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Supporting biodiversity by prescribed burning in grasslands — A multi-taxa approach

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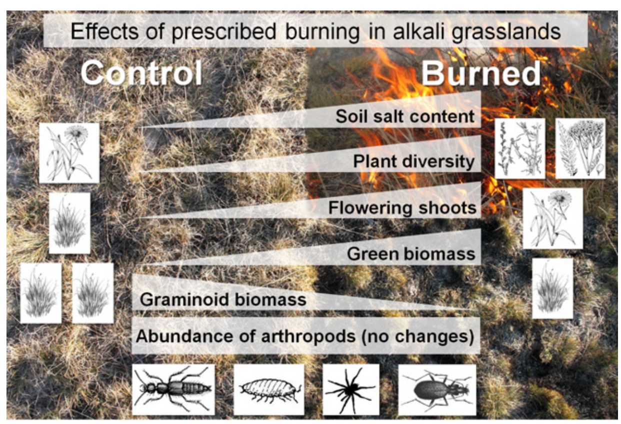
HIGHLIGHTS

- We studied the effects of fire on plant and arthropod diversity in dry grasslands.
- Fire increased soil salt content, plant diversity and number of flowering shoots.
- Fire increased green, forb and total biomass, while decreased graminoid biomass.
- Fire did not decrease the abundance and species richness of the arthropods.
- Patch-burning is feasible for the biodiversity conservation of alkaline grasslands.

GRAPHICAL ABSTRACT



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ABSTRACT

There are contrasting opinions on the use of prescribed burning management in European grasslands. On the one hand, prescribed burning can be effectively used for the management of open landscapes, controlling dominant species, reducing accumulated litter or decreasing wildfire risk. On the other hand burning can have a detrimental impact on grassland biodiversity by supporting competitor grasses and by threatening several rare and endangered species, especially arthropods. We studied the effects of prescribed burning in alkaline grasslands of high conservation interest. Our aim was to test whether dormant-season prescribed burning can be an alternative conservation measure in these grasslands. We selected six sites in East-Hungary: in three sites, a prescribed fire was applied in November 2011, while three sites remained unburnt. We studied the effects of burning on soil characteristics, plant biomass and on the composition of vegetation and arthropod assemblages (isopods, spiders, ground beetles and rove beetles). Soil pH, organic matter, potassium and phosphorous did not change, but soluble salt content increased significantly in the burnt sites. Prescribed burning had several positive effects from the nature conservation viewpoint. Shannon diversity and the number of flowering shoots were higher, and the cover of the dominant grass *Festuca pseudovina* was lower in the burnt sites. Graminoid biomass was lower, while total, green and forb biomass were higher in the burnt plots compared to the control. The key finding of our study

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was that prescribed burning did not decrease the abundance and diversity of arthropod taxa. Species-level analyses showed that out of the most abundant invertebrate species, 10 were not affected, 1 was negatively and 1 was positively affected by burning. Moreover, our results suggest that prescribed burning leaving unburnt patches can be a viable management tool in open landscapes, because it supports plant diversity and does not threaten arthropods.

1. Introduction

Fire is a natural disturbance which shapes species distributions and ecological processes worldwide. A global simulation model pointed out that the distribution and ecosystem properties of several biomes are driven by the global fire regime (Bond et al., 2005; Bond and Keeley, 2005). In regions with dry continental climate, regular wildfires are typical and play an important role in maintaining open landscapes by consuming biomass, controlling tree and shrub encroachment and increasing the area of open soil surfaces (Fernandes et al., 2013). Fire modifies several attributes of the abiotic and biotic environment via the alteration of microclimate, soil chemical composition, carbon reservoirs and physical attributes (Fernández-Fernández et al., 2015; Novara et al., 2013; Pereira et al., 2010, 2013a; Vacchiano et al., 2012). Several plant and animal species, which live in places with at least moderately frequent wildfires benefit from fires because of their resilience and adaptation to the regional fire regimes (Clavero et al., 2011; Keeley et al., 2012; Reside et al., 2012), while other species are damaged during fire or have poor post-fire regeneration ability. Thus, changes in the species composition and abundance of plants and animals are good indicators of fire resistance and post-fire resilience of ecosystems (Cerdà, 1998).

Grasslands have suffered from large-scale land use changes worldwide including drainage, conversion to arable lands or forest plantations, agricultural intensification and the cessation of traditional management practices (Dengler et al., 2014). Thus, many plant and animal species associated to grasslands became threatened in the past centuries (Habel et al., 2013; Horváth et al., 2013; Magura and Ködöböcz, 2007). Grasslands harbor an extremely high proportion of specialist plant species which require open microhabitats for their establishment. This holds especially for environmentally stressed grasslands, such as alkaline grasslands of the Pannonian biogeographical region (Valkó et al., 2014a). To sustain the optimal habitat quality for grassland specialist plant and animal species, it is crucial to remove accumulated biomass, control the abundance of competitor grasses and create microhabitats for specialist forbs. To fulfill these goals, prescribed burning can be a viable and cost-effective option in places where traditional management practices (i.e. grazing or mowing) are not feasible any more (Valkó et al., 2014b). As effects of fire can be site- and habitat-specific, regional studies are needed before large-scale application of burning. With small-scale prescribed burning experiments we can test fire as a potential management tool and monitor the effects of fire on grassland structure and grassland specialist species.

