Accepted Manuscript

Title: Prospects and limitations of prescribed burning as a management tool in European grasslands

PII: S1439-1791(13)00149-7
DOI: http://dx.doi.org/doi:10.1016/j.baae.2013.11.002
Reference: BAAE 50751

To appear in:

Please cite this article as: Prospects and limitations of prescribed burning as a management tool in European grasslands, *Basic and Applied Ecology* (2013), http://dx.doi.org/10.1016/j.baae.2013.11.002

Prospects and limitations of prescribed burning as a management tool in European grasslands

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Running head: Grassland conservation by burning

Word count for title: 13

Word count for abstract: 256

Word count for text: 4490

Running title: Prescribed burning in European grasslands

Abstract

Grassland managers and scientists are increasingly interested in cost-effective alternative ways of grassland biodiversity conservation. Prescribed burning is a promising management tool which should be integrated in the planning of management efforts. In addition, small-scale prescribed burning is an effective fire suppression strategy to decrease the serious negative impacts of uncontrolled burnings on ecosystems and human life. Prescribed burning forms an integral part of the North-American grassland management practice, while in Europe it is rarely applied, despite the fact that uncontrolled burning occurs frequently in some regions. Our goal was to evaluate the use of prescribed burning as a promising but neglected management tool in European grasslands. We found that European studies on prescribed burning of grasslands are scarce and we conclude that annual burning is usually not an appropriate option for the conservation of species-rich grasslands. We reviewed burning studies from North-America to identify findings which might be adapted to the European grassland conservation strategy. In North-America, contrary to Europe, the application of burning is fine tuned in terms of frequency and timing, and usually combined with other restoration measures (grazing or seed sowing). Thus, we conclude that with the application of carefully designed prescribed burning, multiple conservation goals, e.g. invasion control and increasing of landscape-level heterogeneity, can be linked with an effective fire suppression strategy. We emphasize that for the application of prescribed burning in Europe, the general findings of carefully designed case studies should be combined with the practical knowledge of conservation managers concerning the local application circumstances to reach specific management objectives.

Keywords: Biomass; Ecosystem services; Fire; Grazing; Mowing; Prairie.

Introduction

Grasslands are of crucial importance in maintaining landscape-level biodiversity and are vital elements of the historical landscape of Europe. The area and species richness of grasslands have been in constant decline in many parts of Europe. Still existing grasslands are threatened by the cessation of traditional management (Kahmen, Poschlod & Schreiber 2002); which can lead to (i) litter accumulation (Ryser, Langenauer & Gigon 1995); (ii) increased fuel loads resulting in regular wildfires (Baeza, Luís, Raventós & Escarre 2002), (iii) encroachment of herbaceous competitors (Kahmen et al. 2002; Köhler, Gigon, Edwards, Krüsi, Langenauer et al. 2005) or (iv) invasion of woody species (Hansson & Fogelfors 2000), each resulting in the decline of target grassland species in the long term.

Traditional grazing and mowing are no longer sustainable in many regions because of the significant decrease in livestock-numbers and a reduced demand for forage. On the other hand, grazing and mowing can have relatively high costs in grasslands with difficult accessibility and located far from settlements (Köhler et al. 2005). Thus, conservation managers and scientists are seeking less costly and labour-intensive approaches which can also maintain grassland species richness and eliminate the negative consequences of abandonment (Köhler et al. 2005; Liira, Issak, Jögar, Mändoja & Zobel 2009). It seems important to test whether prescribed burning is an appropriate substitution of grazing and mowing in European grasslands based on carefully designed evidence-based case studies.

