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BURNING HAY AS A TOOL IN CONSERVATION OF MOUNTAIN GRASSLAND VEGETATION IN PROTECTED AREAS

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ABSTRACT

In some areas of Polish Carpathians high nature value grasslands are managed only because of agri-environmental subsidies or as an active preservation measures in protected areas. Due to the abandonment of livestock farming the problem is the dispose of collected biomass. In the Pieniny National Park in some cases the hay harvested and collected in pile is burned. The aim of the study was to evaluate the impact of the burning of a large amount of hay on vegetation and assess the possibility of using this measure in preservation of species rich plant communities. In 1997 piles of hay were burned on 17 plots. On the burned plots plant and soil analysis were determined in years 1998–2001 and repeated in 2014. During the first four years there was a significant increase in the content of available phosphorus, potassium and soil pH. As a result, at the beginning, increased growth of legumes, was observed. Next, the grass species began to appear in greater number. After 17 years soil parameters of burnt plots were similar to that of surrounding areas and no considerable differences in plant composition was observed. However, some of burnt plots were still distinguishable on the meadow. Under certain conditions, the burning of hay can be used in management of grassland.

Keywords: fire ecology, grassland management, nature conservation

INTRODUCTION

Grasslands and pastures are an integral element of the landscape of mountains, shaped by the effects of many centuries of traditional agriculture (Hejcman et al., 2013; Dengler et al., 2014). The grasslands of the Carpathian Mountains are included among plant communities with the highest species diversity in the world (Wilson et al., 2012). Grazing, animal husbandry and processing of animal products have led to the development of numerous local customs, increasing cultural diversity. In some parts of the Carpathians traditional farming continues to function (Babai and Molnár, 2014), but in many cases social and economic transformations are leading to the disappearance of traditionally managed grasslands (MacDonald et al., 2000; Hejcman et al., 2013; Nagata and Ushimaru, 2016).

Agri-environmental programmes can help to preserve multi-species, semi-natural grassland communities (Kampmann et al., 2012), and mowing is an active conservation measure in protected areas. The main purpose of management of grassland and pastures has been to produce feed for animals. Recent decades, however, have seen a sharp decline in the size of the livestock population in mountain regions in Europe (Huyghe et al., 2014) thus a decrease in the demand for feed. The problem is especially important in the Polish Carpathians (Zarzycki and Korzeniak, 2013). In Pieniny National Park (PNP) the problem

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of utilization of biomass concerns low-quality, spoilt hay accumulated in clearings, which is difficult to transport. In this case biomass accumulated in a pile is burned. This method was used in the past and is still used in many countries, but only in exceptionally, in the case of unusable hay. It is subject to numerous legal restrictions, but in protected areas the use of fire for environmental protection purposes is often governed by separate regulations (Montiel and Kraus, 2010). Burning hay is in compliance with the conservation plan of PNP.

Fire is increasingly finding application in nature conservation in Europe (Goldammer et al., 1997; Montiel and Kraus, 2010). In the case of heaths it is an element of their traditional management, having been used for centuries, for example, in the UK (Webb, 1998). In other types of grassland communities the traditional use of fire has been relatively rare. Currently, due to the high costs of mowing, the possibility of burning as an alternative is being explored (Pyke et al., 2010; Pereira et al., 2012; Valkó et al., 2014, 2016).

In contrast with burning of grassland sward, burning a large quantity of biomass in one place has a considerably more intensive and long-lasting effect, but on a limited area. The objective of the study was to analyze changes in the species composition of sites on which a large quantity of hay was burned, in connection with changes in selected chemical parameters of the soil within the first four years after the burning, and then to analyze the state of these plots after 17 years, in order to assess the potential for using this treatment in active conservation of grassland communities.

MATERIALS AND METHODS

The site of the experiment was Pieniny National Park (49°25'N, 20°24'E), situated in the Carpathian Mountains on the border between Poland and Slovakia. The clearings where the study was carried out are located in a forested zone at an elevation of 610–780 m a.s.l. The substrate consists of Eutric Cambisols (Skiba et al., 2002). The mean annual air temperature is 3.9–6.3°C, and the annual precipitation totals are 690–850 mm (Perzanowska, 2004). Grasslands account for nearly 20% of the area of the park and are one of the main objects of conservation. They are dominated by semi-natural mesic grassland communities of the order *Arrhenatheretalia*, especially the association *Anthyllidi-Trifolietum montani*, counted among the most species-rich plant communities in Poland (Kaźmierczakowa et al., 2004).