The effects of fire largely depend on the fire season, intensity and severity, and the phenological stage of plant and animal populations at the time of fire. In grasslands, dormant-season prescribed burning is the most frequently applied regime (Rowe, 2010), because plant species can regenerate faster after dormant-season fires compared to growing-season ones (Pyke et al., 2010). However, there are contrasting opinions on the use of prescribed burning management in European grasslands. Milberg et al. (2014) found that spring burning in many consecutive years is an inappropriate management option in the long run, because it leads to the decrease of grassland specialist plants. Based on indoor germination experiments, spring burning reduces the germination of several grassland-specialist plants, thus its application should be considered carefully (Ruprecht et al., 2013). Based on Lithuanian stakeholders' perceptions, Pereira et al. (2015) found that in many habitat types vegetation recovers quickly after burning and generally, burning does not have a negative effect on biodiversity. Nature conservationists' observations in Hungary suggest that fire can be a promising tool for the conservation of several endangered species and habitats (Deák et al., 2014a). A review on prescribed burning studies in European grasslands found that most of the published studies used annual burning in the same patch for many consecutive years (even up to 28 years; Wahlman and Milberg, 2002), which is an inappropriate management regime; however, current burning regimes could be fine-tuned based on the North-American practices (Valkó et al., 2014b). Longer fire return intervals, burning in a spatially and temporally diverse pattern might be a promising management tool in several European grassland types.

Even though several grassland species are tolerant of fire, first-order fire effects, such as the injury or death of individuals can be detrimental for some plant and animal taxa. This holds especially for invertebrates which are considered as the most vulnerable taxon to fire (Lyon et al., 2000). Immediate first-order fire effects, such as the injury or death of individuals during fire, can be detrimental for arthropod individuals. However, second-order fire effects (such as increased food availability or decreased amount of litter) can be favorable at the population level (Engstrom, 2010; Lyon et al., 2000). It has also been shown, that detrimental first-order fire effects can be minimized at the population level if prescribed burning is applied in smaller patches, which can be recolonized by plant and animal populations during the fire-return intervals (Deák et al., 2014a; Swengel, 2001). Prescribed burning is a potentially promising nature conservation method when second-order fire effects are beneficial for maintaining grassland biodiversity. Second-order fire effects often support landscape openness, thus prescribed burning can be effectively used for the management of open landscapes, by the reduction of accumulated litter and by creating open microhabitats and increasing landscape-scale heterogeneity (Cummings et al., 2007; Fuhlendorf and Engle, 2004; Valkó et al., 2014b).

One of the main purposes of applying prescribed burning is to provide an advantage for subordinate species by controlling dominant species (Davies et al., 2014; Young et al., 2014). The use of prescribed burning should be considered carefully when developing the management plan for a site: it is necessary to consider the costs and benefits for all taxa for which the site is considered to be important and incorporate into the management plan that the potential benefits outweigh the costs. It is important to ensure that populations of endangered taxa do not decline as a result of prescribed burning action, i.e. their decrease after burning is compensated by post-fire recovery. Nature conservation actions generally aim to support the whole ecosystem, or in special cases their specific objective is to support a set of endangered species. Usually there are populations benefiting and others declining as a result of the conservation actions (Moretti et al., 2004). Thus, it is crucial to evaluate the effects of nature conservation actions on multiple taxa and try to find an alternative which supports the most and damages the least of taxa (Deák et al., 2014a). Multi-taxa approaches are the best to overcome this issue, and to consider the requirements of multiple plant and animal species (Nascimbene et al., 2014; Pryke and Samways, 2012). However, most of the prescribed burning studies focus on certain plant or animal taxa and they often lack the analysis of the abiotic environment. There are only a few studies on the effects of fire on multiple arthropod taxa, from the South-African fynbos (Pryke and Samways, 2012), North-American prairies (Hartley et al., 2007), deciduous forests in the Southern Alps (Moretti et al., 2004), Russian steppes (Nemkov and Sapiga, 2010) or Central-European sand grasslands (Samu et al., 2010). However, comprehensive studies on the effects of fire on plants and multiple animal taxa are missing from the Eurasian temperate grasslands.

We analyzed the effects of dormant-season (late-autumn) prescribed burning on the biodiversity of plants and multiple arthropod taxa in low-productivity steppe grasslands of high conservation importance. We also studied the abiotic and biotic parameters (soil parameters and plant biomass), which were considered to be crucial factors in shaping the microhabitats of plant and animal species in open landscapes. Our aim was to test whether dormant-season prescribed fire can be an alternative conservation measure in these grasslands to decrease litter accumulation, increase the amount of open soil surfaces and the diversity of plant and arthropod species.