For developing improved grassland management strategies, the evaluation of fire effects on grassland structure and species composition is crucial. Prescribed burning studies can contribute to the understanding of the ecological impacts of uncontrolled wildfires and arson, which are present in many regions of Europe. According to recent climate change scenarios, climate will be warmer and drier, which will increase the probability of wildfires, especially in the Mediterranean region (Pausas 1999). Due to warmer and drier climate and increased fuel loads caused by abandonment, the probability of wildfires will increase even in those countries which are scarcely affected by wildfires recently. Thus, fire suppression strategies against uncontrolled wildfires will need to be developed in the future (Castellnou, Kraus & Miralles 2010). Application of carefully designed, small-scale prescribed burnings can be an effective fire suppression strategy to mitigate the serious negative impacts of wildfires and uncontrolled burning (Baeza, Luís, Raventós & Escarre 2002). To meet long-term resource management and conservation goals, the application of prescribed burning under specified fuel and weather conditions is necessary (Castellnou et al. 2010).

Our goal was to evaluate the results of European attempts to use prescribed burning in grassland management, and assess whether the targeted objectives were achieved. We discussed burning studies from North-America as a reference system to identify which elements of fire management can be adapted to the European grassland conservation strategy.

Material and methods

We obtained information from three levels: (i) a literature search of scientific electronic databases, (ii) a search in professional networks and (iii) direct contact with conservation experts. First, we collected papers by searching in the database ISI Web of Knowledge for the period 1975-2012, using the keywords ‘prescribed fire’ OR ‘prescribed burn*’ AND 'grassland' which yielded 480 hits (last accessed 18/12/2012). The terms 'Europe' and 'North-America' were omitted from the search keywords as suggested by the systematic review protocol of Pullin et al. (2006), because relevant studies that do not mention these terms may have been missed. We restricted the results to (i) European countries yielding 26 hits and (ii) North-American countries yielding 397 hits. The significant bias between European and North-American studies on the topic did not allow us to execute a meta-analysis.

The study inclusion criteria were the following:

- Relevant subjects: all types of grasslands in Europe or North-America; shrublands, marshlands and heathlands were not considered
- Types of treatment: prescribed burning; excluding wildfires and arson
- Types of comparator: comparison with similar grassland plots which were not burned; at least unmanaged (control), but if other management types were studied, we considered them as well (e.g. mowing, mulching or grazing)
- Types of variables: species richness or abundance of any taxa or functional groups (e.g. woody species, tall herbs) and ecosystem properties (e.g. amount of litter)

Out of the 26 results found for European countries, none matched these criteria. Thus, we started an additional search using the keywords 'fire' OR 'burn*' AND 'grassland' (resulting in 3,833 studies in total) focusing on European countries, which yielded 595 results. All the 595 studies were scanned at title, abstract and full-text level and finally 8 studies matched the selection criteria.

Second, we searched altogether 18 volumes of *International Forest Fire News*, which is not indexed in scientific electronic databases (http://www.fire.uni-freiburg.de/iffn/iffn_online.htm) and also the website of the Eurasian Fire in Nature Conservation Network (http://www.fire.uni-freiburg.de/programmes/natcon/natcon.htm). This search resulted in further three papers matching the study inclusion criteria. Finally, to have a clearer view of the current European situation, we contacted several grassland specialists across Europe to gain information concerning: (i) the regulation of burning by law, (ii) the occurrence and frequency of wildfires and arsons in grasslands and (iii) the possibilities and limitations of the use of prescribed burning in European countries. We distributed questionnaires via e-mailing and through the mailing lists of the European Dry Grassland Group and European Vegetation Survey (1,600 people), and we gained information from 49 colleagues from 19 countries.

Published evidence on grassland conservation using prescribed burning in Europe

Altogether we found eleven European studies meeting the selection criteria (Table 1). In most of the studies dormant-season burning was applied on an annual basis with a valuable long-term monitoring (up to 28 years, Wahlman & Milberg 2002). Generally no data about pre-burn species composition was given, only a brief description. Only a few studies evaluated effects of burning on animals. Most studies were comparative experiments of potential alternatives (e.g. burning or mulching) for traditional grazing or mowing, thus they did not focus on the application of burning. Burning was chosen as a labour- and cost-effective method compared to other management measures. In these studies burning was not combined with any other management or post-fire rehabilitation.

