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Is regular mowing the most appropriate and cost-effective management maintaining diversity and biomass of target forbs in mountain hay meadows?

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ABSTRACT

Conservation of grassland biodiversity is a key issue in the EU agro-biodiversity policy. We assessed the effects of yearly mowing on target forb biomass in years with contrasting precipitation (2006–2007) in mountain fen and dry-mesophilous hay meadows in NE-Hungary. We hypothesised: (i) Species richness and biomass of target forbs is higher in mown than in abandoned stands. (ii) Mowing has more an effect on the biomass of target forbs, graminoids and litter than precipitation.

Mowing increased the species richness of forbs and target forbs. The biomass of forbs and target forbs was not affected by mowing because of the specific responses of certain forbs. The majority of target species were supported, but tall forbs (*Succisa pratensis*; *Lathyrus pratensis*) were suppressed by mowing. Precipitation affected only the amount of litter in dry-mesophilous meadows and forb biomass in fen meadows. In the dry year, the biomass of target forbs decreased but the proportion of the species did not change. Our results showed that mowing is necessary to maintain overall plant biodiversity in hay meadows by removal of graminoid biomass and litter, but not all target forbs were favoured by regular yearly mowing. Decreased mowing frequency (mowing in every second or third year) on the entire meadow or temporarily changing mosaics of mown and unmown stripes might be the most suitable management option for maintaining the highest biodiversity of forbs.

Introduction

Major changes in agro-economy and altered land use in the last several decades formed a threat for grassland biodiversity in many places in Europe and probably elsewhere (Bakker and Berendse, 1999; Pullin et al., 2009; Novák and Prach, 2010). In Eastern European countries these changes resulted in mostly the entire cessation of traditional management by mowing or grazing in extent grasslands areas (Poschlod et al., 2005). This phenomenon was especially true for isolated mountain hay-meadows because of high costs of management caused by low rate and possibility of mechanical harvest and transport of hay (Stampfli and Zeiter, 1999).

Mountain hay meadows were created by tree cutting and maintained by regular mowing (Grime, 1979; Grace, 1999). Hay meadows in mountain areas are characterized by outstandingly high species richness and many endangered species, which are key elements of grassland conservation policy in the EU (Bakker and Berendse, 1999; Jongepierová et al., 2007; Lüth et al., 2011; Pullin et al., 2009). Mowing in general alters the competitive environment in grasslands by suppressing dominant graminoid competitors (Ilmarinen and Mikola, 2009; Hejcman et al., 2010) and favouring several characteristic grassland forbs (Stampfli and Zeiter, 1999; Klimek et al., 2007; Williams et al., 2007). Mowing also alters light availability in the ground layer (Bobbink et al., 1989) which can decrease the mortality of light-demanding seedlings (Tilman, 1993) and promote their survival (Overbeck et al., 2003). Mowing combined with raking reduces total biomass and prevents litter accumulation (Hejcman et al., 2011; Huhta et al., 2001; Ryser et al., 1995).

Based on these evidences it is generally concluded that regular mowing increases and/or maintains plant species richness in grasslands. Thus, to conserve and/or improve species richness regular mowing is widely suggested (Stampfli and Zeiter, 1999; Williams et al., 2007). It is also stressed that responses of plants to mowing can be highly specific. Some of the studies indicated that some target species were suppressed by regular mowing, which is generally underrated in light of the increase of species richness (Billeter et al., 2007; Diemer et al., 2001).

To study the effect of mowing on biomass production of target species, abandoned and mown dry-mesophilous and fen meadows were selected and their biomass was sampled in years with different precipitation totals (moist and dry year). Our goal was the analysis of the specific responses of grassland target species

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to mowing, and the evaluation of the necessity of yearly mowing based on biomass data. In particular, we tested the following hypotheses: (i) Species richness and biomass of target forbs is higher in mown than in abandoned stands. (ii) Mowing has more an effect on the biomass of target forbs, graminoids and litter than precipitation.

