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Restoration of grazing management and its effect on vegetation in an upland grassland

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Abstract

Question: How are plant species and functional group composition, and potential sward height affected by implementation of different grazing regimes on previously abandoned semi-natural grassland?

Location: The Jizerské mountains, northern Czech Republic.

Methods: We established a randomized block experiment with the following treatments: unmanaged control (U), intensive (IG) and extensive (EG) continuous grazing, first cut followed by intensive (ICG) and first cut followed by extensive (ECG) continuous grazing for the rest of the growing season. The percentage cover of all vascular plant species was recorded in 40 permanent plots.

Results: Total plant species richness increased in all managed treatments, whereas species number was reduced in U at the end of the experiment. Tall forbs (*Aegopodium podagraria, Galium album, Anthriscus sylvestris, Cirsium arvense*) as well as tall grasses (*Elytrigia repens* and *Alopecurus pratensis*) were more abundant in U. Species associated with both grazing treatments (IG, EG) were *Dactylis glomerata, Festuca rubra* agg. and *Phleum pratense*. *Agrostis capillaris, Taraxacum* spp., *Trifolium repens*, *Ranunculus repens* and *Cirsium vulgare* were promoted by ECG and ICG. Abundance of tall grasses and tall forbs reflected the intensity of management in the order U>EG, ECG>IG, ICG. Prostrate forbs, on the other hand, increased their cover with increasing intensity: ICG>IG>ECG>EG.

Conclusions: Plant species composition of semi-natural grasslands is affected by the defoliation regime. Continuous grazing on abandoned grassland alters the sward structure towards a permanent pasture with short, light-sensitive grasses and prostrate forbs. To maintain or enhance plant species richness in semi-natural grasslands, understanding the effects of different grazing regimes on plant species composition is necessary.

Keywords: Abandoned semi-natural grassland; Grazing intensity; Pasture; Principal response curve; Vegetation trait.

Nomenclature: Kubát et al. (2002).

Abbreviations: ECG = Extensive grazing after first cut; EG = Extensive grazing; ICG = Intensive grazing after first cut; IG = Intensive grazing; PRC = Principal response curve; RDA = Redundancy Analysis; U = Unmanaged control.

Introduction

During the last two decades considerable changes in the utilization of grassland in Europe have occurred. The most remarkable changes occurred in eastern and central European countries, which had to build up a market economy in the 1990s. Continued intensification of cattle production by introducing highly digestible forages from arable land and concentrates will probably further decrease demand for grassland areas in the future (Isselstein et al. 2005).

Absence of grassland defoliation frequently leads to a decrease in plant species diversity (Bakker 1989; Smith & Rushton 1994; Pecháčková & Krahulec 1995; Losvik 1999; Tasser & Tappeiner 2002; Pykälä 2004; Pavlů et al. 2005). Extensive grazing is characterized by a strongly variable sward height and species composition (Correll et al. 2003). The main mechanism by which grazing livestock maintains high biodiversity in pastures is the creation and maintenance of sward structure heterogeneity (Schlapfer et al. 1998; Rook et al. 2004). Patchiness created by extensive grazing is particularly interesting for nature conservation. Therefore, extensive grazing is frequently recommended as an alternative way of managing semi-natural hay meadows (Bakker 1998; Adler et al. 2001; Bakker et al. 2004), but not in all type of grasslands (Fisher & Wipf 2002). In practice, there is an urgent need to find a type of management acceptable for both farmer's profitability and nature conservation targets (Watkinson & Ormerod 2001).

The impact of grazing management on vegetation dynamics has been widely studied in western Europe during the last two decades (e.g. Bakker 1989; WallisDeVries et al. 1998; Marriott et al. 2002). However, research on livestock grazing in central Europe has concentrated on a small number of case studies although the use of grazing management has dramatically increased due to socio-economical changes in the rural economy since the 1990s. Several experiments describe attempts to restore abandoned mountain grasslands via livestock grazing

(Krahulec et al. 2001; Matějková et al. 2003) but, so far, with little attention paid to the restoration of upland grasslands, although they are one of the most frequent of all grassland types. This is the reason why we set up a grazing experiment on abandoned upland grassland to determine the long-term changes in sward structure following the introduction of continuous extensive and intensive grazing or first cut followed by both grazing intensities. Although the use of single species response gives us important information, a functional analysis of vegetation may help to understand and predict the impact of management in more general ways (de Bello et al. 2005; Louault et al. 2005). Therefore, the aim of our study was to answer the following questions: 1. How are plant species composition, plant species diversity, proportion of plant functional groups and potential sward height affected by implementation of different grazing regimes on previously abandoned semi-natural grassland? 2. When do changes in sward structure under different grazing regimes occur?

