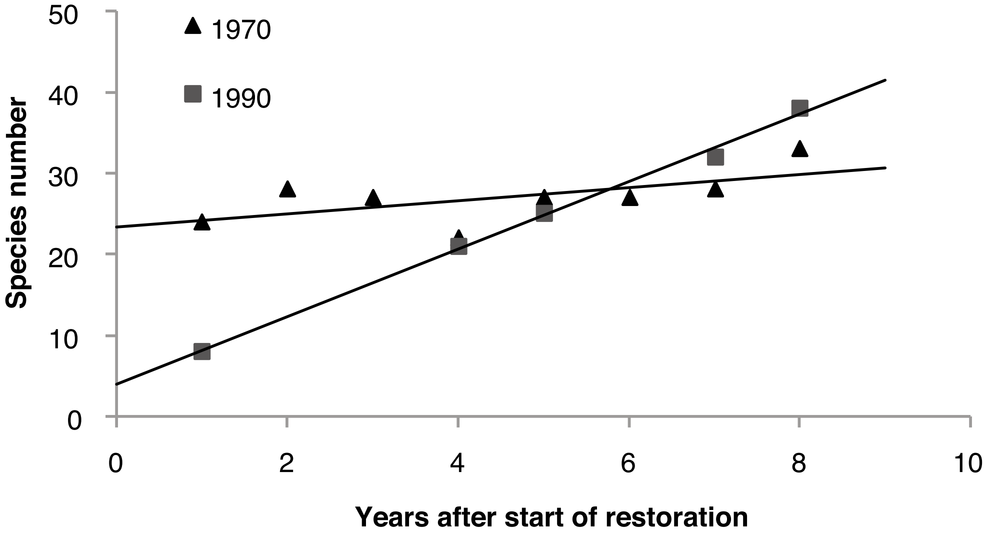

Figure 10.2 Species number as a function of the number of years since restoration began for plots where restoration began in either 1970 or 1990. All plots were the same size (2.25 m^2). Speed of the restoration process as represented by the slope of the linear regression line was significantly different ($p < 0.05$) in 1970–1977 compared with 1990–1997

Source: after Willems and Bik (1998), with permission

Restoration of grasslands on ex-arable land

Effective spontaneous restoration of dry grasslands on ex-arable land was reported from drier sites in central and southern Europe (Ruprecht 2006). Assisted restoration, mostly by seeding or hay transfer, is a common restoration activity in recent years around Europe (Fagan *et al.* 2008; Kiehl *et al.* 2010, 2014). Studies at different spatial scales have been conducted in the UK, the Netherlands, France, Germany, Czech Republic and Hungary. In terms of practical restoration advice, studies are most important if they are conducted at large spatial scales, include multiple sites, and compare different restoration methods (Fagan *et al.* 2008; Török *et al.* 2011; Prach *et al.* 2013, 2015). We present here, as examples, two studies that we have been involved with.

Large-scale restoration of dry grasslands in the Carpathian Mountains

This study was conducted in the White Carpathian Mountains Protected Landscape Area and Biosphere Reserve, eastern Czech Republic (Jongepierová 2008; Prach *et al.* 2013, 2015). Thousands of hectares of dry grasslands in this region have been managed as hay meadows for several centuries (Hájková *et al.* 2011; Jongepierová 2008). However, many of these grasslands were ploughed, overfertilized or abandoned between 1950 and 1990. About 4,000 ha of semi-natural hay meadows remain; these are now protected under national legislation and are internationally recognized as Natura 2000 habitats (Jongepierová 2008). These grasslands are among the most diverse communities in the world at scales < 100 m^2 (Wilson *et al.* 2012) and were used as reference sites in this study.