We hypothesized that after a dormant-season prescribed fire, the following effects are expected: (i) green biomass production increases and (ii) the amount of litter decreases after prescribed fire, (iii) soil parameters do not change significantly after a dormant-season prescribed fire, (iv) cover and diversity of plants increase and the number of flowering shoots is higher and (v) abundance and diversity of arthropods increases.

2. Materials and methods

2.1. Study sites

The study sites are located in the Pannonian biogeographical region, which includes the plains of the Central Danube and Tisza rivers in the Carpathian Basin and is rich in steppe-specialist and endemic species (Molnár and Borhidi, 2003). Our study sites are in the Hortobágy National Park, in East-Hungary (N 47°16′08″; E 20°49′46″). The climate of the region is moderately continental, characterized by a mean annual temperature of 9.5 °C and a mean annual precipitation of 550 mm (Lukács et al., 2015). Intense summer evaporation and high groundwater-level with a high salt-content lead to salt-accumulation in the upper soil layers (Valkó et al., 2014a). The typical soil type of the region is Gleyic Solonetz (Clayic, Columnic; WRB, 2015). The characteristic vegetation type of the sites is dry alkaline grassland (Kelemen et al., 2013, 2015). Alkaline grasslands of the region are species-poor, their dominant grass species is *Festuca pseudovina*; typical salt-tolerant forb species include *Scorzonera cana*, *Bupleurum tenuissimum*, *Artemisia santonica* and *Trifolium angulatum* (Kelemen et al., 2015). Alkaline grasslands are included in the Habitats Directive of the Natura 2000 system as priority habitats (Deák et al., 2014b). In the study area wildfires are most typical during summer and autumn, when patches of surface water, which are typical in spring, disappear resulting in the desiccation of the vegetation (Végvári et al., 2016).

2.2. Sampling setup and treatments

We sampled six sites of dry alkaline grasslands; we selected a 50×50-m sized plot in each site in June 2011. All the sites were extensively grazed in late autumn to reduce fire severity (80 cattle grazed in an even distribution in a total area of 100 ha for three weeks). Three plots were designated as unburnt control, and three plots as burnt. We applied prescribed burning in the three burnt plots on 10th November 2011. We made a pilot survey of the vegetation before prescribed burning (in June 2011). Results of multivariate analysis (PCA) confirmed that the species composition of the plots designated as 'control' and 'burnt' was not different at that time.

2.2.1. Soil sampling

Three soil samples per plot (4 cm diameter, 5 cm depth) were randomly taken from the top soil layer with an auger from each plot on three sampling dates: (1) prior to prescribed burning (10th November 2011), (2) two weeks after prescribed burning (24th November 2011) and (3) four months after prescribed burning (8th March 2012). Hence, the total number of soil samples was fifty four. The soil samples were analyzed according to the relevant Hungarian standards of soil analysis in an accredited pedological laboratory (NAT/0782/2011). The following soil parameters were measured: $pH_{(H_2O)}$, soluble salt content (%), organic matter content (%), readily available (AL-soluble) phosphorus (P_2O_5 mg·kg^{-1}) and potassium (K_2O mg·kg^{-1}) content.

The measured soil parameters and applied methods of laboratory analysis are as follows. $pH_{(H_2O)}$ was measured on a 1:2.5 soil:distilled water suspension with WTW inoLab Lab 9310 IDS type pH meter (Number of national standard: MSZ-08-0206:1978 2.1). Total soluble salt content was quantified by measuring EC with a conductivity meter (Tetra Con 325) in a saturated paste of soil and water (Number of national standard: MSZ-08-0213:1978 2.2). Soil organic matter content (%) was quantified by the Turin method. Appropriate quantity of soil sample (0.5–1 g) was weighed into an Erlenmeyer flask and 25 ml of acidic $K_2Cr_2O_7$ solution (40 g of potassium dichromate were dissolved in 1000 ml of distilled water and 1000 ml of cc. H_2SO_4) was added to it. The flask was heated for 5 min at the boiling point. After oxidation of soil organic matter, unused potassium dichromate was titrated with a standard solution of ammonium ferrous sulfate using ferroin indicator. The obtained results of organic carbon content were multiplied by correction factor of 1.172 to get organic matter content (Number of national standard: MSZ-08-0210:1977 2.2). Amount of readily available phosphorous content of soil samples (AL-soluble phosphorus content; mg kg^{-1}) was extracted using the ammonium lactate (AL) method after Egnér et al. (1960) by shaking 5 g of soil in 100 ml of 0.1 M ammonium lactate and 0.4 M acetic acid for 2 h. The extract was filtered and analyzed using reduced molybdophosphate photometric method (Zeiss Spekol 1100) (Number of national standard: MSZ 20135:1999 4.2.1, 5.4.2). Amount of readily available potassium content of soil samples (AL-soluble potassium content; mg kg^{-1}) was quantified from AL-extraction using FAES method (Varian SpectrAA10) (Number of national standard: MSZ 20135:1999 4.4.1, 5.3).