Material and Methods

Study site

The experiment was undertaken in the Jizerské mountains in the northern Czech Republic, 10 km north of the township of Liberec (50°50' N, 15°06' E). The site is underlain by granite bedrock and medium deep brown soil (cambisol) with the following attributes: pH/KCl = 5.1, C_{ox} =3.9%, available P content = 64 $mg.kg^{-1}$, available K content = 95 $mg.kg^{-1}$ and available Mg content = 92 $mg.kg^{-1}$. The altitude is 420 m a.s.l., the mean annual precipitation is 803 mm and the mean annual temperature is 7.2 °C (Liberec meteorological station). The experimental area was drained, ploughed and reseeded with a highly productive grass/clover mixture in the 1980s and was intensively managed by cutting and grazing. In the early 1990s mulching was applied once a year only (in August) and then the grassland was abandoned. There was no agricultural management in the five years before the start of the experiment in 1998. According to the phytosociological nomenclature (Moravec 1995) the vegetation before introduction of experimental treatments was classified as upland hay meadow (*Arrhenatherion*). The dominant species of the unmanaged sward were *Agrostis capillaris*, *Alopecurus pratensis*, *Festuca rubra* agg., *Aegopodium podagraria* and *Galium album*.

Experimental design

The experiment was established in the spring of 1998. Treatments applied were: intensive grazing (IG), first cut followed by intensive grazing (ICG), extensive grazing (EG), first cut followed by extensive grazing (ECG) and unmanaged grassland (U) as the control. Each grazed paddock was ca. 0.35 ha and the unmanaged control was 0.12 ha. Experimental paddocks were replicated twice in a randomized block design. Descriptions of the treatments applied are shown in Table 1.

Sward height was measured weekly by the first contact method (Pavlů 1997) between 1998-2001 and by the rising-plate meter method (Castle 1976) between 2002-2004. To maintain the target sward height, an additional non-sampling area with the requested sward height was added during the course of the grazing season. All treatments were grazed continuously by young heifers with initial live weights of 150-220 kg in each grazing season. Grazing was applied from early May to late October and the mean productivity of the pasture varied from 2 to 4 $t.ha^{-1}.yr^{-1}$ dry matter.

Plant species composition

Permanent 1 m × 1 m plots were analysed using a continuous grid of nine 0.33 m × 0.33 m subplots in four replications in each paddock. We recorded the proportional cover of all vascular species. Plant cover values in each subplots were visually estimated before the treatments started in early May each year from 1998 to 2004. The mean of nine subplots was used for statistical evaluation. An initial estimate was conducted before the first experimental manipulation to provide baseline data for each plot. Based on descriptions of vascular plants in the regional flora (Kubát et al. 2002), all plant species within the study area were *a priori* categorized according to their main traits. We recognized four categories: short grasses, tall grasses, prostrate forbs (dicot perennial species with creeping or prostrate growth) and tall forbs (Table 2).

Table 1. Descriptions of the investigated treatments.

Treatment	Description	Target sward height during grazing	Date of first cut	Start of grazing
U	Unmanaged control	( )	No cut	No grazing
IG	Intensive grazing	5 cm	No cut	Early May
ICG	First cut followed by intensive grazing	5 cm	Early June	Mid-June
EG	Extensive grazing	10 cm	No cut	Mid-May
ECG	First cut followed by extensive grazing	10 cm	Early June	Late June

Table 2. Functional groups of the study sward.