Materials and methods

Site description and history

The study site (Gyertyán-kúti meadows) is in the Zemplén Mountains (NE Hungary; 48°26.1–26.7′N; 21°21.6–22.3′E) between the villages of Regéc and Telkibánya on a plateau at a height of 640–720 m a.s.l. Mean annual temperature of the site is approximately 7.5–8.0 °C. The bedrock is amphibol-rich andesite, on which podzolic brown forest soils with acidic topsoil were formed. The meadows are surrounded by oak-hornbeam (*Quercus petraea* and *Carpinus betulus*) and mountain beech (*Fagus sylvatica*) forests and spruce plantations (*Picea abies*). The meadows with a 100 ha extension total in the past were created in the 18th century by forest cut, and were traditionally mown with scythe combined with raking once a year, with a cutting height of 0–5 cm above ground level, in late July–early August. No grazing by livestock and no mineral and/or organic fertilizers were applied. The meadows harbour over 350 vascular species, including 40 legally protected ones. The gradual cessation of management in the 1960s was followed by the colonization of wind-dispersed tree species (mostly *Betula pendula* and *Carpinus betulus*). Large stands of the established young birch forests were cut and traditional management was gradually resumed since 1985 (Valkó et al., 2011).

Sampling setup

Mown and abandoned stands of the two most widespread acidic meadow types, fen meadows (Junco-Molinion) located in lower elevations, and dry-mesophilous meadows (Cirsio pannonicae-Brachypodion pinnati) located in higher elevations were studied. The soils of the studied fen meadow stands are characterised by a pH of 4.2–4.3, a humus content of 7.1–8.6%, and nutrient scores of 21.7–30.2 mg/kg for NH_4–N; 51.0–56.5 mg/kg for P_2O_5–P and 128.0–156.0 mg/kg for K_2O–K. Fen meadows are characterised by high cover of *Molinia arundinacea*. The soils of the studied dry-mesophilous meadow stands are characterised by a pH of 4.2–4.4, humus content of 5.5%, and nutrient scores of 20.4–28.1 mg/kg for NH_4–N; 30.0–35.5 mg/kg for P_2O_5–P and 165.0–260.0 mg/kg for K_2O–K. In dry-mesophilous meadows the typical graminoid species are *Brachypodium pinnatum*, *Calamagrostis arundinacea* and *Carex montana*.

Four stands (two mown and two abandoned) of both meadow types, were selected for study. In mown stands traditional management (mowing once a year by scythe and raking from late July till early August) was resumed in 1993. Abandoned stands were left unmanaged from the early 1960s till the end of our study. In each stand 32 10 cm × 10-cm sized aboveground biomass samples were collected. All green biomass and litter were harvested exactly above the soil surface in a moist year (2006) and a dry year (2007) at the peak of biomass production in late July before mowing. The yearly precipitation was 784 mm from the mowing at the beginning of August 2005 to sampling in the end of July 2006 (Moist year), and 397 mm from August 2006 to July 2007 (Dry year). To minimize sample heterogeneity, eight pooled biomass samples per each stand in each year were used for statistical analyses (in each pooled sample four randomly chosen 10 cm × 10-cm biomass samples were pooled). The biomass samples were dried (60 °C, 24 h) than sorted to litter, and green biomass. Thereafter, the green biomass was sorted to graminoid and forb groups. Dicots, and non-graminoid monocots (Liliaceae, Iridaceae, Orchidaceae) were considered as forbs reflecting their contrasting responses to mowing compared to graminoids. Finally, the forb group was sorted into species. We used the term 'total biomass' for the joint amount of aboveground green biomass and litter. All dry weights were measured with an accuracy of 0.01 g.

Data processing

Because of identification difficulties vegetative Orchidaceae were excluded from analyses (out of the 512 sub-samples they were found only in 4 sub-samples). Legally protected and stress tolerant forbs characteristic to the studied meadow types were considered as target forbs (according to Borhidi, 1995; Grime, 1979). Characteristic species of mown and abandoned meadows in the two years were identified by the IndVal procedure based on the species composition of biomass samples (Dufrêne and Legendre, 1997). In the calculations 10,000 random permutations were used.