Multivariate field experiments are the best approach to studying the impact of particular treatments on vegetation. However, simple observations on selected plots, despite numerous limitations, are often used in a practical approach to conservation (Galvanek et al., 2015). In this case as the experimental plots were selected places where hay gathered as an active conservation measure had been burned. Due to the use of management measures rather than a planned experiment, the plots differed in size and in the amount of biomass burned, and therefore in the impact of the burning on the soil and vegetation. For this reason the plots were not treated as replications, but general trends were analyzed for each of the plot. About 300 kg of dried hay was burned at the end of July in 1997 on a surface about 3 m in diameter. The ashes were dispersed using a hay tedder. In 1998 two distinguishable zones originated, the central zone was covered by a layer of charred biomass and was surrounded by the edge zone with luxuriantly growing plants. In each zone the species composition was recorded on 17 plots where biomass has been burned the previous year. The results of further analyses were presented for only 8 plots, which were definitively identified in 2014. Plant species composition was evaluated using the Braun-Blanquet scale (Braun-Blanquet, 1964). Until 2001 the evaluation was conducted every year - first separately in the central and edge zone, and then jointly when the entire surface was covered with homogeneous vegetation. In 2014 the evaluation was continued on the plots where burning had taken place and on the area around up to 2 m from the burnt place. In 1998 soil samples were collected from the top layer of the 8 selected plots – from the central zone, from the edge zone where the effect of burning was evident, and from the area surrounding the burnt place. In 1999–2001 and in 2014 from the central zone and edge zone together and from the surrounding area. From each zone three soil subsamples were collected from a depth of 0–10 cm. Then they were mixed forming a collective sample. In cases where there was a layer of ash and charcoal, it was removed.

In the soil samples pH was determined by the potentiometric method, and the content of available phosphorus and potassium by the Egner-Riehm method. Changes in the species composition of the plots were analyzed by detrended correspondence analysis (DCA) using Canoco software (ter Braak and Smilauer, 2002).

RESULTS

Chemical properties of the soil

Combustion of a large quantity of plant biomass led to mineralization of organic compounds and a sharp increase in the content of some elements on a small surface. In the first year after the burning, the potassium content ranged from 20 to 112 mg kg^{-1} in the central zone of the plot. The range was similar in the edge strip (42–115 mg kg^{-1}); in individual plots potassium content was higher or lower than in the ash-covered central zone, but substantially exceeded the normal potassium concentration in the soils of the surrounding area (see: Fig. 1a). Phosphorus content in the central zone ranged from 23 to 87 mg kg^{-1}. In the edge zone of all plots a decrease in this concentration was noted; it ranged from 13 to 45 mg kg^{-1}, but was still higher than in the soil of unburnt areas (4–9 mg kg^{-1}) (see: Fig. 1b). Burning of biomass also caused a considerable increase in the pH of the top layer of the soil, especially in the central zone, where it ranged from 6.2 to 6.9 and was higher than in the edge zone (5.2 to 6.4) and much higher than in the surrounding area (4.8 to 5.3) (see: Fig. 1c).

On most of the plots potassium content decreased from year to year, (see: Fig. 2a), but in 2001 it was still higher than in the surrounding area, in some plots reaching even 400%. While increased potassium content was observed in the case of five plots in 2014, these differences were small. Content of available phosphorus (see: Fig. 2b) was substantially elevated with respect to the surrounding area. In the first three years after the biomass was burned it remained at a similar level, far exceeding (600–1.400%) the level in the surrounding area. In 2001 it increased further, to as high as 2.700% of the phosphorus level in the unburnt area. In 2014 the phosphorus content in the burnt areas differed only very slightly from the values in the surrounding soil, and in the case of two plots was even lower (see: Fig. 2b). The reduction in soil pH was relatively slow. As in the case of phosphorus and potassium, despite the overall downward trend, on individual plots a temporary increase in soil pH was noted in some years. After 17 years a slight increase in pH persisted on 6 plots (see: Fig. 2c).

