CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Czech University of Life Sciences Prague
Faculty of Environmental Sciences

Department of Ecology

THE EFFECT OF DIFFERENT GRAZING INTENSITIES ON SWARD STRUCTURE

(*Vliv různé intenzity pastvy na strukturu travního porostu*)

PhD Thesis

Vendula Ludvíková

Supervisor: doc. Dr. Ing. Vilém Pavlů

Prague 2012

I thereby declare that I wrote the Ph.D. thesis myself using the results of my own work or collaborative work with my colleagues and with help of other publication resources which are properly cited.

Prohlašuji, že jsem vypracovala disertační práci samostatně, s využitím výsledků mé vlastni práce, výsledků spolupráce s mými kolegy a dalších publikovaných zdrojů, které jsou náležitě citovány.

In Prague, 1st October 2012 ………………………………..
Vendula Ludvíková

Acknowledgements

First of all I would like to thank to my supervisor Vilda Pavlů, who guided me very patiently and supported me throughout all my PhD studies, who helped me with writing papers and who gave me many and many of valuable advices.

Special thanks should go also to many of my colleagues from the Department of Ecology (CULS) especially to my colleagues and former colleagues from the office for creating kind and friendly working environment and to my colleagues from the Research Institute of Crop Production Liberec that provided me the important backgroung of the experiment in Oldřichov v Hájích (from care of animals on pasture to data collection and manuscript preparations). I also thank to Milan Guerovich Andaluz for providing the data from the years 2003 and 2004.

I am grateful to my family for their invaluable help and support during my studies and also for their help in field with data collection.

The research was supported by grants awarded by the Ministry of Agriculture of the Czech Republic (Project No. 0002700604), the Ministry of the Environment of the Czech Republic (Project No. VaV SP/2D3/179/07), Czech Science Foundation (Project No 521/08/1131) and the Internal Grant Agency of the Faculty of Environmental Sciences - Czech University of Life Sciences Prague (IGA 200642113126; IGA 200742113131; IGA 201042113146).

Contents

Chapter 1	General Introduction	4
	1.1 Effect of grazing on a sward	4
	1.2 Grazing intensity and species diversity	4
	1.3 Grazing intensity and floristic composition	5
	1.4 Grazing behaviour	6
	1.5 Sward structure and its stability	7
	1.6 Patch grazing	7
	1.7 Plant functional classifications	8
	1.8 Changes in utilization of grasslands	10
	1.9 References	11
	1.10 Objectives of the thesis	11
Chapter 2	Long term defoliation by cattle grazing with and without trampling differently affects soil compaction and plant species composition	18
Chapter 3	Structure of sward-height patches under intensive and extensive grazing management in Central Europe	34
Chapter 4	Plant strategies in relation to different grazing intensities	50
Chapter 5	Effect of different grazing systems on sward structure during the first vegetation season after management introduction	55
Chapter 6	Reindroduction of grazing management after deforestation of formerly abandoned grassland and its effect on early vegetation changes in the Western Carpathians (Slovakia)	60
Chapter 7	Principal Conclusions of the Thesis	77
Chapter 8	Recommendations for Further Research	79
Chapter 9	Souhrn (Summary in Czech)	80
List of publications	....	82

Chapter 1

General Introduction

1.1 EFFECT OF GRAZING ON A SWARD

The grazing of large herbivores is the most common land use of grassland worldwide. Recently the aspects of grazing are the subjects of research and in the field of science deserve respected attention. In contrast to cutting, grazed grasslands are influenced by several factors (Rook et al. 2004). Grazing is not only the removal of leaf material from plants; the effects of defoliation by grazing are complex. As is widely known, the effect of grazing on vegetation can be subdivided into the following categories: the selective defoliation by animals, trampling and nutrient cycling by urine and faeces (Rook et al. 2004). Many and many studies have focused on the effects of grazing defoliation (e.g. Distel et al. 1995; Cingolani et al. 2003; Pavlů et al. 2007); less studies were focused on trampling (e.g Cole 1995; Guthery & Bingham 1996; Kobayashi et al. 1997) and on dung or urine deposition and nutrient availability (e.g. Malo & Suarez 1995; Dai 2000; Kohler et al. 2004; Güsewell et al. 2005; Auerswald et al. 2009) on different types of grasslands. Therefore grazing management usually leads to enhanced structural heterogeneity of the sward canopy. The specific effects of grazing also depend on the type of grazing animals, grazing pressure, the timing and duration of grazing (Ausden 2007), type of habitat and on spatial scale (Olff & Richie 1998).

Despite the fact that trampling and nutrient addition by urine and faeces are inseparable from grazing, very often studied effects of grazing management are interpreted as results of only selective defoliation and manipulation of nutrients availability and trampling effects are frequently underestimated or ignored. As mentioned above only a few studies have underlined the impacts of dung deposition and trampling on vegetation and have shown an indeed impact of these disturbances on plant species pattern. To date majority studies dealing with the effect of cattle trampling have been short-term, and so the results can only show the typical temporary changes that mostly follow after introduction of a new management treatment or they reflect an inter-seasonal dynamic (Kohler et al. 2004), thus we focused our research (described in **Chapter 2**) on how long-term absence/presence of trampling affects the plant species composition.

1.2 GRAZING INTENSITY AND SPECIES DIVERSITY

With changes in socio-economics aspects and inferential changes in landscape management over the whole Europe in recent years (Marriott et al. 2004), a number of studies have focused on how changes in plant species diversity are affected by a change in grassland management. The impact of implementation of grazing management on abandoned grasslands in the Czech Republic was studied by several authors (Krahulec et al. 2001; Matějková et al. 2003; Pavlů et al. 2003, 2006a; Hejcman et al. 2008).

Extremes in the grazing intensity can lead to land degradation and thereby to the loss of species diversity (Watkinson & Ormerod 2001). Most authors confirm that grazing has a positive effect on species richness compared to unmanaged grasslands (e.g. Smith & Rushton 1994; Tasser & Tappeiner 2002; Pykälä et al. 2005), or compared to too little grazing which can lead to the loss of grassland habitat. Together with grazing intensity, Sternberg et al. (2000) showed how timing of grazing affects species diversity. The lowest species diversity was observed under heavy late grazing in contrast to early grazing treatments with a higher number of species. Wang et al. (2001) recorded higher species diversity under intensive but short-term rotational grazing and lower diversity in continuously stocked paddocks. The results of Scimone et al. (2007) showed that purely grazing intensity had generally small effect on plant species composition, but the botanical diversity was more dependent on the interaction of grazing intensity and local site characteristics. A strong grazing effect was observed in nutrient poor soils (Güsewell et al. 2005) or on limestone bedrock (Başnou et al. 2009) where low intensity pressure has distinctively changed floristic composition. But if the grazing is established on nutrient rich and productive (grass-dominated) grasslands, species diversity may decrease also under lenient grazing intensity (Scimone et al. 2007).

1.3 Grazing intensity and floristic composition

Both the analyses of the quantitative aspects of species diversity as well as the analyses of the qualitative aspects of vegetation such as floristic composition present important methods of diagnosing grassland conditions after grazing management (Sasaki et al. 2005). The problem is that the impact of grazing is very heterogeneous and most present knowledge derives from simple model systems such as perennial reygrass-white clover and from the fact that there has been done relatively little research in more complex communities.

Continuous grazing causes the decrease of potential sward height and therefore leads to the replacement of tall dominants by prostrate and stolonate species (Pavlů et al. 2003, 2007). The short sward of overgrazed patches favours species like *Taraxacum* spp., *Trifolium repens*, *Hypochaeris radicata*, *Glechoma hederacea*, *Veronica serpyllifolia*, *Ranunculus repens* etc., because of the availability of light. According to Ter Heerdt et al. (1991) it is an important determinant for the presence of these species in heavily grazed patches. These species are intolerant to shading and would be rapidly suppressed in higher vegetation; on the contrary they are very resistant to intensive grazing and trampling (Grime et al. 1988) and also are very promptly able to colonize non-shaded areas with a short sward height (Hejcman et al. 2005) or bare ground areas (Thórhallsdóttir 1990). Short grass *Agrostis capillaris* is very often promoted by grazing in low productive grasslands (Hellström et al. 2003; Louault et al. 2005; Pavlů et al. 2006b, 2007) and creates the dominant of short and intensely used patches in particular (Jewell et al. 2005). Tall forbs and tall grasses (*Aegopodium podagraria, Galium album, Alopecurus pratensis, Holcus mollis* etc.) occur in patches where grazing is rare or none (e.g.

Correl et al. 2003; Pavlů et al. 2007). These patches are characterised with species with a good light competition. Both Mitchley (1988) and Belsky (1992) described the replacement of tallgrasses by midgrasses or shortgrasses under frequent defoliation. However, taller and rarely grazed patches do not consist of single species, but have nearly the same species composition as the heavily grazed patches (Bakker et al. 1983).

1.4 Grazing behaviour

Grazed grasslands often consist of the mosaic of patches of different vegetation structure, which vary in forage availability and nutritive value (WallisDeVries et al. 1994). Cattle are conceived as grazing generalists. It means that the sward is grazed less selectively due to a large body size because, first, large animals need a large number of biomass for their daily nutrition (Hejcman et al. 2002) and second, due to a relatively large gut capacity (Illius & Gordon 1993).

Herbivores’ feeding decisions are influenced by their effort to maximize their energy balance (Dumont 1997). Their foraging decision is highly sensitive to the spatial distribution of plant components (Griffiths et al. 2003). According to Distel et al. (1995) the selection of what to feed is not based on patch height only, but also on density and herbage mass. For example cattle avoid short dense ryegrass patches when offered a tall and dense alternative, but prefer the short dense patches when the alternative is short and sparse (Distel et al. 1995). Cattle graze without any preference all types of patches at the beginning of the season, because even tall patches are not in mature stage and therefore they are palatable for grazing animals (Dumont et al. 2007). Dumont et al. (1995a, 1995b) discovered that animals preferred vegetative patches and the preference for them linearly increased with sward height. As the sward matures, they graze chiefly on vegetative regrowths and still ignore ungrazed patches, because the green material in vegetative patches is of higher quality than leaves from reproductive patches. Herbage from tall patches often represents a poor-quality, but highly available source from which in periods of food scarcity (summer drought and late autumn) animals could benefit exploiting reproductive swards to satisfy a part of their requirements (Dumont et al. 1995b). The sward height decreases and a rate of vegetative patches increases in the end of grazing season (Dumont et al. 2007) because cattle continue to graze previously grazed areas (Ring et al. 1985; Gibb & Ridout 1988; Dumont et al. 2007) and thus intensify a mosaic structure of a sward (sensu Adler et al. 2001). Heifers under the extensive grazing repeatedly used short patches (Cid & Brizuela 1998). The overgrazing of the same patches could be also conditioned by spatial memory of cattle (in case of steers, Laca 1998; in case of heifers, Bailey et al. 1989). Cattle can remember the location of preferred patches and hark back to them. However, the limit of their spatial memory is still not known (Dumont 1997). In case of maximal grazing pressure in intensive grazing, when animals repeatedly overgraze short vegetation, the selectivity between high patches is given to a presence or non-presence of faeces or thistles (Cid & Brizuela 1998). It can be concluded that the incurred micro-pattern of sward is determined by the presence of isolated clumps of individuals of avoided species in the canopy before grazing starts (Bakker et al. 1983)

1.5 SWARD STRUCTURE AND ITS STABILITY

Because herbivores graze selectively between species and between plant parts within species (Rook & Tallowin 2003), they create a heterogeneous structure of the sward with a mosaic of different heights (Bakker et al. 1983). The total biomass production is generally higher under intensive then under extensive grazing (Pavlů et al. 2006c). For detail study of sward structure the number of grass tillers, stolon growing points of white clover or number of other plants are often used (e.g. Laidlaw et al. 1995; Brock et al. 1996; Pavlů & Velich 2001). It has been concluded that the density of grass tillers increases and their size decreases with increasing intensity of livestock grazing (Laidlaw & Steen 1989; Orr et al. 1990; Matthew et al. 1995). Johnson & Parsons (1985) revealed that grazing intensity had a considerable positive effect on the total number of tillers, but a negative effect on the number of reproductive tillers in ryegrass in a pure grass pasture. Different grazing intensities cause the distinctions in the proportion of sward patchiness. Greater variability in sward height is more evident in the extensive grazing than in the intensive grazing (Pavlů et al. 2006c, 2009). Also Correll et al. (2003) found out that intensively grazed grassland in comparison with extensively grazed grassland is relatively more homogeneous. The amounts of short patches vary not only between different grazing intensities but also in time (Cid & Brizuela 1998; Cid et al. 2008). Patch location is more stable at lower stocking densities (Cid & Brizuela 1998). The tall patches containing reproductive or unpalatable grasses remain relatively stable (Dumont et al. 2010). At high stocking densities the vegetation is less stable or unstable, especially due to the highest dung deposition. Dung pats affect micro-successions at fine scale, where plant communities react rapidly to changes of nutrient availability at seasonal scale (Gillet et al. 2010). Mikola et al. (2009) assume that the spatial variation of soil nutrients (as a result of dung and urine deposition) is one of the key mechanisms through which herbivores can control grasslands. It results from the presented studies that the main difference between the grassland structure of various grazing intensities is in the rate of sward patches with different height and less in the plant composition.

1.6 PATCH GRAZING

Generally, a sward height is designated as an important predictor of species reaction to defoliation intensity (e.g. Diaz et al. 2001; Pavlů et al. 2003; Pykälä 2004, Naujeck et al. 2005). It should be noted that both the floristic composition and the heterogeneity of the vegetation in temperate grasslands are usually in relationship with a grazing intensity together with palatability to animals (Sasaki et al. 2005; Pettit et al. 1995). Short patches are preferred by cattle due to a higher quality of biomass compared to non grazed old patches and during the season the selection for short patches decreases (Dumont et al. 1995b; Correl et al. 2003;

Dumont et al. 2007). Thereby the patchy structure becomes reinforced (Pavlů et al., 2006c) and can remain stable for months (Cid & Brizuela 1998; Rossignol et al. 2011). On the other hand, under the extensive grazing the patches neglected by herbivores predominate as a result of an excess supply of forage over a demand (Pavlů et al. 2006a; Dumont et al. 1995b). These non-grazed patches can increase total species diversity providing at the same time niches for generative reproduction of species less tolerant to grazing (Correll et al. 2003).

It is not only grazing animals that affect vegetation. On the contrary, animal behaviour can also be affected by the vegetation and feedback. The sward structure, sward height and rate of dead material were detected as main factors affecting grazing behaviour of heifers and sheep under different grazing intensity (Dumont 1997; Dumont et al. 2007). For example, a secondary effect of the changes in structure and community brought about by grazing is the feedback on the grazing behaviour of the animals by changing the choices available to them (Rook & Tallowin 2003).

The immediate effect of grazing on heterogeneity of vegetation depends on the interaction between the pre-existing spatial pattern of vegetation and the spatial pattern of grazing in a small scale (Adler et al. 2001) and also in a landscape scale (Kohler et al. 2006). If the spatial heterogeneity of grazing is stronger than the spatial heterogeneity of vegetation, then the spatial heterogeneity of vegetation will increase following the grazing and will form a "patch grazing" (Adler et al. 2001).

The impact of grazing management on floristic composition and spatial pattern has been widely studied over the world in many types of grasslands, but its effect depends on regional variation of majority of habitat characteristics, such as soil fertility, water availability and inferential number of plant species (Olff & Ritchie 1998). However, it seems that the structure of patchiness plays a very important role in vegetation studies especially under experiments concerning different grazing managements because the variation in grazing intensity inside a paddock may be larger than between paddocks (WallisDeVries et al. 1998). Detailed vegetation studies focusing directly on sward-height patches are not common (see Willms et al. 1988; Van Den Bos and Bakker 1990; Sasaki et al. 2005; Dumont et al. 2007; Marion et al. 2010), and studies from Central European temperate species-rich grasslands are even rarer (Sahin Demirbag et al. 2009). To date, there have been only a few studies concerning the relationship between stocking intensity and the height structure of sward patches in detail (Wrage et al. 2012; Dumont et al. 2012). Given the importance of the structure of patchiness as outlined above, we focused our research on patch structure (**Chapter 3)** comparing different classes of sward-height patches under two different contrasting stocking densities. **Chapter 3** deals with the rate of sward-height patches and its floristic composition.

1.7 PLANT FUNCTIONAL CLASSIFICATIONS

Predicting the effects of grazing with changing land use or climate and atmospheric changes on vegetation patterns (Lavorel et al. 1997) lead to the creation of some classification schemes that put together groups of plant species according to their responses to different environmental factors. With an increasing number of studies in different biotic or abiotic conditions, the scientists have tried to find the best concept of plant functional classifications to integrate the research results across the geographical areas (Weiher et al. 1999; Díaz et al. 2001; Adler et al. 2005).

Ellenberg et al. (1992) constructed a system of ecological indicator values involving relation of plants to light, temperature, continentality, moisture, soil reaction and to the nitrogen. This system is applicable only for the central Europe and above all, it is usable for studying long-term changes of plant communities. Other research concepts were based on plant functional types (PFTs) defined as biotic components of ecosystem that perform the same or similar function within the ecosystem (Gitay & Noble 1997). PTFs are composed by easily measured traits, so-called “plant traits”. Many functional traits and set of traits have been studied in dependence on response to different grazing regimes such as a flowering season, specific leaf area (SLA), leaf length, plant height, seed mass, number of growing leaves per shoot, main life forms (shrubs, grasses, forbs, legumes or annuals, biennials, perennials), Raunkiaer classification of life-forms and many others (e.g. Trémont 1994; Kahmen et al. 2002; Pavlů et al. 2003; Louault et al. 2005). For example Coley et al. (1985) and Herms & Matson (1992) mentioned SLA as a very good predictor, which connects the investment of plants to growth versus a defence and reserve deposition. By contrast, Díaz et al. (2001) and Louault et al. (2005) did not find SLA as a suitable plant trait. They came to a conclusion that a good predictor to grazing was plant height and leaf rigidity. Plant height showed a good effect on species’ responses to grazing also in further studies (de Bello et al. 2005; Pavlů et al. 2003).

One of the important functional types of the plant communities’ composition is a “plant strategy” because plant species exposed to similar selection pressure can respond variously in dependence on it. Grime (1974) developed a CSR scheme based on response of plants to disturbances, competition and environmental stress. Westoby (1998) proposed a plant ecology scheme called LHS (light-height-seed) scheme explained as a specific leaf area (SLA), height of the plant’s canopy at maturity and seed mass. The LHS scheme is based on three single plant functional traits that could be measured easily. Comparing it to Grime’s CSR scheme SLA reflects variation in responsiveness to opportunities for rapid growth (comparable with competitiveness and stress tolerance) and height and seed mass reflect separate aspects with disturbance (coping with ruderality). The LHS scheme is based on three single plant functional traits that could be measured easily whereas the CSR scheme is composed by incorporated traits that were allocated experimentally. To interpret the CSR scheme a spreadsheet-based tool was developed, which calculates functional signatures within the context of the C-S-R life strategies (Hunt et al. 2004). Both strategy schemes are widely used to predict the vegetation changes in different conditions of the environment. Moog et al. (2005) in their comparative study of these strategy schemes considered to improve the LHS scheme by including the traits possession of underground stolons and/or a seasonal germination niche into analysis to be applicable on the global scale.

As observed above, the knowledge of plant strategies may be important in analysing the distribution and the population dynamics of species and may be useful in predicting the consequences of changes under different management regimes (Grime et al. 1988). The CSR scheme is still probably the most developed scheme proposed for plants to date (Silwertown & Charlesworth 2001). A pasture is formed by the mosaic of short and tall sward patches. The canopy of different sward patches can be an important indicator of the presence of different life strategies. According to Grime (1977) grazing causes a disturbance that favours mainly R-strategists (ruderals). These species are taking benefit from a gap formation and from trampling. The support of R-strategy caused by grazing was also confirmed by many authors (e.g. Ejarnæs & Bruun 2000; Bullock et al. 2001; Moog et al. 2005), particularly in intensively defoliated patches which are typical for managed pastures. Typical species are annuals or small-growing legumes. C-strategists are characterised by a relatively tall stature with good light competition ability and with a capacity to withdraw resources from the environment at rapid rates. C-strategy occurs in undisturbed productive conditions (Grime et al. 1988) and it is typical for late succession stages. Those species with a predominating C-strategy are possible to be found in ungrazed plots (Hellström et al. 2003). S-strategists are species able to response to chronically low productivity, so their number may increase in the long-term in case of extensive management if the nutrient pool in the soil decreases (Hellström et al. 2003). Cerabolini et al. (2009) in their case study demonstrated that the character of adaptive strategies for dominant species had greater predictive power than species richness. Underlying the importance of the structure of patchiness as outlined in Chapter 1.6, we focused our research on patch structure addressing the rate of each C-S-R strategy in a given sward-height patch categories in **Chapter 4**.

1.8 CHANGES IN UTILIZATION OF GRASSLANDS

In the second half of the twentieth century considerable changes in the utilization of grasslands in Europe occurred as a result of two contrasting processes. Firstly, there was an intensification of grassland utilization, and large areas were reseeded with highly productive grass and grass-clover mixtures and intensively managed by mechanized agriculture. Secondly, many low-production grasslands and those inaccessible to machinery were abandoned (Isselstein et al., 2005).

Papers presented in **Chapter 5** and **Chapter 6** concern with early vegetation after introduction of applied management. Because vegetation changes in grazed grasslands occur due to diverse mechanism of response of individual species to different grazing regimes and season (Bullock et al. 2001), we focused our research (**Chapter 5**) on changes in detail during the whole course of the first vegetation season after different management introduction in a previously intensively grazed pasture. It should be noted that these types of studies evaluated seasonal vegetation changes are rare (e.g. Kohler et al. 2004) because most studies dealing with vegetation changes examines these changes year on year (e.g. Marriott et al. 2002). The abandonment of temperate European grasslands and its resulting vegetation succession leading to afforestation and its effect on vegetation have been widely studied (e.g. Kesting et al., 2009; Pykälä et al., 2005). However, the opposite process of natural and/or man-made deforestation has not been studied in the context of temperate areas in Central Europe and there is little information on its potential impact. Local deforestation in temperate areas can lead to the establishment of species-rich grassland communities (Novák, 2008), which can also support valuable insect communities (Marini et al., 2009). The effects of initial vegetation changes after reintroduction grazing management after deforestation are described in **Chapter 6**.

1.9 References

Adler P.B., Raff A.D. & Lauenroth W.K. (2001): The effect of grazing on the spatial heterogeneity of vegetation. *Oecologia* 128: 465-479.

Adler P.B., Milchunas D.G., Sala O.E., Burke I.C. & Lauenroth W.K. (2005): Plant traits and ecosystem grazing effects: comparison of U.S. Sagebrush steppe & Patagonian steppe. *Ecological Applications* 15: 774–792.

Auerswald K., Mayer F. & Schnyder H. (2009): Coupling of spatial and temporal pattern of cattle excreta patches on a low intensity pasture. *Nutrient Cycling in Agroecosystems* 88: 275-288.

Ausden M. (2007): Habitat Management for Conservation: A Handbook of Techniques. Oxford University Press. NY, pp. 411.

Bailey D.W., Rittenhouse L.R., Hart R.H. & Richards R.W. (1989): Characteristics of spatial memory in cattle. *Applied Animal Behaviour Science* 23: 331-340.

Bakker J.P., de Leeuw W. & van Wieren S.E. (1983): Micro-patterns in grassland vegetation created and sustained by sheep grazing. *Vegetatio* 55: 153-161.

Başnou C., Pino J. & Šmilauer P. (2009): Effect of grazing on grasslands in the Western Romanian Carpathians depends on the bedrock type. *Preslia* 81: 91–104.

de Bello, F., Lepš, J. & Sebastia, M.T. (2005): Predictive value of plant traits to grazing along a climatic gradient in the Mediterranean. *Journal of Applied Ecology* 42: 824-833.

Belsky A.J. (1992): Effects of grazing, competition, disturbance and fire on species composition and diversity in grassland communities. *Journal of Vegetation Science* 3*:* 187-200.

Brock J.L., Hume D.E. & Fletcher R.H. (1996): Seasonal variation in the morphology of perennial ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*) plants and populations in pastures under intensive sheep grazing. *Journal of Agricultural Science* 126: 37-51.

Bullock J.M., Franklin J., Stevenson M.J., Silvertown J., Coulson S.J., Gregory S. & Tofts R. (2001): A plant trait analysis of responses to grazing in a long-term experiment. *Journal of Applied Ecology* 38: 253-267.

Cerabolini B., Pierce S., Luzzaro A. & Ossola A. (2009): Species evenness affects ecosystem processes in situ via diversity in the adaptive strategies of dominant species. *Plant Ecology* 207: 333-345.

Cid M.S. & Brizuela M.A. (1998): Heterogeneity in tall fescue pastures created and sustained by cattle grazing. *Journal of Range Management* 51: 644-649.

Cid M.S. Ferri C.M., Brizuela M.A. & Sala O. (2008): Structural heterogeneity and productivity of tall fescue pasture grazed rotationally by cattle at four stocking densities. *Grassland Science* 54: 9-16.

Cingolani A.M., Cabido M.R., Renison D. & Solís Neffa V. (2003): Combined effects of environment and grazing on vegetation structure in Argentine granite grasslands. *Journal of Vegetation Science* 14: 223-232.

Cole D.N. (1995): Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology* 32: 203-214.

Coley P.H., Bryant J.P. & Chapin S.F. (1985): Resource availability and plant antiherbivore defense. *Science* 230: 895-899.

Correll O., Isselstein J. & Pavlů V. (2003): Studying spatial and temporal dynamics of sward structure at low stocking densities: the use of an extended rising-plate-meter method. *Grass & Forage Science* 58: 450-454.

Dai X. (2000): Impact of cattle dung deposition on the distribution pattern of plant species in an alvar limestone grassland. *Journal of Vegetation Science* 11: 715-724.

Diaz S., Noy-Meir I. & Cabido M. (2001): Can grazing of herbaceous plants be predicted from simple vegetative traits? *Journal of Applied Ecology* 38: 497-508.

Distel R.A., Laca E.A., Griggs T.C. & Demment M.W. (1995): Patch selection by cattle: maximalization of intake rate in horizontally heterogeneous pastures. *Applied Animal Behaviour Science* 45: 11-21.

Dumont B., Petit M. & D'hour P. (1995a): Choice of sheep and cattle between vegetative and reproductive cocksfoot patches. *Applied Animal Behaviour Science* 43: 1-15.

Dumont B., D'hour P. & Petit M. (1995b): The usefulness of grazing test for studying the ability of sheep and cattle to exploit reproductive patches of pasture. *Applied Animal Behaviour Science* 45: 79-88.

Dumont B. (1997): Diet preferences of herbivores at pasture. *Ann Zootech* 46: 105-116.

Dumont B., Garel J.P., Ginane C., Decuq F., Farruggia A., Pradel P., Rigolot C. & Petit M. (2007): Effect of cattle grazing a species-rich mountain pasture under different stocking rates on the dynamics of diet selection and sward structure. *Animal* 1: 1042-1052.