The effect of year and management on important biomass fractions was analyzed using LMEM for both types of meadows separately (Zuur et al., 2009). Year and management were chosen as fixed factors, and the meadow ID as a random factor. The similarity of biomass composition of both years and meadow types were plotted based on dry-weight scores using Bray–Curtis similarity and NMDS ordination (Legendre and Legendre, 1998). Statistical analyses were performed using the R statistical environment (version 2.13.1, R-Development Core Team, 2011).

Results

Target forbs

Altogether 84 forb species were found in biomass samples. In dry-mesophilous meadows 70, in fen meadows 59 forb species were detected. The two meadow types shared 45 forb species. Altogether 57 target species were identified in biomass samples; there were 50 species in dry-mesophilous meadows and 37 species in fen meadows. The two meadow types shared 30 target forb species. In fen meadows 34 target forb species were detected in the moist and 28 species in the dry year. In dry-mesophilous meadows 43 target forb species were found in the moist and 38 in the dry year.

In dry-mesophilous meadows 20 forb species, including 13 target forbs, were identified as significant character species by IndVal (at least for one of the study years, at least in 5 biomass samples detected, Appendix 1). Out of the 11 significant characteristic target forbs in mown stands, four species, *Cytisus nigricans*, *Helianthemum ovatum*, *Linum catharticum* and *Veronica officinalis*; and in abandoned stands *Cruciata glabra* were found to be significant character species in both years. In fen meadows altogether 26 forb species, including 18 target forbs proved to be significant character species by IndVal (Appendix 2). Out of the 14 significant target forbs in the mown stands six species, *Campanula patula*, *Linum catharticum*, *Polygala vulgaris*, *Ranunculus acris*, *R. polyanthemos*, and *Viola canina* were found and classified as character species for both years. In abandoned meadows *Galium boreale* and *Succisa pratensis* were significant character species for both years. Regardless of meadow type and year, *Linum catharticum* was identified as a significant character target species of mown stands.

In dry-mesophilous meadows the proportion of the target forbs' biomass varied between 5.3% and 8.6% of the total biomass in mown, and 1.1%–5.9% in abandoned stands. These figures ranged in fen meadows from 4.8% to 11.0% for mown, and from 1.0% to 5.4% for abandoned stands, respectively.

Table 1
Effects of management and year on the biomass characteristics of the dry-mesophilous meadows tested with LMEM. Significant effects ($p < 0.05$) marked with boldface.

Dry-mesophilous meadows	Mowing		Year		Mowing × year	
	t	*p*	*t*	*p*	*t*	*p*
Species numbers						
Forb	**5.464**	**<0.001**	1.338	0.186	0.670	0.505
Target forb	**4.320**	**<0.001**	1.156	0.252	0.688	0.493
Biomass						
Total	**6.739**	**<0.001**	1.709	0.092	0.433	0.667
Forb	0.734	0.466	0.269	0.789	1.286	0.203
Target forb	1.732	0.088	0.177	0.860	1.163	0.250
Graminoid	**2.263**	**0.027**	1.385	0.171	1.924	0.059
Litter	**8.079**	**<0.001**	**3.227**	**0.002**	1.532	0.131

Table 2
Effects of management and year on the biomass characteristics of the fen meadows tested with LMEM. Significant effects ($p < 0.05$) are marked with boldface.

Fen meadows	Mowing		Year		Mowing × year	
	t	*p*	*t*	*p*	*t*	*p*
Species numbers						
Forb	1.192	0.237	0.188	0.851	0.621	0.536
Target forb	**2.794**	**0.007**	0.489	0.627	1.334	0.187
Biomass						
Total	**9.953**	**<0.001**	0.567	0.573	**2.224**	**0.003**
Forb	0.088	0.930	**3.012**	**0.004**	1.510	0.137
Target forb	0.974	0.336	1.611	0.113	**2.012**	**0.048**
Graminoid	**4.865**	**<0.001**	0.562	0.576	0.815	0.418
Litter	**9.867**	**<0.001**	1.432	0.157	**2.200**	**0.032**