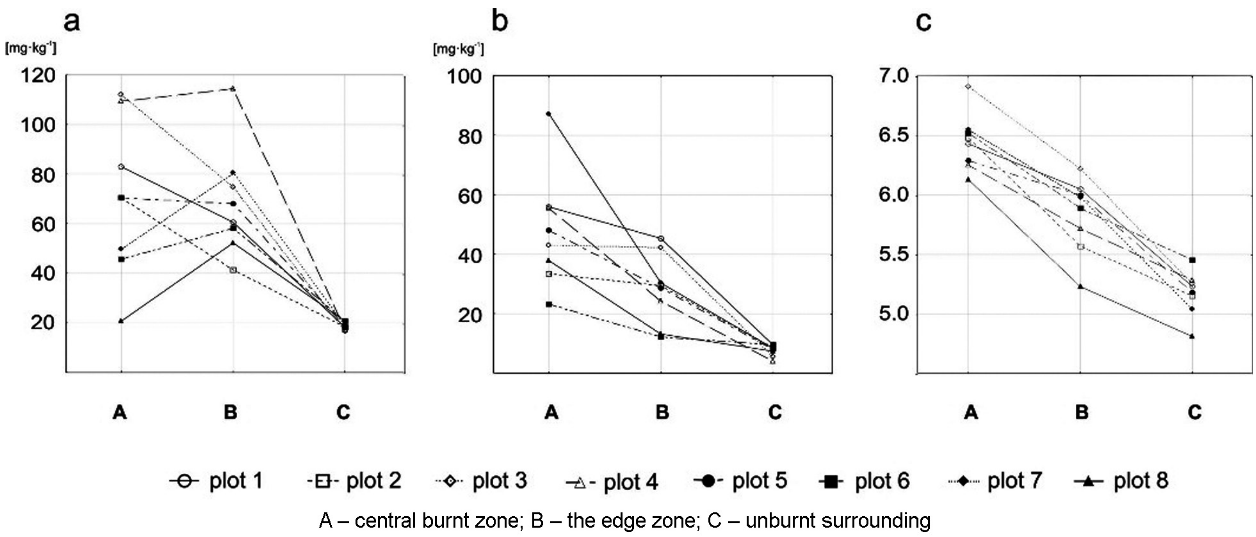

Fig. 1. The chemical parameters of soil a year after burning (1998): a) available potassium content; b) available phosphorus content; c) soil reaction (pH)

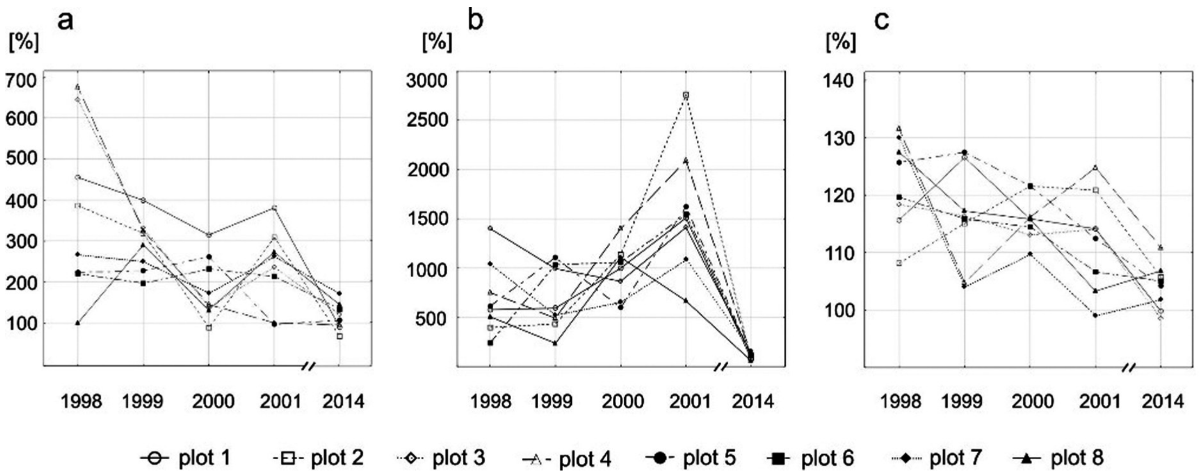

Fig. 2. The chemical parameters (1998–2014) of soil of burnt plots in relation to the same parameters in surrounding areas: a) available potassium content; b) available phosphorus content; c) soil reaction (pH)