The European studies concluded that annual burning alone is not appropriate to maintain the desirable structure and species richness of the studied grasslands. In the long term, species richness usually decreased in the burning treatment compared to grazing or mowing treatments. Burning led to the increased dominance of competitor species like *Brachypodium pinnatum* (Kahmen et al. 2002; Köhler et al. 2005), and resulted in an untargeted species composition, similar to that of abandoned plots. The reason why burning proved inappropriate in these studies might be because annual burning was applied for many years, and the vegetation did not have enough time to regenerate between burns.

Only minor and not always significant advantages of burning were identified in the reviewed papers. Although burning did not result in the targeted species composition, it promoted some rare or endangered species of dry limestone grasslands like *Aster amellus*, *Gentianella ciliata* or *Thesium bavarum* (Köhler et al. 2005). The elimination of litter layer (e.g. Liira et al. 2009; Ryser et al. 1995) and the delay of woody encroachment were also mentioned as positive effects (Moog, Poschlod, Kahmen & Schreiber 2005; Page & Goldammer 2004). Promising examples about the use of prescribed burning in the management of steppic grasslands on viticulture terraces were published by Page & Goldammer (2004) and Rietze (2009) (Table 1).

The use of burning in European grasslands based on a questionnaire survey

We received answers to our questionnaire from 49 grassland experts from Austria, Bulgaria, Czech Republic, Estonia, France, Germany, Greece, Hungary, the Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Ukraine and the United Kingdom. In the following, we refer to the results of the questionnaire survey by indicating country names.

Based on the questionnaire survey, burning was a traditional grassland management tool, to improve forage quality, reduce woody encroachment and litter accumulation in many countries (Austria, Czech Republic, Estonia, Greece, Hungary, Poland, Russia, Slovakia). Recently, traditional fire use has disappeared from many countries because of intensification of agriculture and socio-economic changes (Castellnou et al. 2010). Traditional burning practices and the traditional ecological knowledge on grassland burning might hold great potential for planning current grassland management. There is very little written information on traditional burning practices, thus, further historical and ethnographic research is needed to improve our knowledge on this topic (Castellnou et al. 2010).

Illegal, uncontrolled burning is practiced nowadays in extensive areas of Central-, Southern- and Eastern-European countries, posing serious conservation and socio-economic problems (Romania, Hungary, Bulgaria and Ukraine). There are several motives for setting fires illegally, such as: (i) the improvement of pastures in mountain areas (Greece, France or Romania); (ii) to gain Natura 2000 subsidies without labour-intensive management, especially in lowland hay-meadows (Romania) or (iii) fires are set just for "fun" and vandalism (Hungary, Romania and Ukraine). Given the unpredictable and often negative impacts of uncontrolled fires, even prescribed burning is prohibited in most of the European countries, to mitigate air pollution (Austria) and/or to protect human life and property (Greece). There are some countries where prescribed burning is permitted with strict regulations regarding the timing and extension of prescribed fires and the appropriate fuel and weather conditions for burning (Germany, France, Spain, Portugal, the United Kingdom, the Netherlands and Slovenia). There are detailed codes and training for professional teams who apply prescribed burning mainly for heathland and shrubland management and fire hazard reduction (Castellnou et al. 2010). In a few countries, prescribed burning is included in the management of protected areas (e.g. in France or Portugal), but only a few studies are available in English and their majority focuses on shrublands and heathlands.

Key findings of North-American case studies

Historically, fire had a higher impact shaping grasslands in North-America than in Europe. As suggested by a global simulation model (Bond, Woodward & Midgley 2005), North-American grasslands are more fire-prone than European ones. North-American grasslands are mainly characterized by the more fire-adapted C4 grasses, while in Europe C4 grasslands are not typical. Thus, fire was likely not a factor in the evolutionary history of many grassland species from Europe. Another difference in fire regimes between the two continents is that in North-America, fuel loads were more continuous than in Europe until recent times. In Europe urbanization processes (creating fire breaks by linear infrastructures and settlements) started much earlier than in North America, which decreased the extent and magnitude of wildfires.