Short grasses	Tall grasses	Prostrate forbs	Tall forbs	Others
Agrostis capillaris	*Alopecurus pratensis*	*Alchemilla* spp.	*Achillea millefolium*	*Cardamine pratensis*
Anthoxanthum odoratum	*Dactylis glomerata*	*Anemone nemorosa*	*Aegopodium podagraria*	*Cerastium holosteoides*
Lolium perenne	*Deschampsia cespitosa*	*Campanula patula*	*Anthriscus sylvestris*	*Glechoma hederacea*
Poa annua	*Elytrigia repens*	*Campanula rotundifolia*	*Cirsium arvense*	*Lychnis flos-cuculi*
Poa pratensis	*Festuca pratensis*	*Capsella bursa-pastoris*	*Cirsium palustre*	*Stellaria graminea*
	Festuca rubra	*Leontodon autumnalis*	*Cirsium vulgare*	*Veronica arvensis*
	Holcus lanatus	*Plantago lanceolata*	*Galium album*	*Veronica chamaedrys*
	Holcus mollis	*Plantago major*	*Heracleum sphondylium*	
	Phleum pratense	*Ranunculus acris*	*Hypericum maculatum*	
	Poa trivialis	*Ranunculus repens*	*Lathyrus pratensis*	
	Trisetum flavescens	*Taraxacum* spp.	*Leucanthemum vulgare*	
		Trifolium dubium	*Lotus uliginosus*	
		Trifolium pratense	*Rumex acetosa*	
		Trifolium repens	*Rumex obtusifolius*	
		Veronica serpyllifolia	*Senecio ovatus*	
			Urtica dioica	
			Vicia cracca	

Potential height of sward

To reveal the expected relationship between mean height of a particular species and their response to treatments, the mean height of species (Kubát et al. 2002) were weighted according to their cover in a particular relevé. Potential height of sward was defined to generalize reaction of all sward components together and to test the effect of grazing systems on replacement of sward dominants according to their heights. Potential height of sward (instead of actual heights – which define only intensity of grazing) enables us to briefly reveal changes in species composition of sward in relation to grazing treatments.

Data analysis

Repeated measures ANOVA was used to evaluate species diversity and functional group data. The community response was analysed by constrained ordinations. The redundancy analysis (RDA, Lepš & Šmilauer 2003) in the CANOCO package (ter Braak & Šmilauer 2002) followed by a Monte Carlo permutation test was used to evaluate trends in plant species composition. A split plot design was used in the permutation type to cope with repeated measures. We used 999 permutations in all performed analyses. Our data form used repeated observations with the baseline data (measurements performed before the introduction of grazing), thus the interaction of treatments and year were the most important variables. The mean of nine subplots was used for statistical evaluation. A standard biplot ordination diagram as well as principal response curves (PRC) constructed by the CanoDraw program (ter Braak & Šmilauer 2002) was used to visualize the results of the CANOCO analyses. The resulting response curve shows us the extent and directions of development of grassland vegetation under different experimental treatments, compared with the control treatment (Lepš & Šmilauer 2003). The vertical scores of PRC curves are based on the scores of environmental variables from an RDA, the sampling time indicators are used as covariables and the interaction between the treatment levels and sampling times stand as environmental variables. No differences were found between blocks, therefore the effect of block was not taken in account data analysis.

Results

Potential sward height

Before the start of the experiment the mean potential heights of the sward were 64, 71, 63, 71 and 70 cm under the EG, ECG, IG, ICG and U treatments, respectively (Fig. 1). During the first four years of the study, the potential sward height was similar under all studied treatments. Then a gradual decrease under IG, ICG and ECG treatments was recorded whereas under EG and U

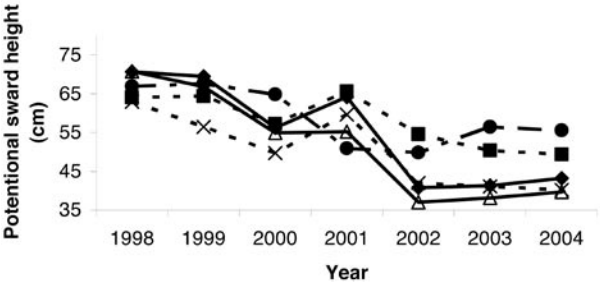

Fig. 1. Potential sward height for different treatments ECG (◆), EG (■), ICG (▲), IG (×), U (●) between 1998-2004.