Dumont B., Carrére P., Rossignol N., Chadoeuf J, Faruggia A., Ginane C. & Louault F. (2010): Selective grazing, patch stability and vegetation dynamics in a rotationally-grazed pasture. *Grassland Science in Europe* 15: 937-939.

Dumont B., Rossignol N., Loucougaray G., Carrère P., Chadoeuf J., Fleurance G., Bonis A., Farruggia A., Gaucherand S., Ginane C., Louault F., Marion B., Mesléard F. & Yavercovski N. (2012): When does grazing generate stable vegetation patterns in temperate pastures? *Agriculture, Ecosystems & Environment*. 153: 50–56.

Ejrnæs R. & Bruun H.H. (2000): Gradient analysis of dry grassland vegetation in Denmark. *Journal of Vegetation Science* 11: 573-584.

Ellenberg H., Weber H.E., Düll R., Wirth V. & Werner W. (1992): Zeigerwerte von Pflanzen in Mitteleuropa. 3nd edition Scr. Geobotanica. Göttingen, pp. 262.

Gibb M.J. & Ridout M.S. (1988): Application of double normal frequency distributions fitted to measurements of sward height. *Grass and Forage Science* 43: 131-136.

Gillet F., Kohler F., Vandenberghe Ch. & Buttler A. (2010): Effect of dung deposition on small-scale patch structure and seasonal vegetation dynamics in mountain pastures. *Agriculture, Ecosystems & Environment* 135: 34-41.

Gitay H. & Noble I.R. (1997): What are functional types and how should we seek them? In: Smith T.M., Shugart H.H. & Woodward F.L. (eds.): Plant Functional Types: their relevance to ecosystem properties and global change. Cambridge University Press. UK, pp. 3-19.

Griffiths W.M., Hodgson J. & Arnold G. C. (2003): The influence of sward canopy structure on foraging decision by grazing cattle. I. Patch selection. *Grass and Forage Science* 58: 112-124.

Grime J.P. (1974): Vegetation classification by reference to strategies. *Nature* 250: 26-31.

Grime J.P. (1977): Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist* 111: 1169-1194.

Grime J.P., Hodfson J.G. & Hunt R. (1988): Comparative plant ecology: a functional approach to common British species, Unwin Hyman Ltd, London, UK, pp. 742.

Güsewell S., Jewell P.L. & Edwards P.J. (2005): Effects of heterogenous habitat use by cattle on nutrient availability and litter decomposition in soils of an Alpine pasture. *Plant and Soil* 268: 135-149.

Guthery F.S. & Bingham R.L. (1996): A theoretical basis for study and management of trampling by cattle. *Journal of Range Management* 49: 264-269.

Hejcman M., Pavlů V. & Krahulec F. (2002): Pastva hospodářských zvířat a její využití v ochranářské praxi. *Zprávy České botanické společnosti, Praha* 37: 203-216.

Hejcman M., Auf D., Gaisler J. (2005): Year-round cattle grazing as an alternative management of hay meadows in the Giant mts. (Krkonoše), the Czech Republic, *Ekológia Bratislava* 24: 419-429.

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

Hellström K., Huhta A.-P., Rautio P., Tuomi J, Oksanen J. & Laine K. (2003): Use of sheep grazing in the restoration of semi-natural meadows in northern Finland. *Applied Vegetation Science* 6: 45-52.

Herms D.A. & Matson W.J. (1992): The dilemma of plants: To grow or defend. *The Quarlerly Review of Biology* 67: 283-335.

Hunt R., Hodgson J.G., Thompson K., Bungener P., Dunnett N.P. & Askew A.P. (2004): A new practical tool for deriving a functional signature for herbaceous vegetation. *Applied Vegetation Science* 7: 163-170.

Illius A.W. & Gordon I.J. (1993): Diet selection in mammalian herbivores: constraints and tactics. In: Hughes R.N. (ed.): Diet Selection: An Interdisciplinary Approach to Foraging Behaviour. Blackwell Scientific, Oxford UK, pp. 223.

Isselstein J., Jeangros B. & Pavlů V. (2005): Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe – A review. *Agronomy Research* **3:** 139–151.

Jewell P.L., Güsewell S., Berry N.R., Käuferle D., Kreuzer M. & Edwards P.J. (2005): Vegetation patterns maintained by cattle grazing on a degraded mountain pasture. *Botanica Helvetica* 115: 109-124.

Johnson I.R. & Parsons J. (1985): Use of a model to analyse the effects of continuous grazing managements on seasonal patterns of grass production. *Grass and Forage Science* 40: 449-458.

Kahmen S., Poschold P. & Schreiber K.F. (2002): Conservation management of calcareous grasslands. Changes in plant species composition and response of functional traits during 25 years. *Biological Conservation* 104: 319-328.

Kesting S., Wrage N. & Isselstein J. (2009): Herbage mass and nutritive value of herbage of extensively managed temperate grasslands along a gradient of shrub encroachment. *Grass and Forage Science* 64: 246–254.

Kobayashi T., Hori Y. & Nomoto N. (1997): Effects of trampling and vegetation removal on species diversity and micro-environment under different shade conditions. *Journal of Vegetation Science* 8: 873-880.

Kohler F., Gillet, F., Gobat, J-M. & Buttler A. (2004): Seasonal vegetation changes in mountain pastures due to simulated effects of cattle grazing. *Journal of Vegetation Science* 15/2:143-150.

Kohler F., Gillet F., Reust S., Wagner H.H., Gadallah F., Gobat J-M. & Buttler A. (2006): Spatial and seasonal pattern of cattle habitat use in a mountain wooded pasture. *Landscape Ecology* 21: 281-295.

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

Laca E.A. (1998): Spatial memory and food searching mechanisms of cattle. *Journal of Range Management* 51: 370-378.

Laidlaw A.S. & Steen R.W.J. (1989): Turnover of grass laminae and white clover leaves in mixed swards continuously grazed with steers at a high- and low-N fertilizer level. *Grass and Forage Science* 44: 249-258.

Laidlaw A.S., Withers J.A. & Toal L.G. (1995): The effect of surface height of swards continuously stocked with cattle on herbage production and clover content over four years. *Grass and Forage Science* 50: 48-54.

Lavorel S., McIntyre S., Landsberg J. & Forbes T.D.A. (1997): Plant functional classifications: from general groups to specific groups based on response to disturbance. *Trends in Ecology and Evolution* 12: 474-478.

Louault F., Pillar V.D., Aufrère J., Garnier E. & Soussana J.-F. (2005): Plant traits and functional types in response to reduced disturbance in a semi-natural grassland. *Journal of Vegetation Science* 16: 151-160.

Malo J.E. & Suárez F. (1995): Establishment of pasture species on the cattle dung: the role of endozoochorous seeds. *Journal of Vegetation Science* 6: 169-174.

Marion B., Bonis A. & Bouzillé, J.-B. (2010): How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? *Écoscience* 17: 229-239.

Marini L., Paolo F., Battisti A. & Gaston K.J. (2009): Response of orthopteran diversity to abandonment of semi-natural meadows. *Agriculture, Ecosystems and Environment* 132: 232–236.

Marriott C.A., Carol A., Bolton G.R., Barthram G.T., Fisher J.M. & Hood K. (2002): Early changes in species composition of upland sown grassland under extensive grazing management. *Applied Vegetation Science* 5: 87-98.

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

Matějková I., van Diggelen R. & Prach K. (2003): An attempt to restore a central European species-rich mountain grassland through grazing. *Applied Vegetation Science* 6: 161-168.

Matthew C., Lemaire G., Sackville Hamilton N.R. & Hernandez-Garray A. (1995): A modified self-thinning equation to describe size/density relationships for defoliated swards. *Annals of Botany* 76: 579-587.

Mikola J., Setälä H., Virkajärvi P., Saarijärvi K, Ilmarinen K., Voigt W. & Vestberg M. (2009): Defoliation and patchy nutrient return drive grazing effects on plant and soil properties in a dairy cow pasture. *Ecological Monographs* 79: 221-244.

Mitchley J. (1988): Control of relative abundance of perennials in chalk grassland in southern England. II. Vertical canopy structure. *Journal of Ecology* 76: 341-350.

Moog D., Kahmen S. & Poschlod P. (2005): Application of CSR- and LHS-strategies for the distincion of differently managed grasslands. *Basic and Applied Ecology* 6: 133-143.

Naujeck A., Hill J. & Gibb M.J. (2005): Influence of sward height on diet selection by horses. *Applied Animal Behaviour Science* 90: 49-63.

Novák J. (2008): *Pasienky, lúky a trávniky* (Pastures, meadows and lawns). Patria I. spol. s r.o., Prievidza, SK. (in Slovak).

Olff H. & Ritchie M.E. (1998): Effects of herbivores on grassland plant diversity. *Trends in Ecology and Evolution* 13: 261-265.

Orr R.J., Parsons A.J., Penning P.D. & Treacher T.T. (1990): Sward composition, animal performance and the potential production of grass/white clover swards continuously stocked with sheep. *Grass and Forage Science* 45: 325-336.

Pavlů V. & Velich J. (2001): The effect of rotational and continuous grazing on sward. *Rostlinná Výroba* 47: 154-159.

Pavlů V., Hejcman M., Pavlů L. & Gaisler J. (2003): Effect of rotational and continuous grazing on vegetation of an upland grassland in the Jizerské hory Mts., Czech Republic. *Folia Geobotanica* 38: 21-34.

Pavlů V., Hejcman M., Pavlů L., Gaisler J., Hejcmanová-Nežerková P. & Meneses L. (2006a): Changes in plant densities in a mesic species-rich grassland after imposing different grazing management treatments. *Grass and Forage Science* 61: 42-51.

Pavlů V., Gaisler J., Hejcman M. & Pavlů L. (2006b): Effect of different grazing system on dynamics of grassland weedy species. *Journal of Plant Diseases and Protection* 20: 377-383.

Pavlů V., Hejcman M, Pavlů L., Gaisler J. & Nežerková P. (2006c): Effect of continuous grazing on forage quality, quantity and animal performance. *Agriculture, Ecosystems and Environment* 113: 349-355.

Pavlů V., Hejcman M., Pavlů L. & Gaisler J. (2007): Restoration of grazing management and its effect on vegetation in an upland grassland. *Applied Vegetation Science* 10: 375-382.

Pavlů V., Hejcman M. & Mikulka J. (2009): Cover estimation *versus* density counting in species-rich pasture under different grazing intensities. *Environmental Monitoring and Assessment* 156: 419-424.

Pettit, N.E., Froend R.H. & Ladd P.G. (1995): Grazing in remnant woodland vegetation changes in species composition and life form groups. *Journal of Vegetation Science* 6: 121-130.

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

Pykälä J., Luoto M., Heikkinen R.K. & Kontula T. (2005): Plant species richness and persistence of rare plants in abandoned semi-natural grasslands in northen Europe. *Basic and Applied Ecology* 6: 25-33.

Ring C.B., Nicholson R.A., Lauchbaugh J.L. (1985): Vegetational traits of patch-grazed rangeland in west-central Kansas. *Journal of Range Management* 38: 51-55.

Rook A.J. & Tallowin J.R.B. (2003): Grazing and pasture management for biodiversity benefit. *Animal Restoration* 52: 181-189.

Rook A.J., Dumont B., Isselstein J., Osoro K., WallisDeVries M.F., Parente G. & Mills J. (2004): Matching type of livestock to desired biodiversity outcomes in pastures –a review. *Biological Conservation* 119: 137-150.

Rossignol N., Chadoeuf J., Carrère P., & Dumont B. (2011): A hierarchical model for analysing the stability of vegetation patterns created by grazing in temperate pastures. *Applied Vegetation Science* 14: 189-199.

Sahin Demirbag N., Röver K.-U., Wrage N., Hofmann M. & Isselstein J. (2009): Herbage growth rates on heterogeneous swards as influenced by sward-height classes. *Grass and Forage Science* 64: 12-18.

Sasaki T., Okayasu T., Takeuchi K., Jamsran U. & Jadambaa S. (2005): Patterns of floristic composition under different grazing intensities in Bulgan, South Gobi, Mongolia. *Grassland Scienc*e 51: 235-242.

Scimone M., Rook A.J., Garel J.P. & Sahin N. (2007): Effects of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. *Grass and Forage Science* 62: 172-184.

Silwertown J.W. & Charlesworth D. (2001): Introduction to Plant Population Biology. 4th Edition. Blackwell Science Ltd, Oxford, UK, pp. 346.

Smith R.S. & Rushton S.P. (1994): The effects of grazing management on the vegetation of mesotrophic (meadow) grassland in Northen England. *Journal of Applied Ecology* 31: 13-24.

Sternberg M., Gutman M., Perevolotsky A., Ungar E.D. & Kigel J. (2000): Vegetation response to grazing management in a Mediterranean herbaceous community: a functional group approach. *Journal of Applied Ecology* 37: 224-237.

Tasser E. & Tappeiner U. (2002): Impact of land use changes on mountain vegetation. *Applied Vegetation Science* 5: 173-184.

Ter Heerdt G.N.J., Bakker J.P. & De Leeuw J. (1991): Seasonal and spatial variation in living and dead plant material in a grazed grassland as related to plant species diversity. *Journal of Applied Ecology* 28: 120-127.

Thórhallsdóttir T.E. (1990): The dynamics of a grassland community: a simultaneous investigation of spatial and temporal heterogeneity at various scales. *Journal of Ecology* 78: 884-908.

Trémont R.M. (1994): Life-History Attributes of Plants in Grazed and Ungrazed Grasslands on the Northern Tablelands of New South Wales. *Australian Journal of Botany* 42: 511-530.

Van Den Bos J. & Bakker J.P. (1990): The development of vegetation patterns by cattle grazing at low stocking density in the Netherlands. Biological Conservation 51: 263-272.

WallisDeVries M.F & Daleboudt C. (1994): Foraging strategy of cattle in patchy grassland. *Oecologia* 100: 98-106.

WallisDeVries M.F., Bakker J.P. & Van Wieren S.E. (1998): Grazing and Conservation Management. Kluwer Academic Publishers. The Netherlands, pp. 373.

Wang S.P., Wang, Y.F., Chen Z.Z. & Schnug E. (2001): The influence of different grazing systems on plant diversity of an *Artemisia frigida* community in the Inner Mongolia steppe, China. *Grassland Science in Europe.* 6: 123-125.

Warren S.D., Thurow T.L., Blackburn W.H. & Garza N.E. (1986): The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *Journal of Range Management* 39: 491-495.

Watkinson A.R. & Ormerod S.J. (2001): Grasslands, grazing and biodiversity: editors' introduction. *Journal of Applied Ecology* 38: 233-237.

Weiher E., van der Werf A., Thompson K., Roderick M., Garnier E. & Eriksson O. (1999): Challenging Theophastrus: A common core list of plant traits for functional ecology. *Journal of Vegetation Science* 10: 609-620.

Westoby M. (1998): A leaf-height-seed (LHS) plant ecology strategy schneme*. Plant and Soil* 199: *213-227.*

Whalley R.D.B. & Hardy M.B. (2000): Measuring botanical composition of grasslands. – In: 't Mannetje, L. & Jones, R.M. (eds.), Field and laboratory methods for grassland and animal production research. CABI Publ., Wallingford. UK, pp. 67-102.

Willms W.D., Dormaar J.F. & Schaalje G.B. (1988): Stability of grazed patches on rough fescue grasslands. *Journal of Range Management* 41: 503-508.

Wrage N., Sahin Demirbag N., Hofmann M. & Isselstein, J. (2012): Vegetation height of patch more important for phytodiversity than that of paddock. *Agriculture, Ecosystems and Environment* 155: 111–116.

1.10 OBJECTIVES OF THE THESIS

The summarizing aims of the thesis are to answer the following questions:

i) How does the a long-term absence of trampling affect vegetation height, plant species richness, abundance of main functional groups and plant species composition?

ii) Can the long-term effects of no trampling be detected by differences in soil compaction?

iii) What is the effect of different intensity of cattle grazing on the proportion of the patches?

iv) How are simple vegetation traits and plant species composition affected by sward different patches?

v) What is the effect of different intensities of cattle grazing on primary plant strategies?

vi) What is the effect of different grazing management on sward structure in an upland grassland, during the first vegetation season after management introduction?

vii) What are the effects of initial vegetation changes after the reintroduction of grazing management following deforestation?

Chapter 2

Long term defoliation by cattle grazing with and without trampling differently affects soil compaction and plant species composition in temperate grassland

Vendula Ludvíková, Vilém Pavlů, Jan Gaisler, Michal Hejcman, Lenka Pavlů

Submitted to: *Plos One* (August 2012)

Created patch of bare ground after trampling by cattle hooves [Photo: V. Ludvíková].

Long term defoliation by cattle grazing with and without trampling differently affects soil compaction and plant species composition in temperate grassland

Vendula Ludvíková[1], Vilém Pavlů[12*], Jan Gaisler[2], Michal Hejcman[1], Lenka Pavlů[2]

[1]Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, CZ-16521, Prague, Czech Republic;

[2]Department of Plant Ecology and Weed Science, Grassland Research Station, Research Institute of Crop Production Prague, Rolnická 6, CZ-46011, Liberec, Czech Republic

*Corresponding author: E-mail address: pavlu@vurv.cz (V. Pavlů), Tel.: +420 48 480 0562

Abstract

There are no long-term experimental studies dealing with soil compaction and plant community responses to trampling. Here we report the results for soil compaction and plant species changes in mesotrophic temperate Central European grassland after 12-years of grazing management with and without trampling. Five grazing treatments (intensive and extensive grazing; cut for hay in June followed by intensive or extensive grazing, and intensive grazing with no trampling under permanent electric fencing) with two replicate blocks have been applied since 1998. In 2010 species richness, the cover of vascular plant species and bryophytes, sward height and soil penetration resistance were recorded in five distantly triplet plots. For statistical analyses we used one way ANOVA and RDA with the Monte Carlo test. Long term grazing by large herbivores had a significant effect on soil compaction. The lowest soil compaction was recorded in the 'not trampled' treatment. Legumes, particularly *Trifolium repens,* and short forbs (especially *Veronica serpyllifolia*) were supported by intensively defoliated and trampled treatments, whereas tall forbs (mainly *Aegopodium podagraria, Hypericum maculatum*) prevailed under the extensive ones. The cover of tall and short graminoids was not dependent on applied treatments. The 'not trampled' treatment had the highest prevalence of bryophytes (with more than 95% domination of *Rhitidiadelphus squarosus*) and was also the richest in a number of vascular plant species, on the other hand had the least Shannon's species equitability index. Long-term defoliation by grazing animals without trampling does not lead to the creation of a typical pasture community. Species forming pasture communities are essentially dependent on both types of disturbances i) regular defoliation by grazing and ii) regular trampling by hooves, which causes a high degree of soil compaction as well as sward disruption.

1. Introduction

The sward under grazing management is mainly affected by i) defoliation; ii) manipulation of nutrient availability by removal of biomass or by deposition by urine and faeces, and iii) trampling [1]. Studied effects of grazing management are often interpreted as results of only defoliation and manipulation of nutrient availability, and trampling effects are frequently underestimated or ignored. Only a few studies have underlined the impacts of dung deposition [2] and trampling [3], [4] on vegetation, and these have shown a marked impact of these disturbances on plant species pattern.

Trampling by large herbivores usually causes soil compaction [5], [6], [7], which afterwards increases moisture runoff, water erosion and thus evaporation. Animals also directly cause variation in sward through disturbances by hooves. They create patches of bare ground which subsequently leads to germination gaps [8] where the higher temperatures at the disturbed soil surface are a very important factor limiting species establishment [9].

Generally, herbage growth declines with increasing trampling intensity. According to [10] this is caused mainly by a decrease in tiller density, although higher grass tiller density was found under intensive than extensive grazing by [11]. Pasture cover and the impact of trampling damage is higher on wet soils and also in the summer, when many tillers are developing flowers [12]. Trampling generally promotes species with rosettes, prostrate, rhizomatous (e.g. [13]) or tussock growth-forms [9] and thus reduces vegetation height (e.g. [14], [15]) and a herbage yield [16]. Conversely, the absence of trampling supports a well-developed litter layer [17].

To date, the majority of studies dealing with the effect of cattle trampling have been short-term, and so the results can only show the typical temporary changes that mostly follow after introduction of a new management treatment, or they reflect an inter-seasonal dynamic [4]. No data exist on how long-term absence/presence of trampling affects the plant species composition.

The effects of the fence-lines of pastures have previously attracted attention (e.g. [18], [19]). For example the effect of fencing on plant diversity and community composition plots were studied in South Africa [20]. However, there is an absence of studies in temperate grasslands on plant species composition directly under permanent electric fences where animals are not allowed to create disturbance with their hooves. According to our long term visual observations the vegetation under fences was conspicuously different in plant species richness and structure from other grazed plots, but it has not previously been recorded. Therefore we performed a comparative study inside the long-term Oldřichov Grazing Experiment (OGE) [21], in which trampling and the presence of faeces deposition of young cattle under electric fence lines had been completely absent throughout the 12years since the OGE was established. There were additional treatments where defoliation and trampling were applied to areas with different long term grazing intensities.

Through the following questions we analysed how the absence of cattle trampling affects vegetation in species-rich temperate grassland with a 12-year history of grazing: i) how does the absence of trampling affect vegetation height, plant species richness, abundance of main functional groups and plant species composition ii) can the long term effects of no trampling be detected by differences in soil compaction?

2. Material and methods

2.1 *Study site*

The study was performed in the long-term Oldřichov Grazing Experiment (OGE) in 2010. The OGE is situated in the Jizera Mountains, 10 km north of the city of Liberec, in the northern part of the Czech Republic (lat. 50° 50′ N, long. 15° 06′ E) in Oldřichov v Hájích village. The study site is on a northwest slope with inclination 5°; the bedrock is biotic granite overlain by Cambisol with pH KCl 5.45 and organic C content 4.53 % in the upper 10 cm soil layer. Soil concentrations of plant available P, K, Ca and Mg analysed by the Mehlich III extraction procedure [22] are 28 mg P kg^{-1} (sufficient availability), 67 mg K kg^{-1} (low availability), 1728 mg Ca kg^{-1} and 58 mg Mg kg^{-1} (low availability) respectively. Full plant rooting is apparent until 14 cm in the Ah horizon (0 to 24 cm). The Bv horizon (24 to 45 cm) contains 50-60 % of the soil weathered skeleton of up to 22 cm. The average annual precipitation is 803 mm and the mean annual temperature is 7.2°C (meteorological station in Liberec). The altitude of the study site is 420 m a. s. l. Prior to the introduction of experimental treatments the grassland was classified as upland hay mesophile meadow (alliance *Arrhenatherion*) [23]. Lately, the alliance *Cynosurion cristati* is developing under long term grazing management.

2.2 *Experimental design*

The trampling experiment was established and conducted in 2010 after twelve years of different management under OGE. . The experimental site was established in 1998 on formerly abandoned grassland [21]. Since then the experimental pasture was continuously stocked every year with young heifers from May to October. The spatial arrangement of the experiment was a set of 0.33 m x 1 m study plots (Fig. 1). The experiment was arranged in two completely randomized blocks. Each experimental paddock was approximately 0.35 ha. Under the permanent electric fencing in the border line between neighbouring paddocks intensive defoliation by grazing with no trampling (GNT) and no faeces deposition has been applied since 1998. The electric fences were fixed by two horizontal wires 50 cm and 100 cm above ground level which allowed animals to graze beneath the line but not to tread or defecate there (see Appendix A.1).

The following five treatments were applied: i) extensive grazing (EG) - stocking rate adjusted to achieve a mean target sward surface height more than 10 cm; ii) cutting in June and extensive grazing aftermath (ECG); iii) intensive grazing (IG) – stocking rate adjusted to achieve a mean target sward surface height less than 5 cm; iv) cutting in June and intensive grazing aftermath (ICG). The forage harvest in ECG and ICG treatments was done by three machines: cutting at 5 cm, haymaker and pick-up hay-loader. The excessive biomass under permanent electric fencing between all treatments was cut to 3 cm by a brush cutter and then removed by raking in June. The mean stocking rates were at about 500 kg liveweight (two heifers) per 1 ha and 1000 kg liveweight (four heifers) per 1 ha for EG (ECG) and IG (ICG) treatments, respectively. The sward surface heights were measured weekly across each experimental plot (100 measurements) using a rising plate meter [24], and stocking density was adjusted accordingly by increasing or decreasing the area available for grazing by moving fences with a set number of stock per plot.

2.3 *Soil compaction measurements*

Soil compaction measurement was performed by certificated penetrometer reading according the standard No. EN ISO 22476-2:2005. The penetrometer was used to measure soil penetration resistance (MPa) among studied treatments. Over all study paddocks and under the electric fencing there were randomly selected five sites where six measurements within each selected area were performed. This resulted in 300 measurements in total (five treatments x two blocks x five areas x six measurements).The absolute soil moisture (%) was measured at 30-cm depth using an electronic humidity meter GMH 3850 simultaneously with soil penetration resistance measurements in all sites. Mean absolute soil moisture was 16.7 % during these measurements. To exclude short-term deviations occurring after heavy rains we carried out all measurements of soil characteristics after 14 days without any rain.

2.4 *Sward measurements*

Prior to grazing in May three relevés were collected in these study plots using a grid of 0.33 m x 0.33 m subplots in five distant triplet plots along the permanent fence, and then protected against grazing (Fig. 1). The distance between plots within the triplet was 1.66 m, with a gap of 3 m between the next two triplets. This distance of 1.66 m from the permanent fences was chosen to avoid the effects of excessive trampling by heifers, because the animals prefer to walk up and down fences lines. The sward height of each subplot was measured after finishing all relevés collection at the beginning of June. The method of “compressed sward height” (CSH) by rising plate meter was used [25], [24]. All vascular plant species present within the study were categorized according to their main traits based on mean height descriptions in the regional flora [26]. The functional groups were: tall graminoids (> 50 cm), short graminoids (< 50 cm), tall forbs (> 50 cm), short forbs (< 50 cm), legumes and bryophytes (Table 1). To show the effect of the absence of trampling on the species richness of the community, the mean number of species and the Shannon and equitability indices were calculated for each treatment. The species richness of vascular plant species was assessed by number of plant species, Shannon’s (H) species diversity index and Shannon’s (J) species equitability index [27]. The mean of three subplots was used for statistical evaluation of sward measurement data.

2.5 *Data analysis*

One-way ANOVA followed by *post-hoc* Tukey comparison was performed to identify significant differences in the variability of sward heights, species richness, Shannon and equitability indices, cover of vascular plant species and bryophytes. Statistica 7.0 was used to perform ANOVA statistical procedures (Statsoft, Tulsa, AZ, USA). To reveal the effects of grazing intensity and trampling on plant species composition a redundancy analysis (RDA) followed by Monte Carlo permutation test in the CANOCO program [28] was used. Each analysis was performed with 999 permutations. Species data were log-transformed ($y'=\log_{10}(y+1)$). The blocks were treated as covariables. Ordination diagrams constructed in CanoDraw program [28] were used to visualize the results of the analyses.