Restoration goals especially included improved connectivity among the remnant grasslands. Plant species composition was compared between the reference sites and 82 dry grassland stands restored on ex-arable land. Restored sites were sown either with a species-rich regional seed mixture (44 species, >500 ha) or a species-poor commercial clover-grass seed mixture, or were left to experience spontaneous succession. The ordination results (Figure 10.3) demonstrate the convergence of grasslands restored by different methods towards reference grasslands. Soil characteristics, especially P content, had the strongest effects, followed by restoration method, proximity, and age.

Overall, regional seed mixtures were the best method to re-establish dry grasslands on ex-arable land, though spontaneous succession, and even regrassing with commercial seed mixes provided reasonable results at sites in close vicinity of reference sites. However, these two methods supported restoration trajectories towards rather mesic grasslands instead of targeted dry grasslands. Soil characteristics and landscape context need to be considered during restoration projects, along with the selection of proper restoration methods.

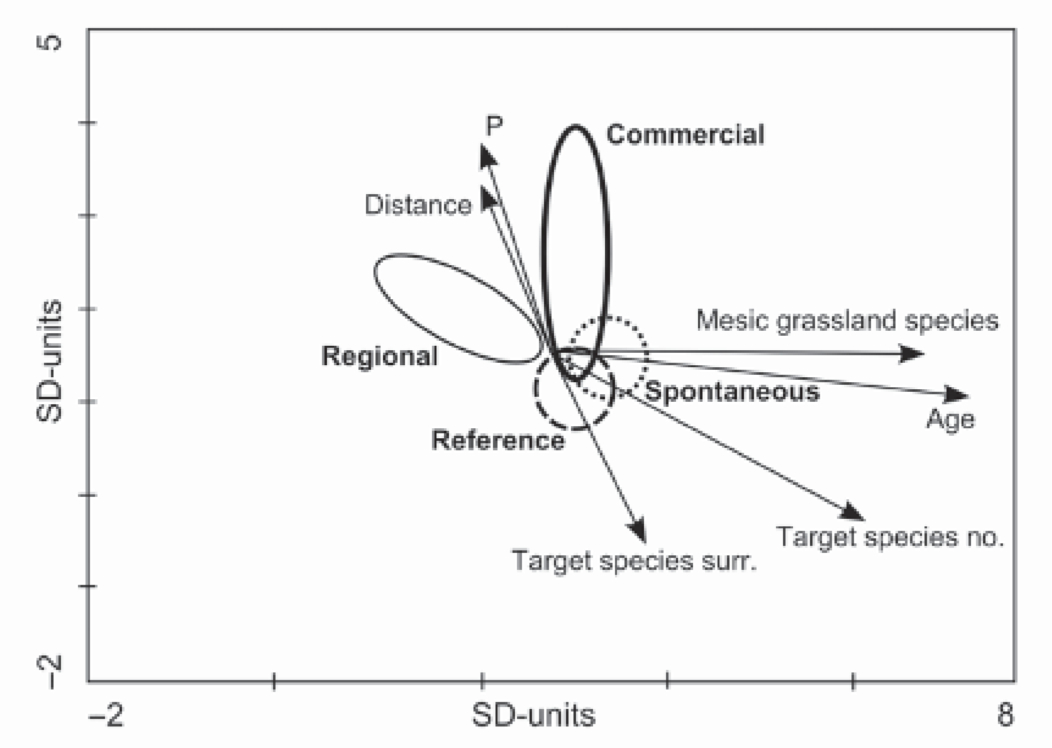

Figure 10.3 Unconstrained ordination (detrended correspondence analysis) of vegetation samples, community characteristics, and most significant environmental factors from grasslands restored by three different methods: using regional seed mixtures (Regional), commercial seed mixtures (Commercial) and spontaneous succession (Spontaneous). Vegetation samples from reference dry grasslands were passively projected (Reference), as well as the community characteristics and environmental factors: the number of target species typical for dry grasslands (Target species no.) and mesic grassland species both occurring in the restored grasslands; the number of target species occurring in the surroundings (Target species surr.), distance to the nearest reference grassland (Distance), total soil phosphorus (P) and time since restoration started (Age)