VEGETATION

The next year after burning a surface had emerged on which two zones could be distinguished: a central zone still partly covered with ash, on which only isolated plants appeared and attained small area cover, approximately 50%, and an edge zone, with complete vegetation cover (see: Table 1). The species appearing on the burnt surfaces were those occurring in the grassland surrounding these plots. We can distinguish the species which only slightly penetrated the central zone, or not at all, and those which developed fairly rapidly in the central zone and attained relatively high area cover in comparison to edge zone (see: Table 1). Among such species taking advantage of the altered habitat conditions, plants of the *Fabaceae* family are dominant. In comparison to edge zone, kidney vetch (*Anthyllis vulneraria*) is very common. Other species of the *Fabaceae* family appearing abundantly at the hay burning sites include zigzag clover (*Trifolium medium*), red clover (*T. pratense*), white clover (*T. repens*) and bird's-foot trefoil (*Lotus corniculatus*). appeared on just a few plots, but with very high area cover. Some plant species occurred commonly around the central zone, but only sporadically appeared on these sites (see: Table 1). These include cock's-foot (*Dactylis glomerata*) and meadow fescue (*Festuca pratensis*) among grasses.

All plots were distinguishable from the surrounding grassland vegetation until 2001. They were characterized by considerably greater mean plant height (more than two-fold) and highly luxuriant growth of *Fabaceae* species. Individual plots differed, however, in species composition; they were often dominated by single species such as meadow pea (*Lathyrus pratensis*), yellow false oat (*Trisetum flavescens*), zigzag clover, red clover that colonized the plots in the first year after the hay burning (see: Table 2). In 2014, so after 17 years of hay burning, plots still had slightly darker color of sward, but in most cases their species composition did not differ from that of the surrounding areas. On the DCA diagram (see: Fig. 3) showing the variation in species composition of the plots, the phytosociological relevés made in 1998 in the central zones formed the most distinct group, associated with *Fabaceae* species. The differences in species composition between these plots are due to the random colonization of these plots by grassland species. In subsequent years (up to 2001) the species composition on the plots was getting less diverse. In 2014 the relevés from the burnt plots form a cluster together with the relevés made on the surrounding grasslands.

Table 1. Frequency and cover coefficient of plant species on burnt and edge zone (17 plots) in one year after biomass burning. Only species with frequency more than 60% are displayed.

Plant group	Species	Burnt zone		Unburnt zone	
		Total plant cover [%]			
		< 50%		> 100%	
		Frequency [%]	Cover coefficient	Frequency [%]	Cover coefficient
G	*Agrostis capillaris*	88	415	94	2618
H	*Tragopogon orientalis*	88	313	76	328
L	*Trifolium medium*	88	974	88	1752
L	*Anthyllis vulneraria*	82	386	6	1
H	*Potentilla erecta*	76	36	76	503
L	*Trifolium pratense*	71	678	65	722
L	*Trifolium repens*	71	636	65	166
G	*Festuca rubra*	65	35	100	1104
L	*Lotus corniculatus*	65	326	71	458
H	*Pimpinella major*	60	195	94	489
H	*Centaurea scabiosa*	60	444	76	666
H	*Hypericum maculatum*	47	136	82	622
H	*Rumex acetosa*	47	5	82	66
G	*Anthoxanthum odoratum*	41	164	82	842
H	*Plantago lanceolata*	41	33	82	197
H	*Centaurea jacea*	35	32	100	621
H	*Ranunculus acris*	35	4	65	35
H	*Alchemilla species*	35	4	60	166
L	*Vicia cracca*	35	106	71	167
G	*Dactylis glomerata*	29	32	100	461
H	*Ranunculus polyanthemos*	29	3	94	182
H	*Achillea millefolium*	29	32	76	139
H	*Rhinanthus minor*	18	2	94	154
H	*Campanula glomerata*	18	2	65	35
H	*Veronica chamaedrys*	12	30	82	8
H	*Cruciata glabra*	12	1	65	6
G	*Festuca pratensis*	6	1	76	299
G	*Trisetum flavescens*	6	1	60	606
H	*Astrantia major*	6	1	76	328
L	*Trifolium montanum*	0	0	65	122

