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Grazing effects on vegetation composition and on the spread of fire on open sand grasslands

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Running Title: Ónodi, G. et al.: Grazing effects on vegetation and fire

Abstract

We studied the effects of sheep [*Ovis aries* (L.)] and rabbit [*Oryctolagus cuniculus* (L.)] grazing on the spread of induced fire on an open sand grassland community in the Hungarian Plain. Patches of open sand grassland were grazed by sheep in April and by sheep and rabbit in May of 2003. Half of each patch was burned in July. Canopy cover of the litter and vascular plant species, species number, plant height, burnt area and the speed of fire-spread were estimated in one by one meter quadrates. Burnt area was significantly smaller with late sheep grazing, while the speed of fire-spread decreased significantly due to rabbit grazing compared to that of the control. Plant height was significantly decreased by early and late sheep grazing, while rabbit grazing resulted in significantly lower canopy cover values of vascular plants compared to the control. Early sheep grazing resulted in overcompensation of the canopy cover of vascular plants. Species number was not affected by the grazing treatments. This one-year experiment demonstrated that moderate grazing has no short-term effects on the species diversity of the semiarid open sand grassland, furthermore, late spring grazing decreased the spread of fire on the grassland portions of the community, thus it may inhibit the burning of large areas of the semiarid forest-steppe.

Keywords: burning, field experiment, forest-steppe, land use, management, rabbit, sheep

Introduction

Grazing and fire regimes are the most important large scale disturbances on semiarid and arid grassland communities (van Langevelde et al. 2003, Ghermandi et al. 2004, Feldman and Lewis 2005). In most cases, fire and herbivory are independently investigated (Archibald et al. 2005), although more and more recent studies have examined these two disturbances together (Collins 1987, Belsky 1992, Noy-Meir 1995, Boer & Stafford Smith 2003, Harrison et al. 2003, Fuhlendorf & Engle 2004, Fynn et al. 2005, Archibald et al. 2005). However, there is very little research on how these two agents influence the function of each other (Archibald et al 2005). In our study, we intended to look deeper into how herbivory affects fire-spread and species composition of an open semiarid sand grassland community.

Changing climate and land use lead to remarkable changes of grassland vegetation all over the world (Frank et al. 1998, van Langevelde et al. 2003). In closed grassland communities, fire-spread is positively correlated with increased amounts of combustible material on the soil surface and with dry weather conditions (Gibson et al. 1990, Whelan 1995).

Coarse sand soil results in an extreme moisture regime due to high hydraulic conductivity and low moisture retention. The habitat of sand grasslands is edaphically arid; i.e., water uptake of the vegetation is limited by the high infiltration of the precipitation. Biomass production is highly variable, both in space and in time, because water availability depends upon topography (sand dunes and depressions), as well as the distribution of precipitation. Variation of humid and dry years, as has occurred in the last decades on the Hungarian Plain, results in an accumulation of vegetation material during the wet periods which can easily catch fire during the dry periods, especially in the drought sensitive sand vegetation. There were extensive wildfire events in the Kiskunság National Park (Hungary) in the area of Kiskunság Sand Ridge in 1976, 1993 and 2000, which caused considerable damage to expansive areas of the National Park. Extensive fires are expected to become more frequent due to climate change, as has similarly occurred in the Mediterranean (Veblen et al. 2003).

Herbivore density has decreased in the Kiskunság National Park since the beginning of the 1990s (Katona et al. 2004). One important cause for this was the decline in stock density of cattle and sheep in Hungary. Additionally, the abundance of rabbit decreased dramatically in 1994 and 1995 due to a combination of myxomatosis and hemorrhagic disease, followed by an exceptionally long snow cover that winter. We assumed that decreased herbivory increases the extent of both anthropogenic and naturally ignited wildfires.

Our former field experiments showed that sheep mainly eat monocotyledons while rabbits consume more dycotiledons on the same grassland, thus herbivore species have different grazing habits and different effects on vegetation. There are various models in the literature regarding compensatory growth of vegetation due to herbivory on semiarid grasslands (McNaughton 1983 but see Belsky 1987). Our results show that semiarid, open, perennial sand grasslands compensate the effects of controlled moderate grazing, which has favourable effects on species density, while heavy grazing pressure results in degraded grasslands (Ónodi et al. 2006).

In this article, we present a field experiment conducted on a forest-steppe mosaic of open sand grassland and *Juniperus-Populus* woody patches in the Kiskunság National Park. We wanted to know whether moderate rabbit and sheep grazing could affect the spread of fire in this open grassland community as has been demonstrated with persistent heavy grazing in denser communities (Archibald et al. 2005). We studied the short term effects of grazing and fire on vegetation composition. We expected that moderate grazing treatments would decrease the spread of fire. However, we expected that fire coupled with moderate grazing would not lead to short term compositional changes on the sand grassland. We conducted our experiment on the grassland patches which play a substantial role in transmitting fire among the woody patches of the *Juniperus-Populus* community in the forest-steppe vegetation.