Biomass production

Mowing significantly affected several biomass fractions in both meadow types (Tables 1 and 2). In abandoned fen meadows a two- to three-times higher total biomass (ranging from 1961 to 2668 g m^{-2}) was sampled than in mown fen meadows (894–1162 gm^{-2}: Table 3). In mown stands of dry-mesophilous meadows means of total biomass scores ranged from 765 to 1095 g m^{-2}, while in abandoned stands higher scores were typical (means ranging from 1362 to 1881 g m^{-2}). The same magnitude of difference was also typical for graminoid biomass and litter in both years and meadow types (Table 3). The amount of accumulated litter was higher than 1000 g m^{-2} in almost every abandoned meadow stand in the two year. In dry-mesophilous meadows the species richness of forbs and target forbs and in fen meadows the species richness of target forbs were significantly increased by mowing.

Conversely, for total biomass of forbs no significant effect of mowing was detected in both types of meadows; but a higher rate of variability for both scores was typical in abandoned meadows (Table 3). In fen meadows the amount of forb biomass was significantly affected by the year. In the moist year the amount of forb biomass was two-times higher than in the dry year. These differences showed similar pattern, but with lower differences for target forbs. In dry-mesophilous meadows the amount of litter was affected by the year. Higher amount of litter was sampled in the dry year than in the moist year in almost every meadow stand regardless to management.

The NMDS ordination was based on the dry-weight scores of biomass (Fig. 1). The two meadow types became separated along the first axis of NMDS ordination. The management types (mown and abandoned) were separated along the second axis of NMDS ordination. The pattern plotted for the moist year was very similar to that of the dry year in both meadow types. A lower variation of species composition in forb biomass was found in mown meadows than in abandoned ones in both years (Fig. 1).

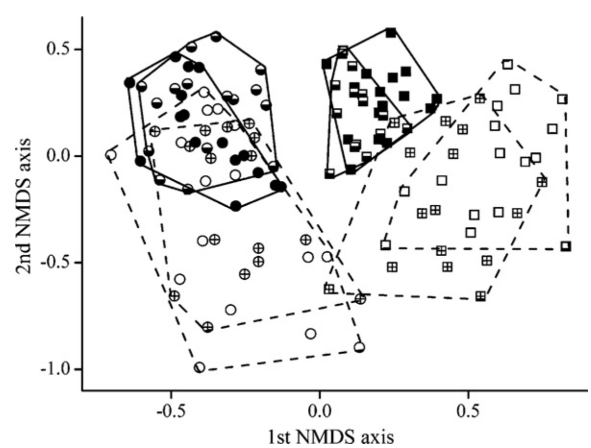

Fig. 1. The similarity of dry-mesophilous and fen meadow stands in 2006 and 2007, based on dry biomass (Bray–Curtis similarity, NMDS ordination, stress = XY). Notations: ● – dry-mesophilous meadows, mown, 2006; ○ – dry-mesophilous meadows, abandoned, 2006; ◒ – dry-mesophilous meadows, mown, 2007; ⊕ – dry-mesophilous meadows, abandoned, 2007; ■- – fen meadows, mown, 2006; □ – fen meadows, abandoned, 2006; ⬓ – fen meadows, mown, 2007; ⊞ – fen meadows, abandoned, 2007.

Discussion

Specific responses to mowing

Our results showed that yearly mowing supports the overall species richness of forbs and target forbs in both meadow types which is in line with other studies (Billeter et al., 2007; Mašková et al., 2009). More forb species proved to be significant character species for mown stands than for abandoned ones in both meadow types. These results support the findings of Billeter et al. (2007). No such difference was obtained for forb biomass and target forb

Table 3
Species richness and biomass scores of the studied meadows (mean ± SE). Species richness scores are calculated for the biomass samples size (0.04 m^2), whereas biomass scores were re-calculated to g/m^2.