In North-America prescribed burning is frequently used in grassland management programs, and it is indicated by the large number of studies on this topic. In North-America, burning is not only used as a substitutive tool for other management measures, but often combined with other tools (grazing or seed sowing) and the overall aim of burning is often the reintroduction of natural disturbance regimes (MacDougall & Turkington 2007). Prescribed burning is used as a management tool in various North-American grassland types, mainly in tall-grass and short-grass prairies and Mediterranean annual grasslands. In the following section, we summarize the most important experiences of North-American burning practices which could, at least partly, be adapted to European grasslands.

Timing of burning. In North-America both dormant- and growing-season burning are applied to achieve management goals considering the phenology (e.g. germination, seed set and dispersal) of target and unwanted species (Pyke, Brooks & D'Antonio 2010). Dormant-season burning is most effective for the reduction of accumulated litter (Rowe 2010). Natural fire regimes are best simulated by growing-season mid-July burns, at the peak of lightning-season (Howe 1994). Most prescribed burning is applied in the spring in the USA, but summer burning is also applied (Fuhlendorf, Engle, Kerby & Hamilton 2009). Summer fires can be used (i) to suppress unwanted species in a phenological state most susceptible to fire; or (ii) to give advantage to early-growing species which can regenerate after fire in autumn (Howe 1994). Summer fires can cause serious damages in grassland species, as most plant and animal species are active in this period (Fuhlendorf et al. 2009). Besides burning season, fire effects also depend on fuel moisture and weather conditions (Twidwell, Fuhlendorf, Engle & Taylor 2012).

Frequency of burning. To mimic natural disturbance regimes and maintain grassland biodiversity, burning every 2-3 years is recommended in tallgrass prairies (Fuhlendorf et al. 2009). This interval resembles most the natural wildfire regimes required for the regeneration of grasslands (Rowe 2010). To control invasive species, high-frequency burning in several consecutive years is needed. Repeated burning may prevent the regeneration of the invasive species from vegetative buds or seed bank, and burning should be repeated until the seed bank of the invasive species is destroyed and there is a low risk of re-colonization (Alexander & D'Antonio 2003, Pyke et al. 2010).

Combination of grazing and burning – patch-burning. Fire and grazing interact through positive and negative feedbacks resulting in a shifting spatial and temporal mosaic (fire-grazing model; Fuhlendorf & Engle 2001). The model is based on the principle that free-ranging grazers preferentially select recently burned patches with high-quality forage for grazing. Grazers rarely choose patches that have not been burnt for several years. This leads to litter and biomass accumulation, increased fuel loads and a higher probability of wildfires there. A conservation effort can be fulfilled by the application of patch-burning management to mimic natural disturbance regimes and to improve spatio-temporal heterogeneity of grasslands (Fuhlendorf et al. 2001). Within a large area, burning is applied in patches, each patch is being burnt periodically, e.g. once three years to leave time for grassland regeneration to the pre-fire state. Patch-burning management has several advantages compared to homogenous burning: (i) The co-existence of various fire regimes can maximize species richness (Parr & Andersen 2006). (ii) The increased landscape-scale heterogeneity promotes the coexistence of species with different habitat requirements. (iii) Grazing animals can freely select patches with the best forage quality. (iv) Patch-burning can help to suppress large wildfires by creating heterogeneous fuel structure where low-fuel patches can act as fire breaks (Hobbs 1996).