Material and Methods

Our study site lies on the Hungarian Plain, in the outskirts of Orgovány (N46˚47.369, E19˚26.829), on a forest-steppe area, which is one of the westernmost extensions of the forest-steppe zone in Europe (Kovács-Láng et al 2000). The area is part of the Kiskunság

National Park. The study site is a mosaic of open sand grassland and woody patches of *Juniperus communis* (L.), *Populus alba* (L)., and *Populus nigra* (L), based on the nomenclature of Simon (2000). The largest part of the grassland belongs to the plant association *Festucetum vaginatae* (Rapaics), which is dominated by perennial grasses [*Festuca vaginata* (W. et. K.), *Stipa borysthenica* (Kolokov), *Koeleria glauca* (Schkuhr) DC., *Bothriochloa ischaemum* (L.) Keng]. There are also some disturbed patches of the plant association *Brometum tectorum* (Hargitai) dominated by annual plants. *Festucetum vaginatae* is an endemic and pioneer association (Fekete 1992) in the Carpathian basin, growing in semiarid climatic conditions on calcareous sand soil with low humus content. The vegetation has a semi-desert character because of the extreme soil moisture regime due to the coarse sand texture (Molnár 2003). Our study site is located on the Pleistocene calcareous sand deposit of the Danube river consisting of a nutrient-deficient (humus content <1 %) Calcaric Arenosol (World Reference Base for Soil Resources, 2006). The sand content is greater than 96 % and both the silt and clay contents are less than 2 %. The $CaCO_3$ content is approximately 10 % and the pH is between 8 and 8.5 (Kovács-Láng et al 2000). The climate is temperate continental with Sub-Mediterranean effects (Zólyomi et al. 1997). Annual mean precipitation is around 500-550 mm and mean monthly temperatures range from -1.8°C in January to 21°C in July (Kovács-Láng et al 2000). The main growing season in the open sand grassland is late spring.

We conducted the experiment in 2003. The size of the study site was one hectare, which we fenced before the first sampling date in order to minimize the effects of uncontrolled herbivory. Within the study site we marked 10 blocks of the open sand grassland among the woody patches. Each block consisted of four differently treated grassland patches, namely an ungrazed control plot, an early sheep grazed (middle of April), a late sheep grazed (end of May) and a rabbit grazed (end of May). Each patch contained four one by one meter quadrates

(Fig. 1.) The patches were fenced during the grazing period which lasted until the sheep or rabbit (one animal per patch) reduced the original vegetation cover to 50 percent (estimated visually) through plant removal and trampling. When we fenced the patches, we established a trampling path in each patch around the quadrates, allowing sheep to walk near the fence without trampling the vegetation within the quadrates. We set the four patches of each block close to each other, thus the vegetation was likely similar within each block. We performed the burning treatment in July for all blocks on the same day. We burned half of each patch, including two of the four quadrates. There remained two unburned quadrates in each patch to examine regeneration following the grazing treatments. Due to the high danger of starting a wildfire, we chose the minimum possible area to burn. We encircled half of each patch with wet rugs and then lit the fire along a line at the edges of the two quadrates. Fire could spread freely within the circled area. There was a low (5-15 km h^{-1}) Northwest wind while performing the fire treatment.

We took samples three times in 2003. Sampling periods were before the grazing treatments in April, before the burning treatment in July and after the burning treatment in September.

We sampled canopy cover in the quadrates using visual estimation which has a low expected errors at larger scale (above 0.06 m^2 quadrate size), especially in nutrient–deficient habitats (Klimes 2003). We estimated the percentage values for each plant species, litter, open sand surface and burnt area. In order to reduce subjective error, the same person performed all of the estimations. We also recorded the species number of the vascular plants. Before the burning treatment we measured the maximum height of vegetation at ten random points in the sampling quadrates using a ruler. We recorded the time span between the start and the end of the burning in each quadrate allowing us to calculate the speed of fire-spread (dm^2 s^{-1}) by dividing the burnt area by the burning time.

We estimated the effects of treatments and sampling date on the species number, canopy cover of the vascular plants and litter using a three-way repeated measure ANOVA. Treatments (grazing, burning) were fixed factors, while the third factor, the block was random. We assumed the interactions of the random factor to be non-significant, thus we did not include them in the model. Repeated-measure ANOVA partialled out the effect of pre-treatment differences between plots. We analyzed the effects of grazing on plant height, burnt area and speed of fire-spread by two-way ANOVA with one fixed factor (grazing) and one random factor (block). After both ANOVA analyses, pair wise comparisons by Tukey's HSD test were carried out. We calculated Spearman's rank correlations between measured variables to show their relationships. We used Statistica 6.0 (© StatSoft Inc.) for data analysis.