	Moist year				Dry year			
	I. Mown	II. Mown	I. Abandoned	II. Abandoned	I. Mown	II. Mown	I. Abandoned	II. Abandoned
Dry-mesophilous meadows								
Species richness								
Forb	15.00 ± 0.38	17.38 ± 1.00	5.63 ± 0.91	14.50 ± 0.38	15.00 ± 1.31	14.25 ± 0.77	5.63 ± 0.91	13.50 ± 0.63
Target forb	11.13 ± 0.61	13.50 ± 0.95	3.88 ± 0.72	11.88 ± 0.72	11.75 ± 1.05	10.38 ± 0.68	4.00 ± 0.71	11.25 ± 0.59
Biomass								
Total	765 ± 33	875 ± 33	1423 ± 82	1595 ± 101	894 ± 88	1095 ± 66	1362 ± 121	1881 ± 188
Forb	80 ± 10	91 ± 10	43 ± 16	110 ± 12	90 ± 13	75 ± 9	25 ± 6	78 ± 7
Target forb	64 ± 10	74 ± 6	34 ± 16	94 ± 13	77 ± 13	58 ± 8	16 ± 5	65 ± 6
Graminoid	240 ± 25	251 ± 19	368 ± 45	317 ± 21	180 ± 20	189 ± 14	342 ± 50	466 ± 94
Litter	444 ± 20	533 ± 26	1006 ± 43	1168 ± 93	624 ± 87	831 ± 57	995 ± 102	1336 ± 113
Fen meadows								
Species richness								
Forb	15.13 ± 1.17	19.75 ± 0.65	9.88 ± 0.95	15.50 ± 1.09	14.25 ± 1.03	19.13 ± 0.97	7.13 ± 0.77	12.50 ± 1.25
Target forb	11.00 ± 0.60	12.13 ± 0.64	7.00 ± 0.85	11.38 ± 0.68	10.00 ± 1.13	12.25 ± 0.82	5.50 ± 0.93	8.38 ± 1.24
Biomass								
Total	996 ± 79	894 ± 125	2398 ± 182	2668 ± 232	1162 ± 144	908 ± 73	2282 ± 214	1961 ± 139
Forb	126 ± 8	115 ± 13	70 ± 16	174 ± 19	71 ± 9	83 ± 9	31 ± 6	64 ± 15
Target forb	110 ± 7	63 ± 7	55 ± 14	143 ± 18	58 ± 10	43 ± 5	24 ± 6	51 ± 13
Graminoid	408 ± 33	262 ± 50	652 ± 84	759 ± 125	356 ± 17	228 ± 30	532 ± 62	618 ± 121
Litter	462 ± 50	517 ± 116	1676 ± 133	1736 ± 149	735 ± 129	597 ± 61	1719 ± 171	1279 ± 106

biomass, which was likely caused by the contrasting response of particular species to mowing.

The majority of target species was supported by mowing and several studies found similar responses for these species. It was found by others that *Campanula persicifolia*, *Centaurea jacea*, *Leontodon hispidus*, *Linum catharticum*, *Lysimachia nummularia*, *Myosotis palustris*, *Lychnis flos-cuculi* and *Ranunculus acris* were supported by mowing (Berlin et al., 2000; Billeter et al., 2007; Hejcman et al., 2005; Rosenthal, 2010).

There were some target species in our sampling plots which were suppressed by mowing. Three target species (*Campanula persicifolia*, *Crepis praemorsa* and *Cruciata glabra*) were character species of abandoned dry-mesophilous meadows, and four target species were character species (*Achillea ptarmica*, *Betonica officinalis*, *Galium boreale* and *Succisa pratensis*) of abandoned fen meadows. Billeter et al. (2007) found that 18 species, including character species were suppressed by mowing. In line with findings of others we found that mowing likely suppress tall growing forbs like *Succisa pratensis*, *Lathyrus pratensis* and *Lysimachia vulgaris* (Billeter et al., 2007; Hejcman et al., 2005; Rosenthal, 2010).