The use of burning for invasion control. Burning is a more natural measure for invasion control than the application of herbicides, which can persist in the soil and can be detrimental to grassland species (DiTomaso 2000). Burning can be used for invasion control in cases when the phenology of invasive and target native species is different or they are differently adapted to fire (MacDougall & Turkington 2007, Pyke et al. 2010). Timing of burning plays a crucial role, as inappropriately timed burning can even facilitate invasion in arid and semiarid ecosystems (Keeley 2006). Burning can increase the effectiveness of herbicides providing a better contact between the herbicide and the plant by removing litter (DiTomaso 2000). There are promising examples for the use of prescribed burning in the control of *Taeniatherum* *caput-medusae* (Davies & Sheley 2011) or *Lespedeza cuneata* (Cummings et al. 2007). Combination of burning and grazing can also be used to control invasive plants. After fire, unpalatable invasive plants allocate most of their energy to regeneration and less energy to defensive organs and secondary metabolites and therefore they can be more effectively suppressed by grazing (for *Lespedeza cuneata*; Cummings, Fuhlendorf & Engle 2007).

Post-fire rehabilitation techniques. These can be used to improve grassland recovery and mitigate unwanted effects of burning on grassland species. To prevent soil erosion of burned sites seeding of sterile and non-persistent cereal grains (nurse crop) can be applied (Keeley 2006). A more effective way of post-fire rehabilitation is mulching or transfer of plant material, which can reduce erosion, but at the same time, propagules of target species can be introduced to the site (Kiehl, Kirmer, Donath, Rasran & Hölzel 2010).

What can be learned from European and North-American studies?

Besides the increasing interest for alternative grassland management measures, only a few studies address the applicability of prescribed burning in European grasslands. An important reason for the limited number of European studies is that due to legislative limits in most countries, evaluation of prescribed burning experiments is difficult or even impossible. European publications on prescribed burning of grasslands mainly used a simplistic approach, i.e. yearly burning of the entire grassland site for many years. On the contrary, in North-America, prescribed burning is frequently and successfully used in grassland management programs, indicated also by the huge number of studies on the topic. There is a need for focused case studies to test whether the well-developed North-American burning regimes can be adapted to the European grassland conservation strategy.

Given the differences in history, climate and composition of grasslands in the two continents, the elements of North-American burning practice can only partly be applied in Europe. A major difference is that in North-America, more fire-prone C4 grasslands are typical, while European grasslands are mainly characterised by C3 grasses. Thus, as a first step, North-American burning regimes should be evaluated to determine in which European grasslands prescribed burning can be a proper management option. European studies on prescribed burning are available mostly from dry and mesophilous grasslands, where too frequent (annual) burning proved to be an inappropriate method. Thus, we cannot draw general conclusions for the proper management of these grassland types. Based on the identified failures and successes of the reviewed studies, the most promising management objectives of prescribed burning experiments could be the following.

Reducing accumulated biomass. Both European and North-American studies proved that dormant-season burning can effectively remove accumulated biomass from abandoned grasslands (Ryser et al. 1995; Rowe 2010). Based on these findings, prescribed burning should be tested on sites, where management by grazing or mowing is not feasible, like in limestone grasslands (Ryser et al. 1995). Besides effective biomass removal, burning in abandoned grasslands can result in untargeted species composition if applied too frequently, as it was found in most European studies. Thus, proper fire return periods should be tested in various grassland types and also fine-tuned to site characteristics (e.g. the rate of litter accumulation or the presence of noxious competitor species in the vegetation). Fire return periods applied in the more fire-prone tall-grass prairies (2-3 years, Fuhlendorf et al. 2009) suggest that at least three years may be appropriate in European grasslands because they are evolutionary less adapted to fire than North-American ones.

Supporting target species by burning. Some European studies mentioned positive effects of burning on several rare or protected species. Fire promoted some limestone grassland species probably by creating suitable germination microsites (Köhler et al. 2005). Prescribed burning can also favour xerophilous target species by providing warmer and drier microclimate in steppic grasslands on abandoned vineyards (Page &Goldammer 2004). Focused case studies on certain target species could be integrated in future conservation actions. However, based on North-American experiences, burning is not recommended at sites, where remnant populations of endangered species are present (MacDougall & Turkington 2007).