Results

Grazing and fire effects changed over time in the case of most of the variables during the experimental period (Table 1).

In the case of canopy cover of the litter, we did not find any differences among the grazing treatments for any of the three sampling dates. However, canopy cover of litter increased between April and July in the case of the grazing control quadrates, while it did not change in relation to the three grazed treatment types.

We found differences in canopy cover of vascular plants among the grazing treatments before the first treatment in April (Fig. 2.), namely, the values for early sheep grazing were lower compared to that of the control. Between April and July the canopy values decreased, however, there was no change in the case of early sheep grazing. Consequently, in July before the burning treatment we found no difference between grazing control and early sheep grazing, while rabbit grazing decreased the canopy cover compared to both the control and the early sheep grazing. Late sheep grazing resulted in non-significantly lower canopy values.

Canopy cover of vascular plants increased from July to September in all grazing treatments. Early sheep grazing resulted in higher values compared to the control in September.

Plant height was lower in the grazed quadrates due to the early and late sheep grazing compared to the control, while rabbit grazing resulted in intermediate values (Fig. 3.).

Burnt area was smaller in the case of late sheep grazing compared to that of the early sheep grazing and the control, while rabbit grazing insignificantly decreased the extent of fire (Fig. 4.). The speed of fire-spread decreased due to rabbit grazing compared to the control (Fig. 5.).

Species number was not affected by the grazing treatments. We found a difference among the differently treated patches, but this was persistent from the very beginning to the end of the study (Fig. 6.).

Fire decreased the canopy cover of litter and of vascular plants, as well as the species number, compared to the non-burnt quadrates measured in September, two months after the fire event.

The canopy cover of litter measured before the burning treatment correlated to the burnt area (Spearman's correlation $N=80$, $R=0.7505$, $p<0.0001$) and the speed of fire-spread (Spearman's correlation $N=80$, $R=0.6717$, $p<0.0001$). Similarly, we found that the canopy cover of vascular plants correlated to the burnt area (Spearman's correlation $N=80$, $R=0.5302$, $p<0.0001$) and the speed of fire-spread (Spearman's correlation $N=80$, $R=0.5338$, $p<0.0001$). Furthermore, plant height correlated to the burnt area (Spearman's correlation $N=80$, $R=0.5581$, $p<0.0001$) and the speed of fire-spread (Spearman's correlation $N=80$, $R=0.4466$, $p<0.0001$).

Discussion

We found that the effect of sheep grazing on the extension of fire depends upon the timing of the grazing treatments. According to our expectation, sheep grazing in late spring decreased the extension of fire during the mid-summer drought on the open sand grassland, while despite our preliminary assumption, sheep grazing in April had no effects on fire-spread. The reason for this is that the vegetation of the patches grazed in April had enough time to regenerate before July, thus the canopy cover of the vegetation was similar to the control prior to the burning treatment. The green vegetation of the patches grazed in late spring, either by sheep or by rabbit, did not regenerate by July, but was regenerated by September. Furthermore, mid-spring grazing, before the main growing season, might have an unexpected effect on fire-spread, because it resulted in overcompensation. We found higher canopy cover of the vascular plants in September in the case of sheep grazing in April compared to the control. Consequently, mid-spring grazing may increase the amount of the litter in the following year, thus it may increase the severity of a possible fire event. In contrast, we did not find overcompensation after the late spring grazing treatments in September. On the prairie, long-term heavy grazing has a negative effect on fire-spread, because it breaks up the homogenous grass layer (Gosz & Gosz 1996, Archibald et al 2005). We found that even moderate grazing causes decreased fire-spread on open sand grasslands. Grazing not only removes the combustible material from the vegetation, but even moderate trampling leads to gap formation in the litter and cryptogamous layer of the open sand grassland due to the low mechanical resistance of the surface of the coarse sand soil.

However, species identity is also important in the case of fire-spread, because only rabbit grazing significantly decreased the speed of fire-spread, and only sheep grazing in May significantly decreased the extension of fire. These two animals have different grazing habits. Sheep eat the top of the vegetation, while rabbits consume the interior portions of it. Accordingly, sheep grazing resulted in a stronger decrease in plant height, while rabbit grazing more strongly decreased canopy cover of vascular plants. Our results show that both the amount of combustible biomass (canopy cover of vascular plant and litter) and the structure of the vegetation (height) play a role in the spread of fire (speed of fire spread and burnt area). The amount of dry biomass could increase significantly from April to July only with a lack of herbivory in the control patches, because grazing treatments removed approximately 50 percent of the green vegetation, resulting in less litter on the grazed patches during the early summer. Cheney (1993) found that wind speed is the most important factor ruling fire-spread. In contrast with his results, we found that the amount and height of the above-ground vegetation correlate with the burnt area and the speed of fire-spread.