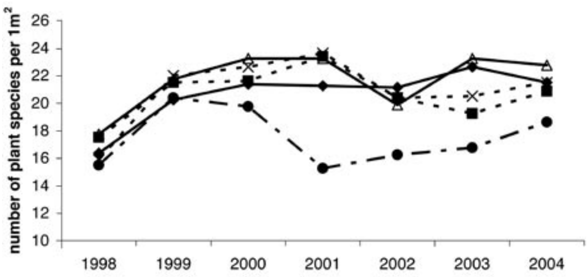

Fig. 2. Number of plant species per 1 m^2 for different treatments ECG (◆),EG (■), ICG (△), IG (×), U (●) between 1998-2004.

a slight decrease ($P = 0.006$, interaction time and treatment). At the end of the experiment, the mean potential heights of the sward were 49, 43, 40, 40 and 56 cm under the EG, ECG, IG, ICG and U treatments respectively.

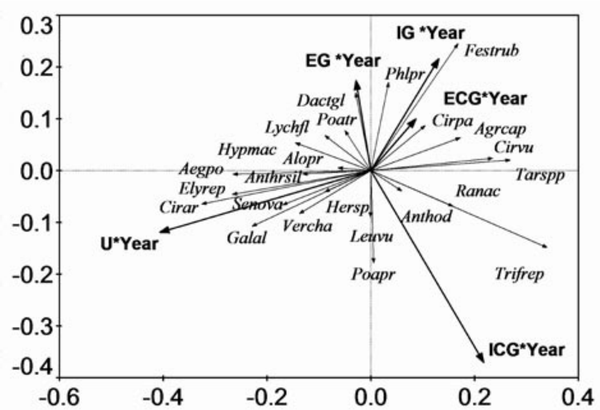

Fig. 3a. Ordination diagram showing the result of RDA analysis. First and second axis.

Abbreviations: IG, ICG, EG, ECG and U treatments (see Table 1); * indicates interaction of environmental variables; Aegpo = *Aegopodium podagraria*, Agrcap = *Agrostis capillaris*, Alopr = *Alopecurus pratensis*, Anthod = *Anthoxanthum odoratum*, Anthrsil = *Anthriscus sylvestris*, Cirar = *Cirsium arvense*, Cirpa = *Cirsium palustre*, Cirvu = *Cirsium vulgare*, Dactgl = *Dactylis glomerata*, Elyrep = *Elytrigia repens*, Festrub = *Festuca rubra*, Galal = *Galium album*, Hersp = *Heracleum sphondylium,* Hypmac = *Hypericum maculatum,*Leuvu = *Leucanthemum vulgare*, Lychfl = *Lychnis flos cuculi*, Phlpr = *Phleum pratense*, Poapr = *Poa pratensis*, Poatr = *Poa trivialis*, Ranac = *Ranunculus acris*, Ranrep = *Ranunculus repens*, Senova = *Senecio ovatus*, Tarspp = *Taraxacum* spp., Trifrep = *Trifolium repens*, Vercha = *Veronica chamaedrys*.

Plant species richness and composition

Significant differences in the number of plant species as a function of management were recorded ($P = 0.011$, interaction time and treatment). Similar numbers of species (16.4, 17.5, 17.8, 15.9 and 15.5 per plot in the ECG, EG, ICG, IG and U treatment respectively) were present initially in all treatments (Fig. 2). The total plant species richness increased to at least 20 in all managed treatments over six years.

There were significant differences between treatments, as well as successional development, independent of the treatments. (see Table 3, analysis A1 and A2 for details).

Tall forbs (*Aegopodium podagraria, Galium album, Anthriscus sylvestris, Cirsium arvense, Senecio ovatus*) as well as tall grasses (*Elytrigia repens, Alopecurus pratensis*) had higher abundance in the U treatment (Fig. 3). Species associated with both grazed only treatments (IG, EG) were *Dactylis glomerata, Festuca rubra* agg. and *Phleum pratense*. *Agrostis capillaris, Taraxacum* spp., *Trifolium repens*, *Ranunculus acris* and *Cirsium vulgare*, on the other hand, were supported by both cut (ECG and ICG) treatments. Results of repeated measurements ANOVA analyses showed a significant effect of treatment*year on cover of tall grasses ($P = 0.0002$), short grasses ($P = 0.011$), tall forbs ($P < 0.001$) and prostrate forbs ($P < 0.001$).