3. Results

3.1 *Soil compaction*

Soil compaction expressed as penetration resistance showed significant differences among investigated treatments (Fig. 2). The subsurface layer of the soil under trampled treatments had significantly higher penetration resistance up to c. 30 cm in comparison with the GNT treatment. The highest soil compaction was apparent at a depth of 24 cm (2.25, 2.08, 2.10 and 2.2 MPa) in all trampled treatments (IG, ICG, EG and ECG respectively) and at a depth of 32 cm (1.79 MPa) in the GNT treatment.

3.2 *Sward height*

Measurements of the actual mean sward heights, tested by one-way ANOVA, showed significant differences between the treatments. The shortest sward height was recorded in the treatment with the absence of trampling (GNT), then in IG treatment, whereas the highest sward was recorded in the ECG treatment (Fig. 3).

3.3 *Species richness of vascular plants*

Significant differences in the number of vascular plant species were detected between treatments. In the GNT treatment, there was a significantly higher number of species compared to the trampled treatments (Fig. 4). The Shannon diversity H and equitability J indices (in brackets) for plant species richness were 1.77 (0.66), 1.76 (0.74), 1.84 (0.75), 1.77 (0.76) and 1.91 (0.74) for GNT, IG, ICG, EG and ECG treatments, respectively. The differences among the treatments were not significant for H (F = 1.60, P = 0.177) but were significant for J (F = 14.05, P < 0.001).

3.4 *Plant functional groups*

A significant effect of treatment on the cover of short graminoids, tall graminoids, short forbs, tall forbs, legumes and bryophytes was found (see Table 2, analysis A1 for details). Graminoids (regardless of height classification) profited from the presence of cattle trampling (Fig. 5a) whereas bryophytes became dominant with the GNT treatment. Legumes were supported by intensively defoliated and trampled treatments (IG, ICG), whereas tall forbs responded in the opposite way. Short forbs responded negatively to both extensive treatments (EG, ECG).

3.5 *Plant species composition*

The percentage cover of vascular plant species and of bryophytes in the treatments is shown in Fig. 6. The lowest coverage of vascular plant species and significantly highest cover of bryophytes occurred in the GNT treatment, where more than 95% of bryophytes were represented by *Rhitidiadelphus squarrosus* (see Appendix A.2). In the other grazed treatments the cover of *Rhitidiadelphus squarrosus* was less than 25% from all presented bryophytes species. The RDA showed significant differences in the plant species composition among treatments (see Table 2, analysis A2 for details). Species became associated into three groups according defoliation by grazing and trampling intensities: extensive grazing and trampling (EG, ECG), intensive grazing and trampling (IG, ICG) and intensive defoliation by grazing and no trampling (GNT) (Fig. 5b). The diagram also identifies species dependent on trampling but independent of grazing intensity. Those species were *Agrostis capillaris* under intensive treatments (IG, ICG), and *Elytrigia repens* under extensive treatments (EG, ECG). The species that benefited from the absence of trampling (GNT treatment) were bryophytes and *Ranunculus repens*, *Rumex acetosa*, *Lychnis flos-cuculi*, *Luzula campestris*, *Galium uliginosum*, *Cirsium palustre*, *Heracleum sphondylium* and *Poa pratensis*. In the IG and ICG treatments the species with the highest abundance was *Trifolium repens*. Other species which were supported by the intensive grazing treatments were *Cerastium holosteoides*, *Veronica serpyllifolia*, *Veronica arvensis*, *Taraxacum* spp., *Poa annua* and *Plantago major*. In the EG and ECG treatments the species with the highest abundance were *Aegopodium podagraria*, *Hypericum maculatum*, *Dactylis glomerata*, *Vicia sepium*, *Anthoxantum odoratum* and *Alopecurus pratensis*. A large amount of dead above-ground biomass was accumulated in these two treatments.

4. Discussion

Although the lowest soil penetration resistance was recorded in the GNT treatment, a significant difference was also found between extensive (EG, ECG) and intensive (IG, ICG) treatments. Lower soil compaction was observed under the EG and ECG treatments, especially in upper soil layers. This is in accordance with the study by [29], where the penetration resistance was higher under higher stocking rates even in a short term experiment.

The no trampled treatment significantly diverged from others not only in soil compaction but also in all other studied characteristics: species richness of vascular plants, plant species composition, cover of bryophytes and in sward height. Bryophytes were found to be a major component of the vegetation in the GNT treatment. They were observed to (especially *Rhitidiadelphus squarrosus*) form “a carpet” with sparse density of vascular plants. In accordance with previous studies [30]-[33] there was a negative correlation between the abundance of bryophytes and vascular plants in grasslands. Although bryophytes are considered to be poor competitors with vascular plants [34], they can prevent seed germination or seedling survival [35]. In particular, if there is an absence of any bare-ground disturbance, which would create germination gaps and low nutrient availability, then bryophytes can prevail over vascular plants. However, during grazing in the GNT treatment cattle could pull up bryophytes with their mouths together with vascular plants. Usually they spit these out and tufts of bryophytes are visible on pasture surfaces especially in autumn (Vilém Pavlů, personal observation). This factor probably causes small disturbances, which can lead to the formation of germination gaps. The prevalence of bryophytes in the ‘not trampled' treatment resulted in the lowest compressed sward height in this treatment. Previous studies [9], found that trampling itself significantly suppresses vegetation height but the trampling in their study was not separated from grazing. Therefore their results are consistent only with our IG treatment, where vegetation was defoliated by grazing and trampled.

The GNT treatment was found to be richest in the number of vascular plant species, but on the other hand it was also the least equitable one. As stated above, bryophytes prevailed there and were accompanied by lower cover of vascular plant species. The lowest rate of bryophytes with regard to the abundance of vascular plants was under all grazed treatments where vegetation was defoliated and trampled. However there was tendency towards lower bryophyte cover under the ECG and ICG treatments, where the biomass of vascular plants was removed by regular harvests at the end of spring. As the bryophytes achieve their highest growth and abundance from autumn to spring [34] the absence of vegetation removal appeared to limit light availability, similarly as reported by [36].

There were no species closely connected with the GNT treatment which did not occur in the other treatments. The occurrence of other vascular plant species seems to be random and the community response might be dependent on the presence of the surrounding species pool. Species with the highest abundance in the GNT treatment were semi-rosettes whose distribution is centred on plant communities in which competition is limited by moderate impacts of disturbance, and which are mostly absent from heavily disturbed habitats [37]. Species like *Luzula campestris* or *Lychis flos-cuculi* belonging to these plots are species which are usually present on meadows rather than in pastures, and are better adapted to vegetation removal than to other type of disturbances. *T. repens* (the dominant legume species) had the highest cover, especially in the IG and ICG. From previous studies performed in comparable climatic and soil conditions it can be concluded that *T. repens* is restricted to intensively grazed swards with good light conditions [38], [39], [24], [40], [41]. From our study it appears that not only an intensive defoliation, which ensures suitable light conditions, is important for the prevalence of *T. repens*, but also the disturbances associated with trampling. [4] or [9] also acknowledge that the abundance of legumes (especially *T. repens*) was related to trampling. Furthermore, short graminoids (including dominant *A. capillaris*) were negatively correlated with the GNT treatment. In general *A. capillaris* is described as a species promoted by regular defoliation in low-production temperate grasslands [42], [43], [21], [44]. However the present study demonstrates that only the interaction of defoliation with trampling promotes the abundance of such species. This means that not only defoliation by itself, but also disturbance associated with trampling is one of the key factors responsible for supporting typical pasture species as *T. repens* and *A. capillaris.*

5. Conclusions

In conclusion, long-term defoliation by grazing animals without trampling does not lead to the creation of typical pasture communities. In our study we demonstrated that the species present in pasture swards do not profit only from regular defoliation resulting in good light conditions for remain species. They also need bare-ground disturbances and sward compaction which favour them in strong intraspecific competition with other plant species. Species forming pasture communities are essentially dependent on both types of disturbances i) regular defoliation by grazing and ii) regular trampling by hooves.

6. Acknowledgements

This study was supported by the Ministry of Agriculture of the Czech Republic (Project No. 0002700604), the Ministry of the Environment of the Czech Republic (Project No. VaV SP/2D3/179/07) and Czech Science Foundation (Project No 521/08/1131). We have to thank to Dr. Jan Mládek for idea imprinting to do this experiment. We are grateful to Dr. Patrik Prikner for his help with soil compaction measurements and to František Paška for his help with a fieldwork. We are also very indebted to Rosemary Collins and Alan Hopkins for his useful comments and for a language revision.

Appendix - Supporting Information

A.1. Photographs fence line

A.2. Photographs of a GNT treatment with bryophytes dominance

7. References

1. WallisDeVries MF (1998) Large herbivores as key factors for nature conservation. In: WallisDeVries MF, Bakker JP, Van Wieren SE, editors. Grazing and Conservation Management. Dordrecht: Kluwer Academic Publishers. pp. 1–20.
2. Dai X (2000) Impact of cattle dung deposition on the distribution pattern of plant species in an alvar limestone grassland. J Veg Sci 11: 715–724.
3. Curll ML, Wilkins RJ (1983) The comparative effects of defoliation, treading and excreta on a *Lolium perenne-Trifolium repens* pasture grazed by sheep. J Agric Sci 100: 451–460.
4. Kohler F, Gillet F, Gobat J-M, Buttler A (2004) Seasonal vegetation changes in mountain pastures due to simulated effects of cattle grazing. J Veg Sci 15: 143–150.
5. Witschi PA, Michalk DL (1979) The effect of sheep treading and grazing on pasture and soil characteristics of irrigated annual pastures. Aust J Agr Res 30: 741–750.
6. Taboada MA, Lavado RS (1993) Influence of cattle trampling on soil porosity under alternate dry and ponded conditions. Soil Use Manage 9: 139–143.
7. Betteridge K, Mackay AD, Shepherd TG, Barker DJ, Budding PJ, et al. (1999) Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. Aust J Soil Res 37: 743–760.
8. Ausden M (2007) Habitat management for conservation, a handbook of techniques. New York: Oxford University Press. 411 p.
9. Kobayashi T, Hori Y, Nomoto N (1997) Effects of trampling and vegetation removal on species diversity and micro-environment under different shade conditions. J Veg Sci 8: 873–880.
10. Pande TN, Yamamoto H (2006) Cattle treading effects on plant growth and soil stability in the mountain grassland of Japan. Land Degrad Dev 17: 419–428.

11. Pavlů V, Hejcman M, Pavlů L, Gaisler J, Hejcmanová-Nežerková P, et al. (2006) Changes in plant densities in a mesic species-rich grassland after imposing different grazing management treatments. Grass Forage Sci 61: 42–51.
12. Edmond DB (1963) Effects of treading perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures in winter and summer at two soil moisture levels. N Z J Agr Res 6: 265–376.
13. Posse G, Anchorena J, Collantes MB (2000) Spatial micro-patterns in the steppe of Tierra del Fuego induced by sheep grazing. J Veg Sci 11: 43–50.
14. Bakker JP, de Leeuw W, van Wieren SE (1983) Micro-patterns in grassland vegetation created and sustained by sheep grazing. Vegetatio 55: 153–161.
15. Cole DN, Bayfield NG (1993) Recreational trampling of vegetation: Standard experimental procedures. Biol Conserv 63: 209–215.
16. Edmond DB (1964) Some effects of sheep treading on the growth of 10 pasture species. N Z J Agr Res 7: 1–16.
17. Kauffman JB, Krueger WC, Vavra M (1983) Effects of late season cattle grazing on riparian plant communities. J Range Manage 36: 685–691.
18. Tanner CB, Mamaril CP (1959) Pasture soil compaction by animal traffic. Agron J 51: 329–331.
19. Cingolani AM, Cabido MR, Rension D, Solís NV (2003) Combined effects of environment and grazing on vegetation structure in Argentine granite grasslands. J Veg Sci 14: 223–232.
20. Todd SW, Hoffman MT (1999) A fence-line contrast reveals effects of heavy grazing on plant diversity and community composition in Namaqualand, South Africa. Plant Ecol 142: 169–178.
21. Pavlů V, Hejcman M, Pavlů L, Gaisler J (2007) Restoration of grazing management and its effect on vegetation in an upland grassland. Appl Veg Sci 10: 375–382.
22. Mehlich A (1984) Mehlich No. 3 soil test extractant, a modification of Mehlich No. 2. Commun Soil Sci Plant Anal 15: 1409–1416.
23. Chytrý M, editor (2007) Vegetace České republiky. 1. Travinná a keříčková vegetace (Vegetation of the Czech Republic. 1 Grassland and Heathland Vegetation). Prague: Academia. 528 p.
24. Correll O, Isselstein J, Pavlů V (2003) Studying spatial and temporal dynamics of sward structure at low stocking densities, the use of an extended rising-plate-meter method. Grass Forage Sci 58: 450–454.
25. Castle ME (1976) A simple disc instrument for estimating herbage yield. J Br Grassland Soc 31: 37–40.
26. Kubát K, Hrouda L, Chrtek J jun, Kaplan Z, Kirschner J, et al., editors (2002) Klíč ke květeně České republiky (Key to the flora of the Czech Republic). Prague: Academia. 927 p.
27. Begon M, Townsend CR, Harper JL (2006) Ecology: from individuals to ecosystems. - 4th ed. Oxford: Blackwell Publishing Ltd. 738 p.
28. ter Braak CJF, Šmilauer P (2002) CANOCO Reference Manual and CanoDraw for Windows User's Guide, Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, New York.
29. Novák J (2009) Trávne porasty po odlesnení a samozalesnení (Grasslands after deforestration and self-reforestration). Brno: Tribun EU. 166 p.
30. Common TG, Hunter EA, Floate MJS, Eadie J, Hodgson J (1991) The long-term effects of a range pasture treatments applied to three semi-natural hill grassland communities. 1. Pasture production and botanical composition. Grass Forage Sci 46: 239–251.
31. Virtanen R, Johnston AE, Crawley MJ, Edwards GR (2000) Bryophyte biomass and species richness on the Park Grass Experiment, Rothamsted, UK. Plant Ecol 151: 129–141.
32. Bergamini A, Pauli D, Peintinger M, Schmid B (2001) Relationships between productivity, number of shoots and number of species in

bryophytes and vascular plants. J Ecol 89: 920–929.

33. Hejcman M, Száková J, Schellberg J, Šrek P, Tlustoš P, et al. (2010) The Rengen Grassland experiment: bryophytes biomass and element concentrations after 65 years of fertilizer application. Environ Monit Assess 166: 653–662.
34. van Tooren BF, den Hertog J, Verhaar J (1988) Cover, biomass and nutrient content of bryophytes in Dutch chalk grasslands. Lindbergia 14: 47–54.
35. Kotorová I, Lepš J (1999) Comparative ecology of seedling recruitment in an oligotrophic wet meadow. J Veg Sci 10: 175–186.
36. Al-Mufti MM, Sydes CL, Furness SB, Grime JP, Band SR (1977) A quantitative analysis of shoot phenology and dominance in herbaceous vegetation. J Ecol 65: 759–791.
37. Grime JP, Hodgson JG, Hunt R (1988) Comparative plant ecology, a functional approach to common British species. London: Unwin Hyman Ltd. 752 p.
38. Ter Heerdt GNJ, Bakker JP, De Leeuw J (1991) Seasonal and spatial variation in living and dead plant material in a grazed grassland as related to plant species diversity. J Appl Ecol 28: 120–127.
39. Adler PB, Raff AD, Lauenroth WK (2001) The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128: 465–479.
40. Hejcman M, Schellberg J, Pavlů V (2010) Long-term effects of cutting frequency and liming on soil chemical properties, biomass production and plant species composition of *Lolio-Cynosuretum* grassland after the cessation of fertilizer application. Appl Veg Sci 13: 257-269.
41. Pavlů V, Schellberg J, Hejcman M (2011) Cutting frequency vs. N application: effect of a 20-year management in *Lolio-Cynosuretum* grassland. Grass Forage Sci 66: 501–515.
42. Hellström K, Huhta A-P, Rautio P, Tuomi J, Oksanen J, et al. (2003) Use of sheep grazing in the restoration of semi-natural meadows in northern Finland. Appl Veg Sci 6: 45–52.
43. Louault F, Pillar VD, Aufrère J, Garnier E, Soussana J-F (2005) Plant traits and functional types in response to reduced disturbance in a semi-natural grassland. J Veg Sci 16: 151–160.
44. Mašková Z, Doležal J, Květ J, Zemek F (2009) Long-term functioning of a species-rich mountain meadow under different management regimes. Agric Ecosyst Environ 132: 192–202.

Table 1. Functional groups of the study sward.

Short graminoids	Tall graminoids	Short forbs	Tall forbs	Legumes
Agrostis capillaris	*Alopecurus pratensis*	*Alchemilla* sp.	*Aegopodium podagraria*	*Lathyrus pratensis*
Anthoxantum odoratum	*Dactylis glomerata*	*Campanula patula*	*Achillea millefolium*	*Lotus uliginosus*
Luzula campestris	*Deschampsia caespitosa*	*Cardamine pratensis*	*Cirsium palustre*	*Trifolium pratense*
Poa annua	*Elytrigia repens*	*Cerastium holosteoides*	*Galium album*	*Trifolium repens*
	Festuca pratensis	*Galium uliginosum*	*Heracleum sphondylium*	*Vicia cracca*
	Festuca rubra agg.	*Glechoma hederacea*	*Hypericum maculatum*	*Vicia sepium*
	Holcus lanatus	*Leontodon autumnalis*	*Ranunculus acris*	
	Holcus mollis	*Lychnis flos-cuculi*	*Rumex acetosa*	
	Poa pratensis	*Plantago lanceolata*	*Rumex obtusifolius*	
	Poa trivialis	*Plantago major*	*Urtica dioica*	
	Trisetum flavescens	*Ranunculus repens*		
		Stellaria graminea		
		Stellaria media		
		Taraxacum spp.		
		Veronica arvensis		
		Veronica chamaedrys		
		Veronica serphyllifolia		

Table 2. Results of the RDA analyses. % expl. = explained by axis 1 (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.

Analysis	Expl. var.	Covariables	% expl.	*F*-ratio	*P*-value
A1: Different management regimes have no effect on the abundance of plant functional groups composition.	Management regime	blocks	53.3 (70.3)	61.7 (31.9)	0.001 (0.001)
A2: Different management regimes have no effect on plant species composition.	Management regime	blocks	24.9 (48.4)	18.9 (12.7)	0.001 (0.001)

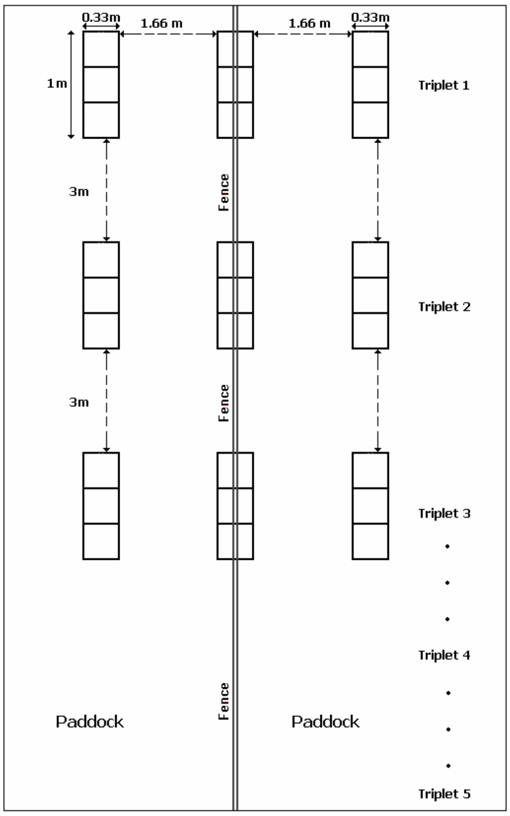

Figure 1. Spatial arrangement of study plots.

Main plots (0.33 m x 1.00 m) were divided into three 0.33 m x 0.33 m subplots for monitoring. There were three study plots (one triplet) in one row. In total there were five triplets within each of four experimental paddocks (4 paddocks x 5 triplets x 3 study plots x 3 subplots=180 subplots in total).

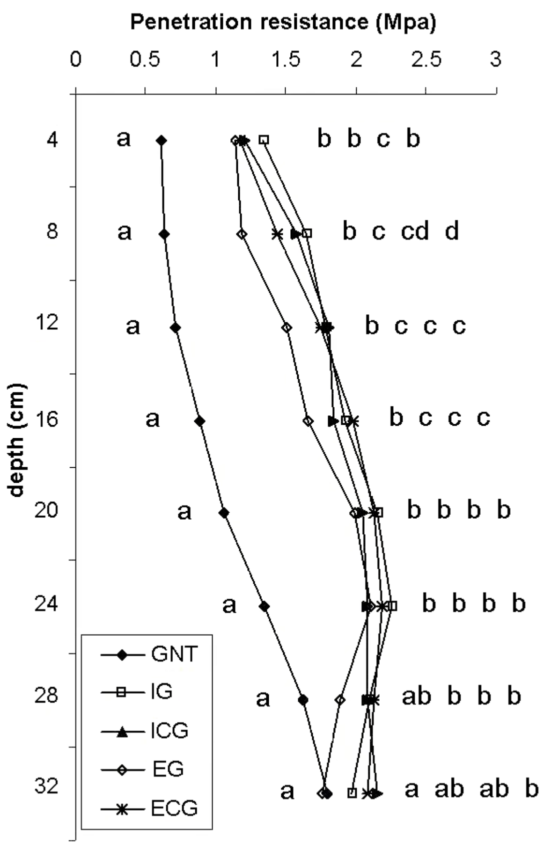

Figure 2. Soil penetration resistance measurements.

The results of soil penetration resistance (MPa) measurements among treatments from depths of 4 to 32 cm. Significant differences (P < 0.05) according to the Tukey's post hoc test are indicated by different letters in the soil layers.

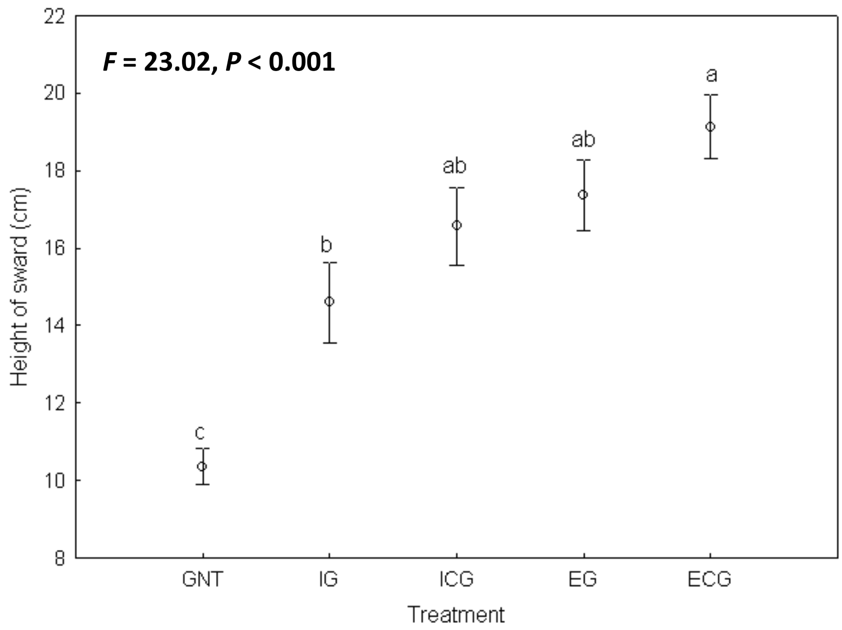

Figure 3. The mean sward height (circle) in each treatment.

F is a value derived from *F* statistics in one-way ANOVA, and *P* is the probability value. Significant differences ($P < 0.05$) according to Tukey's post hoc test are indicated by different letters. Error bars represent standard errors of the mean.

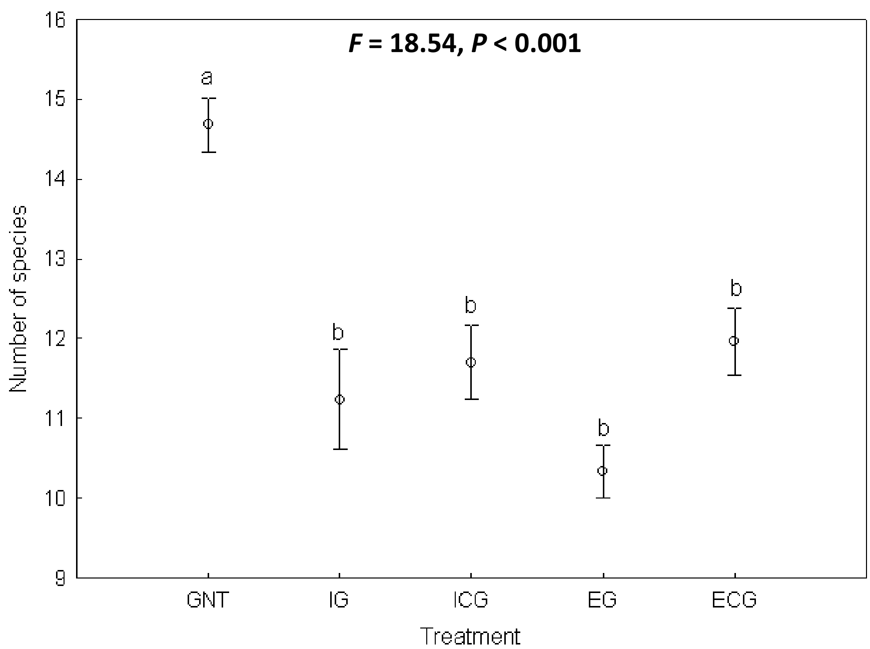

Figure 4. The mean number of vascular plant species (circle) in each treatment.

F is a value derived from *F* statistics in one-way ANOVA, and *P* is the probability value. Significant differences ($P < 0.05$) according to Tukey's post hoc test are indicated by different letters. Error bars represent standard errors of the mean.