2.2.2. Vegetation sampling

Within each plot, we selected twelve 1×1 m quadrats, in which we recorded the percentage cover of vascular plant species in late June 2012. We also recorded the number of flowering shoots of each species. Vegetation height was measured at five randomly selected points in each quadrat. We collected 30 randomly assigned above-ground biomass samples (20×20 cm) in each plot (in total 180 biomass samples) near to the quadrats in late June 2012, at the peak of biomass production. Samples were dried (65 °C, 24 h), then sorted to litter and green biomass of each vascular plant species separately. Dry mass was measured with 0.01 g accuracy.

2.2.3. Arthropod sampling

Ground-dwelling arthropods (isopods, spiders, ground beetles and rove beetles) were collected using unbaited pitfall traps in 2012. Traps consisted of 100 mm diameter plastic cups (volume 500 ml) and contained 200 ml 70% ethylene glycol as a killing-preserving solution and detergent to break the surface tension of the liquid. Pitfall traps were protected by fiberboard from litter, rain and small vertebrates. There were ten randomly placed traps at each plot (in total 60 traps). Traps were placed at least 10 m apart from each other and from the margins of the plot to provide statistically independent samples and true replicates (Digweed et al., 1995). We emptied the traps monthly from May to October 2012. Monthly samples from each pitfall trap were pooled for the analyses.

2.3. Data analyses

Plant species were classified to the following functional groups: perennial graminoids, perennial forbs, short-lived graminoids and short-lived forbs. The temporal changes in soil parameters were analyzed

Table 1
Soil parameters of the control and burnt plots before and after prescribed burning (repeated measures GLM and Fisher LSD test, mean ± SD). Notations for sampling dates: (1) – prior to prescribed burning (10 Nov 2011), (2) – two weeks after prescribed burning (24 Nov 2011) and (3) – four months after prescribed burning (8 Mar 2012). * = $p < 0.05$; n.s. = non-significant. Different letters in superscript indicate significant differences.

	Control plots			Burnt plots			p
Date	(1)	(2)	(3)	(1)	(2)	(3)	
pH $_{(H_2O)}$	6.03 ± 0.27	6.05 ± 0.19	6.10 ± 0.22	6.17 ± 0.14	6.14 ± 0.24	6.18 ± 0.33	n.s.
Soluble salt content (%)	0.080 ± 0.023^{ab}	0.077 ± 0.021^{ab}	0.072 ± 0.029^{a}	0.089 ± 0.015^{ab}	0.087 ± 0.017^{ab}	0.096 ± 0.023^{b}	*
Organic matter (%)	3.81 ± 1.30	3.52 ± 0.76	3.38 ± 0.51	3.25 ± 0.30	3.29 ± 0.46	3.50 ± 0.88	n.s.
Phosphorus (mg kg^{-1})	34.93 ± 8.50	34.22 ± 7.24	33.21 ± 7.30	32.87 ± 7.25	29.49 ± 6.41	34.08 ± 11.42	n.s.
Potassium (mg kg^{-1})	251.67 ± 52.43	253.00 ± 54.13	252.22 ± 48.36	258.78 ± 30.33	262.00 ± 40.66	292.78 ± 74.15	n.s.

using repeated-measures GLM and Fisher LSD tests, using management as a fixed factor and sampling date as repeated-measures factor ($p < 0.05$). We used Generalized Linear Models (GLMs) to test the effect of burning on the diversity and cover of plants, diversity and abundance of arthropods and on biomass fractions ($p < 0.05$; McCulloch et al., 2008). We also analyzed specific responses of the most abundant arthropod species, having more than 1% of all trapped individuals. Response variables (number of flowering shoots, arthropod abundances and species numbers) were regarded as following a Poisson distribution accounting for overdispersion using the Pearson Chi^2 (with log link function, McCulloch et al., 2008). All the other response variables followed normal distribution; thus, we ran the models using normal distribution and log link function. All univariate statistics were calculated using Statistica 7.0 program. To assess the plant species composition of the burnt and control sites, a PCA ordination was calculated based on the covariance matrix, using CANOCO 4.5 program (Lepš and Šmilauer, 2003). In the PCA, specific cover scores were included as main matrix, while main biomass fractions (total biomass, total green biomass, graminoid biomass, forb biomass, moss biomass, lichen biomass and litter) were included as overlay.

3. Results

3.1. Soil parameters

We found that most of the tested soil parameters (pH$_{(H_2O)}$, AL-soluble phosphorus content, organic matter content) were not influenced by burning, but AL-soluble potassium content moderately increased (as a tendency) in the topsoil of burnt plots. Burning had significant effects only on total soluble salt content of the topsoil ($p < 0.05$). It increased significantly in the burnt plots four month after burning, while it decreased in the control plots (Table 1).