Decreased abundance of tall grasses, represented mainly by *A. pratensis*, was recorded in all treatments during the run of the experiment (Fig. 4a). The highest decrease was revealed in the IG treatment and the lowest in U treatment. Increased abundance of tall forbs was

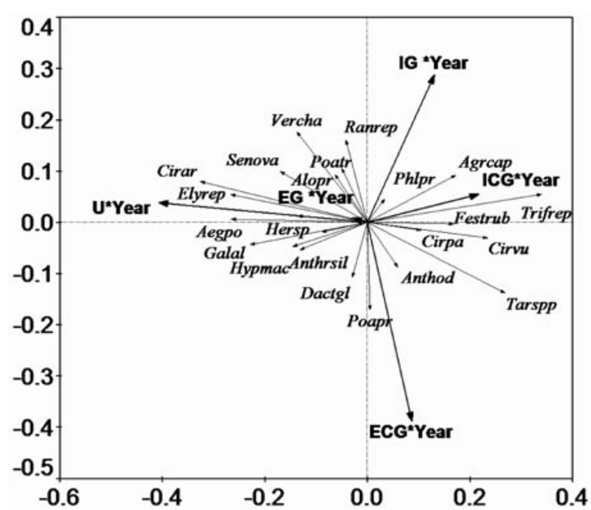

Fig. 3b. Ordination diagram showing the result of RDA analysis. Axes 1 and 3 are shown.

Table 3. Results of the RDA analyses of cover estimates. IG, ICG, EG, ECG, U = treatments abbreviations, see Table 1; PlotID = plot identifier; % expl. variability = species variability explained by one (all) ordination axes (measure of explanatory power of the explanatory variables); *F*-ratio = *F* statistics for the test of particular analysis; *P*-value = corresponding probability value obtained by the Monte Carlo permutation test; Int = grazing intensity.
Tested null hypotheses: A1 There are no directional changes in time in the species composition, that are common to all the treatments or specific for particular treatments; A2 The temporal trend in the species composition is independent of all treatments.

Analysis	Explanatory variables	Covariables	% expl. 1st (all)axis	*F*-ratio 1st axis (all axes)	*P* 1st axis (all axes)
A1	Year,Year*IG, Year*EG, Year*ICG, Year*ECG, Year*U	Plot ID	31.4 (37.7)	107.59 (28.89)	0.001 (0.001)
A2	Year*IG, Year*EG, Year*ICG, Year*ECG, Year*U	Year, Plot ID	11.7 (17.2)	31.28 (12.19)	0.001 (0.001)

recorded in the unmanaged control, an opposite trend (Fig. 4b). Substantial cover reduction was revealed in all managed treatments, particularly in both intensively managed plots (IG and ICG). Tall forbs were represented by two dominants, *A. podagraria* and *G. album*. Short grasses, mainly *A. capillaris*, were promoted by all managed treatments, especially by intensive grazing, whereas they decreased in cover in treatment U (Fig. 4c). Prostrate herbs were suppressed by no defoliation management in the control, on the other hand they increased under all defoliation regimes (Fig. 4d). *T. repens* increased cover as a function of defoliation intensity (ICG > IG > ECG > EG), whereas *Taraxacum* spp. was strongly promoted by the first cut followed by both grazing intensities (ICG, ECG). In general, there was a shift from tall to short plant species in all managed treatments, which indicated the change in grassland community. PRC analyses based on RDA shows that diversification in plant species composition created by different defoliation occurred in the fourth year of the study (Fig. 5). All management treatments with negative PRC scores have higher abundance of *Taraxacum* spp., *A. capillaris* and *T. repens*, whereas unmanaged plots become dominated by tall species (*Aegopodium podagraria, Galium album, Alopecurus pratensis, Holcus mollis, Vicia cracca, Cirsium arvense, Hypericum maculatum* and *Urtica dioica)*.