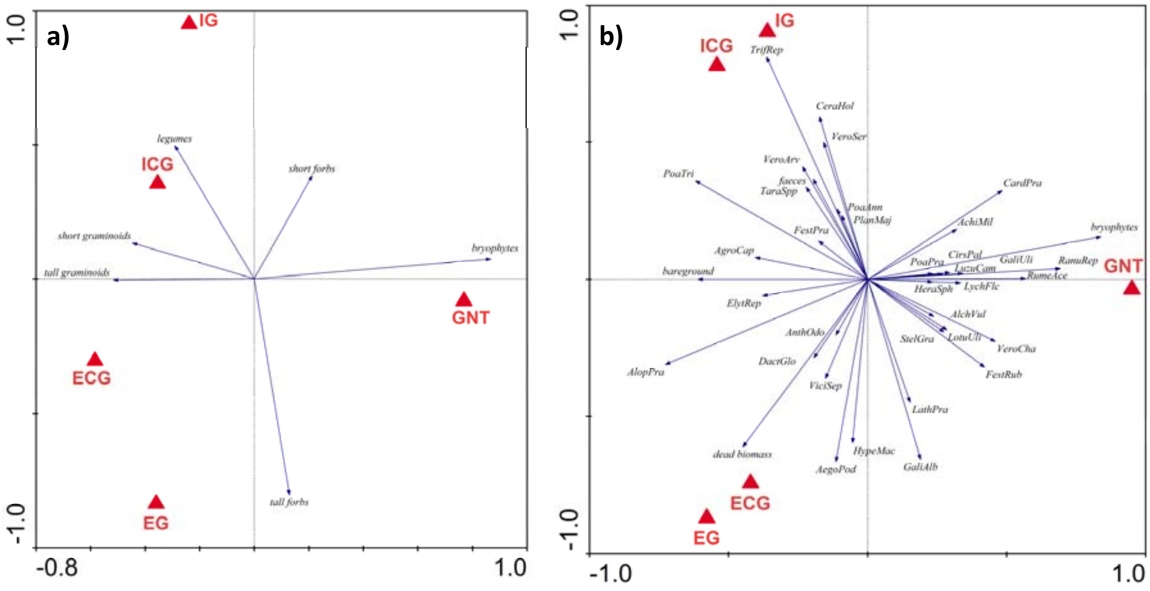

Figure 5. Ordination diagrams showing the results of redundancy analyses of plant species composition data.

Abbreviations: GNT = defoliation by grazing with no trampling; EG = extensive grazing; ECG = extensive grazing and cutting; IG = intensive grazing; ICG = intensive grazing and cutting; ; AchilMil = *Achillea millefolium;* AegoPod = *Aegopodium podagraria*; AgroCap = *Agrostis capillaris*; AlchVul = *Alchemilla vulgaris* agg.; AlopPra = *Alopecurus pratensis*; AnthOdo = *Anthoxantum odoratum*; CardPra = *Cardamine pratensis*; CeraHol = *Cerastium holosteioides;* CirsPal = *Cirsium palustre;* DactGlo = *Dactylis glomerata*; FestPra = *Festuca pratensis*; FestRub = *Festuca rubra*; GaliAlb = *Galium album*; HeraSph = *Heracleum sphondyllium*; HypeMac = *Hypericum maculatum*; LathPra = *Lathyrus pratensis*; LotuUli = *Lotus uliginosus;* LuzuCam = *Luzula campestris*; LychFlc = *Lychnis flos-cuculi*; PlanMaj = *Plantago major*; PoaAnn = *Poa annua*; PoaPra = *Poa pratensis*; PoaTri = *Poa trivialis*; RanuRep = *Ranunculus repens;* RumeAce = *Rumex acetosa;* StelGra = *Stellaria graminea*; TaraSpp = *Taraxacum* spp.; TrifRep =*Trifolium repens*; VeroArv = *Veronica arvensis*; VeroCha = *Veronica chamaedrys*; VeroSer = *Veronica serpyllifolia*; ViciSep = *Vicia sepium*.

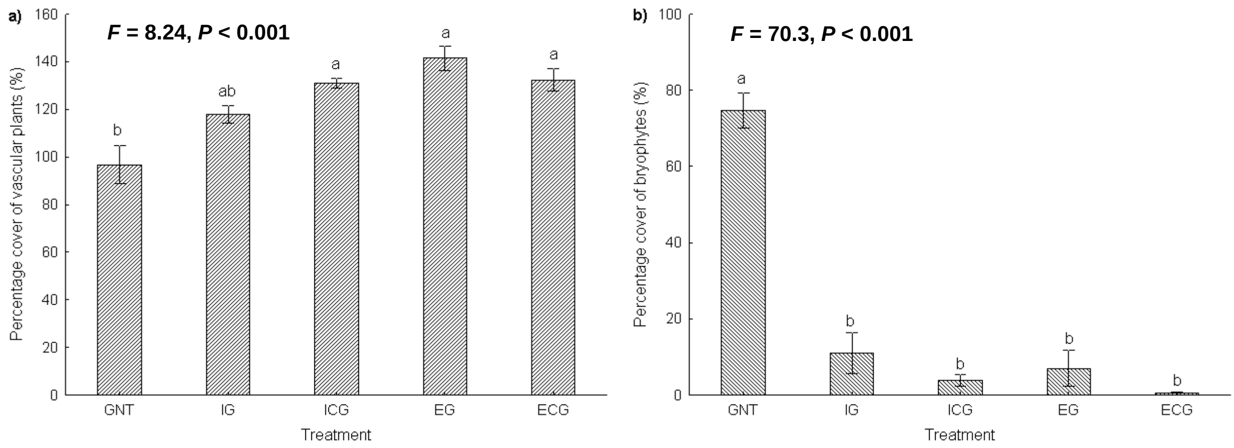

Figure 6. The mean percentage cover of vascular plant species (a) and of bryophytes (b).

F is a value derived from *F* statistics in one-way ANOVA, and *P* is the probability value. Significant differences ($P < 0.05$) according to Tukey's post hoc test are indicated by different letters. Error bars represent standard errors of the mean.

Appendix A.1. Photographs fence line.

Appendix A.2. Photographs of a GNT treatment with bryophytes dominance after 12 years of defoliation by grazing without trampling.

Chapter 3

Structure of sward-height patches under intensive and extensive grazing management in Central Europe

Vendula Ludvíková, Vilém Pavlů, Lenka Pavlů, Jan Gaisler, Michal Hejcman

Submitted to: *Journal of Environmental Management* (August 2012)

Patchy structrure of sward under intensive grazing in the Jizerské Mts. [Photo: V. Ludvíková].

Structure of sward-height patches under intensive and extensive grazing management in Central Europe

Vendula Ludvíková[a], Vilém Pavlů[a,b]*, Lenka Pavlů[b], Jan Gaisler[b], Michal Hejcman[a,b]

[a]Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, CZ-165 21, Prague, Czech Republic, [b]Department of Plant Ecology and Weed Science, Grassland Research Station, Research Institute of Crop Production Prague, Rolnická 6, CZ-460 11, Liberec, Czech Republic

*Corresponding author: E-mail address: pavlu@vurv.cz (V. Pavlů), Tel.: +420 48 480 0562

Abstract

Patchiness is one of the important features of grazed temperate grasslands, but little is known of the structure of sward height patches under different grazing intensities. The present study examined the effect of continuous intensive and extensive stocking of heifers on the proportions of sward-height patch categories (short <5cm, moderate 5.5-10 cm, tall >10.5 cm) and their plant species composition. A four-year study was performed on species-rich grassland maintained under a long-term grazing experiment in the Jizera Mountains (Jizerské hory), Czech Republic. The main difference between intensive and extensive grazing management of species-rich grassland was seen in the proportions of short and tall sward-height patches, while the proportion of moderate-height patches was similar under both stocking densities. Floristic composition of patches within the same sward height depended upon stocking density. Moderate and tall patches under a given stocking density had similar botanical composition. Vegetation within short patches differed considerably from that of other patches under extensive grazing, whereas under intensive grazing the differences between short, moderate and tall sward-height patches were small. The findings show grazing intensity is a key driver of the proportion as well as the floristic composition of sward-height patches.

Keywords: heifers grazing, floristic composition, pasture, patch category, RDA, vegetation

1. Introduction

Grazing by large herbivores is the most common use of grassland worldwide. In contrast to cutting, grazed grasslands are influenced by several factors including trampling, *in situ* nutrient addition by urine and faeces, seed dispersal, and selective defoliation by animals (Rook et al., 2004). Therefore, grazing management usually leads to enhanced structural heterogeneity of the sward canopy and the specific effects of grazing depend on the type of grazing animal, grazing pressure, and the timing and duration of stocking (Ausden, 2007). Because herbivores may graze selectively on species and on plant parts within species (Rook and Tallowin, 2003), they create a heterogeneous sward structure with a mosaic of different heights (Bakker et al., 1984). Generally, sward height is recognized as an important predictor of plants response to defoliation intensity (e.g. Diaz et al., 2001; Pavlů et al., 2003; Pykälä, 2004; Naujeck et al., 2005).

Floristic composition and heterogeneity of the vegetation in temperate grasslands are usually related to grazing intensity together with animals' preferences (Pettit et al., 1995; Sasaki et al., 2005) and result in a patchy structure of swards. Shorter patches are preferentially grazed by cattle due to their higher quality of biomass in comparison with patches of taller herbage that are either ungrazed or rarely grazed, and the selection for short patches increases through the course of the grazing season (Dumont et al., 1995; Correl et al., 2003; Dumont et al., 2007; Rossignol et al., 2011). The patchy structure thereby becomes reinforced (Pavlů et al., 2006c) and can remain stable for months (Cid and Brizuela, 1998; Rossignol et al., 2011). Under extensive grazing management, the patches neglected by herbivores predominate as the available forage supply is higher than herbivores' demand (Dumont et al., 1995; Pavlů et al., 2006a). These non-grazed patches can increase total species diversity while at the same time providing niches for generative reproduction of species less tolerant to grazing (Correll et al., 2003).

The immediate effect of grazing on the heterogeneity of vegetation depends on the interaction between the pre-existing spatial pattern of vegetation and the spatial pattern of grazing, not only at the paddock scale (Adler et al., 2001) but also at the landscape scale (Kohler et al., 2006). If the spatial heterogeneity of grazing is stronger than the spatial heterogeneity of vegetation, then the spatial heterogeneity of vegetation will increase following grazing and stable patches will thus be formed (Adler et al., 2001). Thus, variations in grazing intensity within a paddock may be greater than that among paddocks (WallisDeVries et al., 1998). However there are generally few references to the structure of patchiness, even though it is one of the most important indicators of pasture conditions (Bakker et al., 1984), and one which distinguishes pastures from meadows. Detailed vegetation studies focusing directly on sward-height patches are not common (see Willms et al., 1988; Van Den Bos and Bakker, 1990; Sasaki et al., 2005; Dumont et al., 2007; Marion et al., 2010), and studies from Central European temperate species-rich grasslands are even rarer (Sahin Demirbag et al., 2009). To date, there have been only a few studies concerning the relationship between stocking intensity and the height structure of sward patches in detail (Wrage et al., 2012; Dumont et al. 2012). Given the importance of the structure of patchiness as outline above, we developed two conceptual theories for predicting effects of increasing stocking density: (1) If grazing is rather spatially homogeneous then, on average, all the sward will experience higher grazing intensity (higher biomass uptake) and will show higher relative cover of short patches and on the other hand lower cover of taller patches; (2) If grazing is spatially heterogeneous (patch grazing *sensu* Adler et al., 2001), relative cover of short patches will increase during the vegetation season but tall ungrazed patches will keep the same height. So if grazing is spatially heterogeneous, stocking density is expected to affect mainly relative cover of different classes of sward height patches without changing the average characteristics of the patches. We hypothesized that a given sward-height patch category is grazed at the same intensity regardless of stocking density and therefore will display the same floristic composition between stocking density treatments. To examine these hypotheses, fixed transects were established in long-term experimental pasture to allow detailed study of sward-height patch heterogeneity.

Against this background, the aim of the study was to answer the following two questions: What is the effect of two contrasting grazing densities on the structure of different sward-height patch categories? How is the plant species composition of a particular sward-height patch category affected by two contrasting grazing densities?

2. Material and methods

2.1 Study site

The study site was on an experimental grassland in the Jizera Mountains, 10 km north from the city of Liberec in the northern part of the Czech Republic (lat 50° 50.34‘ N, long. 15° 05.36‘ E; 420 m a.s.l.) at the village Oldřichov v Hájích. It is situated on an exposed north-westerly slope. The bedrock is formed of locally widespread biotic granite and overlain by a typical brown shallow soil (cambisol) with a pH (KCl) of 5.45 and an organic C content of 4.53%. As analysed according to the Mehlich III method (Mehlich, 1984), the contents of plant available P, K, Ca and Mg per 1 kg of soil were 28 mg, 67 mg, 1728 mg, and 58 mg, respectively. Average total annual precipitation is 803 mm, and the mean annual temperature is 7.2°C (data from the meteorological station at Liberec). The grassland was classified as upland hay mesophile meadow (alliance *Arrhenatherion*) (Chytrý, 2007). The dominant species of the swards were: *Agrostis capillaris*, *Festuca rubra* agg., *Trifolium repens* and *Taraxacum* spp.

2.2 Experimental design

The experimental site was located on the long-term Oldřichov Grazing Experiment (OGE), established on formerly abandoned grassland in 1998 (Pavlů et al., 2007). Since 1998, the experimental pasture has been continuously stocked with young heifers each year from May to October. Two contrasting stocking densities were applied: i) extensive grazing management (EG), where the stocking rate was adjusted to achieve a mean target sward surface height of greater than 10 cm; and ii) intensive grazing management (IG), in which the stocking rate was adjusted to achieve a mean target sward surface height of less than 5 cm. The mean stocking rates were approximately 500 kg liveweight (two heifers) per 1 ha and 1000 kg liveweight (four heifers) per 1 ha for EG and IG, respectively. The compressed sward heights were measured weekly across each experimental plot (100 measurements) using a rising plate meter (Correll et al., 2003), and stocking density was adjusted accordingly by increasing or decreasing the area available for grazing by moving fences with a set number of stock per plot (Pavlů et al. 2007). The experiment was arranged in two completely randomized blocks. Each experimental plot was approximately 0.35 ha. To study sward-height patches, two permanent transects lines of 42 m per plot for both stocking densities (EG and IG) were established in 2003 in areas that were available for grazing all the grazing season.

2.3 Measurements

Measurements were performed at 40 fixed sampling points at 1 m intervals along the line transect. The percentage cover for all vascular species, bare ground, and faeces was estimated up to 100% within circles of diameter 30 cm. Plant species nomenclature follows Kubát et al. (2002). Because of identification problems related to grazing, *Poa* spp. was defined to include *Poa pratensis*, *P. annua* and *P. trivialis*. Compressed sward height was measured in the same circles in which the cover was recorded. According to the sward height we arbitrarily assigned patch height categories, because we would like to avoid potential biases. The following patch categories were identified: a) short patches (SH), height from 0 to 5 cm; b) moderate patches (MO), height from 5.5 to 10 cm; c) tall patches (TA), height > 10.5 cm. This arbitrary approach is based on experience with sward response to grazing and is commonly used in temperate grasslands (Bakker et al., 1984; Scimone et al., 2007; Sahin Demirbag et al., 2009; Rossignol et al., 2011). The data from transects were collected in 2003, 2004, 2006 and 2007 two times in each year during both the summer (S) and autumn (A) grazing seasons. There were 2560 botanical records in total (2 stocking densities x 2 blocks x 2 transects x 40 points per transect x 2 times per year x 4 years). The variability of sward-height patch proportions was assessed by the Shannon (*H*) and evenness (*J*) indices (Begon et al., 2006). Low *H* and *J* values indicate a predominance of one sward-height patch category and high *H* and *J* values indicate an even distribution of all three patch categories (Hmax ~ 1.099).

2.4 Data analysis

The proportions of sward-height patches and four dominant plant species presented in all three sward height patches under both stocking densities were analysed by repeated measures ANOVA. One-way ANOVA was performed to identify significant differences in the variability of sward-height patch proportions as expressed by the Shannon and evenness indices. To examine whether stocking density or belonging to particular sward-height patch categories is the key driver for plant species composition a redundancy analysis (RDA) in the CANOCO program (ter Braak and Šmilauer, 2002) was used and followed by a Monte Carlo permutation test. Each analysis was performed with 999 permutations. We log-transformed the species data ($y'=\log_{10}(y+1)$. The blocks were treated as covariables. Ordination diagrams constructed in CanoDraw (ter Braak and Šmilauer, 2002) were used to visualize the results of the analyses.

3. Results

3.1 Proportion of patches

A significant interaction was found between time and patch category for the relative proportion of sward-height categories, thus indicating non-parallel development of at least one category of sward-height patches ($F = 6.4$; $P < 0.001$). The relative proportions of the specific sward-height patch categories differed between IG and EG (Table. 1). Except in autumn 2003 the seasonal proportion of MO sward-height patches ranged from 35% to 50% under both stocking densities, and differed by the proportion of SH and TA sward-height patches. The Shannon diversity and evenness indices for proportions of sward-height patch categories were 0.82 (0.74) and 0.86 (0.78) for IG and EG, respectively, and differences between the two stocking densities were not significant ($P = 0.657$). The relatively high H and J values show that all three patch categories occurred in the paddocks under both stocking densities but were not distributed in equal amounts.

3.2 Plant species composition

Based on RDA analyse the interaction of stocking density and patch category explained the largest proportion of vegetation data in comparison with solely the patch category or stocking density (Table 2). Stocking density affected the plant species composition (Fig. 1a; Table 2, analysis A1) more than did patch categories (Fig. 1b; Table 2, analysis A2), however in both cases the explanatory power was relative small. A similar plant species composition was found between taller patch categories (MO and TA) under IG as well as between taller patch categories under EG. Under IG, the SH patch category did not substantially differ in botanical composition from MO and TA, but it did under EG. The botanical composition of MO and as well as TA patch categories differed considerably between both stocking densities (Fig. 1c; Table 2, analysis A3). Mosses frequently occurred in SH patch categories under both stocking densities. Tall forbs (e.g. *Rumex acetosa, Ranunculus acris, Urtica dioica, Galium album, Hypericum maculatum*, *Lathyrus pratensis, Vicia sepium, Vicia cracca, Lotus uliginosus*) as well as tall graminoids (e.g. *Alopecurus pratensis, Dactylis glomerata, Holcus lanatus, Festuca rubra*) occurred in taller swards and thus had higher abundance in MO and TA patch categories under EG (Fig. 1c; Table 2, analysis A3). The highest cover of bare ground was present in the TA patch category in EG plots, as indicated in Fig. 2. The highest numbers of heifer faeces were recorded in the MO and TA patch categories in the IG plots.

The results of repeated measures ANOVA analyses (Table 3) showed that the abundance of *F. rubra* changed throughout the years and season, as well as between stocking densities. However, interaction of patch category and season was insignificant. *F. rubra* had a higher cover in MO and TA patch categories under EG (Fig. 2a). Dominant species *Taraxacum* spp. (Fig. 2b) and *Trifolium repens* (Fig. 2c) together with other short forbs (*Plantago lanceolata, Veronica serpyllifolia, Achillea millefolium*) and short grasses (such as *Agrostis capillaris*) (Fig. 2d) were present in all patch categories under IG. All effects tested by repeated measures ANOVA analyses on the abundance of *A. capillaris* were significant except for season and interaction of patch category and season (Table 3).

T. repens had a high cover also in the SH patch category under EG. The RDA analysis showed other short forbs (*Cerastium holosteoides*, *Glechoma hederacea*, *Ranunculus repens*, *Plantago major*, *Hypochaeris radicata*) had higher abundance under IG than under EG and occurred in the MO and TA patch categories. Although all study effects tested by repeated measures ANOVA were significant for the cover of *T. repens*, the cover of another short forb, *Taraxacum* spp., was stable throughout the season and independent of patch category (see Table 3). The most common grass species of the sward, *A. capillaris*, dominated in all patch categories under IG (Fig. 2d).

4. Discussion

4.1 Proportions of patches

The differences in the proportions of sward-patch categories were affected by the contrasting stocking densities applied and both treatments generated a similar level of heterogeneity in sward structure, because it was generated by similar proportions of contrasting sward height classes. On the other hand Berg et al. (1997) reported that contrasting sward micro-patterns occur especially on extensively grazed pastures with high sward-height variability. This variability under extensively grazed pastures was also mentioned in previous studies from OGE (e.g. Correl et al., 2003; Pavlů et al., 2006c, 2009), and also for Argentinian pastures (Cid and Brizuela, 1998; Cid et al., 2008). This micro-pattern indicates a variability in plant species. However as we showed in our study the variability of different sward-height patches exists also on intensively grazed pastures, although is not so initially obvious as on extensively grazed ones. As expected, short patches dominated under IG within all study seasons, the tall patches were represented only sporadically there, the reverse being observed under EG. This shows that in the case of continuous intensive grazing the forage availability does not significantly exceed demand, cattle graze less selectively and therefore the percentage of short patches increases. In case of high grazing pressure under intensive stocking, when animals repeatedly overgraze short vegetation, the grazing of tall patches is restricted by the presence or non-presence of faeces or thistles (Cid and Brizuela, 1998).

In autumn 2003, the swards were shorter than in autumn of the other studied years. The absence of tall patches under IG and their reduction to only 5% under EG in autumn 2003 can be explained by insufficient precipitation in August 2003, during which rainfall was only 14.5 mm, compared with the 30-year average of 88 mm (Liberec meteorological station). This extraordinary drought reduced the usual aboveground sward biomass growth and standing biomass substantially.

During the course of the vegetation season the proportion of short patches usually successively increased under both stocking densities through to the end of the grazing season, which is similar to the findings of Dumont et al. (2007). It is known from previous studies (Ring et al., 1985; Gibb and Ridout, 1988) that at the end of the vegetation season cattle still continue to feed on previously grazed areas, as occurred under both of our stocking densities. This supports the creation and stability of a mosaic sward structure (Adler et al., 2001; Rossignol et al., 2011).

According to sward height measurements, heifers under EG repeatedly grazed short patches in particular; similar to the findings of Cid and Brizuela (1998). At OGE, the maximum proportion of those patches under EG was only 15% in the paddocks and demonstrated the greater forage availability for animals. Repeated grazing of the same patches is not only driven by the mechanical and momentary necessity to graze the high-quality sward that short patches provide, as mentioned above, but it could also be conditioned by the spatial memory of cattle (Bailey et al., 1998; Laca, 1998). Cattle can remember the location of preferred patches to some extent, but the limit of their spatial memory is still not known (Dumont, 2000).

4.2 Plant species composition

In accordance with previous studies, the short grass *A. capillaris* was promoted by grazing in low-productivity grasslands (e.g. Hellström et al., 2003; Louault et al., 2005; Pavlů et al., 2006b, 2007) and, especially under IG, it became the dominant sward species of short and moderate patches, as occurred in the OGE. Jewell et al. (2005) also found that *A. capillaris* occurred mostly in intensively and heavily grazed plots. However Grime et al. (1988) characterized *A. capillaris* as a common species in permanent pastures, and especially in mountain grasslands. It is regarded as a patch-forming species. Several prostrate or short species (*Taraxacum* spp., *T. repens*, *H. radicata*, *G. hederacea*, *V. serpyllifolia* and *R. repens*) were represented especially in short patches for both stocking densities, where the availability of light is an important determinant for the presence of those species (Ter Heerdt et al., 1991). Those species are intolerant to shading and would be outcompeted by taller species. By contrast, they are very resistant to intensive grazing and trampling (Grime et al., 1988). Therefore, prostrate species such as *Taraxacum* spp. or *T. repens* are very promptly able to colonize non-shaded areas with a short sward height (Pavlů et al., 2003; Hejcman et al., 2005). Selective grazing of prostrate forbs (*Taraxacum* spp. and *T. repens*) can explain the stability of patches over the grazing season, especially in lightly grazed grasslands (Rossignol et al., 2011). Nevertheless, these species also could dominate in tall patches under IG. This was because a majority of this patch category under IG was formerly short vegetation infested by faeces and/or urine and was consequently refused by animals (personal observation). The floristic composition in MO and TA patches under the IG was very similar. The abundance of species present in those patches changed only within the season. This is probably affected by micro-successions caused by dung pats at a fine scale, where plant communities react rapidly to changes in nutrient availability at the seasonal scale (Cid and Brizuela, 1998; Gillet et al., 2010). In contrast, the majority of tall patches under EG were usually made up of non-grazed vegetation because the amount of forage on offer exceeds the demand of the grazing animals. Tall forbs and tall graminoids such as *Aegopodium* *podagraria, G. album, H. maculatum, A. pratensis, Holcus mollis,* and *D. glomerata* were associated with TA and MO patches under EG, where grazing is light or null (Correl et al., 2003; Pavlů et al., 2007). Those patches are characterized by species with a good light competitiveness. Forage from the tall patches usually is poor in quality, yet it is a highly available resource from which in periods of food scarcity (e.g. summer drought and late autumn) animals can benefit by exploiting the reproductive swards to satisfy a part of their forage requirements (Dumont et al., 1995). Sometimes, taller or rarely grazed patches do not consist of single species but have nearly the same plant species as do short or heavily grazed patches (Bakker et al., 1984). They differ, however, in the relative cover of tall and short species with different resistance to grazing.

5. Conclusion

This study has shown that the main difference in patchiness between intensively and extensively grazed species-rich grassland was in the proportions of short and tall sward-height patches, whereas the proportion of moderate-height patches was similar under both stocking densities. Floristic composition of patches with the same sward height was dependent on stocking density. Moderate and tall sward-height patches under a particular stocking density had similar botanical compositions. Therefore it seems that moderate sward-height patches resulted from partly grazed tall ones. The floristic composition of short-height patches differed considerably from other patches under extensive grazing, whereas under intensive grazing the differences between short, moderate and tall sward patches were small. The absence of large differences in floristic composition among sward height patches under intensive grazing may suggest that this stocking density promotes rather botanically homogeneous sward despite the occurrence of a heterogeneous height structure of the sward. Grazing intensity is a key driver of the proportion as well as the floristic composition of sward-height patches. These findings have implications for nature conservation as they support the recommendation for an extensive management of species-rich grasslands.

Acknowledgements

This study was supported by the Ministry of Agriculture of the Czech Republic (Project No. 0002700604) and by the Ministry of the Environment of the Czech Republic (Project No. VaV SP/2D3/179/07). We are grateful to Milan Guerovich Andaluz for data collecting in years 2003 and 2004 and František Paška for his help with a fieldwork. We are also very indebted to Alan Hopkins and Mariecia Fraser for his useful comments.

References

Adler, P.B., Raff, A.D., Lauenroth, W.K., 2001. The effect of grazing on the spatial heterogeneity of vegetation. Oecologia 128, 465-479.

Ausden, M., 2007. Habitat management for conservation, a handbook of techniques. Oxford University Press, New York.

Bailey, D.W., Rittenhouse, L.R., Hart, R.H., Richards, R.W., 1989. Characteristics of spatial memory in cattle. Appl. Anim. Behav. Sci. 23, 331-340.

Bakker, J.P., de Leeuw, W., van Wieren, S.E., 1984. Micro-patterns in grassland vegetation created and sustained by sheep grazing. Vegetatio 55, 153-161.

Begon, M., Townsend, C.R., Harper, J.L., 2006. Ecology: from individuals to ecosystems. - 4th ed. Blackwell Publishing Ltd., Oxford.

Berg, G., Esselink, P., Groeneweg, M., Kiehl, K., 1997. Micropatterns in *Festuca rubra*-dominated salt-marsh vegetation induced by sheep grazing. Plant Ecol. 132, 1-14.

Chytrý, M. (ed.), 2007. Vegetace České republiky. 1. Travinná a keříčková vegetace (*Vegetation of the Czech Republic. 1 Grassland and Heathland Vegetation*). Academia, Prague.

Cid, M.S., Brizuela, M.A., 1998. Heterogeneity in tall fescue pastures created and sustained by cattle grazing. J. Range Manage. 51, 644-649.