Management of open landscapes. Several European studies found that prescribed burning can help in the maintenance of open landscapes by the prevention of woody encroachment (Page & Goldammer 2004). In extended open landscapes, like Central- and Eastern European steppes, the introduction of patch-burning management can increase landscape-level heterogeneity. Based on North-American experiences, combination of fire and grazing can provide patches characterised by different amounts of green biomass and litter (Fuhlendorf & Engle 2001). The increased structural and functional diversity can promote the coexistence of species with different habitat requirements. In extent grassland areas, prescribed burning can also be a proper tool for preventing extent and uncontrolled wildfires and accordingly it can contribute to the protection of personal safety and private property (Baeza et al. 2002).

Invasion control. Beside of the serious conservation problems posed by invasive species, in Europe the application of fire against invasives has not been studied yet. In North-America, carefully designed prescribed burning is effectively used against several invasive species. For the application of prescribed burning in invasion control, the followings should be considered: (i) Based on North-American studies, growing-season fires can be the most effective in the suppression of invasive species. For appropriate timing, the most susceptible period of the given invasive species should be identified. (ii) Since growing-season fire can have detrimental effects on most grassland species, invasion control by prescribed burning should be first tested in degraded grasslands to avoid damaging populations of rare species. (iii) To achieve long-term results, burning should be repeated until the invasive species disappears both from the aboveground vegetation and the seed bank. (iv) For the recovery of natural grassland vegetation, post-fire rehabilitation by sowing seeds of native grasses is necessary. (v) Prescribed burning could also increase the effectiveness of other invasion control methods, like grazing or herbicide application, thus, complex methods should also be tested.

We pointed out that prescribed burning of grasslands should be integrated in the European nature conservation practice. However, given the limited number of case studies in Europe; further habitat-specific experiments are needed to find specific management objectives and application circumstances.

Acknowledgements

We are thankful for the scientists who participated in the questionnairie (U. Biereznoj, S. Boldogh, J. Dengler, A. Fenesi, P. Fernandes, D. Galvánek, J. Goldammer, J. Greksza, I.

Hődör, I. Jongepierová, M. Kaligarič, I. Kapocsi, J. Kapocsi, R. Ketner-Oostra, A. Kyriazopoulos, B. Lambert, J. Liira, R. Marrs, J. Mitchley, D. Molina, A. Molnár, E. Nebot, B. Oyunsanaa, H. Page, V. Papanastasis, K. Prach, N. Ribet, E. Rigolot, E. Ruprecht, N. Sauberer, A. Schmotzer, B. Seitz, F. Sipos, K. Sipos, R. Steemson, R. Šuvada, S. Todorova, R. Tzonev, O. Vasyljuk, V. Virók, M. Vrahnakis, C. Werpachowski, W. Willner and S. Znamenskiy). We are indebted to J. Mitchley, who kindly improved our English. We are indebted to the reviewers and editors for their improvements made on the earlier draft of the paper. The authors were supported by TÁMOP-4.2.4.A/2-11-1-2012-0001 (OV, PT), TÁMOP-4.2.1./B-09/1/KONV-2010-0007 and TÁMOP-4.2.2_B-10_1-2010-0024 projects, the Bolyai János Research Scholarship (PT), OTKA PD 100192 and the Internal Research Grant of Debrecen University (OV).