In some cases it was difficult to judge whether mowing positively or negatively affected a certain species. We found that *Cruciata glabra* was a character species for both mown fen and abandoned dry-mesophilous meadows. In our study *Veronica chamaedrys* was found as a character species for mown dry-mesophilous meadows, but in mesophilous meadows in the Czech Republic this species was found to be suppressed by mowing (Hejcman et al., 2005). Character species of abandoned fen meadows in this study were found to be supported by mowing in some other studies (e.g. *Galium boreale* in dry-mesic grasslands in Sweden – Berlin et al., 2000; or *Achillea ptarmica* in wet meadows in Germany – Rosenthal, 2010).

From data of both years we found that *Succisa pratensis* was a significant character species of abandoned fen meadows. However, it was found that mowing can have both positive and negative effects on this particular species. Mowing affected negatively leaf length (Diemer et al., 2001), reproductive success (Billeter et al., 2007) but positively the seedling establishment of *S. pratensis* (Billeter et al., 2003). Such specific responses can be also influenced by nutrient availability and other site conditions (Hejcman et al., 2007).

Effects of mowing and years with different precipitation

Mowing had a significant effect on most of the biomass and species richness scores regardless to year-to-year variation that likely was caused by the different amounts of precipitation. In line with others our results showed that mowing significantly supported the number of target species and decreased the amount of litter, total and graminoid biomass in both meadow types (Beltman et al., 2003; Billeter et al., 2007; Mašková et al., 2009).

Only the forb biomass in fen meadows and the amount of litter in dry-mesophilous meadows was affected significantly by differences in precipitation. These results only partly correspond with the findings of Mašková et al. (2009), where no significant correlation of biomass production and climatic parameters was found in mountain hay meadows. In the moist year in fen meadows, forb biomass scores in our research area were two-times higher than those in the dry year.

Higher amount of litter sampled in dry-mesophilous meadows in the dry year can have been resulted from a lower rate of litter decomposition in drier circumstances, which was proven by Reed et al. (2009) to be the case in tall-grass prairie. Litter accumulation negatively affects overall biodiversity as it can inhibit the germination and decrease the seedling survival of certain target species (Kupferschmid et al., 2000) changing the physical and chemical environment of the upper soil layers (Facelli and Pickett, 1991).

We found that the sample-by-sample composition and biomass of forbs in mown meadows was more even than the respective scores of abandoned ones. This may have been caused by the more homogenous vegetation structure in mown stands (see Fig. 1). Tussock forming grass species in both meadow types, like *Calamagrostis arundinacea* or *Molinia arundinacea*, were more frequent in absence of mowing, forming large tussocks and a heterogeneous vegetation structure (see also Bartoš et al., 2011). In accordance with others it was found that dominant *Molinia arundinacea* can be suppressed by mowing in fen meadows (Diemer et al., 2001; Valkó et al., 2011). The well-developed tussock-structure supports the co-existence of species by separation of species regeneration niches (Janeček and Lepš, 2005). The tussock-structure of *Molinia* provides heterogeneous safe-site patterns for establishment of certain species like *Arabis hirsuta* (Kupferschmid et al., 2000). In our study, the more even distribution of subordinate forbs in mown meadows may be caused by decreased tussock sizes resulting in a more homogenous graminoid matrix structure compared to abandoned meadow stands.

Management options and implications for practice

We found that for maintaining biodiversity of vascular plants in hay meadows, regular mowing is necessary to remove graminoid biomass and litter. However, in order to maintain a high biodiversity of grassland target plant species more sophisticated management design is needed than mere regular mowing in a certain time of the year. This supports the majority of target species, while others, mostly tall forbs become suppressed by mowing. Consequently, a good management strategy to maintain the highest target species richness might be to have a spatial and temporal mosaic of different mowing practices (different date and frequency) including fallow periods, because each management type promotes different species. This resulted quite clearly from our study and also from other, similar investigations (Köhler et al., 2005; Bissels et al., 2006).