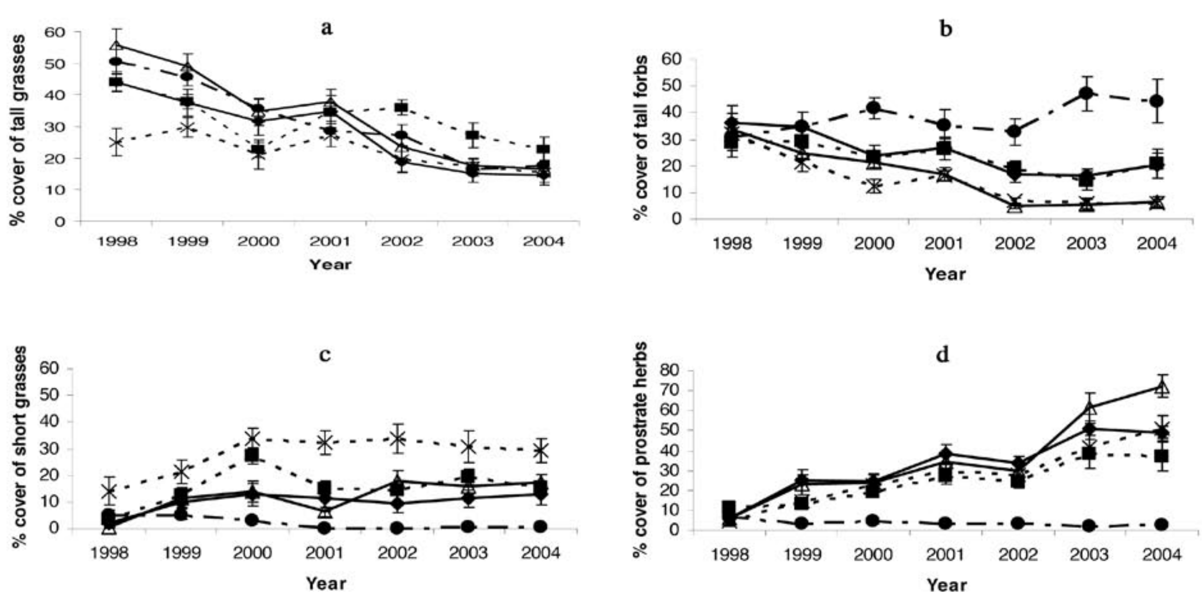

Fig. 4. Changes in cover (%) of (**a**) tall grasses, (**b**) short grasses, (**c**) tall forbs and (**d**) prostrate forbs for different treatments ECG (◆), EG (■), ICG (▲), IG (×), U (●) between 1998-2004. Standard errors are indicated by vertical lines.

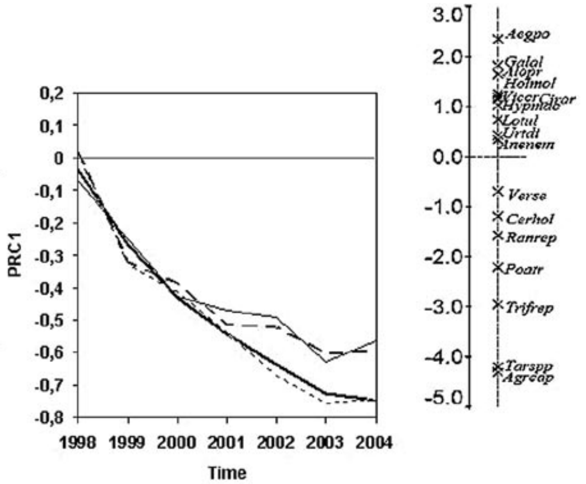

Fig. 5. Principal response curves for different treatments ECG (- - - -), EG (——), ICG (········), IG (**——**) during the experiment. The unmanaged treatment (U) was taken as a reference (zero control) treatment.