Cid, M.S., Ferri, C.M., Brizuela, M.A., Sala, O., 2008. Structural heterogeneity and productivity of tall fescue pasture grazed rotationally by cattle at four stocking densities. Grassland Sci. 54, 9-16.

Correll, O., Isselstein, J., Pavlů, V., 2003. Studying spatial and temporal dynamics of sward structure at low stocking densities, the use of an extended rising-plate-meter method. Grass Forage Sci. 58, 450-454.

Diaz, S., Noy-Meir, I., Cabido, M., 2001. Can grazing of herbaceous plants be predicted from simple vegetative traits? J. Appl. Ecol. 38, 457-508.

Dumont, B., D'hour, P., Petit, M., 1995. The usefulness of grazing test for studying the ability of sheep and cattle to exploit reproductive patches of pasture. Appl. Anim. Behav. Sci. 45, 79-88.

Dumont, B., 1997. Diet preferences of herbivores at pasture. Ann. Zootech. 46, 105-116.

Dumont, B., Garel, J.P., Ginane, C., Decuq, F., Farruggia, A., Pradel, P., Rigolot, C., Petit, M., 2007. Effect of cattle grazing a species-rich mountain pasture under different stocking rates on the dynamics of diet selection and sward structure. Animal 1, 1042-1052.

Dumont, B., Rossignol, N., Loucougaray, G., Carrère, P., Chadoeuf, J., Fleurance, G., Bonis, A., Farruggia, A., Gaucherand, S., Ginane, C., Louault, F., Marion, B., Mesléard, F., Yavercovski, N., 2012. When does grazing generate stable vegetation patterns in temperate pastures? Agric. Ecosyst. Environ. 153, 50–56.

Gibb, M.J., Ridout, M.S., 1988. Application of double normal frequency distributions fitted to measurements of sward height. Grass Forage Sci. 43, 131-136.

Gillet, F., Kohler, F., Vandenberghe, Ch., Buttler, A., 2010. Effect of dung deposition on small-scale patch structure and seasonal vegetation dynamics in mountain pastures. Agric. Ecosyst. Environ. 135, 34-41.

Grime, J.P., Hodfson, J.G., Hunt, R., 1988. Comparative plant ecology, a functional approach to common British species. Unwin Hyman Ltd, London.

Hejcman, M., Auf, D., Gaisler, J., 2005. Year-round cattle grazing as an alternative management of hay meadows in the Giant mts. (Krkonoše), the Czech Republic, Ekológia (Bratislava) 24, 419-429.

Hellström, K., Huhta, A.-P., Rautio, P., Tuomi, J., Oksanen, J., Laine, K., 2003. Use of sheep grazing in the restoration of semi-natural meadows in northern Finland. Appl. Veg. Sci. 6, 45-52.

Jewell, P.L., Güsewell, S., Berry, N.R., Käuferle, D., Kreuzer, M., Edwards, P.J., 2005. Vegetation patterns maintained by cattle grazing on a degraded mountain pasture. Bot. Helv. 115, 109-124.

Kohler, F., Gillet, F., Reust, S., Wagner, H.H., Gadallah, F., Gobat, J.-M., Buttler, A., 2006. Spatial and seasonal pattern of cattle habitat use in a mountain wooded pasture. Landscape Ecol. 21, 281-295.

Kubát, K., Hrouda, L., Chrtek, J. jun., Kaplan, Z., Kirschner, J., Štěpánek, J. (eds), 2002. Klíč ke květeně České republiky (Key to the flora of the Czech Republic). Academia, Prague.

Laca, E.A., 1998. Spatial memory and food searching mechanisms of cattle. J. Range Manage. 51, 370-378.

Louault, F., Pillar, V.D., Aufrère, J., Garnier, E., Soussana, J.-F., 2005. Plant traits and functional types in response to reduced disturbance in a seminatural grassland. J. Veg. Sci. 16, 151-160.

Marion, B., Bonis, A., Bouzillé, J.-B., 2010. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Écoscience 17, 229-239.

Mehlich, A., 1984. Mehlich No. 3 soil test extractant, a modification of Mehlich No. 2. Commun. Soil Sci. Plant Anal. 15, 1409–1416.

Naujeck, A., Hill, J., Gibb, M.J., 2005. Influence of sward height on diet selection by horses. Appl. Anim. Behav. Sci. 90, 49-63.

Pavlů, V., Hejcman, M., Pavlů, L., Gaisler, J., 2003. Effect of rotational and continuous grazing on vegetation of an upland grassland in the Jizerské hory Mts., Czech Republic. Folia Geobot. 38, 21-34.

Pavlů, V., Hejcman, M., Pavlů, L., Gaisler, J., Nežerková, P., Meneses, L., 2006a. Changes in plant densities in a mesic species-rich grassland after imposing different grazing management treatments. Grass Forage Sci. 61, 42-51.

Pavlů, V., Gaisler, J., Hejcman, M., Pavlů, L., 2006b. Effect of different grazing system on dynamics of grassland weedy species. J. Plant Dis. Prot. 20, 377-383.

Pavlů, V., Hejcman, M, Pavlů, L., Gaisler, J., Nežerková, P., 2006c. Effect of continuous grazing on forage quality, quantity and animal performance. Agric. Ecosyst. Environ. 113, 349-355.

Pavlů, V., Hejcman, M., Pavlů, L., Gaisler, J., 2007. Restoration of grazing management and its effect on vegetation in an upland grassland. Appl. Veg. Sci. 10, 375-382.

Pavlů, V., Hejcman, M., Mikulka, J., 2009. Cover estimation versus density counting in species-rich pasture under different grazing intensities. Environ. Monit. Assess. 156, 419-424.

Pettit, N.E., Froend, R.H., Ladd, P.G., 1995. Grazing in remnant woodland vegetation changes in species composition and life form groups. J. Veg. Sci. 6, 121-130.

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

Ring, C.B., Nicholson, R.A., Lauchbaugh, J.L., 1985. Vegetational traits of patch-grazed rangeland in west-central Kansas. J. Range Manage. 38, 51-55.

Rook, A.J., Tallowin, J.R.B., 2003. Grazing and pasture management for biodiversity benefit. Anim. Res. 52, 181-189.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biol. Conserv. 119, 137-150.

Rossignol, N., Chadoeuf, J., Carrère, P., Dumont, B., 2011. A hierarchical model for analysing the stability of vegetation patterns created by grazing in temperate pastures. Appl. Veg. Sci. 14, 189-199.

Sahin Demirbag, N., Röver, K.-U., Wrage, N., Hofmann, M., Isselstein, J., 2009. Herbage growth rates on heterogeneous swards as influenced by sward-height classes. Grass Forage Sci. 64, 12-18.

Sasaki, T., Okayasu, T., Takeuchi, K., Jamsran, U., Jadambaa, S., 2005. Patterns of floristic composition under different grazing intensities in Bulgan, South Gobi, Mongolia. Grassland Sci. 51, 235-242.

Scimone, M., Rook, A.J., Garel, J.P., Sahin, N., 2007. Effect of livestock breed and grazing intensity on grazing systems: 3. Effects on diversity of vegetation. Grass Forage Sci. 62, 172-184.

ter Braak, C.J.F., Šmiluer, P., 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide, Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, New York.

Ter Heerdt, G.N.J., Bakker, J.P., De Leeuw, J., 1991. Seasonal and spatial variation in living and dead plant material in a grazed grassland as related to plant species diversity. J. Appl. Ecol. 28, 120-127.

Van Den Bos, J., Bakker, J.P., 1990. The development of vegetation patterns by cattle grazing at low stocking density in the Netherlands. Biol. Conserv. 51, 263-272.

WallisDeVries, M.F., Bakker, J.P., Van Wieren, S.E., 1998. Grazing and Conservation Management. Kluwer Academic Publishers, Dordrecht.

Willms, W.D., Dormaar, J.F., Schaalje, G.B., 1988. Stability of grazed patches on rough fescue grasslands. J. Range Manage. 41, 503-508.

Wrage, N., Sahin Demirbag, N., Hofmann, M., Isselstein, J., 2012. Vegetation height of patch more important for phytodiversity than that of paddock. Agric. Ecosyst. Environ. 155, 111–116.

Table 1. Mean sward height (cm) in summer (S) and autumn (A), standard error of the mean (SE), and number of observations (n) for short (SH), moderate (MO), or tall (TA) sward patches under intensive (IG) and extensive (EG) grazing management, in each study year.

Year/ Season	Stocking density	Patch category	Mean	SE	n
2003 S	IG	SH	3.63	0.085	116
		MO	7.08	0.212	36
		TA	13	0.567	8
	EG	SH	4.33	0.667	3
		MO	8.67	0.154	64
		TA	14.74	0.368	93
2003 A	IG	SH	2.91	0.088	144
		MO	6.63	0.202	16
		TA	-	-	0
	EG	SH	3.96	0.195	24
		MO	7.77	0.111	128
		TA	12.75	0.526	8
2004 S	IG	SH	4.11	0.096	72
		MO	7.59	0.164	59
		TA	13.34	0.382	29
	EG	SH	4.4	0.169	20
		MO	8.11	0.151	80
		TA	14.6	0.478	60
2004 A	IG	SH	3.69	0.093	102
		MO	7.685	0.167	54
		TA	11.75	0.479	4
	EG	SH	4.16	0.206	19
		MO	8.31	0.147	80
		TA	13.05	0.324	61
2006 S	IG	SH	3.68	0.123	72
		MO	7.85	0.144	74
		TA	12.21	0.405	14
	EG	SH	3.85	0.308	10
		MO	8.69	0.142	81
		TA	13.56	0.509	69
2006 A	IG	SH	3.51	0.109	91
		MO	7.26	0.172	63
		TA	11.5	0.516	6
	EG	SH	4.23	0.253	15
		MO	8.42	0.141	85
		TA	13.7	0.559	60
2007 S	IG	SH	3.91	0.106	66
		MO	7.88	0.184	60
		TA	13.53	0.398	34
	EG	SH	4	0.366	6
		MO	8.21	0.168	68
		TA	15.59	0.550	86
2007 A	IG	SH	3.48	0.105	101
		MO	7.47	0.172	54
		TA	11.6	0.400	5
	EG	SH	4.32	0.205	11
		MO	8.54	0.153	67
		TA	14.62	0.352	82

Table 2. Results of the redundancy analyses. % expl. = explained by axis 1 (all ordination axes), a measure of the explanatory power of the explanatory variables; *F*-ratio = *F*-statistics for the test of a particular analysis; *P*-value = corresponding probability value obtained by the Monte Carlo permutation test.

Analysis	Explanatory variable	Covariables	% expl.	*F*-ratio	*P*-value
A1: Stocking density has no effect on plant species composition.	stocking density	blocks	4.3	122.1	0.001
A2: Patch categories have no effect on plant species composition.	patch categories	blocks	1.8 (1.9)	49.2 (26.6)	0.001 (0.001)
A3: The interaction of stocking density and patch categories has no effect on plant species composition.	patch categories * stocking density	blocks	10.5 (11.4)	318.7 (70.4)	0.001 (0.001)

Table 3. Results of repeated measurements ANOVA analyses for percentage cover of four dominant species. *Df* = degrees of freedom, *F*-ratio = *F*-statistics for the test of a particular analysis, *P*-value = corresponding probability value. * indicates interaction of environmental variables. Abbreviations: StockDen = stocking density, PatchCat = patch category.

Tested variable	Effect	*Df*	*F*-ratio	*P*-value
Festuca rubra	Year	3	141.02	< 0.001
	StockDen	1	348.52	< 0.001
	Season	1	40.33	< 0.001
	PatchCat	2	15.39	< 0.001
	PatchCat*Year	6	14.50	< 0.001
	PatchCat*StockDen	2	3.41	0.033
	PatchCat*Season	2	0.65	0.520
Taraxacum spp.	Year	3	5.25	< 0.001
	StockDen	1	519.80	< 0.001
	Season	1	0.01	0.933
	PatchCat	2	2.88	0.056
	PatchCat*Year	6	3.74	< 0.001
	PatchCat*StockDen	2	36.57	< 0.001
	PatchCat*Season	2	0.32	0.727
Trifolium repens	Year	3	49.93	< 0.001
	StockDen	1	304.02	< 0.001
	Season	1	62.78	< 0.001
	PatchCat	2	26.44	< 0.001
	PatchCat*Year	6	8.60	< 0.001
	PatchCat*StockDen	2	24.92	< 0.001
	PatchCat*Season	2	3.29	0.038
Agrostis capillaris	Year	3	27.83	< 0.001
	StockDen	1	471.81	< 0.001
	Season	1	0.46	0.496
	PatchCat	2	8.25	< 0.001
	PatchCat*Year	6	8.11	< 0.001
	PatchCat*StockDen	2	2.11	0.122
	PatchCat*Season	2	0.62	0.539

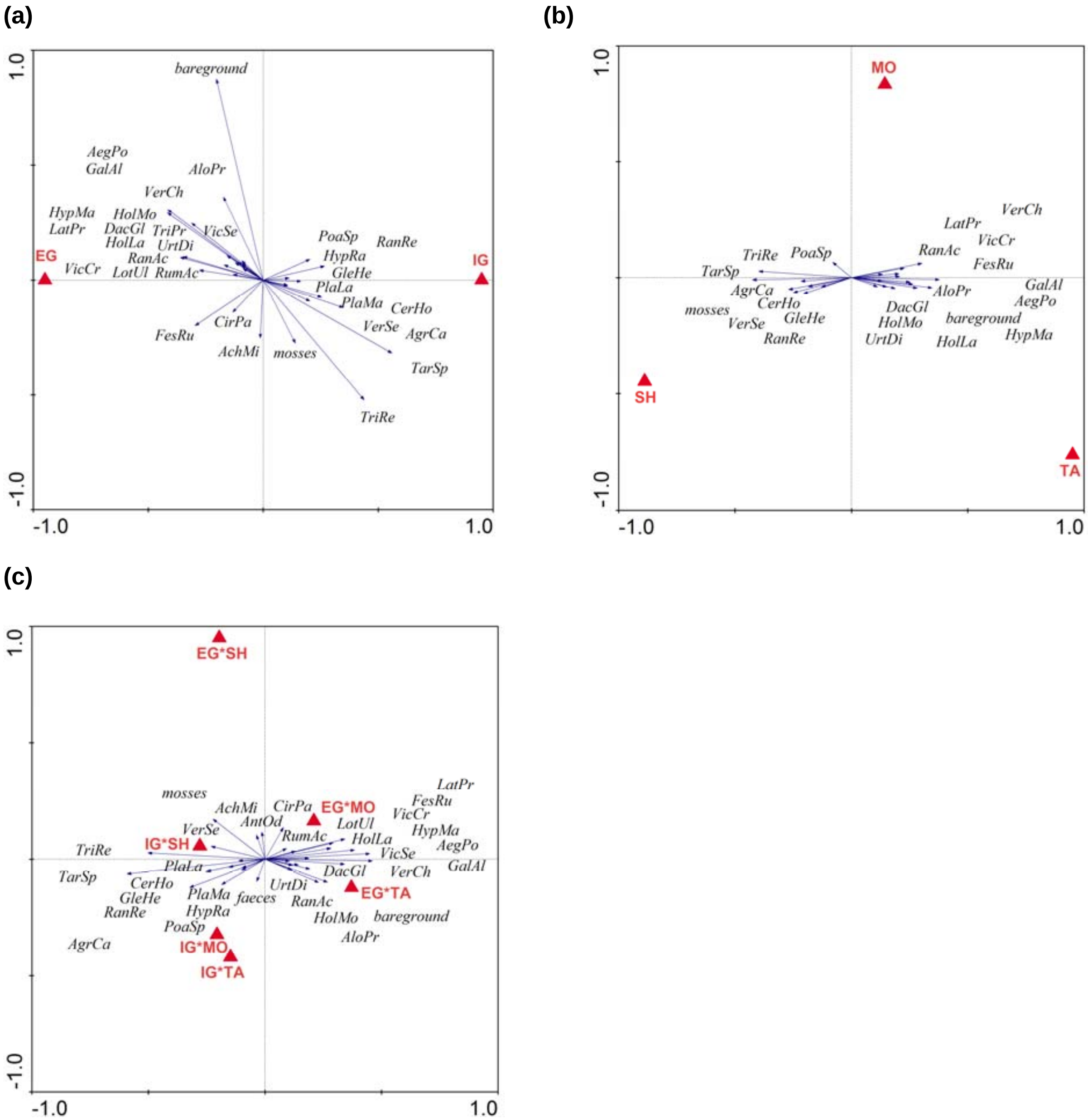

Fig. 1. Ordination diagrams showing the results from redundancy analyses of plant species composition data. * indicates interaction of environmental variables. Abbreviations: EG = extensive grazing; IG = intensive grazing; SH = short, MO = moderate, TA = tall sward-height patch categories; AchMi = *Achillea millefolium;* AegPo = *Aegopodium podagraria*; AgrCa = *Agrostis capillaris*; AloPr = *Alopecurus pratensis*; AntOd = *Anthoxantum odoratum*; CerHo = *Cerastium holosteioides;* CirPa = *Cirsium palustre;* DacGl = *Dactylis glomerata*; FesRu = *Festuca rubra*; GalAl = *Galium album*; GleHe = *Glechoma hederacea*; HolLa = *Holcus lanatus*; HolMo = *Holcus mollis*; HypMa = *Hypericum maculatum*; HypRa = *Hypochaeris radicata;* LatPr = *Lathyrus pratensis*; LotUl = *Lotus uliginosus;* PlaLa = *Plantago lanceolata;* PlaMa = *Plantago major*; PoaSp = *Poa* spp.; RanAc = *Ranunculus* acris; RanRe = *Ranunculus repens;* RumAc = *Rumex acetosa;* SteGr = *Stellaria graminea*; TarSp = *Taraxacum* spp.;TriPr = *Trifolium pratense*; TriRe =*Trifolium repens*; UrtDi = *Urtica* dioica; VerCh = *Veronica chamaedrys*; VerSe = Veronica serpyllifolia; VicCr = *Vicia* cracca; VicSe = *Vicia sepium*.

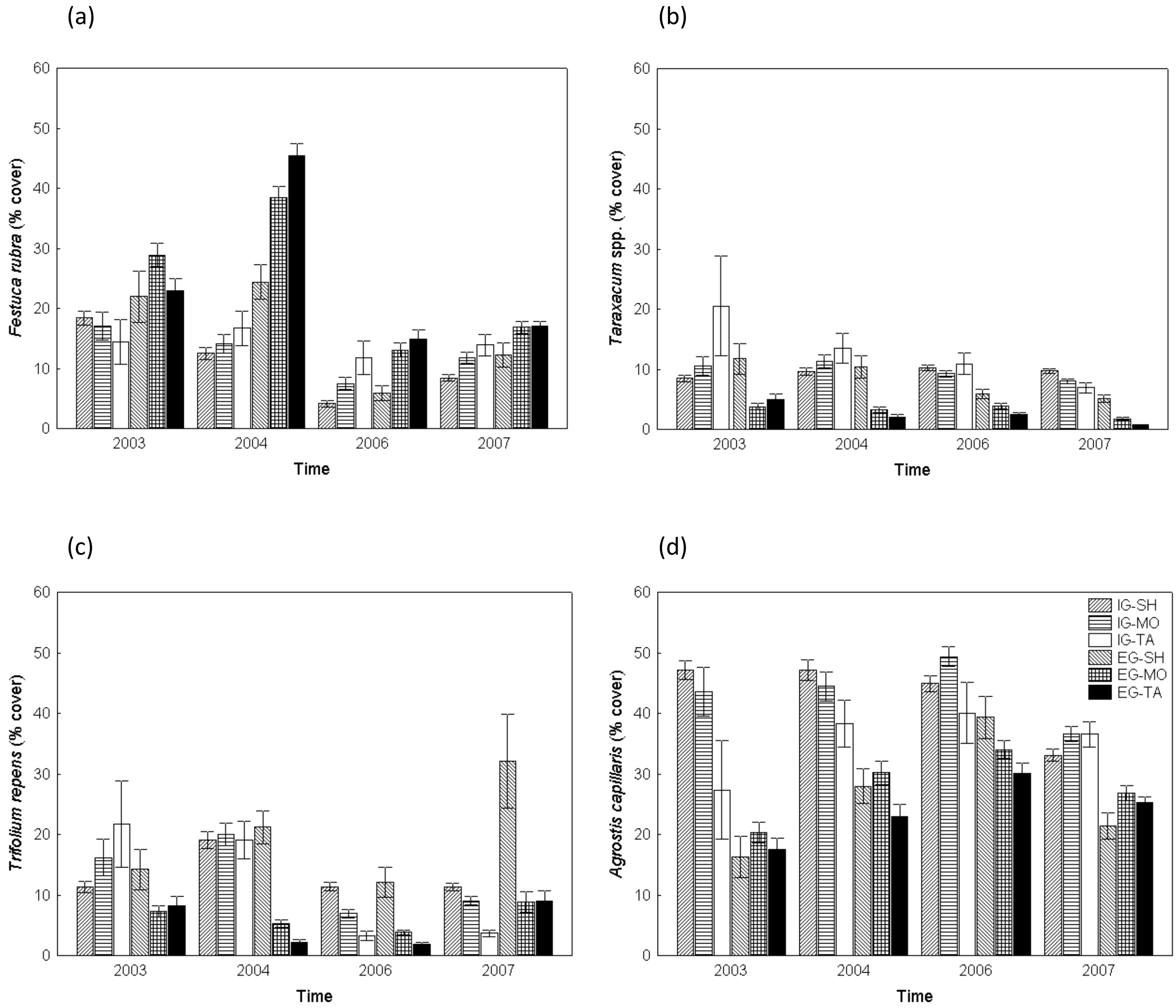

Fig. 2. Changes in coverage (%) of dominant tall graminoid *Festuca rubra* (a), short forb *Taraxacum* spp. (b), *Trifolium repens* (c), and short graminoid *Agrostis capillaris* (d) under investigated treatments from 2003 to 2007. Standard errors are indicated by vertical lines. For abbreviations, see Figure 1.

Chapter 4

Plant strategies in relation to different grazing intensities

Vendula Ludvíková, Vilém Pavlů

Grassland Science in Europe 15, 2010: 815-817.

Mosaic of sward patches with different height in the Jizerské Mts. [Photo: V. Ludvíková].

Plant strategies in relation to different grazing intensities

Ludvíková V.[1] and Pavlů V.[1, 2]

[1] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Department of Ecology, CZ-165 21 Prague, Czech Republic

[2] Research Institute of Crop Production, Prague, Department of Plant Ecology and Weed Science, Grassland Research Station, CZ-460 11 Liberec, Czech Republic

Abstract

The effect of grazing intensity on plant strategies (C-S-R signature) was studied on an experimental pasture in the JizeraMts (Czech Republic). The data collection took place during vegetation seasons 2003 - 2007 in following the treatments: intensive grazing (IG) and extensive grazing (EG). Sward height was the main attribute for the analysis and the two following categories of sward patches were distinguished: i) heavily grazed (*H*): 0 - 5 cm and ii) rarely grazed (*R)*: more than 10.5 cm. The S strategy occurred in all types of patches with the lowest value. The defoliation intensity had no effect on its abundance. In the *H* patches with higher disturbances, the R-components predominated, whereas the C strategy had the lowest value. For example, the ruderals like *Polygonum aviculare* or *Poa annua* were present in those patches only. The C strategy had a higher proportion in the *R* patches. Although it has been shown that IG treatment favours ruderal (R) strategy and EG treatment competitive (C) strategy, the results were affected by the abundance of different sward patches in treatments. Therefore, the rate of each C-S-R strategy was more dependent on the rate of different sward patches in treatments than by the grazing intensity itself.

Keywords: Heifers grazing, CSR strategy, sward height, sward patches

Introduction

Plant species exposed to similar selection pressure can respond variously depending on their life strategy. The knowledge about plant strategies may be important in analysing the distribution and the population dynamics of species and may be useful in predicting the consequences of changes under different management regimes (Grime *et al*., 1988). Sward patches form in a pasture because of selective grazing (Bakker *et al.,* 1983; Willms *et al.,* 1988). Sward height may be an important predictor of species reaction to grazing (Diaz *et al.,* 2001) and can also be a key indicator of the presence of different life strategies. The objective of the paper is to evaluate the effect of different intensities of cattle grazing on primary plant strategies (Grime, 1974).

Material and methods

The study site was carried out in an experimental pasture in the Jizera Mts, 10 km north of the city Liberec, Czech Republic. The average total annual precipitation in the region is 803 mm and the mean annual temperature is 7.2°C. The altitude of the study site is 420 m above sea level. The pasture was continuously stocked with growing heifers. The treatments were: extensive grazing (EG) and intensive grazing (IG). The experiment was arranged in two completely randomized blocks. The paddock area for each EG and IG plot was approximately 0.35 ha. The stocking density in the different treatment was adapted to the target sward height of 10 cm (EG) or 5 cm (IG) and was maintained by varying the grazing area available for the treatment. The grazing season lasted from the beginning of May to the end of October.

The sward height and abundance of vascular plant species and were collected in both treatments from two permanent line transects in each plot. Measurements were performed at 40 fixed points (subplots) along each line transect (2 treatments x 2 blocks x 2 transects x 40 fixed points = 320 subplots). The percentage abundance of vascular plant species and compressed sward height (Corell *et al.,* 2003) was estimated at fixed points in 700 cm^2 circles (diameter 30 cm). Different patch types were distinguished through sward height into the two following categories: a) heavily grazed patches (*H*) with heights from 0 to 5 cm and b) rarely grazed patches (*R*) with heights taller than 10.5 cm. Data were collected in years 2003, 2004, 2006 and 2007, in the early summer (SE), late summer (SL) and in the autumn (A). For every presented plant, a life strategy was assigned, and using a spreadsheet-based tool for calculating functional signatures within the context of the C-S-R life strategies (Hunt *et al.*, 2004) the distribution of C-S-R life strategies was established. Species nomenclature follows Kubát *et al.* (2002). ANOVA and post-hoc comparison using the Tukey HSD was used to evaluate the distribution of C-S-R life strategies in different patches.

Results and discussion

Different grazing intensities of cattle grazing affected the presence of plant species with different life strategies. Significant effect ($P < 0.001$) of defoliation intensity on the presence of C and R strategists was found, but non significant on the presence of S strategists. The interaction of the treatment and patches category was found to be a significant predictor of the distribution of plants with different life strategies under grazing ($P < 0.001$). EG*R* patches had a different proportion of CSR from the others, C-strategy predominated there (Fig. 1). These patches were not preferentially grazed by animals and the taller species with good light competition ability like *Urtica dioica* were dominant there. Conversely, R-strategy was significantly lowest in EG*R* patches, probably because of few sward disturbances. However intensively defoliated patches (IG*H*, IG*R*, EG*H*) promoted R-strategy which is typical for managed pastures (Ejarnæs and Bruun, 2000; Moog *et al.*, 2005). The lowest rate of C-strategy occurred in IG*H* patches, whereas R-strategy predominated there. For example, the ruderals like *Polygonum aviculare* or *Poa annua* were present in those patches only. In the IG*R* patches the representation of C-strategy and of R-strategy was changed year by year. Those patches arise predominantly on places with faeces, which were not stable (Pavlů, pers. comm.). The results have shown that IG treatment favours ruderal strategy whereas EG treatment the competitive strategy. It should be noted that the proportion of C-S-R strategy in the particular sward patches was relatively stable during the study years.