Subordinated herbs play the main role in the determination of species richness on many grasslands (Bakker & Olff 2003), such as our study site. Sheep mainly eat the dominant monocotyledons, while rabbits consume more dycotiledons (Katona et al. 2004). Thus, herbivory governs not only the proportion of the living and dead parts of the plants, but the species composition as well, in accordance with Milchunas et al. (1989). We found no short term decrease in species number due to the grazing treatments, similar to the results of Zaady et al. (2001), who stated that livestock grazing may cause limited damage to the ecosystem in the case of a rehabilitation project. Moreover, we consider herbivores part of the natural regime, and the lack of them may promote degradation processes (Clark 1981, Delibes & Hiraldo 1981). Fire decreased the species number in the short term, although this is attributed to the disappearance of some small forbs during the fire event. We believe that fire may not decrease species diversity on the sand grassland.

Fire and herbivory are two different agents of disturbance with distinct and interactive effects on the community (Noy-Meir 1995). According to North-American studies, which are most relevant to compare to our findings, they have different effects on the spread of shrubs on grasslands. On short grass prairies, intensive and heavy grazing of domestic herds of sheep and cattle decreased the frequency and extent of grassland fires during the past century (Brockway et al. 2002, Taylor 2003). Extensive grazing may result in the invasion of juniper species on semi-arid grasslands, decreasing the fuel load and fire intensity, as has occurred in the western United States (Fuhlendorf & Smeins 1997, Baker & Shinneman 2004). Similarly, van Langevelde found that heavy grazing decreases the role of fire and leads to increased woody vegetation on savannas (van Langevelde et al. 2003). In fire controlled habitats, decreased herbivory may lead to the dominance of grassland vegetation because fire mainly damages woody vegetation and is enhanced due to the increased biomass of the grassland (Belsky 1992).

The Kiskunság Sand Ridge vegetation appears to be limited by fire and lack of consumptive herbivores, according to the description by Bond (2005). Decreased herbivory, due to changes in land use and the local extinction of rabbits, may lead to extensive fire events in the Kiskunság due to the increased vegetation biomass. *Juniperus communis* is highly sensitive to fire (Wink & Wright 1973) and does not regenerate after fire, according to our field observations. This fire-sensitivity is used to reduce one-seed juniper [*Juniperus monosperma* (Engelm.) Sarg.] in the Western United States in order to rehabilitate degradated prairies (Jameson 1962); however, the Kiskunság National Park would like to protect the few *Juniperus-Populus* forest-steppe habitats in the Kiskunság.

We suggest that the accumulation of litter (due to decreased herbivory on the sand grassland patches) might affect the structure of the whole forest-steppe habitat, because an enhanced litter layer on the open grassland can transmit fire among the woody patches. Therefore, in the absence of large herbivores spread of fire may increase in the *Juniperus-Populus* forest-steppe where woody patches are surrounded by a matrix of open sand grasslands. Woody patches play an important role in sustaining biodiversity, although most of the endemic and other protected species live on the sand grasslands. This is because they increase habitat diversity by producing shaded and more humus-rich habitat-patches, which results in the remarkable species richness characteristic of the Sand Ridge vegetation. Fire damages this pattern of the vegetation. According to our long term observations on the Kiskunság, *Juniperus communis* is not able to regenerate after fire; it is replaced by resprouter trees, such as the invasive *Robinia pseudo-acacia* or *Populus* species. Therefore, fire may affect the vegetation, not only in the short-term, but can cause long-term compositional changes, which has a greater effect on the grassland than burning itself.

Conclusions

We found that moderate, late spring grazing may inhibit the burning of large continuous areas of the *Juniperus-Populus* forest-steppe. Timing of grazing treatments proved to be an important factor. Moderate grazing has no short-term effects on the species diversity of semiarid open sand grasslands. Therefore, controlled grazing treatments should be considered as a management tool to maintain the integrity of the semiarid forest-steppe habitats.

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Tables

Table 1. Degrees of freedom, F-values and the levels of TypeI error (* means p<0.05; ** means p<0.01; *** means p<0.001) studied by three-way repeated measure ANOVA in the case of the variables measured from April to September (1) and analysed by two-way ANOVA in the case of the variables measured in July only (2)

	Grazing	Fire	Time	Grazing ×Fire	Grazing ×Time	Fire ×Time	Grazing ×Fire ×Time
D.f.[1]	3, 143	1, 143	2, 18	3, 143	6, 286	2, 286	6, 286
Litter[1]	0.22	22.30***	19.98***	1.99	3.37**	45.94***	0.82
Vascular plants[1]	5.04**	16.06***	8.42**	0.42	6.50***	29.12***	0.95
NDVI[1]	4.12**	12.18***	51.90***	0.80	4.71***	21.71***	0.93
Species number[1]	2.90*	3.25	45.94***	1.38	1.726	12.47***	0.64
D.f.[2]	3, 67						
Plant height[2]	4.30**						
Burnt area[2]	5.68**						
Fire-spread[2]	3.28*						