Discussion

Potential sward height

Potential sward height reflected the intensity of management and was an indicator of the replacement of tall dominants by lower growing species. A decrease of potential sward height in intensively defoliated plots indicates more suitable conditions for the development of a pasture community characterized by a high proportion of prostrate forbs and short grasses. Several studies have shown that plant height seems to be the best single predictor of species reaction to intensive defoliation in regularly grazed species (Díaz et al. 2001; Pavlů et al. 2003; Pykälä 2004).

Plant species richness and composition

Seven years of grazing management did not lead to the development of a very species-rich grassland in our study site; however an increase in the number of plant species at a scale of 1 m^2 in all managed treatments occurred. Increases in plant species number at a fine scale were probably due mainly to a change in plant distribution within the experimental grassland. The reduction in sward height of the previously unmanaged grassland by the defoliation treatments enabled the spread of species surviving frequently in less productive and disturbed sites only. The increase in plant species richness in managed plots was moderate and potentially due to the limited number of species present in the regional species pool and also due to the relatively short duration of the experiment. The diversification of grassland vegetation has been shown to occur as in Hellströms study (Hellström et al. 2003) after only three years of grazing. However, changes in both cover of presented plant species and in plant densities of all grassland components, especially grass tillers, were revealed after the introduction of grazing management (Pavlů et al. 2006c). The positive effect of grazing on species richness compared to unmanaged grassland is well documented in many other studies (e.g. Bakker 1989; Smith & Rushton 1994; Tasser & Tappeiner 2002; Pykälä 2005; Pavlů et al. 2006b). According to Olff & Ritchie (1998), this is a general effect of large herbivore grazers in temperate grasslands. The response of plant species richness to defoliation was shown in all the managed treatments and this increase was higher than in the unmanaged control. These results indicate the necessity of some kind of defoliation to enable coexistence of the many plant species in semi-natural grasslands.

Plant species composition and functional group

The change in grassland community from *Arrhenatherion* to *Cynosurion* (*sensu* Moravec 1995) manifested mostly as an exchange of dominant species. The dominant tall grass in the unmanaged meadows, *Alopecurus pratensis,* was generally replaced by the short grass species *Agrostis capillaris,* on account of defoliation in all the managed treatments. This is in accordance with several previous studies showing that short grass *A. capillaris* (CRS strategy, Grime 1987) is often promoted by grazing in low productive grasslands (e.g. Hellström et al. 2003; Louault et al. 2005; Pavlů et al. 2006a). The most abundant prostrate dicotyledonous species (*T. repens* and *Taraxacum* spp.) increased in cover in all managed treatments, as in other studies testing intensity or grazing itself (Bullock et al. 2001; Pavlů et al. 2003; Pykälä 2005; Louault et al. 2005). However, this study suggests different strategies of *Taraxacum* spp. and *T. repens*. The common pasture legume *T. repens* was more frequent under both intensively grazed treatments (ICG>IG) at the end of the experiment. The clonal growth of *T. repens* enables it to avoid the defoliation of the majority of the above-ground biomass and to quickly colonize bare ground (Thorhallsdottir 1990). In contrast to *T. repens*, *Taraxacum* spp. became more dominant under both first cut treatments than under grazed only. Postponing cutting to late May or early June allowed *Taraxacum* to reproduce and consequently spread its seeds in both first cut treatments. Higher abundance of *Taraxacum* spp. in ICG and ECG can, therefore, probably be ascribed to higher diaspore production. In this study, both tall dominant forbs (*A. podagraria* and *G. album*) were reduced by grazing and they increased in abandoned grassland.

Conclusion

This study has shown that restoration of grazing management on abandoned mesic grassland altered the plant species composition toward increased proportions of short grasses and prostrate forbs. At the conclusion of the experiment, higher numbers of plant species in all managed treatments in comparison to the unmanaged control indicates the necessity of defoliation management to enable co-existence of many plant species in semi-natural grasslands. Similarly with other experiments studying different grazing intensities (Bullock et al. 2001; Scimone et al. 2004), the effect of defoliation intensity on species richness have been found not to be so straightforward. Potential sward height, a parameter based on plant height according to local flora and cover of present species, is useful to reveal the replacement of tall dominants by short species under defoliation. Simple vegetation traits can predict responses to the different managements. However, they are strongly dependent on the several dominant species, sometimes with miscellaneous responses.

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