Conclusion

Although it has shown that IG treatment favours ruderal strategy and EG treatment competitive strategy, the results were affected by the abundance of different sward patches in treatments. Therefore, the rate of each C-S-R strategy was more dependent on the rate of different sward patches in treatments than by grazing intensity itself.

Acknowledgements

This study was supported by the Ministry of Agriculture (grant no. 0002700604) and the Ministry of Environment (grant no. SP/2D3/179/07).

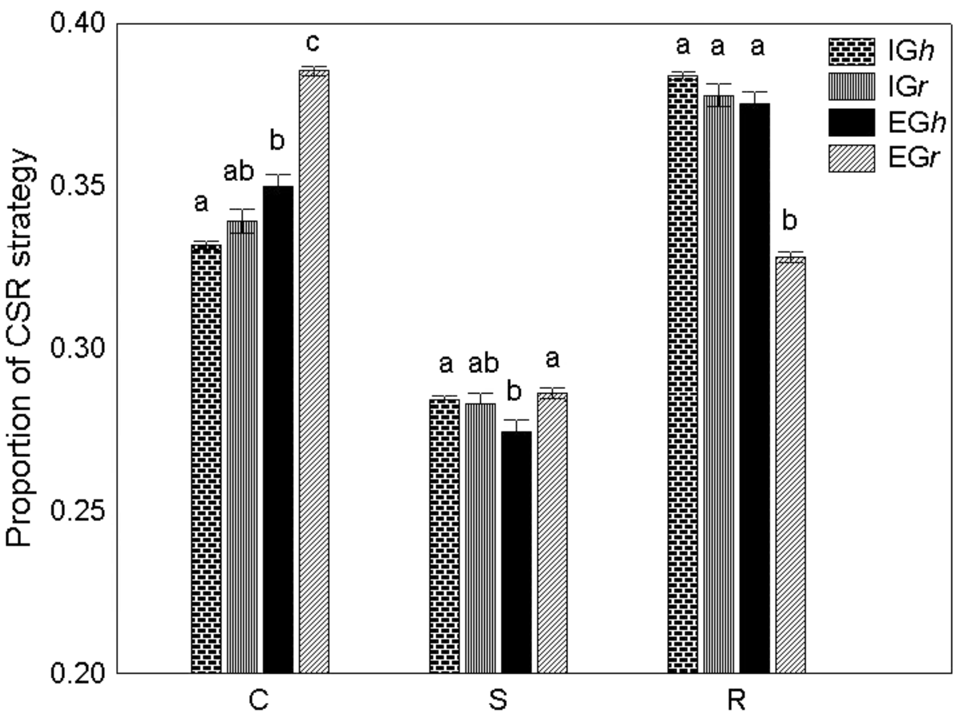

Figure 1. Weighted means of the CSR strategies in particular patches. Error bars represent the standard error of the mean (SE). The individual strategy with the same letter was not significantly different ($P < 0.005$), Tukey HSD test. The abbreviations of the treatments and patch category interactions are given in Material and methods.

References

Bakker J.P., de Leeuw W. and van Wieren S.E. (1983) Micro-patterns in grassland vegetation created and sustained by sheep grazing. *Vegetatio,* 55, 153-161.

Correl O., Isselstein J. and Pavlů V. (2003) Studying spatial and temporal dynamics of sward structure at low stocking densities: the use of an extended rising-plate-meter method. *Grass Forage Science,* 58, 450-454.

Diaz S., Noy-Meir and Cabido M. (2001) Can grazing of herbaceous plants be predicted from simple vegetative traits? *Journal of Applied Ecology,* 38, 457-508

Ejrnæs R. add Bruun H.H. (2000) Gradient analysis of dry grassland vegetation in Denmark. *Journal of Vegetation Science,* 11, 573-584.

Grime J.P, Hodfson J.G. and Hunt R. (1988) *Comparative plant ecology: a functional approach to common British species*, Unwin Hyman Ltd, London, UK, 742 pp.

Grime J.P. (1974): Vegetation classification by reference to strategies. *Nature* 250: 26-31.

Hunt R., Hodgson J.G., Thompson K., Bungener P., Dunnett N.P. and Askew A.P. (2004) A new practical tool for deriving a functional signature for herbaceous vegetation. *Applied Vegetation Science,* 7, 163-170.

Kubát K., Hrouda L., Chrtek J., Kaplan Z., Kirschner J. and Štěpánek J. (eds.) (2002) *Klíč ke květeně České republiky*, Academia, Praha, CZ, 928 pp.

Moog D., Kahmen S. & Poschlod P. (2005) Application of CSR- and LHS-strategies for the distincion of differently managed grasslands. *Basic and Applied Ecology,* 6, 133-143.

Willms W.D., Dormaar J.F. and Schaalje G.B. (1988) Stability of grazed patches on rough fescue grasslands. *Journal of Range Management,* 41, 503-508.

Chapter 5

Effect of different grazing systems on sward structure during the first vegetation season after management introduction

Vilém Pavlů, Šimáčková Hana, Vendula Ludvíková, Gaisler Jan, Pavlů Lenka, Hejcman Michal

Grassland Science in Europe 17, 2012: 105-107.

Exclosure cage (1 m × 1 m) in the experimental site in Oldřichov v Hájích [Photo: V. Pavlů].

Effect of different grazing systems on sward structure during the first vegetation season after management introduction

Pavlů V.[1,2], Šimáčková H.[3], Ludvíková V.[1], Gaisler J.[2], Pavlů L.[2] and Hejcman M.[1,2]

[1] Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences, Prague, Czech Republic

[2] Department of Plant Ecology, Grassland Research Station, Crop Research Institute, Prague, Czech Republic

[3] Institute of Environmental Studies, Faculty of Science, Charles University in Prague, Czech Republic

Corresponding author: pavlu@vurv.cz

Abstract

The aim of this work was to study the effect of different grazing management on sward structure in an upland grassland, during the first vegetation season after management introduction. The following treatments were applied in randomized blocks: intensive continuous stocking (C), extensive rotational grazing with two grazing cycles (2R), intensive rotational grazing with four grazing cycles (4R) and unmanaged control (U). The samples of biomass were collected by cutting (0.1 m × 0.1 m) monthly during the whole vegetation season from May to December. The functional groups of tall and short grasses had the fastest responses to different management and the significant differences were apparent in June. The accumulation of dead material between treatments differentiated following the August sampling and reflected grazing intensity C < 4R < 2R < U. The dominant short grass *A. capillaris* had a greater proportion of biomass in U and 2R treatments. Applied grazing treatments as well as successional development, regardless of treatments, significantly affected thesward structure of upland grassland during the first vegetation season after management introduction. The key factor affecting sward structure during the vegetation season is the behaviour of dominant species, plant biomass growth and dead material accumulation.

Keywords: continuous stocking, rotational grazing, functional groups, plant above-ground biomass

Introduction

Numerous studies performed all over the world have confirmed a positive effect of grazing on the structure and composition of grasslands (e.g. WallisDeVries *et al*., 1998). Vegetation changes in grazed grasslands occur due to a diverse mechanism of response of individual species to different grazing regimes and season (Bullock *et al*., 2001). However, studies that have evaluated changes during the whole vegetation season are rare. Therefore, the objective of this investigation was to evaluate the effect of different grazing systems on sward structure during the course of the first vegetation season after management introduction.

Materials and methods

The experiment was established over a five-year period of intensively grazed plots with *Agrostis capillaris* grassland dominancy (Oldrichov Grazing Experiment; Pavlů *et al*., 2007) in 2002. The study site is situated in the Jizera Mountains, 10 km north of the city Liberec, Czech Republic. The average total annual precipitation is 803 mm, the mean annual temperature is 7.2°C (Liberec meteorological station) and the altitude is 420 m a.s.l. Treatments were performed by controlled manipulation with exclosure cages (1 m × 1 m) as follows: intensive continuous stocking (C) without using exclosure cages, intensive rotational grazing with four grazing cycles (4R), extensive rotational grazing with two grazing cycles (4R) and unmanaged control (U) with permanent exclosure cages. The experiment was arranged in four complete randomized blocks (four treatments × four replicates = 16 plots) with individual plot sizes of 1 m × 1 m. All grazing treatments were grazed by young heifers. The samples (0.1 m × 0.1 m) of above-ground biomass were collected by cutting at ground level monthly from May to December (2 samples per plot × 4 treatments × 4 replications × 8 months; in total 256 samples). The biomass samples were sorted into individual vascular plant species and dead material and then dried (at 80°C) to constant dry matter content, and then weighed. Biomass data were recalculated into kg of DM (dry matter) per m^2. 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 (derived from previous studies, e.g. Pavlů *et al.*, 2007): tall grasses, short grasses, tall forbs, short forbs and legumes. The proportion of dominant species, dead material and functional groups were analysed by ANOVA. Redundancy analysis (RDA) in CANOCO package, followed by a Monte Carlo permutation test was used to evaluate trends in plant species composition under different treatments.

Results and discussion

There were significant differences between treatments, as well as successional development, independent of the treatments (see Table 1, analysis A1 and A2 for details). However, the results of RDA analyses showed similarity of treatment 4R to C with highest grazing intensity. When the botanical observations are conducted during the vegetation season, the time is usually revealed as a significant factor affecting sward structure (Kohler *et al.*, 2004). As well as in our study, the time explained two times more plant species variability than applied treatments. It is usually explained by phenological complementarity of the dominant plants species in temperate grasslands (Mládek and Juráková, 2011). However this complementarity was not revealed in our study. The fastest response to different management was with tall and short grasses where the significant differences (P < 0.001) were revealed in June sampling. Not surprisingly, tall forbs (e.g. *Gallium album*, *Hypericum maculatum*) had a higher occurrence in U treatment whereas short forbs (e.g. *Cerastium holosteoides*, *Alchemilla* sp., *Veronica chamaedrys*) and mosses occurred mostly in frequently grazed ones (C and 4R). The accumulation of dead material differentiated between treatments since August sampling and reflected the grazing intensity C < 4R < 2R < U (Figure 1a). Contrary to our results from previous studies (e.g. Pavlů *et al*., 2007) the dominant short grass *A. capillaris* had higher biomass proportion in U and 2R treatments (Figure 1b). It is because this species, adapted to previous heavy grazing, was allowed to grow with low defoliation frequency (2R) or even without defoliation (U).

Conclusions

Applied grazing treatments as well as successional development, regardless of treatments, significantly affect the sward structure of upland grassland during the first vegetation season after management introduction. The key factor affecting sward structure during the vegetation season is behaviour of dominant species, plant biomass growth and dead material accumulation.

Acknowledgements

This study was supported by the Ministry of Environment of the Czech Republic (VaV SP/2D3/179/07) and the Czech Science Foundation (521/08/1131).

Table 1. Results of RDA analyses. Abbreviations: % expl. = explained by axis 1 (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; M = month; C, 4R, 2R, U = treatment abbreviation.

Analysis	Explanatory variable	Covar.	% expl.	*F*-ratio	*P*-value
A1: Changes in species composition are independent on time and on treatments.	M, M*C, M*4R, M*2R, M*U	PlotID	62.2 (62.7)	178.0 (45.4)	0.001 (0.001)
A2: The short-term changes in species composition are independent on treatments.	M*C, M*4R, M*2R, M*U	PlotID, M	26.5 (26.8)	39.0 (13.2)	0.001 (0.001)

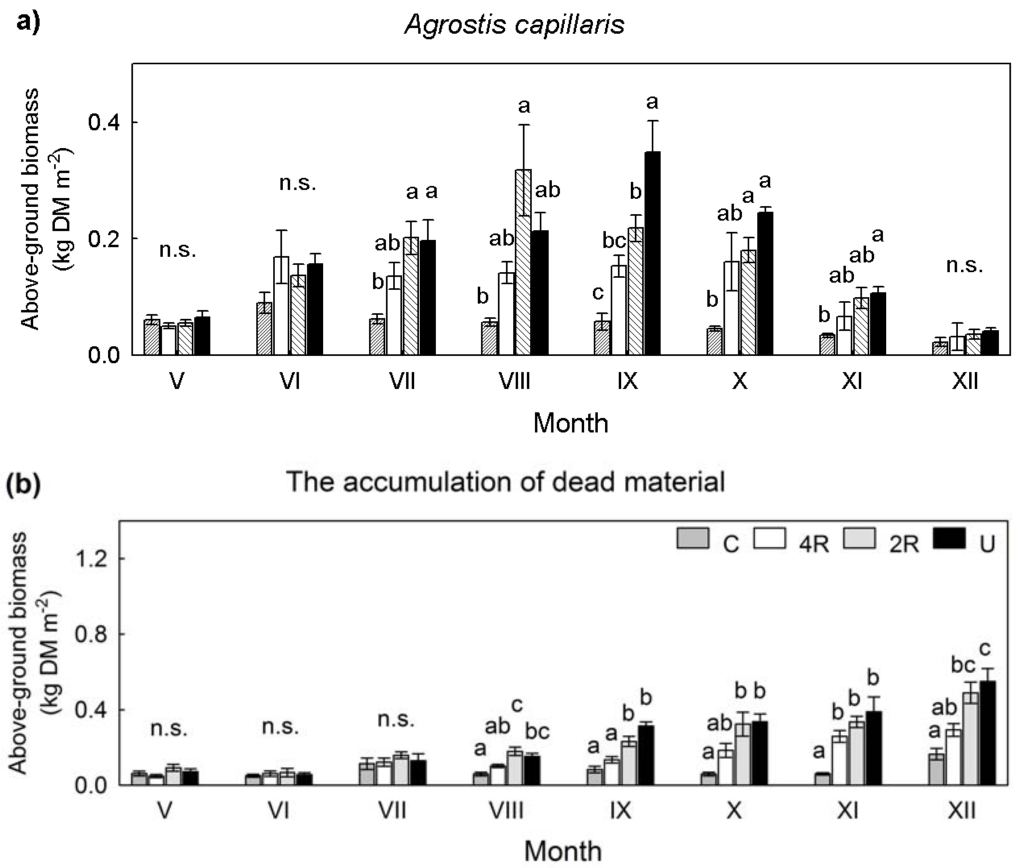

Figure 1. The above-ground biomass of the dominant grass *Agrostis capillaris* **(a)** and of accumulated dead matter **(b)**. Significant differences ($P < 0.05$) with the post-hoc Tukey HSD are indicated with different characters (a-c), n.s. = not significant. C, 4R, 2R, U = treatment abbreviation.

References

Bullock J.M., Franklin J., Stevenson M.J., Silvertown J., Coulson S.J., Gregory S.J. and Tofts R. (2001) A plant trait analysis of responses to grazing in a long-term experiment. Journal of Applied Ecology 38, 253–267.

Kohler F., Gillet F., Gobat J.-M. and Buttler A. (2004) Seasonal vegetation changes in mountain pastures due to simulated effects of cattle grazing. Journal of Vegetation Science 15, 143–150.

Kubát K., Hrouda L., Chrtek J., Kaplan Z., Kirschner J. and Štěpánek J. (eds) (2002) Klič ke květeně České republiky. [Key to the Flora of the Czech Republic.], Academia, Praha. 928 pp.

Mládek J. and Juráková J. (2011) Using phonological progression and phonological complementarity to reveal potential for late grassland harvest. Grassland Science in Europe 16, 139–141.

Pavlů V., Hejcman M., Pavlů L. and Gaisler J. (2007) Restoration of grazing management and its effect on vegetation in an upland grassland. Applied Vegetation Science 10, 375–382.

WallisDeVries M.F., Bakker J.P. and Van Wieren S.E. (eds) (1998) Grazing and conservation management. Kluwer Academic Publishes, Great Britain, Dordrecht. 373 pp.

Chapter 6

Reindroduction of grazing management after deforestation of formerly abandoned grassland and its effect on early vegetation changes in the Western Carpathians (Slovakia)

Ján Novák, Vilém Pavlů, Vendula Ludvíková

Grass and Forage Science, 2012. In press.

Different treatments of management after deforestation in Diel (Slovakia) [Photo: J. Novák].

Reindroduction of grazing management after deforestation of formerly abandoned grassland and its effect on early vegetation changes in the Western Carpathians (Slovakia)

J. Novák[*], V. Pavlů[† ‡], V. Ludvíková [‡]

[*]Department of Grassland Ecosystems and Forage Crops, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture, Nitra, Slovakia, [†]Grassland Research Station, Department of Plant Ecology and Weed Science, Crop Research Institute, Liberec, Czech Republic, and [‡]Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences, Prague, Czech Republic

Correspondence to: V. Pavlů, Grassland Research Station, Department of Plant Ecology and Weed Science, Crop Research Institute, Rolnická 6, CZ-460 11, Liberec, Czech Republic

E-mail: pavlu@vurv.cz

Abstract

Although the process of reforestation of grassland has been widely studied in Europe, little is known about the effect of deforestation on grassland development. Thus, the specific objective of this paper was to evaluate early changes in plant species composition, functional group, yield, and biomass quality after deforestation of long-term abandoned pastures. The experiment was established immediately after deforestation on sparse herbaceous vegetation (mean initial cover 27%) with the following treatments: grazing management only (G0), cutting and grazing aftermath (CG), grazing after seeding of grassland mixture (GS), grazing after a burning treatment in which branches were burned after deforestation (GB), and unmanaged control (U). Very rapid recovery of bare ground by germination and/or sprouting of grassland species was similar under all types of grazing management. Total plant species richness increased in all managed treatments except GB. Similarities according to redundancy analyses in plant species composition were found among G0, CG, and GB treatments, especially for forbs with correlated rosette or creeping growth. The woody species, tall grasses, and tall forbs had higher abundance in the U treatment. The restoration of grassland following deforestation of formerly reforested grassland area by grazing management was a relatively fast process and swards were created after three years. The highest biomass yield was observed under treatments GS and GB. Forage quality of all managed treatments was sufficient for the demands of beef cattle grazing. However, for subsequent grassland preservation some type of grazing management is necessary to prevent reforestation, which can occur immediately after deforestation in unmanaged places.

Keywords: botanical composition, grassland, plant species richness, RDA, reforestation, wooded pasture

Introduction

In the second half of the twentieth century considerable changes in the utilization of grasslands in Europe occurred as a result of two contrasting processes. Firstly, there was an intensification of grassland utilization, and large areas were reseeded with highly productive grass and grass-clover mixtures and intensively managed by mechanized agriculture. Secondly, many low-production grasslands and those inaccessible to machinery were abandoned (Isselstein et al., 2005).

Agricultural abandonment is one of the main drivers of natural reforestation in Europe and it is a part of a global trend that results from ubiquitous socio-economic driving forces (Mottet et al., 2006; Gibon et al., 2010). Abandonment of grasslands usually has a negative effect on the botanical composition as there is a reduction in plant species richness with increasing time after management cessation (Pavlů et al., 2005; Pykälä et al., 2005). Increased accumulation of dead plant material after abandonment affects the decomposition process, which can also alter soil properties (Tappeiner and Cernusca, 1995).

In Central European conditions the sward is usually invaded by trees and shrubs within a few years of abandonment (Öckinger et al., 2006), although grasslands can remain treeless over a long-term period if trees and shrubs are not present when management is terminated (Perssons, 1984) and the existing sward canopy does not allow their germination. An increase in the cover of trees and shrubs due to natural or anthropogenic afforestation may be more detrimental to grassland species than the lack of grassland management (Pykälä et al., 2005). Some traditionally managed woodland pastures can provide a suitable equilibrium between tree density and grazing, and support swards with high plant species diversity (Gillet et al., 1999; Kohler et al., 2006). Regular grazing is able to prevent the encroachment of shrubs and trees into grassland, and grazing can be regarded as an essential management tool for grassland areas, especially in marginal areas (Isselstein et al., 2005).

The abandonment of temperate European grasslands and its resulting vegetation succession leading to afforestation and its effect on vegetation have been widely studied (e.g. Kesting et al., 2009; Pykälä et al., 2005). However, the opposite process of natural and/or man-made deforestation has usually been studied in tropical (Jackson and Ash, 1998; Nangendo et al., 2005) and subtropical (Fynn et al., 2004; Fairfax et al., 2009) areas, especially in savanna stands (Scholes and Archer, 1997; Reich et al., 2001), where fire plays an important role in open woodland ecosystems and this type of disturbance is an inevitable factor for grassland regeneration. Deforestation in tropical rainforest areas usually has a detrimental effect on ecosystem stability (Hanski et al., 2009). In the context of temperate areas in Central Europe there is little information on the potential impact of deforestation. The need to expand agricultural land in the future to meet livestock production requirements might require existing forested areas to be deforested. Although deforestation is often considered to be a key driver of biodiversity changes that has been directly linked to species extinction at a global level (Hanski et al., 2009), local deforestation in temperate areas can lead to the establishment of species-rich grassland communities (Novák, 2008), which can also support valuable insect communities (Marini et al., 2009).

The aim of this study was to describe the effects of initial vegetation changes after the reintroduction grazing management following deforestation. Four specific questions were addressed: How are i) plant species composition, ii) plant species richness, iii) main functional group, and iv) biomass yield and forage quality affected by different types of grazing management after the deforestation of formerly wooded pasture?

Material and methods

Study site

The experiment was established on a reforested pasture in Stolické vrchy Mts, which is part of Slovenské Rudohorie Mts (48°33`N, 19°46`E), in 2006. The altitude is 845 m a.s.l., the average annual precipitation is 927 mm, and the mean annual temperature is 5.1 °C (Sihla meteorological station). The underlying soil is a cambisol and soil attributes for each treatment are shown in Table 1. Soil samples from the 0-10 cm layer were collected in 2006 and analysed using the Mehlich III methodology (Mehlich, 1984) to determine plant-available Ca, P, K, and Mg concentrations. Total N was analysed by the Kjeldahl method and C by means of colorimetry (AOAC, 1984).

The experimental area was part of formerly common land and had been regularly grazed by sheep and cattle for at least the last century. In the 1950s, when large scale agriculture management was introduced, this low productivity pasture was abandoned and successive reforestation occurred. As a result, 45% of the former grassland area was covered by a woody species which comprised *Betula pendula* (27%), *Corylus avellana* (7%), *Populus tremula* (5%), *Fagus sylvatica* (3%) and *Carpinus betulus, Cerasus avium, Rosa canina* (3%). The age of the trees in 2006 was between twenty and forty years. Under the woody vegetation there was a sparse herbaceous vegetation (27%) (comprising mainly *Fragaria vesca*, *Galium odoratum*, *Cruciata laevipes, Veronica chamaedrys*, *Avenella flexuosa*) and bare ground (28%) (Novák, 2009).

Silvo-pastoral grazing management by cattle was introduced in the reforested pasture from 1993. An experimental area of 150m x 50m was established in spring 2006, in which the trees and shrubs were cut down, wood was removed and branches were burned on selected experimental areas (GB treatment). Five treatments were applied: (i) Grazing management (G0), (ii) Cutting and grazing aftermath (CG), (iii) Grazing of seeded grassland (GS), (iv) Grazing after a burning treatment in which branches were burned after deforestation (GB), and (v) Unmanaged control (U). The experiment was arranged in three randomized blocks (5 treatments × 3 replicates = 15 plots altogether) with individual study plot sizes of 2.2 m × 2.2 m (Figure 1). The blocks were not established on sites where herbaceous vegetation and/or soil was excessively disturbed by deforestation activity. To avoid the effect of topography, blocks were separated from each other by 5 m along the contour line. In spring 2006 the bare ground in the GS treatment was disturbed by raking avoiding presented sparse herbaceous vegetation (20-27%). After that it was broadcast seeded with a grass-legume mixture (seeding rate 12.6 kg ha^{-1}) with weight proportions consisting of *Festuca* *pratensis* (20%), *Phleum pratense* (12%), *Poa pratensis* (12%), *Dactylis glomerata* (7%), *Trifolium repens* (42%), and *Lotus corniculatus* (7%). The CG treatment was temporally fenced then cut at the beginning of the June (the traditional date of cutting for this area) and the aftermath was grazed by continuous stocking. The GB treatment was established 3-5 m apart from the separate block to avoid disturbance by fire or ash of other treatments, therefore it was only possible to completely randomise the G0, CG, GS and U treatments (Figure 1). To protect it from grazing animals the U treatment was permanently fenced. G0, GS, GB treatments were continuously stocked by cattle (Charolais breed) at a low stocking rate (from 0.3 to 0.6 standard livestock unit ha^{-1}; Allen et al., 2011). However, because 20% part of pasture was woodland the actual stocking rate related to grassland vegetation was higher. The grazing season lasted from May to October. There was permanent open access of animals to all grazed experimental plots during the grazing season.

Sward sampling

Relevés were made in a permanent 1 m × 1 m plot situated in the centre of each study plot (2.2 m × 2.2 m). The percentage cover up to 100% (Whalley and Hardy, 2000) of all vascular plant species in 1 m^2 was visually estimated before the start of grazing in May each year. Species richness was measured by the number of presented vascular plant species in each plot. Nomenclature of vascular plants followed Marhold and Hindák (1998). An initial estimation was conducted in spring 2006 to obtain baseline data for each plot, and further estimations made in 2007 and 2008. All plant species within the study area were *a priori* categorized into simple functional groups: grasses, forbs, woody species.

A measure of the biomass yield of the herbage was obtained in a random rectangle 0.5 m x 0.5 m in CG and U treatments or under exclosure cages (0.5 m × 0.5 m x 0.5 m) in all grazed treatments. The biomass was cut to a residual 3 cm stubble height in each study plot (avoiding the central plot for vegetation monitoring (1 m × 1 m)) twice a year in 2006 and 2007. The first sampling was made at the beginning of June and the second one at the beginning of September. The exclosure cages were relocated after each sampling to avoid biomass collection on the same place twice. Biomass was dried for 48 h at 70 ^{o}C and weighed and then the yield of dry matter (DM) per hectare was recalculated. Crude protein (CP) and crude fibre (CF) were determined subsequently by Wenden analysis (AOAC, 1984).

Data analysis

One way ANOVA followed by *post hoc* comparison using the Tukey's HSD test was used for evaluation of species diversity, functional group data (grasses, forbs and woody species), soil nutrient concentrations, herbage DM yield, CP and CF. The community response was analysed by constrained ordinations. Redundancy analysis (RDA; Lepš and Šmilauer, 2003) in the CANOCO package (ter Braak and Šmilauer, 2002), followed by a Monte Carlo permutation test was used to evaluate trends in plant species composition, because of linear species responses and a rather homogenous species composition over the plots (Lepš and Šmilauer, 2003). A split-plot design was used in the permutation type to cope with repeated measures. We used 999 permutations in all performed analyses restricted to three split-plots, freely exchangeable whole plots, time series, or linear transect at the split-plot level. Our data-form used repeated observations with the baseline data (measurements performed before the introduction of grazing), and thus the interaction of treatments and year were the most important variables. Centring by species was applied. Species cover data for RDA was log-transformed. A standard biplot ordination diagram constructed by the CanoDraw program (ter Braak and Šmilauer, 2002) was used to visualize the results of the CANOCO analyses.