3.2. Vegetation

We detected altogether 21 vascular plant species in the studied grasslands, 18 species were recorded in the burnt and 20 species in the control plots, respectively. Total vegetation cover was slightly lower in the burnt plots, but this decrease was not significant ($p > 0.05$). Vegetation height was significantly higher in the control plots ($p < 0.001$; Table 2). The cover of perennial graminoids ($p < 0.001$) and the dominant grass species, *F. pseudovina* ($p < 0.001$) was negatively affected by burning. The cover of perennial forbs increased in the burnt plots ($p < 0.001$). We found that the total number of flowering shoots ($p < 0.001$) and Shannon diversity were significantly higher in the burnt plots ($p < 0.001$; Table 2). The cover of lichens benefitted from burning ($p < 0.05$), while the cover of mosses was not affected ($p > 0.05$).

The PCA ordination showed that the control plots had a more homogeneous species composition compared to the burnt plots (Fig. 1). Several specialist species (*S. cana*, *B. tenuissimum*, *Inula britannica*), were plotted towards the direction of burnt plots, while some generalist (*Alopecurus pratensis*, *Lotus corniculatus*) and weedy species (*Bromus mollis*, *Lolium perenne*), were plotted towards the direction of control plots. The dominant grass *F. pseudovina* was also plotted in the direction of control plots (Fig. 1).

3.3. Biomass

Burning decreased graminoid biomass ($p < 0.001$) and the biomass of *F. pseudovina* ($p < 0.001$). Forb biomass ($p < 0.001$), total green biomass ($p < 0.01$) and total biomass ($p < 0.05$) were significantly higher in the burnt plots. There was no difference between the litter scores in the burnt and control plots ($p > 0.05$; Table 3). The biomass of lichens was affected positively by burning ($p < 0.05$), while the biomass of mosses was not affected. The PCA ordination confirmed these patterns: the burnt plots were characterized by higher biomass of forbs, lichens and total green biomass and control plots were characterized by higher graminoid biomass (Fig. 1).

3.4. Arthropods

Altogether 4036 individuals of ground-dwelling arthropods belonging to 71 species were trapped during the study. This included 2037 individuals of 57 species from the burnt plots, while 1999 individuals of 52 species from the control plots. The most numerous species was *Trachelipus rathkii* (Isopoda: Oniscidea) with 407 individuals in the burnt and 356 individuals in the control plots.

Table 2
Vegetation characteristics (mean ± SD) of the control and burnt plots, as well as the results of the Generalized Linear Models for these variables. Significant effects are marked with boldface.

Vegetation characteristics	Control plots	Burnt plots	Estimate	Standard error	Wald statistic	p
Total vegetation cover (%)	91.7 ± 6.3	88.6 ± 7.9	−0.014	0.009	3.600	0.058
Vegetation height (cm)	12.8 ± 3.1	10.5 ± 2.04	−0.099	0.026	13.930	<**0.001**
Cover of *Festuca pseudovina* (%)	76.3 ± 14.9	64.3 ± 7.8	−0.085	0.020	18.410	<**0.001**
Cover of perennial graminoids (%)	81.4 ± 2.6	67.3 ± 1.4	−0.095	0.020	22.940	<**0.001**
Cover of short-lived graminoids (%)	0.1 ± 0.1	0.1 ± 0.1	0.936	0.997	0.881	0.348
Cover of perennial forbs (%)	9.7 ± 0.9	20.2 ± 2.0	0.370	0.087	17.999	<**0.001**
Cover of perennial graminoids (%)	0.2 ± 0.1	0.3 ± 0.1	0.039	0.229	0.028	0.866
Number of flowering shoots	37.5 ± 24.5	62.0 ± 34.5	0.252	0.072	12.133	<**0.001**
Shannon diversity	0.7 ± 0.2	0.9 ± 0.3	0.154	0.037	17.017	<**0.001**
Cover of lichens (%)	8.2 ± 10.8	22.2 ± 24.6	0.496	0.202	6.036	**0.014**
Cover of mosses (%)	3.1 ± 4.31	7.4 ± 11.37	0.439	0.249	3.107	0.078