Figures

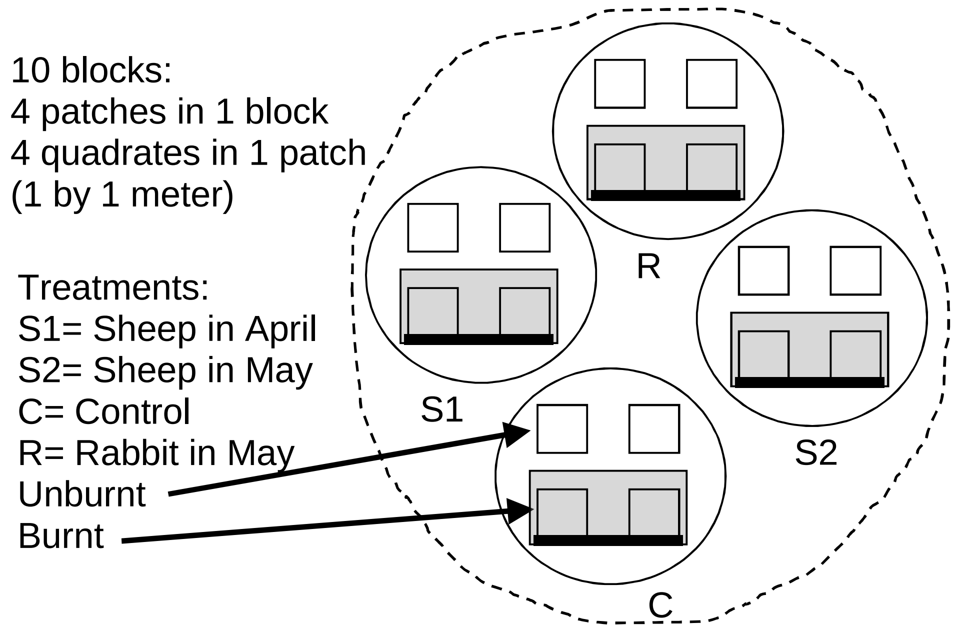

Figure 1. Experimental design of one block out of ten; consists of four differently treated grassland patches including four sampling quadrates. Two of the four quadrates were burned in July of 2003. The fire was set along the bold lines.