Agro-environmental schemes and subsidies are vital elements in the financial support maintaining grasslands with difficult accessibility and management like mountain hay meadows (Kleijn and Sutherland, 2003). However, to get these subsidies in several countries the regular yearly mowing of the entire meadow is required (Whittingham, 2011). Yearly mowing of the entire meadow may decrease spatial heterogeneity and may not be the most proper option to maximize grassland plant species diversity. Applying regular mowing in the central part of a meadow but leaving some strips unmown or mown less frequently (e.g. every second or third year) can be a better management option (Köhler et al., 2005). A mosaic of different mowing regimes is also favourable for the soil fauna (by leaving unmown strips: Humbert et al., 2009) and insects of the meadow canopy (including intermittent fallow periods: Balmer and Erhardt, 2000).

Managers are seeking across Europe for less costly approaches to maintain species diversity in semi-natural grasslands, e.g. using alternative measures like mulching (Gaisler et al., 2004; Mašková et al., 2009) or reducing harvesting frequency to an acceptable minimum (Kleyer, 2007). Mowing only in every second or third year can mitigate costs and might be proper to maintain the species richness in mountain meadows with difficult accessibility with mowing machinery or where the hay is of low quality like in fen meadows. Pavlů et al. (2011) found that in some type of mountain meadows where the implementation of management is costly and difficult, mowing can be skipped in several years without substantial changes in species composition. Köhler et al. (2005) found that in limestone grasslands in Switzerland the effects of mowing every second year on species richness are very similar to that of yearly mowing so it can be an alternative management option. Mikhailova et al. (2000) found the maximum of species richness in steppe grasslands in Russia, where a periodical management regime by mowing or grazing was applied several times in the first year followed by a fallow period in the second year. Mowing can be skipped in dry years in dry-mesophilous meadows but raking may be applied to remove the high amount of accumulated litter.

It is important to choose the proper duration of the fallow period. Short fallow periods can stimulate some species, but long-term abandonment most likely leads to a population decline and the extinction of prostrate and/or rare forb species (Diemer et al., 2001). When mowing is applied to prevent afforestation and to preserve open landscape in wooded meadows, the meadows have to be cleared from woody plants frequently (Poptcheva et al., 2009) or by applying periodic mowing (e.g. in every three years) which can prevent the spreading of woody species.

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Appendix A. Appendix 1

Characteristic forb species of mown and abandoned dry-mesophilous meadow stands were identified by an IndVal procedure (IndVal, $p < 0.05$). The IndVal value shows how characteristic the species is to the differently managed meadow stands in the two years; the maximum score (=100%) is reached when the individuals of the species are present in all plots in the two mown or abandoned, respectively, meadow stands within a year. Abbreviations: IndVal = IndVal score for significant character species, MB = mean biomass ($g m^{-2}$), Fr = frequency scores are the number of plots in which the species occurred (maximum frequency score is 16 in the two mown or abandoned meadow stands in a year). Species present in at least 5 plots in the mown or abandoned stands within a year are listed. Target forbs are indicated with boldface.

	IndVal	*p*	Mown		Abandoned	
			MB	Fr	MB	Fr
Moist year-mown						
Ajuga reptans	54.2	0.031	7.3	11	2.0	7
Campanula persicifolia	49.5	0.070	3.9	10	1.1	9
Cytisus nigricans	36.6	0.042	12.8	7	2.5	4
Fragaria vesca	30.1	0.035	1.3	5	0.2	1
Helianthemum ovatum	69.5	<0.001	10.8	14	2.8	5
Linum catharticum	43.8	0.003	0.2	7		
Pimpinella saxifraga	61.7	<0.001	3.8	10	0.2	1
Potentilla alba	61.4	0.028	9.8	16	6.3	11
Veronica chamaedrys	37.5	0.010	0.6	6		
Veronica officinalis	39.4	0.020	9.2	7	1.1	2
Viola hirta	31.3	0.023	1.1	5		
Moist year-abandoned						
Cruciata glabra	60.3	0.057	2.8	13	6.1	14
Dry year-mown						
Achillea millefolium	42.5	0.010	1.7	7	0.2	2
Campanula patula	48.0	0.012	1.6	9	0.3	4
Cytisus nigricans	34.0	0.055	14.1	6	1.4	3
Helianthemum ovatum	51.0	0.018	7.5	11	2.7	6
Leontodon hispidus	43.5	0.006	6.4	8	0.9	1
Linum catharticum	56.3	<0.001	1.6	9		
Plantago lanceolata	43.8	0.004	4.4	7		
Veronica officinalis	51.3	0.004	6.1	9	0.6	2
Viola canina	62.0	0.024	8.9	16	5.5	10
Dry year-abandoned						
Campanula persicifolia	37.1	0.047	0.8	3	2.0	8
Crepis praemorsa	31.3	0.020			1.3	5
Cruciata glabra	51.1	0.049	1.4	8	3.1	12
Potentilla erecta	61.3	0.036	4.5	11	10.6	14
Stellaria graminea	24.5	0.046	0.2	1	1.1	4