Results

Plant species richness and cover

Similar numbers of species (slightly above 15) were present initially in all treatments apart from in the burned places of the GB treatment (Figure 2a). No significant differences among treatments were detected in the third year of study. In the first year after deforestation the total percentage cover of vascular plant species varied between 48, 29, 18, and 39% in the G0, CG, GS, and U treatments respectively, whereas due to the ash layer cover it was less than 1% (0.38%) in the GB treatment. However, there was a very fast successional development with increasing amounts of percentage cover of all vascular plant species in all treatments (Figure 2b), without any statistical differences in the third year.

Plant species composition and functional group

Remarkable successional development independent of all treatments, as well as significant differences among study treatments were detected (see Table 2, Analyses A1 and A2 for details). The woody species (*Carpinus betulus*, *Cerasus avium, Betula pendula, Populus tremula*, *Rosa* sp., *Rubus* sp.), tall grasses *(Poa trivialis*, *Avenella flexuosa*, *Calamagrostis epigejos*), and tall forbs (*Viscaria vulgaris*, *Galium mollugo*) had higher abundances in the U treatment. In GS plots it was the sown grass species (*Festuca pratensis, Phleum pratense, Dactylis glomerata*) and some prostrate herbs (*Ranunculus lanuginosus, Sagina procumbens, Plantago major*) that dominated.

The ordination diagram RDA (Figure 3) clearly shows similarity among G0, CG, and GB treatments, with a high degree of correlation with the species *Vicia cracca, Pimpinella saxifraga*, and *Poa annua.* Prostrate herbs (*Taraxacum* sp., *Trifolium repens*, *Leontodon autumnalis*) were also most abundant in these grazed treatments. No endangered or rare vascular plant species were recorded in the study area.

Cover of grasses (Figure 4a) was mainly affected by the cover of two dominant grass species, *Festuca rubra* and *Agrostis capillaris,* with their successional development during the study period. In the third year of study the cover of grasses was significantly highest in the seeded treatment (GS), where highly productive species were introduced (*Festuca pratensis, Phleum pratense, Poa pratensis, Dactylis glomerata*), whereas the lowest cover was in the unmanaged treatment (U). In 2008 the highest cover of *A. capillaris* (Figure 4d) was found in G0 and CG treatments (about 15%), and the lowest was in the U (2%) and GB (3%) treatments, whereas *F. rubra* (Figure 4e) was tolerant of all the managed treatments.

The highest proportion of forbs (Figure 4b) was usually found in CG and G0 treatments and the lowest in U and GB treatments in 2007 and 2008. The cover of legumes fully reflected the abundance of the most abundant species *T. repens* (Figure 4f) and dominated especially in the GB treatment. The woody species (shrubs and trees) dominated in the U treatment, where the cover was more than 70% in the third year (Figure 4c).

Yield and forage quality

In 2006 in the first sampling term the lowest biomass yield was in the GB and GC treatments (Figure 5a). In 2006 in the second sampling term and in 2007 in the first sampling term the highest biomass yield was in the GB and GS treatments. There were relatively small differences between all managed treatments in the second sampling term in 2007. The lowest content of CP (< 100 g kg^{-1} DM) was obtained under the U treatment, whereas the highest was under the GB treatment (> 130 g kg^{-1} DM) (Figure 5b). The mean content of CP of the other treatments varied between 100 and 190 g kg^{-1} DM. The content of CF (Figure 5c) was inversely proportional to CP with the peak in the U treatment.

Discussion

Plant species richness and cover

A very fast increase in plant species richness at a scale of 1 m^2 occurred during the first year after deforestation and the introduction of grazing management. Due to burning of soil, high ash layer cover and excessive nutrient content in the upper soil layer, the presence of vascular plant species in burnt places was initially quite low. The gradual increase in number of vascular plant species over the following two years was apparent especially on all managed treatments. The positive effect of grazing on species richness compared to unmanaged grassland is well documented in other studies concerning temperate grasslands (e.g. Bakker, 1989; Smith and Rushton, 1994; Tasser and Tappeiner, 2002; Pykälä et al., 2005; Pavlů et al., 2006; Pavlů et al., 2007; Lanta et al., 2009) and it is a general trend which occurs after the introduction of grazing by large herbivores (Olff and Ritchie, 1998). However this is the first study dealing with deforestation and consequent grassland recreation which clearly shows the very fast introduction of vascular plant species to swards.

Plant species composition and functional group

Only three years of abandonment of deforested sites was required to result in a fast infestation of shrub species (*Rubus idaeus*, *Rosa* sp.) and tree recovery (especially by *Populus tremula*). This afforestation process is usually associated with a decline in typical grassland flora (e.g. Milberg, 1994; Hanson and Fogelfors, 2000; Pykälä et al., 2005) as also occured in our experiment. However, any type of presented defoliation management was able to prevent afforestation sufficiently.

Bare ground covered by ash with a high content of nutrients (K, Ca, Mg, P) in the treatment with wood burning (GB) supported a high percentage cover of legumes, especially *T. repens* (>50%). The ability of legumes to fix nitrogen, as well as the positive effect of burning on germination would provide a competitive advantage for this species (Hanson and

Fogelfors, 2000). Because of creeping stem and clonal growth with a lower probability of removing the majority of aboveground biomass by defoliation, *T. repens* has an advantage in quickly colonizing bare ground (Thórhallsdottir, 1990), as occurred in our case in the GB treatment.

The successional development of grasses was similar for all managed treatments except for the U treatment, where since the second year shrubs and trees have suppressed their cover. However, two dominant grasses, *F. rubra* and *A. capillaris*, behaved differently. *Festuca rubra*, except in the case of the U treatment, had similar progress in all the other treatments. This tall grass species is known to be very plastic in response to different types of management and therefore can be present in various types of grasslands and managements (e.g. Honsová et al., 2007; Mašková et al., 2009; Kesting et al., 2009; Lanta et al., 2009; Hejcman et al., 2010; Pavlů et al., 2011). The cover of *A. capillaris* was supported by grazing or the cutting/grazing treatment, but was reduced by introducing excessive amounts of nutrients after burning, and by the competitive ability of shrubs in the unmanaged treatment. This short grass species (CRS strategy, *sensu* Grime, 1987) is known as an indicator species of young grassland (Waesh and Becker, 2009) and it is common especially in low-production temperate grasslands (e.g. Hellström et al., 2003; Louault et al., 2005; Pavlů et al., 2007; Mašková et al., 2009).

It should be noted that this very fast process of grassland recovery was also possible because of the presence of large areas of pasturelands in the vicinity of the experiment (Novák, 2009) which provided a potential source of desirable seeds in the form of seed rain that could accelerate this process. Similarly, spontaneous succession from appropriate diaspores in the immediate surroundings was recommended by Lencová and Prach (2011) as a cheap tool for establishment of seminatural grassland on ex-arable land.

Yield and forage quality

Herbage DM yield was affected by successive colonization by plant species of bare ground in all treatments, but the highest yields were in seeded and burned places in both years. The initially low biomass yield in burned places was caused by a high ash layer which prevented seedling germination, but in the next sampling terms the biomass yield was substantially increased due to soil enrichment by nutrients from the ash of burned wood. Wood ash has been known for centuries as a natural fertilizer (Semelová et al., 2009) and its high concentration can enrich soil and consequently nutrients in plants for many centuries, as documented by Hejcman et al. (2011). Similarly Ferreiro et al. (2011) found positive effects of wood ash fertilization on the productivity of mountain pasture.

Although the use of exclosure cages has some imperfections, because they can affect grassland environment inside (temperature, moisture and light) and prevent trampling and nutrient enrichment by faeces and urine (Frame, 1993), it is on grazed grasslands the easiest way to assess forage production during the vegetation season.

Not surprisingly, the lowest forage quality occurred in unmanaged grassland, where a high content of CF and low content of CP were revealed, particularly because of the high content of matured and senescent material with a high content of fibre and low CP. Although significant differences among other treatments were also found, the quality of forage was relatively good even in self seeded treatments and was sufficient for the nutritional demands of grazing beef cattle, and in the range reported for temperate grazed grassland with moderate defoliation intensity in Central European conditions (Pavlů and Velich, 1998; Pavlů et al., 2006; Isselstein et al., 2007; Mládek et al., 2011).

We are aware of the imperfections inherent in these types of experimental arrangements, where pasture plots are small and do not allow control of grazing pressure. Probably in our experiment the animals did not graze the plot area evenly and they selected the different treatments differently. On the other hand, despite low grazing pressure in our experiment, by the end of grazing seasons all plant biomass higher than 5 cm was grazed and there were no ungrazed patches in experimental plots. So the selective grazing was not the main limitation for interpretation of our results.

In spite of the abovementioned disadvantages of using these small scale pasture plots they are often conducted (e.g. Hejcman et al., 2005; Lanta et al., 2009; Mládek et al., 2011) where large scale experiments are not possible to establish due to a lack of sufficient area of suitable grasslands and/or shortage of funds for establishing large scale experiments, as occurred in our study. Although results obtained from small scale pasture plots can have some constraints, they can also provide crucial information about the effects of pasture management on vegetation.

Conclusion

The main conclusion of this paper is that the restoration of grassland vegetation on long-term abandoned wooded pasture by deforestation and reintroduction grazing management is a relatively fast process in the case of situations where grasslands are already present in the vicinity of the deforested area. A very rapid recovery of bare ground by germination and growth of grassland species was similar in all types of grazing management that were evaluated. Artificial seeding by target species can further accelerate this process, and the establishment of a sward predominantly composed of productive and nutritionally valuable species can occur very quickly. Furthermore, the forage quality of all managed treatments was sufficient for the nutritional demands of grazed beef cattle. For the subsequent maintenance of the grassland some form of grazing management is necessary to prevent reforestation, which occurs on unmanaged sites immediately after deforestation.

Acknowledgements

The authors are indebted to Rosemary Collins for correcting the English of the text. The study was supported by project no. 1/0851/10 of the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences and finalization of the paper by the project by Ministry of Agriculture of the Czech Republic (0002700604) and Czech Science Foundation (521/08/1131).

References

ALLEN V.G., BATELLO C., BERRETTA E.J., HODGSON J., KOTHMANN M., LI X., MCIVOR J., MILNE J., MORRIS C., PEETERS A. and SANDERSON M. (2011) An international terminology for grazing lands and grazing animals. *Grass and Forage Science*, **66**, 2–28.

AOAC 1984. *Official Methods of Analysis*, *14th ed. Association of Official Analytical Chemists*, Washington, DC, US.

BAKKER J.P. (1989) *Nature Management by Grazing and Cutting*. Dordrecht, NL: Kluwer Academic Publishers.

FAIRFAX R., FENSHAM R., BUTLER D., QUINN K., SIGLEY B. and HOLMAN J. (2009) Effect of multiple fires on tree invasion in montane grasslands. *Landscape Ecology,* **24**, 1363–1373.

FERREIRO A., MERINO A., DIAZ N. and PINEIRO J. (2011) Improving the effectiveness of wood-ash fertilization in mixed mountain pastures. *Grass and Forage Science,* **66**, 337–350.

FRAME J. (1993) Herbage mass. In: DAVIES A., BAKER R.D. GRANT S.A. and LAIDLAW A.S. (eds) *Sward Measurement handbook*, pp. 39-68. Reading, UK: The British Grassland Society.

FYNN R.W.S., MORRIS C.D. and EDWARDS T.J. (2004) Effect of burning and mowing on grass and forb diversity in a long-term grassland experiment. *Applied Vegetation Science,* **7**, 1–10.

GIBON A., SHEEREN D., MONTEIL C., LADET S. and BALENT G. (2010) Modelling and simulating change in reforesting mountain landscape using a social-ecological framework. *Landscape Ecology,* **25**, 267–285.

GILLET F., MURISIER B., BUTTLER A., GALLANDAT J.D. and GOBAT J.M. (1999) Influence of tree cover on the diversity of herbaceous communities in subalpine wooded pastures. *Applied Vegetation Science,* **2**, 47–54.

GRIME J.P. (1987) The C-S-R model of primary plant strategies: origins, implication, and tests. In: Gottlieb, L.D. and Jain, S.K., (eds), *Evolutionary Plant Biology*, pp. 371–394. Chapman and Hall, London, UK.

HANSKI I.**,** MEYKE E. and MIINALA M. (2009) Deforestation and tropical insect extinctions. *Biological Letters,* **23**, 653–655.

HANSON M. and FOGELFORS H. (2000) Management of a semi-natural grassland; results from 15-year-old experiment in southern Sweden. *Journal of Vegetation Science,* **11**, 31–38.

HEJCMAN M., AUF D. and GAISLER J. (2005) Year-round cattle grazing as an alternative management of hay meadows in the Giant Mts. (Krkonoše, Karkonosze), the Czech Republic. Ekológia (Bratislava), **24**, 419–429.

HEJCMAN M., ONDRÁČEK J. and SMRŽ Z. (2011) Ancient waste pits with wood ash irreversibly increase crop production in Central Europe. *Plant and Soil*, **339**, 341–350.

HEJCMAN M., SCHELLBERG J. and PAVLŮ V. (2010) Long-term effects of cutting frequency and liming on soil chemical properties, biomass production and plant species composition of *Lolio-Cynosuretum* grassland after the cessation of fertilizer application. *Applied Vegetation Science,* **13**, 257–269.

HELLSTRÖM K., HUHTA A.-P., RAUTIO P., TUOMI J., OKSANEN J. and LAINE K. (2003) Use of sheep grazing in the restoration of semi-natural meadows in northern Finland. *Applied Vegetation Science,* **6**, 45–52.

HONSOVÁ D., HEJCMAN M., KLAUDISOVÁ M., PAVLŮ V., KOCOURKOVÁ D. and HAKL J. (2007) Species composition of an aluvial meadow after 40 years of applying nitrogen, phosphorus and potassium fertilizer. *Preslia,* **79**, 245–258.

ISSELSTEIN J., GRIFFITH B.A., PRADEL P. and VENERUS S. (2007) Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 1. Nutritive value of herbage and livestock performance. *Grass and Forage Science*, **62**, 145–158.

ISSELSTEIN J., JEANGROS B. and PAVLŮ V. (2005) Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe – A review. *Agronomy Research* **3**, 139–151.

JACKSON J. and ASH A.J. (1998) Tree-grass relationships in open eucalypt woodlands of northeastern Australia: influence of trees on pasture productivity, forage quality and species distribution. *Agroforestry Systems*, **40**, 159–176.

KESTING S., WRAGE N. and ISSELSTEIN J. (2009) Herbage mass and nutritive value of herbage of extensively managed temperate grasslands along a gradient of shrub encroachment. *Grass and Forage Science,* **64**, 246–254.

KOHLER F., GILLET F., REUST S., WAGNER H.H., GADALLAH F.,GOBAT J.M. and BUTTLER A. (2006) Spatial and seasonal patterns of cattle habitat use in a mountain wooded pasture. *Landscape Ecology*, **21**, 281–295.

LANTA V., DOLEŽAL J., LANTOVÁ P., KELÍŠEK J. and MUDRÁK O. (2009) Effects of pasture management and fertilizer regimes on botanical changes in species-rich mountain calcareous grassland in Central Europe. *Grass and Forage Science,* **64**, 443–453.

LENCOVÁ K. and PRACH K. (2011) Restoration of hay meadows on ex-arable land: commercial seed mixtures vs. spontaneous succession. *Grass and Forage Science,* **66**, 265–271.

LEPŠ J. and ŠMILAUER P. (2003) *Multivariate Analysis of Ecological Data Using CANOCO*. Cambridge, UK: Cambridge University Press.

LOUAULT F., PILLAR V.D., AUFRÈRE J., GARNIER E. and SOUSSANA J.-F. (2005) Plant traits and functional types in response to reduced disturbance in a seminatural grassland. *Journal of Vegetation Science,* **16**, 151–160.

MARHOLD K. and HINDÁK F. (1998) Zoznam nižších a vyšších rastlín Slovenska. Bratislava, SK: Veda.

MARINI L., PAOLO F., BATTISTI A. and GASTON K.J. (2009) Response of orthopteran diversity to abandonment of semi-natural meadows. *Agriculture, Ecosystems and Environment,* **132**, 232–236.

MAŠKOVÁ Z., DOLEŽAL J., KVĚT J. and ZEMEK F. (2009) Long-term functioning of a species-rich mountain meadow under different management regimes. *Agriculture, Ecosystems and Environment,* **132**, 192–202.

MEHLICH A. (1984) Mehlich No. 3 soil test extractant: a modification of Mehlich No. 2. *Communication in Soil Science and Plant Analysis,* **15**, 1409–1416.

MILBERG P. (1994) Soil seed bank after eighteen years of succession from grassland to forest. *Oikos,* **72**, 3–13.

MLÁDEK J., HEJCMAN M., HEJDUK S., DUCHOSLAV M. and PAVLŮ V. (2011) Community seasonal development enables late defoliation without loss of forage quality in semi-natural grasslands. *Folia Geobotanica*, **46**, 17–34.

MOTTET A., LADET S., COGUÉ N. and GIBON A. (2006) Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture, Ecosystems and Environment,* **114**, 296–310.

NANGENDO G., STEIN A., TER STEEGE, H. and BONGERS F. (2005) Changes in woody plant composition of three vegetation types exposed to a similar fire regime for over 46 years. *Forest Ecology and Management,* **217**, 351–364.

NOVÁK J. (2008) *Pasienky, lúky a trávniky* (Pastures, meadows and lawns). Patria I. spol. s r.o., Prievidza, SK. (in Slovak).

NOVÁK J. (2009) *Trávne porasty po odlesnení a samozalesnení* (Grasslands after deforestation and reforestation. Brno, CZ: Tribun EU s.r.o. (in Slovak).

ÖCKINGER E., ERIKSSON A.K. and SMITH H.G. (2006) Effects of grassland abandonment, restoration and management on butterflies and vascular plants. *Biological Conservation,* **133**, 291–300.

OLFF H. and RITCHIE M.E. (1998) Effects of herbivores on grassland plant diversity. *Trends in Ecology and Evolution,* **13**, 261–265.

PAVLŮ V., HEJCMAN M., PAVLŮ L. and GAISLER J. (2007) Restoration of grazing management and its effect on vegetation in an upland grassland. *Applied Vegetation Science,* **10**, 375–382.

PAVLŮ V., HEJCMAN M., PAVLŮ L., GAISLER J. and NEŽERKOVÁ P. (2006) Effect of continuous grazing on forage quality, quantity and animal performance. *Agriculture, Ecosystems and Environment*, **113**, 349–355.

PAVLŮ V., HEJCMAN M., PAVLŮ L., GAISLER J., NEŽERKOVÁ P. and GUEROVICH M. (2005) Vegetation changes after cessation of grazing management in the Jizerské Mountains (Czech Republic). *Annales Botanici Fennici,* **42**, 343–349.

PAVLŮ V., VELICH J. (1998) The quality of pasture forage under rotational and continual grazing of heifers. *Rostlinná Výroba*, **44**, 287–292.

PAVLŮ V., SCHELLBERG J. and HEJCMAN M. (2011) Cutting frequency vs. N application: effect of a 20-year management in *Lolio-Cynosuretum* grassland. *Grass and Forage Science*, **66**, 501–515.

PERSSON S. (1984) Vegetation development after the exclusion of grazing cattle in a meadow area in the south of Sweden. *Vegetatio,* **55**, 65–92.

PYKÄLÄ J., LUOTO M., HEIKKINEN R.K. and KONTULA T. (2005) Plant species richness and persistence of rare plants in abandoned semi-natural grasslands in northern Europe. *Basic and Applied Ecology,* **6**, 25–33.

REICH P.B., PETERSON D.W., WEDIN D.A. and WRAGE K. (2001) Fire and vegetation effects on productivity and nitrogen cycling across a forest-grassland continuum. *Ecology,* **82**, 1703–1719.

SEMELOVÁ V., HEJCMAN M., PAVLŮ V., VACEK S. and PODRÁZSKÝ V. (2008) The grass garden in the Giant Mts. (Czech Republic): residual effect of long-term fertilization after 62 years. *Agriculture, Ecosystems and Environment*, **123**, 337–342.

SCHOLES R.J. and ARCHER S.R. (1997) Tree-grass interactions in savannas. *Annual Review of Ecology and Systematics,* **28**, 517–544.

SMITH R.S. and RUSHTON S.P. (1994) The effects of grazing management on the vegetation of mesotrophic (meadow) grassland in Northern England. *Journal of Applied Ecology,* **31**, 13–24.

TAPPEINER U. and CERNUSCA A. (1995) Analysis of changes in canopy structure and microclimate in abandoned alpine grassland ecosystems. In: Bellan, D., Bonin, G. and Emig, C. (eds), *Functioning and dynamics of natural and perturbed ecosystems,* pp. 49-62. Paris, F.: Lavoisier Publishing,

TASSER E. and TAPPEINER U. (2002) Impact of land use changes on mountain vegetation. *Applied Vegetation Science,* **5**, 173–184.

TER BRAAK C.J.F. and ŠMILAUER P. (2002) CANOCO *Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5)*. Ithaca, NY: Microcomputer Power.

THÓRHALLSDOTTIR T.E. (1990) The dynamics of five grasses and white clover in a simulated mosaic sward. *Journal of Ecology,* **78**, 809–923.

WAESCH G. and BECKER T. (2009) Plant diversity differs between young and old mesic meadows in a central European low mountain region. *Agriculture, Ecosystems and Environment,* **129,** 457–464.

WHALLEY R.D.B. and HARDY M.B. (2000) Measuring botanical composition of grasslands. In: 't MANNETJE L. and JONES R.M. (eds) *Field and laboratory methods for grassland and animal production research,* pp. 67–102. Wallingford, UK: CABI Publishing.

Table 1 Results of basic soil chemical analyses (pH, content of total N, and plant available (Mehlich III) concentrations of P, K, Ca and Mg) in 0-10 cm layer at the beginning of the experiment in 2006. Numbers represent average of three replicates, ± values represent standard error of the mean (SE).

†Treatment	pH/KCl	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Mg mg kg^{-1}	Ca mg kg^{-1}
U	6.3±0.04	1690±29	20±5.8	207±17.6	107±8.8	320±5.7
G0	5.9±0.02	2790±15	50±5.8	1003±49.8	177±23.8	1423±17.6
GS	5.5±0.02	2133±23	20±0.8	357±20.3	107±21.9	400±32.1
CG	5.6±0.02	1433±18	20±5.8	417±17.6	127±12.0	787±48.4
GB	7.1±0.02	2003±18	130±17.3	723±38.4	247±23.8	4980±15.3

†U=Unmanaged control, G0=Grazing management, GS=Grazing of seeded grassland, CG= Cutting and grazing aftermath, GB= Grazing of burning place.

Table 2 Results of the RDA analyses of cover estimates. GS, G0, CG, GB, U = treatment abbreviation (see Table 1 footnote); Plot ID, plot identifier; % explained variability = species variability explained by axis 1 (all ordination axes) - measure of explanatory power of the explanatory variables; *F*-ratio, *F*-statistics for the test of particular analysis (all axes); *P*-value, corresponding probability value obtained by the Monte Carlo permutation test (999 permutations).

Tested null hypotheses: A1 The temporal trend in the species composition is independent of all treatments. A2 There is no directional changes in time in the species composition that are common to all the treatments or specific for particular treatments.

Analysis	Explanatory variables	Covarariables	% expl. 1st axe/ all axes	*F* ratio 1st axe/ all axes	*P* 1st axe/ all axes
A1	GSxYear, UxYear, G0xYear, GBxYear, CGxYear	Year, Plot ID	26.0 (38.2)	8.78 (3.86)	0.001 (0.001)
A2	GSxYear, UxYear, G0xYear, GBxYear, CGxYear, Year	Plot ID	32.7 (54.0)	11.67 (5.07)	0.001 (0.001)

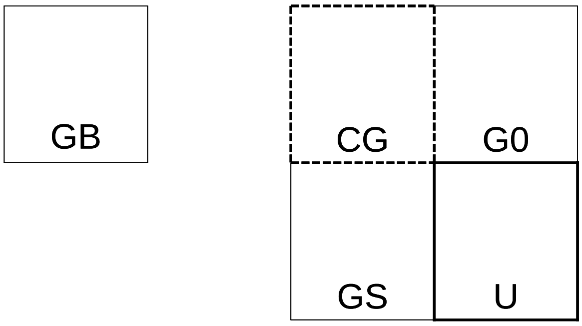

Figure 1 Schematic design of the experiment. Each block consisted of five plots (2.2 m x 2.2 m); unmanaged (U) plots (thick line) were permanently fenced, cutting and grazing (CG) plots (dashed line) were temporally fenced then cut and the aftermath was grazed. Grazing (G0), grazing burned (GB) and grazing seeded (GS) plots were freely accessible to cattle through the whole grazing season.

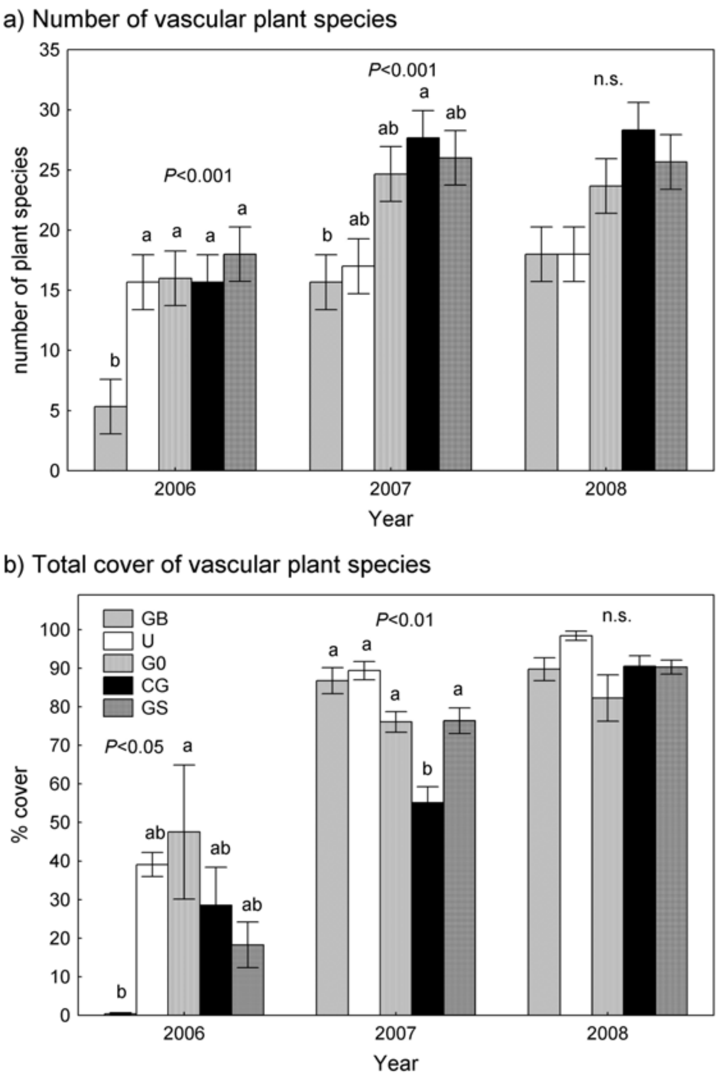

Figure 2 The number of plant species (a) and total plant % cover per 1 m^2 (b) in treatments during the years 2006-2008. *P* represents probability value obtained by one-way ANOVA. Degrees of freedom were four in all analyses. Significant differences (*P*<0.05) according to the Tukey *post hoc* test are indicated by different letters. Error bars represent standard errors of the mean.