Landscape-scale restoration in Hortobágy National Park

In the western part of Hortobágy National Park (east Hungary), 760 ha of former croplands, alkali grasslands, and loess grasslands were recovered using low-diversity regional grass seed mixtures. The aim of the restoration was to eliminate croplands at high elevated places and to increase the landscape-scale connectivity of natural grassland habitats by using secondary restored grasslands to create green corridors. The seed mixtures contained the seeds of characteristic grasses of alkali and loess grasslands in the region (*Festuca pseudovina*, *F. rupicola*, *Poa angustifolia*, *Bromus inermis*) and were sown at a rate of 25 kg/ha between 2004 and 2008. The development of grassland vegetation was followed in permanent plots. Restoration success was influenced both by the seed mixture used and by site history (Török *et al.* 2012). Vegetation development progressed towards reference grasslands: within three years, the former croplands were dominated by the sown grasses and most weeds were effectively suppressed.

However, the seed bank remains dominated by weed seeds. In addition, regular management by mowing and/or grazing is necessary to sustain the desired vegetation composition – because of the high biomass produced in these grasslands, large-scale degradation of the vegetation may occur within a few years if management ceases. The area and fragmentation level of grasslands in the landscape strongly influenced long-term restoration success. The spontaneous colonization capacity of alkali grassland species is generally promising in the region, but loess grasslands are highly fragmented and degraded; thus, many loess specialists cannot reach the restored grasslands (but see Figure 10.4).

Figure 10.4 Restored grassland with high cover of spontaneously immigrated loess specialist *Dianthus pontederae*

Source: Photo by Orsolya Valkó

For loess grassland restoration, the application of hay transfer or the use of a high diversity seed mixture would be the most promising options. However, the use of a high diversity regional seed mixture will only be feasible once local grassland species begin to be propagated, as seeds of these species cannot be obtained from commercial sources (Török *et al.* 2011).

Conclusions

In terms of vascular plants, temperate grasslands are the most species-rich ecosystems in the world at scales of 1–100 m^2 (Wilson *et al.* 2012). Many other organisms are related to this diversity, especially insects. Moreover, these diverse grasslands provide important ecosystem services. Primary grasslands are a natural heritage, and secondary grasslands are also a cultural heritage. Thus, conservation and restoration of these grasslands is a challenge for ecologists. Based on the literature cited and our experiences, we conclude:

- Restoration seems to be easier on moderately nutrient-rich than on nutrient-poor or heavily eutrophied sites.
- Restoration is difficult if water and/or nutrient regimes have been deeply altered.
- Restoration is easier if target species still exist in the site itself or in its immediate surroundings.
- Some restoration measures can be profitable for one group of organisms and detrimental for some others, thus consultancy among experts is needed prior to restoration starting.
- Continuous management must be ensured in the case of secondary grasslands.
- Management activities should be spatially and temporally variable.
- Long-lasting monitoring should be ensured in any grassland restoration project.

Finally, we consider how climate change may affect grassland restoration. Areas that become warmer and drier, and thus have a prolonged dry season, may become more suitable for xerophilous and thermophilous herbaceous species and less suitable for woody species. This could ease the restoration of dry temperate grasslands. Experimental reductions in precipitation sometimes reduce the biomass of dominant competitors, usually graminoids, and consequently increase the diversity of forbs (Holub *et al.* 2013). However, restoration of mesic or wet grasslands, or to achieve other restoration targets such as increased fodder production, could be negatively impacted by climate change. Some areas that potentially become wetter may experience increased woody plant encroachment unless the management intensity is sufficient to prevent this. However, the cumulative effects of climate change on temperate grasslands may also depend on its interactive effects on disturbance regimes, such as fire microbial activity, decomposition rates, and nutrient uptake by plants, and are difficult to predict. It will be important to consider site-specific predictions of climate change and to adaptively manage sites based on those predictions and the site context. However, we also need more multisite observational and experimental studies to make firmer conclusions (Wu *et al.* 2011).

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