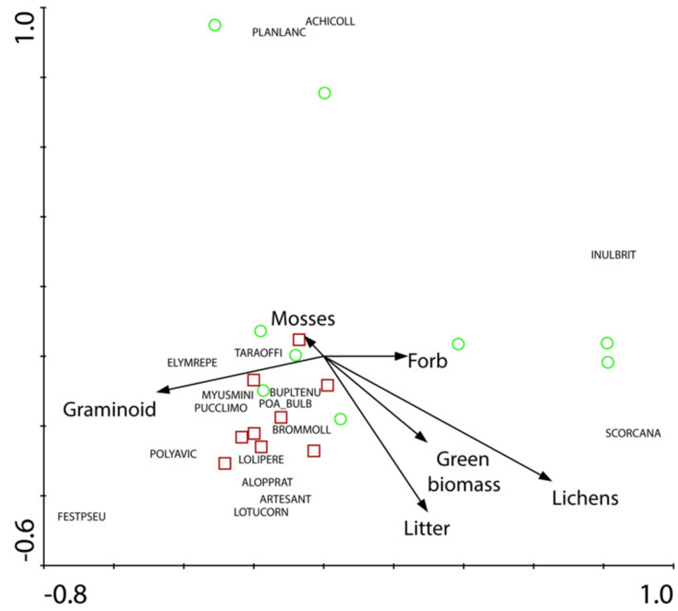

Fig. 1. PCA biplot based on percentage cover scores. Biomass fractions (Graminoid, Forb, Green biomass, Litter, Mosses and Lichens) are used as overlay. Eigenvalues are 0.687 (1st axis) and 0.176 (2nd axis). Cumulative percentage variance of species data are 68.7% and 86.3%, while cumulative percentage variance of species–environment relation are 75.8% and 88.3%, respectively. Notations: green circles — burnt plots, red squares — control plots. Species names are abbreviated using the first four letters of the genus and species names.

Burning had no significant effects on arthropods. We recorded a slight increase in the total numbers of individuals and species in the burnt plots compared to the controls; however, these differences were not statistically significant (Table 4). Numbers of individuals and species as well as Shannon diversity of the three most abundant arthropod groups (spiders, ground beetles and isopods) were not different in the burnt and control plots (Table 4). Out of the 12 most abundant species (recorded with at least 1% of all trapped arthropods, i.e. 40 individuals), ten species was not affected by burning. The abundance of *Titanoteca veteranica* spider species increased and the abundance of *Trochosa robusta* spider species decreased in the burnt plots (Table 5).

4. Discussion

4.1. Effects of fire on soil

Previous studies prove that low-intensity fires can temporarily increase readily available nutrient contents of the soils (Neary et al., 1999; Scharenbroch et al., 2012). Contrary to these observations we found that the dormant-season prescribed fire did not cause significant changes in the majority of the studied soil parameters. Presumably the small amount of flammable biomass generated a small amount of ash, which induced significant changes in few soil chemical attributes only (Pereira et al., 2012, 2014a, 2014b). The observed moderate increase in AL-soluble potassium content and the significant increase in total soluble salt content of the topsoil in burnt sites all indicate the effects of ash. The high potassium and the high water soluble salt and oxide contents of ash were responsible for these changes (Úbeda et al., 2009). Significant differences between total soluble salt content of topsoil in the control and burnt plots were observable even four months after burning. It is very likely that water soluble salts originating from the ash could not be leached out from the topsoil by precipitation during the studied period (Bodi et al., 2014). Leaching processes were limited by the unusually dry weather, since the amount of precipitation (92.6 mm from November 2011 to March 2012) was less than the average of the last 50 years (138.2 mm). Precipitation data is originated from the meteorological station of the Karcag Research Institute of Debrecen University. This could be a reason for the increased soluble salt content in the burnt plots four months after prescribed burning. Slight decrease of the vegetation cover in the burnt sites might be another reason for the increased soil soluble salt content. The created open micro-sites could enhance the level of evaporation, which could moderately facilitate the transportation of the sodium salts from the groundwater to the upper soil layers where they could accumulate (Tóth et al., 1991).

Table 3
Biomass characteristics (mean ± SD) of the control and burnt plots, as well as the results of the Generalized Linear Models for these variables. Significant effects are marked with boldface.

Biomass ($kg\ m^{-2}$)	Control plots	Burnt plots	Estimate	Standard error	Wald statistic	p
Graminoid	0.15 ± 0.06	0.09 ± 0.03	−0.277	0.031	77.450	<**0.001**
Festuca pseudovina	0.15 ± 0.06	0.08 ± 0.03	−0.285	0.033	76.471	<**0.001**
Forb	0.01 ± 0.01	0.02 ± 0.01	0.276	0.053	26.686	<**0.001**
Total green biomass	0.25 ± 0.12	0.33 ± 0.23	0.141	0.048	8.770	**0.003**
Litter	0.19 ± 0.06	0.17 ± 0.07	−0.046	0.028	2.610	0.106
Total biomass	0.44 ± 0.15	0.50 ± 0.26	0.069	0.033	4.322	**0.038**
Lichens	0.07 ± 0.11	0.12 ± 0.16	0.277	0.119	5.424	**0.020**
Mosses	0.02 ± 0.04	0.10 ± 0.22	0.879	0.478	3.379	0.066

4.2. Effects of fire on plants

The prescribed fire had several positive effects from the nature conservation viewpoint. After a single, dormant-season prescribed burning event vegetation recovered quickly (see also Pereira et al., 2013b). Evidence-based experiences of Hungarian nature conservationists show that in most cases single wildfires do not cause degradation of grasslands and the vegetation can recover within a few years (Deák et al., 2014a). Our study provided evidence for this from alkaline grasslands. We detected a slight decrease of total vegetation cover and a significant decrease of vegetation height in the burnt plots, which probably increased the availability of light in the ground-level and provided favorable open microhabitats for the germination and establishment of several plant species. We found that the number of flowering shoots was higher in burnt plots, which is also known from highly fire-adapted habitats, such as temperate grasslands in Australia (Lunt, 1993) and longleaf pine savannas in North-America (Brewer et al., 2009), but was not found in non-fire-prone environments (see Keeley et al., 2012). Especially for short-lived semelparous species, which largely rely on generative reproduction, the increased number of flowering shoots was beneficial for the long-term existence of their populations (Šerá and Šerý, 2004).