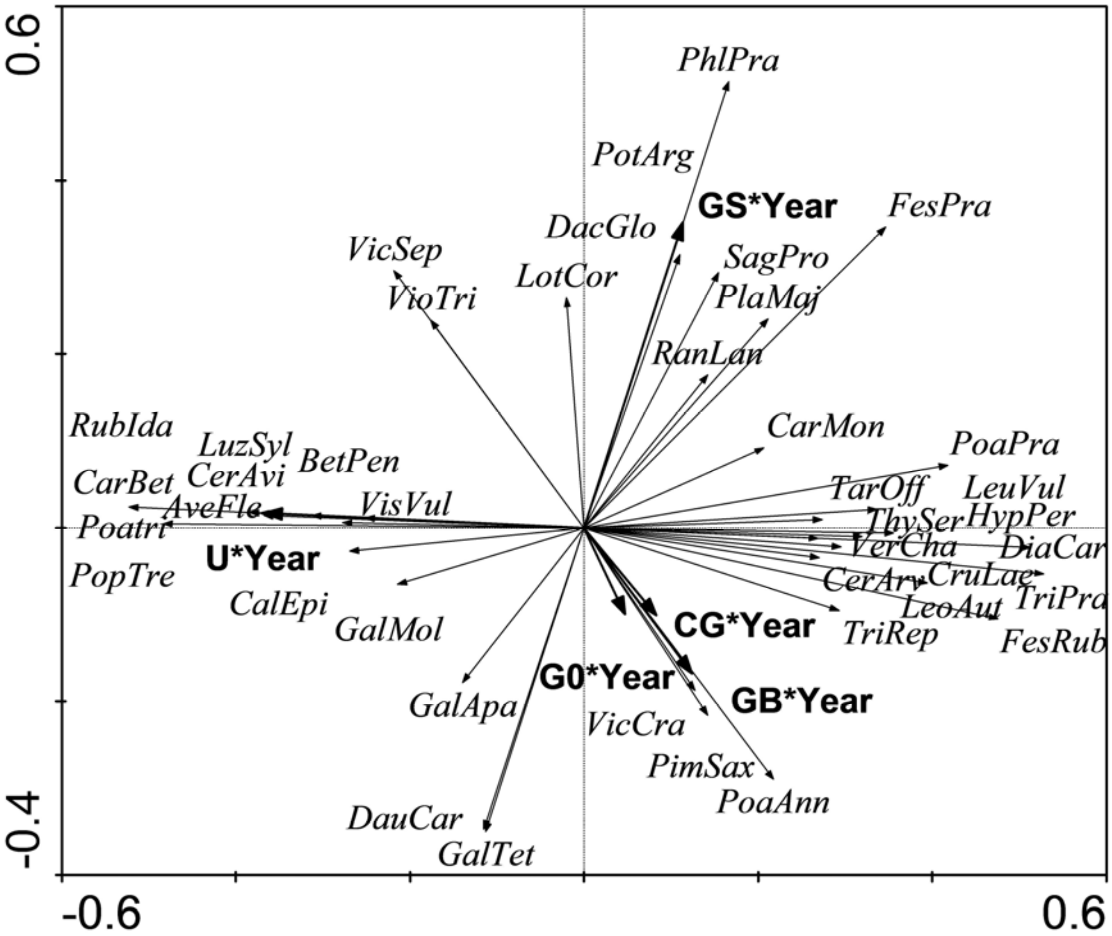

Figure 3 Ordination diagram showing the results of RDA analysis. Abbreviations: G0, CG, GS, GB and U (see Table 1 footnote); * indicates interaction of environmental variables; AveFle – *Avenella flexuosa*, BetPen – *Betula pendula*, CalEpi – *Calamgrostis epigejos*, CarBet – *Carpinus betulus*, CarMon – *Carex montana*, CerArv – *Cerastium arvense*, CerAvi – *Cerasus avium*, CruLae – *Cruciata leavipes*, DacGlo – *Dactylis glomerata*, DauCar – *Daucus carota*, DiaCar – *Dianthus cartusianorum*, FesPra – *Festuca pratense*, FesRub – *Festuca rubra*, GalApa – *Galium aparine*, GalMol – *Galium mollugo*, GalTet – *Galeopsis tetrahit*, HypPer – *Hypericum perforatum*, LeoAut – *Leontodon autumnalis*, LeuVul – *Leucanthemum vulgare*, LotCor – *Lotus corniculatus*, LuzSyl – *Luzula sylvatica*, PhlPra – *Phleum pratense*, PimSax – *Pimpinella saxifraga*, PlaMaj – *Plantago major*, PoaAnn – *Poa annua*, PoaPra – *Poa pratensis*, PoaTri – *Poa trivialis*, PopTre – *Populus tremula*, PotArg – *Potentilla argentea*, RanLan – *Ranunculus lanuginosus*, RubIda – *Rubus idaeus*, SagPro – *Sagina procumbens*, TarOff – *Taraxacum* sp., ThySer – *Thymus serphyllum*, TriPra – *Trifolium pratense*, TriRep – *Trifolium repens*, VerCha – *Veronica chamaedris*, VicCra – *Vicia cracca*, VicSep – *Vicia septum,* VioTri – *Viola tricolor*, VisVul – *Viscaria vulgaris*.

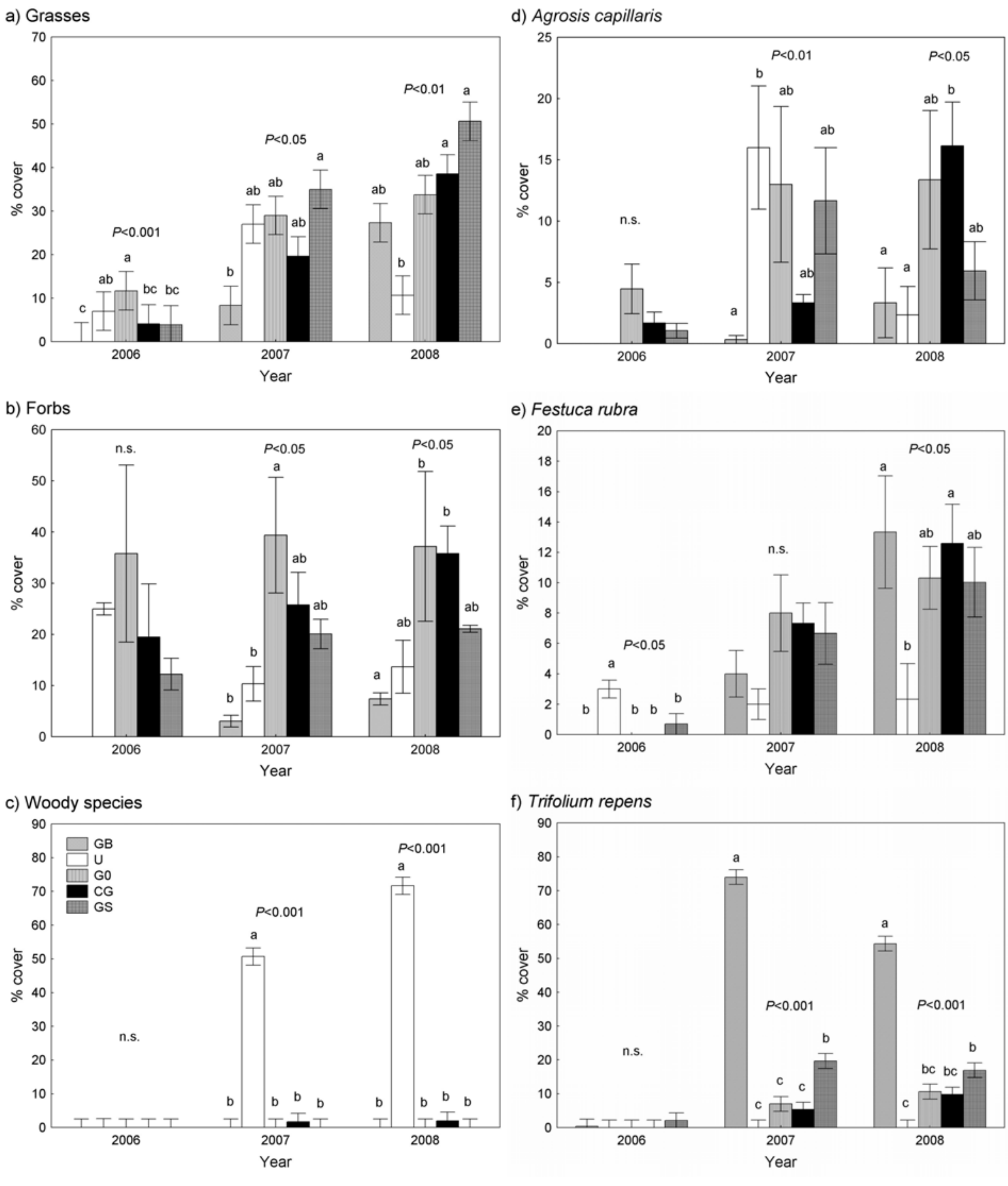

Figure 4 Changes in cover (%) of simple functional traits (a, b, c) and dominant species (d, e, f) per 1 m^2 in treatments during the years 2006-2008. *P* represents probability value obtained by one-way ANOVA. Degrees of freedom were four in all analyses. Significant differences (*P*<0.05) according to the Tukey *post hoc* test are indicated by different letters. Error bars represent standard errors of the mean.

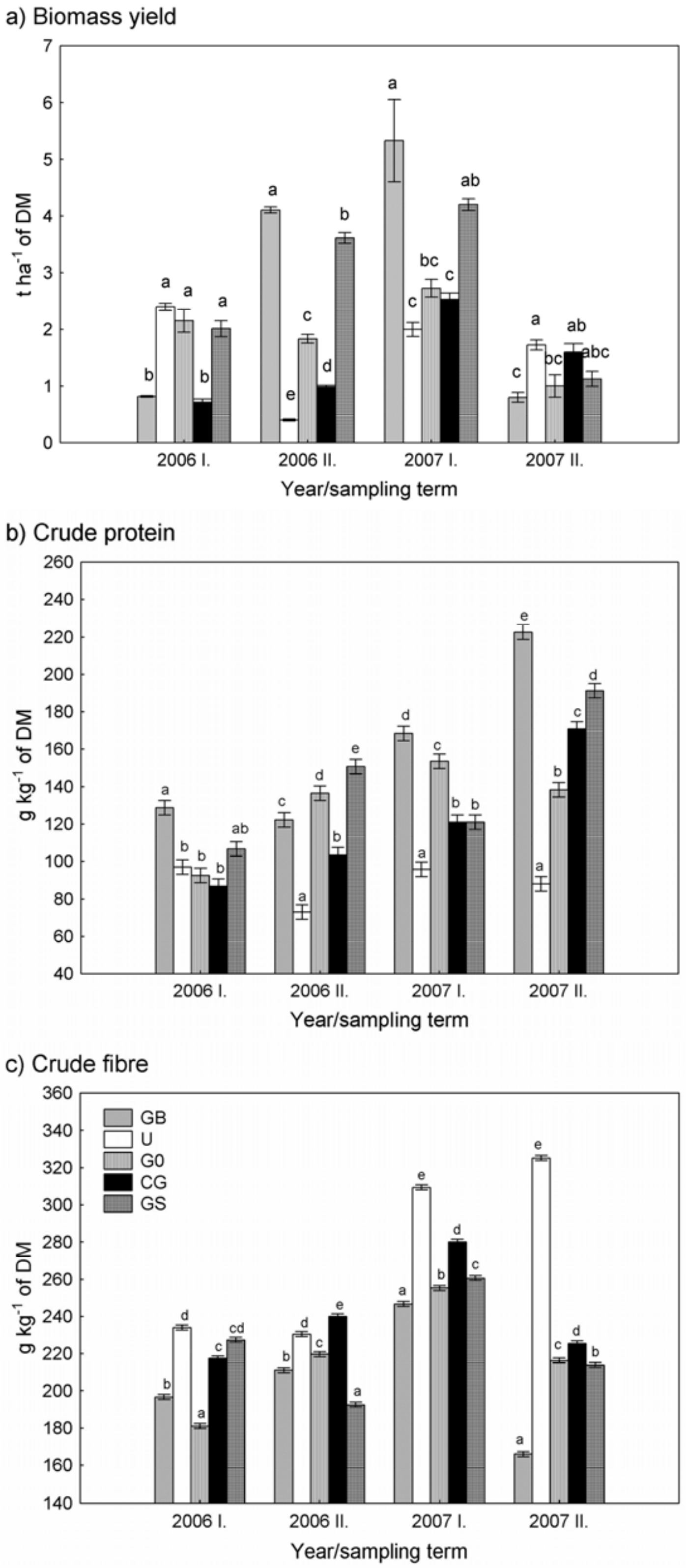

Figure 5 Biomass yield (a) and quality (b,c) in two sampling terms in the years 2006-2007. I.-first term of sampling (June), II. second term of sampling (September). *P* represents probability value obtained by one-way ANOVA for sampling term in each year and was *P*<0.01 for all analyses. Degrees of freedom were four in all analyses. Significant differences (*P*<0.05) according to the Tukey *post hoc* test are indicated by different letters. Error bars represent standard errors of the mean.

Chapter 7

Principal Conclusions of the Thesis

The PhD thesis was focused on the study of cattle grazing, mainly its effect on the sward structure and botanical composition of sward both in a short term as well as in a long term scale. Despite the fact that grazing by large herbivores is being studied worldwide there is still a lack of detailed vegetation studies focused on the relationship between stocking intensity and the height structure of sward patches. Many of studies concerning on the effects of grazing management are often interpreted as results of only defoliation and the other two types of disturbances accompanying grazing processes, trampling and nutrient addition by faeces, are frequently underestimated or ignored. Therefore, the first part of the thesis paid attention to the absence of trampling over the long term and its consequences on grazed swards. Also the knowledge of detailed grassland vegetation characteristics and its evolution after changes in management exploitation of grasslands is very important to be studied in our times of global changes, such as decline of biodiversity or increase in human population and thus the need of livestock. This was the objective of the last part of the thesis.

The contribution of the thesis for the current stage of scientific knowledge is evident from the individual papers mentioned above. Following there is very briefly summarized the main benefit of each paper.

Chapter 2: Species forming typical pasture communities are essentially dependent on both types of disturbances caused by grazing by large herbivores i) regular defoliation by grazing and ii) regular trampling by hooves. In our study we have shown that the species present in pasture swards do not profit only from regular defoliation resulting in good light conditions for remain species. They also need bare-ground disturbances and sward compaction which favour them in strong intraspecific competition with other plant species. Long-term defoliation by grazing animals in the absence of trampling did not lead to the creation of typical pasture structure and in the sward there prevailed bryophytes.

Chapter 3: The main difference in the patch structure of the sward between intensively and extensively grazed species-rich grassland was in the proportions of short and tall sward-height patches, whereas the proportion of moderate-height patches was similar under both stocking densities. The floristic composition of short-height patches differed considerably from other patches under extensive grazing, whereas under intensive grazing the differences between short, moderate and tall sward patches were small. The absence of large differences in floristic composition among sward height patches under intensive grazing may suggest that this stocking density promotes rather botanically homogeneous sward despite the occurrence of a heterogeneous height structure of the sward. These findings have implications for nature conservation as they support the recommendation for an extensive management of species-rich grasslands.

Chapter 4: Different grazing intensity caused the presence of plant species with different plant life strategy (*sensu* Grime 1974). Although it has shown that intensive grazing favours ruderal strategy and extensive grazing competitive strategy, the results were affected by the abundance of different sward patches in treatments. Therefore, the rate of each C-S-R strategy was more dependent on the rate of different sward patches in treatments than by grazing intensity itself.

Chapter 5: Not only applied grazing systems or different grazing intensities have an impact on the composition and the structure of grazed sward but also the successional development, regardless of treatments, significantly affects the sward structure of upland grassland during the first vegetation season after management introduction. As a key factor affecting sward structure during the course of vegetation season appears to be i) behaviour of dominant species, ii) plant biomass growth and iii) dead material accumulation.

Chapter 6: The restoration of grassland vegetation on long-term abandoned wooded pasture by deforestation and reintroduction grazing management is a relatively fast process in the case of situations where grasslands are already present in the vicinity of the deforested area. A recovery of bare ground by germination and growth of grassland species were very fast in all evaluated types of grazing management, moreover, the artificial seeding by target species can further accelerate this process. It should be noted that for the restoration of grassland vegetation there is also very important its subsequent maintenance. For the subsequent maintenance of the grassland, some form of grazing management is necessary to prevent reforestation, which occurs on unmanaged sites immediately after deforestation.

Chapter 8

Recommendations for Further Research

With respect to current scientific knowledge on the impact of grazing and because of the absence of long-term experiments, further research should be focused on the following topics:

- Long-term changes on grazed species-rich grasslands;
- Based on the importance of different sward patches within grazed grasslands to study its seasonal and annual stability under the influence of different grazing intensities;
- The impact of animal's defecations on the dynamic of sward patches;
- Detailed measurements of plant traits on species occurring in all types of sward patches;
- Based on the importance of plant functional types and of plant traits to generalize effects of grazing in different geographic conditions.

Chapter 9

Souhrn (Summary in Czech)

Disertační práce se zabývá studiem pastvy skotu a především jeho vlivu na strukturu travního porostu a jeho druhového složení. Kapitoly 2 – 4 se zabývají vlastnostmi travního porostu utvořenými pod dlouhodobým řízeným pastevním managementem. Kapitoly 5 a 6 se zabývají krátkodobými změnami, které nastanou v travních porostech po změně jejich využívání a to jednak sezónními změnami v porostu po zavedení odlišných způsobů pastevního obhospodařování a jednak vlivem pastvy na odlesněných plochách. Výsledky a přínos jednotlivých studií pro vědecké poznání je patrný z výše uvedených vědeckých článků v kapitolách 2 – 6. V následujících bodech jsou velmi stručně vyjádřeny hlavní aspekty každé studie.

Kapitola 2: Druhy utvářející typická pastevní rostlinná společenstva jsou dlouhodobě závislé na obou typech disturbancí, které pastva velkými herbivory způsobuje a to jednak na i) odstraňování nadzemní biomasy a na ii) sešlapu a narušování vegetačního krytu. V naší studii jsme ukázali, že druhy přítomné v pastevních porostech neprofitují pouze z odstraňování nadzemní biomasy pastvou, které vede ke zlepšení světelných podmínek. Tyto druhy také vyžadují narušování půdního povrchu a sešlap travního drnu, což je upřednostňuje před ostatními druhy v silné mezidruhové konkurenci. Při absenci sešlapu se nevytvořila typická pastevní struktura a v porostu převažovaly mechorosty.

Kapitola 3: Hlavním rozdílem ve struktuře travního porostu mezi intenzivní a extenzivní pastvou byla proporce nízkých spasených a vysokých nespásaných plošek, zatímco podíl středně vysokých plošek byl podobný v obou studovaných intenzitách pastvy. Druhové složení nízkých plošek se pod extenzivní pastvou významně lišilo od ostatních, vyšších a méně spásaných, plošek. Při intenzivní pastvě nebyly rozdíly ve druhovém složení mezi jednotlivými různě vysokými ploškami tak výrazné. Vyplývá z toho tedy, že malé rozdíly ve druhovém složení mezi jednotlivými různě vysokými ploškami, které se vytváří při intenzivní pastvě, může svědčit o tom, že právě intenzivní pastva podporuje botanicky homogenní porost i navzdory jeho heterogenního charakteru ve smyslu různě vysokých plošek travního porostu. Tento výsledek má dopady i v ochraně přírody, neboť tímto podporuje doporučení extenzivní pastvy jako vhodného prostředku využívání druhově bohatých travních porostů.

Kapitola 4: Různá intenzita pastvy způsobila přítomnost rostlinných druhů s různou životní strategií (*sensu* Grime 1974). I přesto, že bylo prokázáno, že intenzivní pastva podporuje ruderální strategii a extenzivní pastva konkurenční strategii, výsledky byly ovlivněny zejména podílem různě vysokých plošek travního porostu v rámci jednotlivých variant intenzity pastvy. Z toho důvodu je míra C-S-R strategie více závislá na podílu různě vysokých plošek na pastvině než na intenzitě pastvy jako takové.

Kapitola 5: Nejen různé pastevní systémy a různá intenzita pastvy mají významný vliv na složení a strukturu travního porostu. Po zavedení různého pastevního obhospodařování dochází k signifikantním změnám již v průběhu první vegetační sezóny a to i bez ohledu na intenzitu pastvy. Jako klíčové faktory ovlivňující strukturu travního porostu v průběhu vegetační sezóny se jeví chování dominantních druhů, nárůst rostlinné biomasy a množství nahromaděné odumřelé biomasy.

Kapitola 6: Obnova bývalého travního porostu po odlesnění a po znovuzavedení pastvy je relativně rychlý proces v případě, že se v okolní blízkosti takové plochy nachází jiný travní porost. Klíčení a růst typických druhů travních porostů bylo velmi rychlé, navíc umělý přísev tento proces ještě urychlil. Nutno podotknout, že při obnově travních porostů je velmi důležitá také jejich následná údržba. Jakákoliv forma pastevního obhospodařování je pro zamezení opětovného zalesnění nevyhnutelná, neboť sukcesí k zalesnění na neobhospodařovaných plochách dochází záhy.

List of publications

Papers in scientific journals with impact factor:

Ludvíková V., Pavlů V., Pavlů L., Gaisler J. & *Hejcman M.,* 2012: Structure of sward-height patches under intensive and extensive grazing on upland species-rich grassland in Central Europe. Submitted paper.

Ludvíková V., Pavlů V., *Gaisler J*., *Pavlů L.* & *Hejcman M*., 2012: What is the effect of cattle trampling on vegetation in a long-term grazing experiment? Submitted paper.

Novák J., Pavlů V. & Ludvíková V., 2012: Reindroduction of grazing management after deforestation of formerly abandoned grassland and its effect on early vegetation changes in the Western Carpathians (Slovakia). *Grass and Forage Science*. In press.

Pavlů V., Gaisler J., Pavlů L., Hejcman M. & *Ludvíková V.*, 2012: Effect of fertiliser application on plant species composition of *Festuca rubra* grassland under cutting management and its after effect under abandonment. *Acta Oecologica* 45: 42-49.

Papers in other scientific journals:

Pavlů V., Šimáčková H., Ludvíková V., Gaisler J., Pavlů L. & Hejcman M., 2012: Effect of different grazing systems on sward structure during the first vegetation season after management introduction. *Grassland Science in Europe* 17: 105-107.

Ludvíková V. & Pavlů V., 2010: Plant strategies in relation to different grazing intensities. *Grassland Science in Europe* 15: 815-817.

Ludvíková V., Pavlů V., Hejcman M. & Gaisler J., 2009: Effect of grazing intensity on the structure of sward patches. *Grassland Science in Europe* 14: 166-168.

Chapters in books:

Pavlů V., Gaisler J., Pavlů L., Ludvíková V. & Hejcman M., 2012: Grasslands: Resumption of grazing management on abandoned upland grasslands in the Jizera Mountains In: Jongepierová I., Pešout P., Jongepier J.W. & Prach K. (eds.): Ecological restoration in the Czech Republic. AOPK ČR, Prague, pp. 49-50, in press.

Papers from the scientific conferences in English:

Ludvíková V., Pavlů V., *Gaisler J. & Pavlů L.*, 2012: What is the effect of cattle trampling on vegetation and soil compaction in a long-term grazing experiment? In: 3rd European Congress of Conservation Biology 2012, Book of abstracts, Glasgow: 67.

Ludvíková V. & Pavlů V., 2009: Diversity of sward structure under different grazing intensity. In: 2nd European Congress of Conservation Biology 2009, Book of abstracts, FŽP ČZU, Praha: 190.

Ludvíková V., Pavlů V., Hejcman M. & Guerovich M., 2007: The effect of different grazing intensity on structure of sward patches. In: De Vliegher A. and Carlier L. (Eds.): Permanent and Temporary Grassland, Plant, Environment and Economy. Occasional meeting of European Grassland Federation, Ghent, Belgium (Book of abstracts): 34.

Papers from the scientific conferences in Czech:

Halušková D., Hosnedl J., Ludvíková V. & Pavlů V., 2010: Vliv různé intenzity pastvy na strukturu porostu – nedopasky x spásané plochy (Effect of different grazing intensity of sward structure – neglected patches x grazed patches) In: Louky: biodiverzita a management (Třeboň 20.-21. března 2010), book of abstracts, Třeboň: 39.

Ludvíková V. & Pavlů V., 2008: Vliv intenzity pastvy na travní porost (Effect of grazing intensity of sward). In: Harabiš F. & Suvorov P. (eds.): Kostelecké inspirování 2008, book of abstracts. FŽP ČZU, Praha: 31.

Ludvíková V., 2007: Dynamika travního porostu na Betlémě (Dynamic of sward in Betlem). In: Vojar J., Svobodová J., Zasadil P., Mrštný L., Podskalská H. (eds.): Kostelecké inspirování 2007, book of abstracts. FLE ČZU, Praha: 22.

Ludvíková V., 2006: Výška travního porostu jako indikátor selektivního vypásání skotem (Sward height as an indicator of selective defoliation of cattle). In: Dvořák J., Natov P. (eds): COYOUS 2006, book of papers on CD. FLE ČZU, Praha.

Ludvíková V., 2006: Vliv různé intenzity pastvy na strukturu travního porostu (Effect of different grazing intensity of sward structure). In: Zasadil P., Mrštný L. & Podskalská H. (eds.): Biodiverzita 2006, book of abstracts. FLE ČZU, Praha: 15.

Ludvíková, V., 2005: Studium flóry v přírodním parku Okolí Okoře (Study of flora in natural park Okolí Okoře). In: Podskalská H. & Zasadil P. (Eds.): Biodiverzita 2005, book of abstracts, Chloumek u Mělníka 5. – 6. 11. 2005, ČZU v Praze: 16.

Papers in professional journals:

Ludvíková V., Pavlů V. & Hejcman M., 2009: Tvorba struktury pastevního porostu (Creation of structure of grazed sward). *Úroda* 8: 48-49.

Ludvíková V., Hejcman M., Pavlů V., Pazdera J., 2006: Jsou třezalky v travních porostech škodlivé? (Are St John's worts harmful when presented in grasslands?). *Úroda* 10: 35-37.