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Zusammenfassung

Graslandmanager und -wissenschaftler sind zunehmend an kostengünstigen Methoden des Biodiversitätsschutzes auf Grasländern interessiert. Kontrolliertes Abbrennen ist eine vielversprechende Methode, die bei der Planung von Managementmaßnahmen berücksichtigt werden sollte. Darüber hinaus ist kleinräumiges kontrolliertes Abbrennen ein effektives Mittel gegen die negativen Auswirkungen von Wildfeuern auf Ökosysteme und das menschliche Leben. Kontrolliertes Abbrennen bildet einen integralen Bestandteil der praktischen Graslandbewirtschaftung in Nordamerika, während es in Europa nur selten angewendet wird, obwohl unkontrollierte Brände in manchen Regionen häufig auftreten. Unser Ziel war, den Nutzen kontrollierten Abbrennens in Europa zu bewerten. Wir fanden, dass europäische Untersuchungen zum kontrollierten Abbrennen auf Grasländern selten sind, und wir schließen, dass jährliches Abbrennen gewöhnlich keine geeignete Option für den Schutz von artenreichen Grasländern darstellt. Wir werteten auch Feuerstudien aus Nordamerika aus, um Befunde, die an die europäische Strategie zum Graslandschutz angepasst werden könnten, zu identifizieren. In Nordamerika ist die Anwendung von Feuer im Gegensatz zu Europa, was Häufigkeit und Zeitpunkt anlangt, fein abgestimmt und normalerweise mit anderen Rekultivierungsmaßnahmen wie Beweidung oder Aussaat kombiniert. Wir schließen somit, dass mit der Anwendung von sorgfältig geplantem kontrolliertem Abbrennen zahlreiche Schutzziele (z.B. Kontrolle von invasiven Arten, Steigerung der Landschaftsheterogenität) mit einer effektiven Feuerschutzstrategie verbunden werden können. Wir betonen, dass für die Anwendung von kontrolliertem Abbrennen die allgemeinen Ergebnisse von sorgfältig geplanten Fallstudien mit dem praktischen Wissen von Naturschutzmanagern über die lokalen Anwendungsumstände kombiniert werden sollten, um spezifische Managementziele zu erreichen.

Table 1. Summary of the results of prescribed burning studies in European grasslands.

Country	Grassland and burning type	Positive effects of burning	Negative effects of burning	Recommendations
Estonia	floodplain meadow, early spring burning, 4 times (within a 6 years' time)	reduction of litter, prevention of woody encroachment	species richness did not increase, contrary to mowing and mulching treatments	burning is not recommended
Germany	calcareous grassland, yearly winter burning (25 years)	reduction of litter	species composition was similar to that of fallow plots, cover of *Brachypodium pinnatum* increased	burning is not recommended
	calcareous grassland, yearly winter burning (25 years)	prevention of woody encroachment	species composition was similar to that of fallow plots, cover of *Brachypodium pinnatum* increased	burning is not recommended
	steppic grassland, late winter burning (1 year)	warmer and drier microclimate, delayed spread of existing trees	decline of snail individuals, the elimination of woody species was not complete	burning is recommended
	steppic grassland, late winter burning twice within a 4 years' time	most of the target species were not sensitive to burning	elimination of woody species and *Solidago gigantea* was not complete with solely burning	burning is feasible jointly with grazing or shrub clearance
Nether-lands	dry dune grasslands, winter burning (1 year)	-	burning was not successful in nutrient removal	burning is feasible jointly with grazing
Sweden	commercial hayfield, early spring burning (1 year)	reduction of litter	species composition was similar to that of fallow plots	burning is not recommended
	semi-natural pasture, yearly early-spring burning (15 years)	reduction of litter	species richness declined, cover of tall herbs increased, untargeted species composition	burning is not recommended
	semi-natural grassland, yearly early spring burning (28 years)	-	species richness declined, untargeted species composition	burning is not recommended
Switzer-land	limestone grassland, yearly winter burning (22 years)	increased cover of several rare plant species	species richness declined, cover of *Brachypodium pinnatum* increased	burning is not recommended
	limestone grassland, yearly winter burning (15 years)	reduction of litter	species richness declined, cover of *Brachypodium pinnatum* increased	burning is not recommended