Both vascular plants and lichens were good indicators of burning. Burning supported a higher diversity of plant species, which was probably a response to the decreased competition of neighboring vegetation (see also Maret and Wilson, 2005). In this study, burning reduced the cover of the dominant grass *F. pseudovina* and provided beneficial establishment conditions for several other species. The PCA ordination also confirmed that several specialist species were more characteristic of the burnt, while generalists and weedy species were characteristic of the control plots. Increased soil salt content probably contributed to the decreased cover of *F. pseudovina* in the burnt plots. The possible reason for the decrease of the dominant grass species is that *F. pseudovina* does not spread by stolons and is not a typical re-sprouter species, thus its post-fire regeneration is less effective (see Pyke et al., 2010). Other studies found that in mesophilous European grasslands, prescribed burning supports the encroachment of the dominant grass species with effective clonal spreading ability, such as *Brachypodium pinnatum* (Kahmen et al., 2002; Ryser et al., 1995) and *Calamagrostis*

Table 4
Number of individuals, species number and the Shannon diversity of the trapped invertebrates (mean ± SD) in the control and burnt plots, as well as the results of the Generalized Linear Models for these variables.

Variables	Control plots	Burnt plots	Estimate	Standard error	Wald statistic	*p*
Spiders						
Number of individuals	48.73 ± 18.40	47.83 ± 24.66	−0.009	0.058	0.026	0.873
Number of species	9.83 ± 2.35	10.33 ± 2.68	0.025	0.032	0.591	0.442
Shannon diversity	1.87 ± 0.25	1.97 ± 0.23	0.026	0.016	2.557	0.110
Ground beetles						
Number of individuals	3.10 ± 2.90	3.53 ± 2.90	0.065	0.113	0.335	0.563
Number of species	1.80 ± 1.10	2.03 ± 1.25	0.061	0.079	0.596	0.440
Shannon diversity	0.55 ± 0.41	0.57 ± 0.50	0.018	0.106	0.027	0.869
Isopods						
Number of individuals	14.53 ± 7.71	16.37 ± 13.21	0.059	0.089	0.442	0.506
Number of species	1.83 ± 0.38	1.67 ± 0.48	−0.048	0.032	2.200	0.138
Shannon diversity	0.39 ± 0.22	0.30 ± 0.25	−0.122	0.090	1.845	0.174
Total						
Number of individuals	66.6 ± 20.2	67.9 ± 28.1	0.010	0.047	0.042	0.837
Number of species	13.7 ± 2.6	14.2 ± 2.5	0.018	0.024	0.560	0.454
Shannon diversity	2.2 ± 0.2	2.2 ± 0.2	0.006	0.012	0.213	0.645

epigejos (Deák et al., 2014a; Házi et al., 2011), which leads to a decrease in biodiversity.

4.3. Effects of fire on biomass

We found that graminoid biomass was lower in the burnt plots compared to the control plots, which was due to the biomass decrease of the dominant graminoid *F. pseudovina*. The total biomass and total green biomass were higher in the burnt plots. These findings are consistent with several studies which suggest that green biomass production generally increases in recently burnt sites (Dhillion and Anderson, 1994; Fuhlendorf and Engle, 2004; Kitchen et al., 2009). Contrary to our expectations and to the findings of many studies (e.g. Hansson and Fogelfors, 2000; Ryser et al., 1995), the amount of litter did not decrease in the burnt plots. One reason was that extensive autumn cattle grazing removed a considerable part of the standing dead (mostly graminoid) biomass in 2011 from both burnt and control plots, thus the amount of litter was similarly low in the two treatments in 2012. We found that the biomass and cover of lichens were significantly higher in the burnt plots, which was consistent with the results of Ketner-Oostra et al. (2006). The increased abundance of lichens was probably due to the more open vegetation after burning, which was also found in North-American grasslands in case of low-intensity fires (Johansson and Reich, 2005).