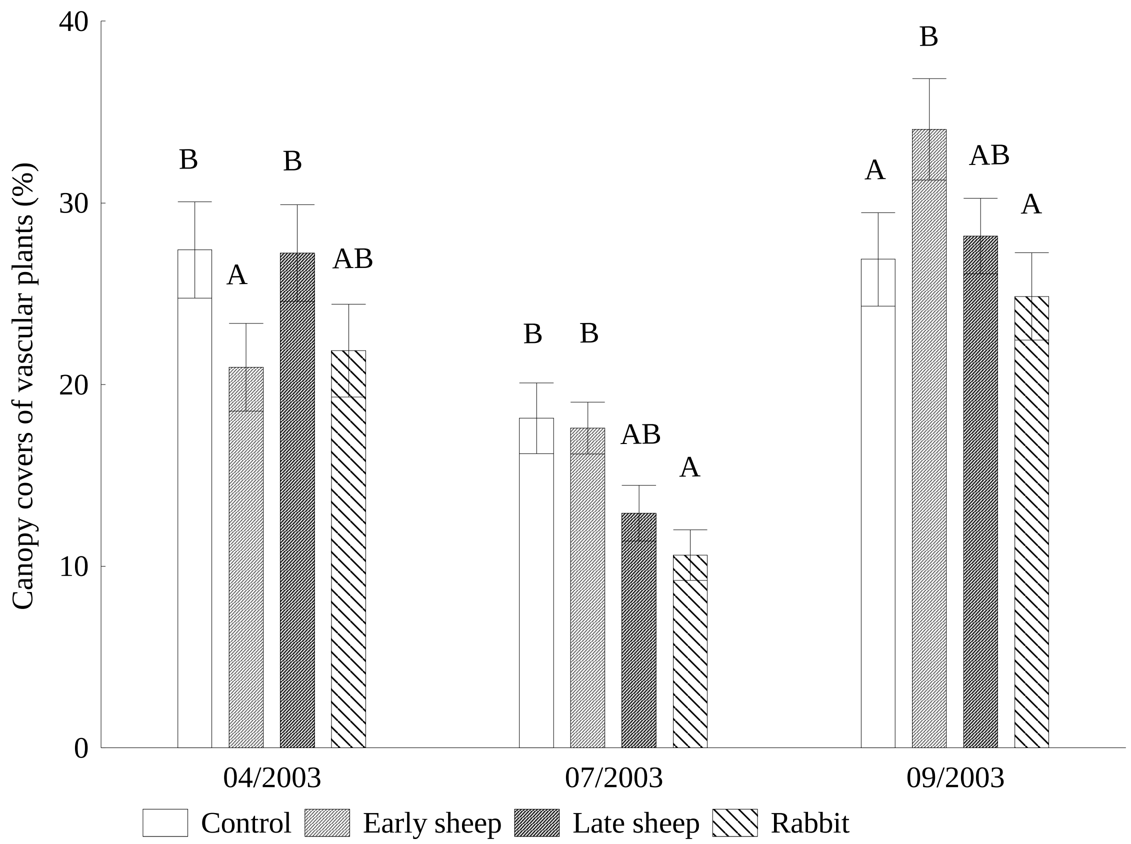

Figure 2. Canopy covers of the vascular plants (mean +/- SE) for the four types of grazing treatments at the sampling dates, before the grazing treatment in April, before the burning treatment in July and two months after the burning in September. Columns in the same cluster followed by the same letter are not significantly different according to Tukey's HSD test. Number of replicates was 10.

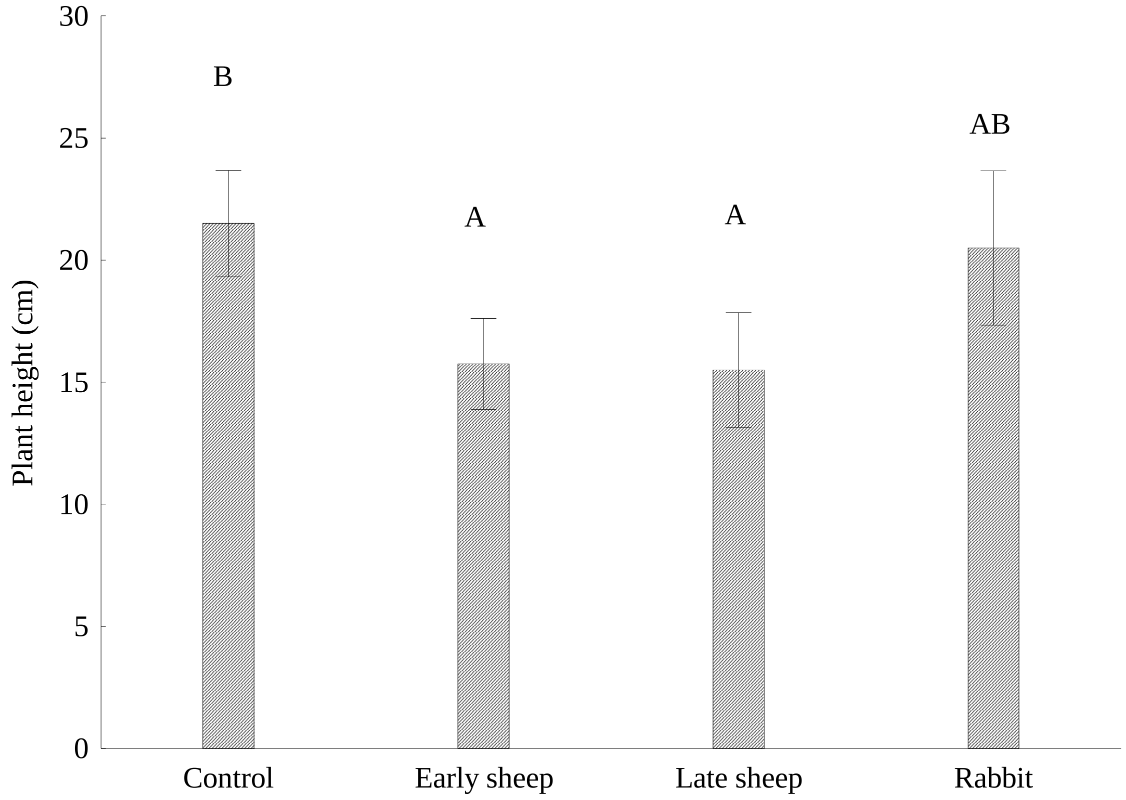

Figure 3. Plant height (mean +/- SE) for the four types of grazing treatments prior to the burning treatment in July. Columns in the same cluster followed by the same letter are not significantly different according to Tukey's HSD test. Number of replicates was 10.