A.1. Appendix 2

Characteristic forb species of mown and abandoned fen meadow stands were identified by an IndVal procedure (IndVal, $p < 0.05$). For abbreviations and notations see Appendix 1.

	IndVal	p	Mown		abandoned	
			MB	Fr	MB	Fr
Moist year-mown						
Campanula patula	87.5	<0.001	1.1	14		
Cruciata glabra	58.2	0.067	7.0	16	5.0	13
Filipendula vulgaris	36.7	0.039	6.7	8	2.5	2
Leontodon hispidus	48.8	0.002	8.6	8	0.2	1
Linum catharticum	35.7	0.020	0.5	6	0.2	1
Lychnis flos-cuculi	31.3	0.020	0.2	5		
Lysimachia nummularia	42.2	0.009	5.2	7	0.2	2
Plantago lanceolata	31.3	0.020	4.5	5		
Polygala vulgaris	67.8	<0.001	3.4	11	0.2	1
Potentilla alba	38.4	0.074	7.8	8	2.3	5
Prunella vulgaris	72.3	<0.001	14.5	14	3.1	3
Ranunculus acris	60.3	0.017	4.7	12	1.1	6
Ranunculus polyanthemos	51.9	0.003	7.0	9	0.6	2
Selinum carvifolia	55.1	0.088	15.6	15	10.9	11
Stellaria graminea	63.8	0.006	3.4	12	0.6	3
Viola canina	97.2	<0.001	21.4	16	0.6	7
Moist year-abandoned						
Achillea ptarmica	53.2	0.075	6.9	12	13.0	13
Betonica officinalis	53.4	0.002	1.3	2	23.1	9
Galium boreale	55.8	0.026	3.9	8	8.6	13
Lathyrus pratensis	42.8	0.014	0.2	2	2.2	7
Lysimachia vulgaris	35.0	0.063	0.5	4	7.2	6
Succisa pratensis	65.3	0.002	2.0	3	39.2	11
Dry year-mown						
Campanula patula	56.3	<0.001	1.3	9		
Centaurea jacea	31.3	0.022	7.0	5		
Hieracium umbellatum	23.8	0.078	0.9	4	0.2	1
Leontodon hispidus	56.3	<0.001	16.4	9		
Linum catharticum	37.5	0.006	1.1	6		
Lysimachia nummularia	47.0	0.005	1.6	8	0.2	1
Myosotis palustris	40. 0	0.044	0.6	8	0.2	4
Plantago lanceolata	50.0	0.001	7.2	8		
Polygala vulgaris	75.0	<0.001	3.3	12		
Prunella vulgaris	63.3	0.002	5.5	13	1.6	3
Ranunculus acris	50.3	0.038	2.3	11	0.8	7
Ranunculus polyanthemos	56.3	<0.001	1.7	9		
Stellaria graminea	76.7	<0.001	1.6	15	0.3	3
Veronica officinalis	50.3	0.010	3.6	10	0.9	3
Viola canina	90.3	<0.001	18.1	16	2.0	7
Dry year-abandoned						
Galium boreale	57.9	0.001	0.5	2	5.0	10
Lathyrus pratensis	50.0	0.001			1.7	8
Lysimachia vulgaris	26.4	0.099	0.5	2	2.5	5
Succisa pratensis	38.9	0.084	3.1	6	10.9	8

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