4.4. Effects of fire on arthropods

Invertebrates, especially ground-dwelling and herb-dwelling arthropods, were identified as the most susceptible animal taxa to fire (Lyon et al., 2000). Fire can be detrimental to them, because they generally live within the combustible material (e.g. litter) and because of their often limited mobility, it can take more time to re-colonize the burnt areas after fire (Polchaninova, 2015; Swengel, 2001). Many studies found that fire had various negative effects on arthropods, and consequently had not recommended the use of prescribed burning in nature conservation (Nemkov and Sapiga, 2010; Polchaninova, 2015; Reed, 1997; Swengel, 1996). Summer fires are the most detrimental for arthropods (see Polchaninova, 2015). However, Swengel (1996) found that dormant-season fires decreased the number of prairie specialist butterflies and increased the number of generalists. In case of late autumn fires, arthropods overwintering in the soil suffer collateral damage, and their abundance in spring remains similar to their abundance before fire (Nemkov and Sapiga, 2010). In late autumn, some arthropods are in mobile life stages and others, such as ground beetles and rove beetles are overwintering in the soil, thus they are not affected by low-severity fires (Thiele, 1977).

An important finding of our study was that dormant-season prescribed burning, applied in a patch structure did not decrease the abundance and diversity of arthropods. A possible reason is that the effects of burning are generally less detrimental in the dormant season, when arthropods are less sensitive for fire compared to growing-season fires and they are out of their main activity period (Lyon et al., 2000). We found that fire did not decrease the abundance, species numbers and Shannon diversity of spiders, ground beetles, isopods or rove beetles. Species-level analyses revealed that most arthropod species were not affected by fire. Out of the most frequent arthropods, the abundance of the grassland specialist spider species *Titanoeca veteranica* increased significantly, probably because the created open soil surfaces provided optimal habitats for this light-demanding spider species. The abundance of the spider species *Trochosa robusta* decreased in the burned plots, possibly because this species is overwintering close to the soil surface (Buchar and Ruzicka, 2002).

Table 5
Number of individuals of the trapped abundant invertebrate species (mean ± SD) in the control and burnt plots, as well as the results of the Generalized Linear Models for these variables. Significant effects are marked with boldface.

Variables	Control plots	Burnt plots	Estimate	SE	Wald statistic	*p*
Armadillidium vulgare (isopod species)	2.67 ± 3.21	2.80 ± 4.23	0.024	0.177	0.019	0.890
Gnaphosa lucifuga (spider species)	0.80 ± 1.16	0.80 ± 1.16	0.000	0.187	0.000	1.000
Gnaphosa rufula (spider species)	5.23 ± 3.62	5.60 ± 2.79	0.034	0.077	0.192	0.662
Harpalus affinis (ground beetle species)	0.77 ± 0.89	1.13 ± 1.59	0.195	0.171	1.312	0.252
Pardosa agrestis (spider species)	5.57 ± 3.34	5.8 ± 2.87	0.021	0.071	0.084	0.772
Pterostichus macer (ground beetle species)	1.60 ± 2.30	1.60 ± 2.50	0.000	0.194	0.000	1.000
Titanoeca veteranica (spider species)	1.53 ± 1.68	2.93 ± 2.18	0.032	0.120	7.364	**0.007**
Trachelipus rathkii (isopod species)	11.87 ± 6.50	13.57 ± 11.01	0.067	0.091	0.545	0.460
Trachyzelotes paedestris (spider species)	1.33 ± 1.42	1.13 ± 1.17	−0.081	0.136	0.357	0.550
Trochosa robusta (spider species)	10.67 ± 5.23	8.13 ± 4.34	−0.136	0.067	4.170	**0.041**
Xysticus kochi (spider species)	1.27 ± 1.48	0.83 ± 1.15	−0.209	0.166	1.594	0.207
Zelotes longipes (spider species)	2.83 ± 2.34	2.4 ± 1.96	−0.083	0.106	0.610	0.435

Our findings suggested that when burning is done in smaller patches within a larger area, it does not harm or damage the invertebrate fauna, because animals can easily re-colonize the burnt patches from the unburnt surroundings (see also Panzer, 2002; Pereira et al., 2016). As the applied burning management significantly increased plant diversity and did not have negative effects on arthropods, it can be recommended as a feasible management method in dry alkaline grasslands. In the future, research on the fire severity as well as on fire season would support the designing of management strategies in alkali grasslands and fine-tuning the application of prescribed burning as a management tool in these landscapes.

5. Conclusions

Contrary to the findings of many European studies, we found that a single dormant-season prescribed burning event had several positive effects and almost no negative effects from the nature conservation viewpoint. Our study showed that prescribed burning applied in the dormant-season and in smaller patches, can be a promising alternative grassland management measure. When fire return periods are set carefully (e.g. burning in every fifth year), the vegetation can recover quickly and burning can have several positive effects. Our findings suggested that most of the soil parameters were not affected, the number of flowering shoots and plant diversity were increased, the cover of the dominant grass and graminoid biomass were decreased, while the total, green and forb biomass were increased by dormant-season prescribed burning leaving unburnt patches. Our results show that a single prescribed fire event had several positive effects on vegetation and biomass from the nature conservation viewpoint, and furthermore it did not decrease the arthropod abundance and diversity. In conclusion, our results suggested that prescribed burning leaving unburnt patches was a viable management tool in open landscapes, because it supports plant diversity and did not threaten the majority of arthropods.

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