Plant group: G – grasses, H – herbs, L – legumes
Frequency: percent of species occurrence on plots in each zone
Cover coefficient = ∑ species cover [%] in all releves / number of all releves

Table 2. Most frequent and dominant species on 8 plots in the 4th (2001) year after biomass burning. Cover in Braun -Blanquet scale.

Plant group	Species	Number of plots	Cover min	Cover max
G	*Agrostis capillaris*	8	+	3
H	*Centaurea jacea*	8	1	3
H	*Achillea millefolium*	8	+	1
H	*Campanula patula*	8	+	1
G	*Dactylis glomerata*	8	1	3
H	*Hypericum maculatum*	8	+	2
H	*Rhinanthus minor*	8	+	1
L	*Trifolium pratense*	7	0	3
L	*Trifolium repens*	7	0	2
G	*Festuca rubra*	7	0	2
H	*Knautia arvensis*	7	0	1
H	*Plantago lanceolata*	7	0	1
L	*Trifolium medium*	7	0	3
H	*Veronica chamaedrys*	7	+	2
L	*Vicia cracca*	7	0	2
H	*Tragopogon pratensis*	6	0	1
G	*Trisetum flavescens*	6	0	4
L	*Lathyrus pratensis*	5	0	4

Plant group: G – grasses, H – herbs, L – legumes

DISCUSSION

Fire affects environment in numerous ways (Pereira et al., 2016). The scale of its impact depends mainly on the intensity of the fire, i.e. the maximum temperature of the fire and its duration (Certini, 2005). Fires affect vegetation mainly through high temperature and the ash left behind (Vogl, 1979; Pereira et al., 2016). Heat generated during grassland fires increases the soil temperature only slightly and the duration of the exposure to the high temperature is short (Zarzycki and Szymacha, 2006; Ruprecht et al., 2013; Aznar et al., 2016). Burning of a large quantity of hay on a small surface, however, is more similar to fires in high-volume forest stands in which the temperature of the soil surface may reach even 850°C (DeBano, 2000).

In the experiment a considerable increase in P and K content was noted on the burnt plots as compared to the levels in the adjacent grassland soils. These values, however, are within the ranges occurring in agricultural soils in Poland (IUNG, 2010). The strong influence of increased pH and available P and K on vegetation may be due to the very low level of these parameters in the soils of the Pieniny Mountain (Kobza, 2002). In the case of available phosphorus a considerable increase in its concentration was observed in the soil of the plots in the fourth year after the burning (see: Fig. 2). This was probably caused by phosphorus speciation in the soil; the content of the available forms of phosphorus is highly subject to the modifying effects of environmental factors (Chen et al., 2012).

Complete combustion of organic matter generates mineral ash (Bodi et al., 2014). Among basic nutrients the increase in the content of P and K after fire (Maksimova and Abakumov, 2015) is most important. Nitrogen, however, may be blown or washed away (Raison, 1979; Niemeyer et al., 2005). The observed elevation of soil pH value influenced plant growth as it is a significant parameter for vegetation development (Nagata and Ushimaru, 2016; Merunkova and Chytry, 2012). After burning of biomass the pH increases due to dissolution of chemical compounds contained in the ash - mainly calcium, magnesium and potassium (Raison, 1979; Bodi et al., 2014; Pereira et al., 2017).