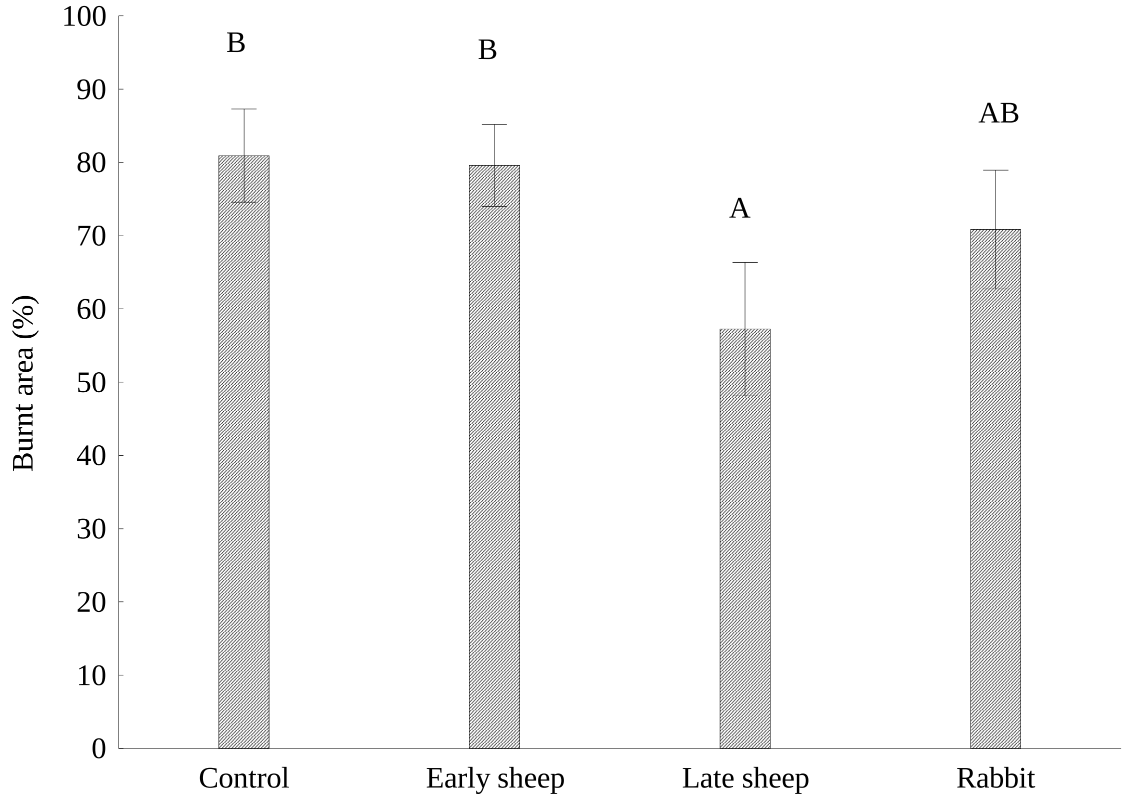

Figure 4. The extension of the fire (mean +/- SE) for the four types of grazing treatments in July. Columns in the same cluster followed by the same letter are not significantly different according to Tukey's HSD test. Number of replicates was 10.