After the hay was burned, in the central part of the plot a surface emerged that was devoid of vegetation and covered with a layer of ash and charcoal from the burnt biomass. In the strip around it all of the vegetation was not destroyed directly, but the concentration of mineral nutrients from the burnt biomass increased, which led to more luxuriant vegetation. The appearance of new specimens on the central, burnt surface was initially impeded by the formation of a layer of ash and charcoal (ash bed) (Raison, 1979). In the first year after the hay burning accidental species growing nearby appeared, as the gaps in vegetation are usually colonized by species of the surrounding vegetation (Cichini et al., 2011). However, only certain species, which were best able to take advantage of the altered soil parameters, attained a large size and substantial area cover. First to settle the burnt area were plants of the *Fabaceae* family. Owing to symbiosis with *Rhizobium* bacteria (Roscher et al., 2011), they may utilize atmospheric nitrogen, but for this they require alkaline soils with high content of phosphorus, potassium and calcium (Divito and Sadras, 2014), whose source in this case is ash. The species with the strongest positive response to the conditions arising after the hay burning was kidney vetch (*Anthylis vulneraria*). In some ecosystems, particularly in warm climates, plants of the *Fabaceae* family are considered able to take advantage of vegetation fires (Towne and Knapp, 1996).

In successive years after the burning various species of forbs and grasses appeared, while a substantial share of *Fabaceae* persisted. This was due to a decrease in the content of minerals (P, K) and enrichment of the soil with nitrogen by *Rhizobium* bacteria (Roder et al., 2007). Warren (2000) observed a similar mechanism whereby the share of grasses was increased due to enrichment of the soil with nitrogen by white clover. Enrichment of the soil with nitrogen owing to increased occurrence of nitrogen-fixing species has also been observed after fires in numerous forest ecosystems (Johnson and Curtis, 2001). Seventeen years after the burning the soil parameters on the burnt plots did not differ from the values noted in the surrounding soil (see: Fig. 2). Similarly, there were no differences in species composition between former burnt plots and surrounding grasslands (see: Fig. 3).

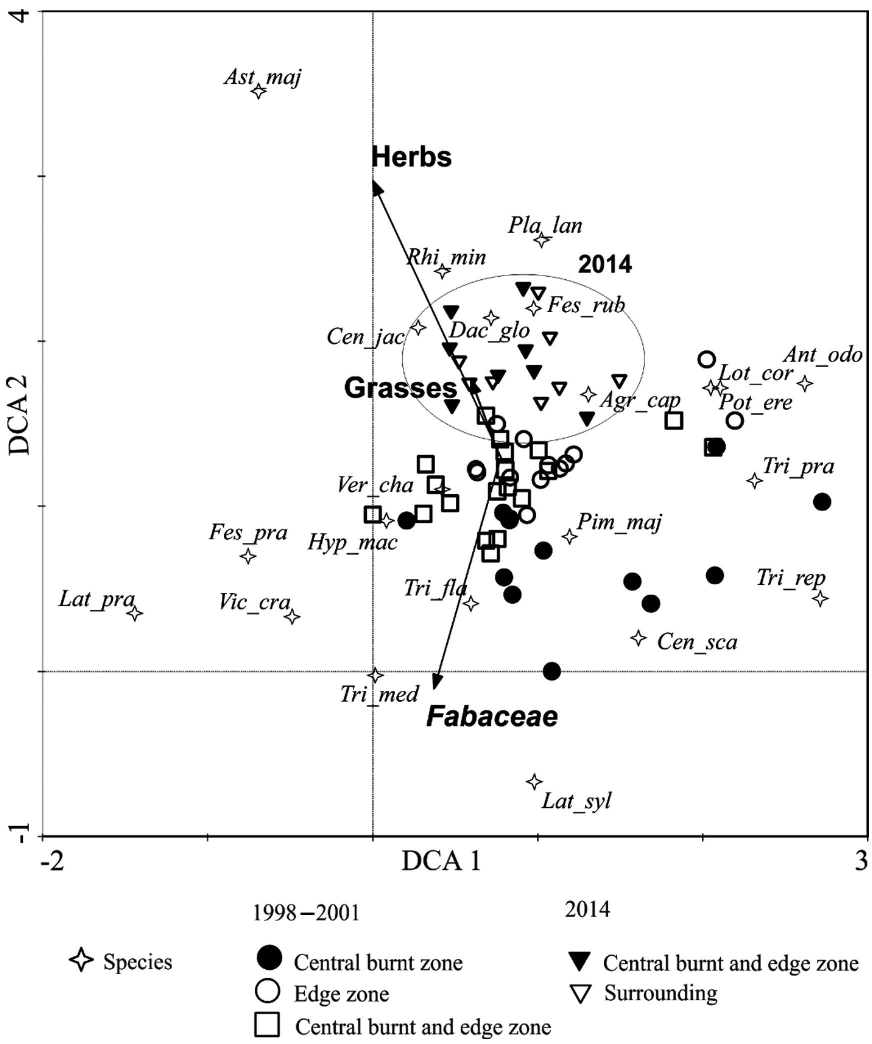

Fig. 3. Ordination diagram of species and plots based on DCA analysis for the whole dataset (1998–2001 and 2014). Only the species that best fit the model are plotted. First ordination axis: λ=0.227, gradient length 2.74, cumulative percentage of variance explained 11.9 %. Second ordination axis: λ=0.156, gradient length 2.163, cumulative percentage of variance explained is 20.1%.

Burning of small patches may lead to a beneficial increase in species diversity by modifying local habitat conditions (Valkó et al., 2016). On poor soils increased nutrient content may be beneficial to diversity (Kopeć et al., 2010), but on fertile soils it is considered the main factor limiting diversity (Marrs, 1993; Merunkova and Chytry, 2012). Modification of the means of burning, involving burning of hay on a grate or burning of smaller amounts of biomass and thorough raking of the ashes, would limit the appearance of highly distinctive surfaces in the landscape.

CONCLUSIONS

Exposure to high temperature and the formation of a layer of ash caused by burning a large quantity of hay on a small surface of grassland leads to the emergence of an area devoid of vegetation, which undergoes succession of species until the initial grassland community is regenerated. The order in which species appear in these areas depends mainly on the species composition of the neighboring vegetation. The increased content of available phosphorus and potassium induced by the mineralization of organic matter, as well as the increase in pH, create favorable conditions for the growth of plants of the *Fabaceae* which with the *Rhizobium* bacteria associated with them improves nitrogen availability and leads to an increase in the proportion of grasses and forbs. The time necessary for patches of vegetation on burnt surfaces to become indistinguishable from the surrounding sward depends on the amount of biomass burnt, and may reach even 17 years. Burning can be used to dispose of unneeded biomass, but the intensity of the effect of burning per unit area should be relatively small, which can be achieved by reducing the amount of biomass burned and by modifying the burning method.

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SPALANIE SIANA JAKO ZABIEG OCHRONY CZYNNEJ W ZACHOWANIU ROŚLINNOŚCI ŁĄK GÓRSKICH NA OBSZARACH CHRONIONYCH

ABSTRAKT

W niektórych częściach polskich Karpat łąki o wysokich walorach przyrodniczych użytkowane są tylko ze względu na dopłaty rolno-środowiskowe lub w ramach zabiegów ochrony czynnej na obszarach chronionych. Z powodu spadku pogłowia zwierząt gospodarskich problemem jest zagospodarowanie biomasy. W Pienińskim Parku Narodowym część zebranego w sterty siana jest spalana. Celem pracy była ocena wpływu punktowego spalenia dużej ilości siana na roślinność i glebę oraz ocena możliwości wykorzystania tego sposobu dla zachowania wielogatunkowych zbiorowisk łąkowych. W 1997 r. na 17 powierzchniach spalono zebrane w sterty siano. Na tych miejscach w latach od 1998 do 2001, a następnie w 2014 dokonano analizy składu gatunkowego roślinności i podstawowych parametrów glebowych. Podczas pierwszych czterech lat nastąpił znaczący wzrost zawartości przyswajalnych form fosforu i potasu oraz odczynu gleby. W rezultacie, na początku, zaobserwowano zwiększony udział roślin bobowatych. W następnej kolejności nastąpił wzrost udziału traw. Po 17 latach parametry glebowe na powierzchniach wypalanych były zbliżone do parametrów gleby w otoczeniu. Nie stwierdzono także odrębności składu gatunkowego roślinności na powierzchniach wypalanych, jednakże niektóre powierzchnie wyróżniały się fizjonomicznie od otaczającej roślinności. W konkluzji stwierdzono, że w uzasadnionych warunkach spalanie siana może być wykorzystane w ochronie zbiorowisk łąkowych.

Słowa kluczowe: użytki zielone, ochrona przyrody, łąki górskie, ekologia, ogień