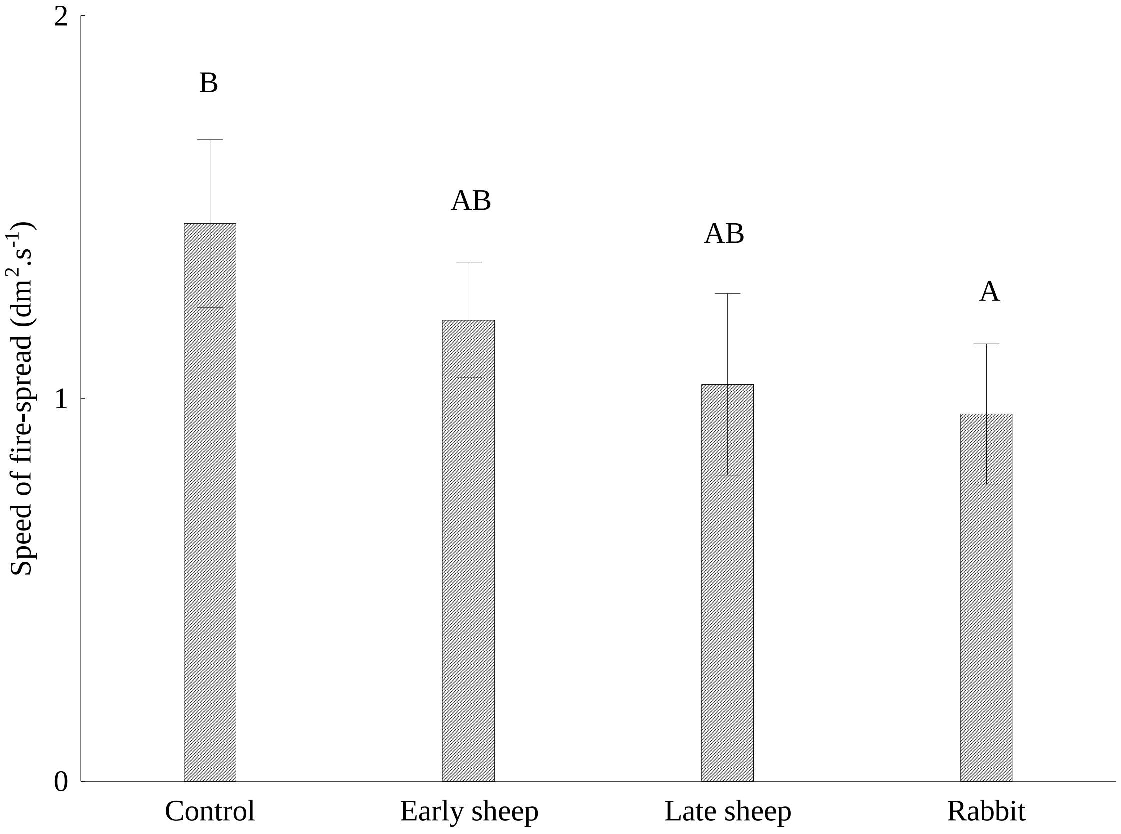

Figure 5. The speed of fire-spread (mean +/- SE) for the four types of grazing treatments in July. Columns in the same cluster followed by the same letter are not significantly different according to Tukey's HSD test. Number of replicates was 10.

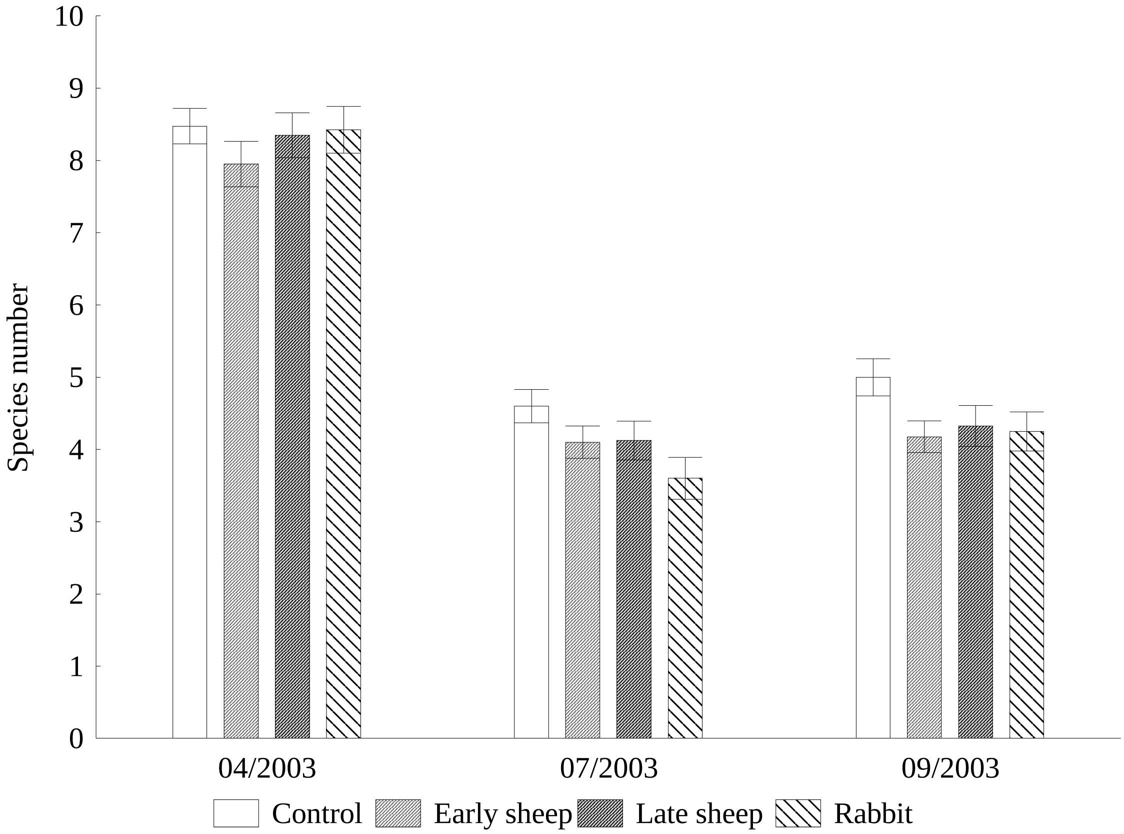

Figure 6. The number of vascular plant species (mean +/- SE) for the four types of grazing treatments at the sampling dates, before the grazing treatment in April, before the burning treatment in July and two months after the burning in September. All inclusive list of species in April, July and September was 80.