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Fire Effects on Productivity and Community Dynamics of Mongolian Grasslands

1. Introduction

Steppe ecosystems cover 65% of Mongolia's territory, of which 15.7% or 245,509 km^2 are located in Eastern Mongolia. The vegetation in arid ecosystems is affected by grazing and fire (Florentine, 1999; Drewa and Havstad, 2001). Major ecological factors that effect on Eastern Mongolian steppe vegetation are livestock and fire. Although fire must be included as an evolutionary force in the development of communities, particularly those ignited by lightning, today's fires are mainly caused by human activities. 60 to 80 major fires are recorded every year in Eastern Mongolia, that is, 80% of the total fires in Mongolia, affecting approximately 700,000 hectares of land annually (Natural Resources of Mongolia, 1998) (Figure 1).

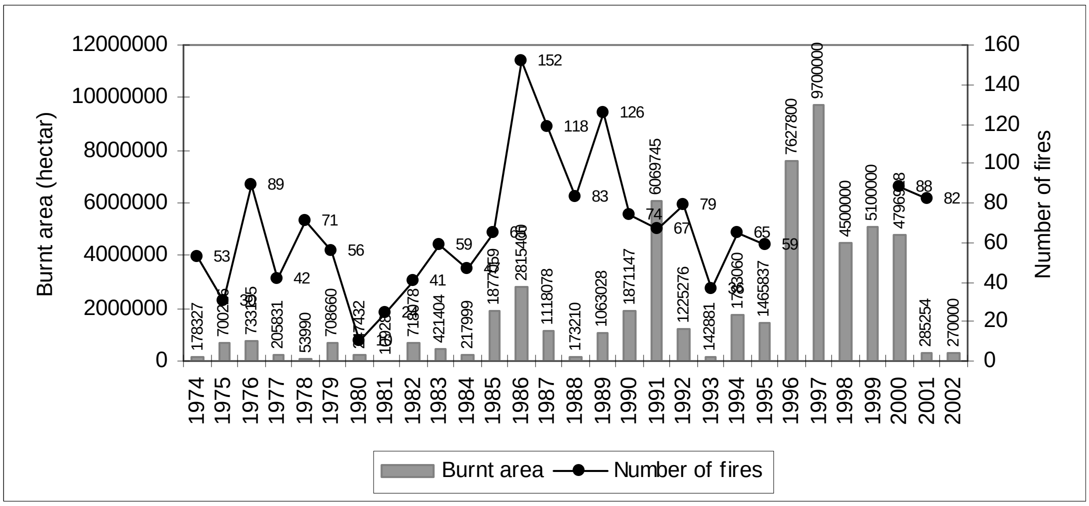


Figure 1. Steppe fire statistics of Mongolia 1974-2002.

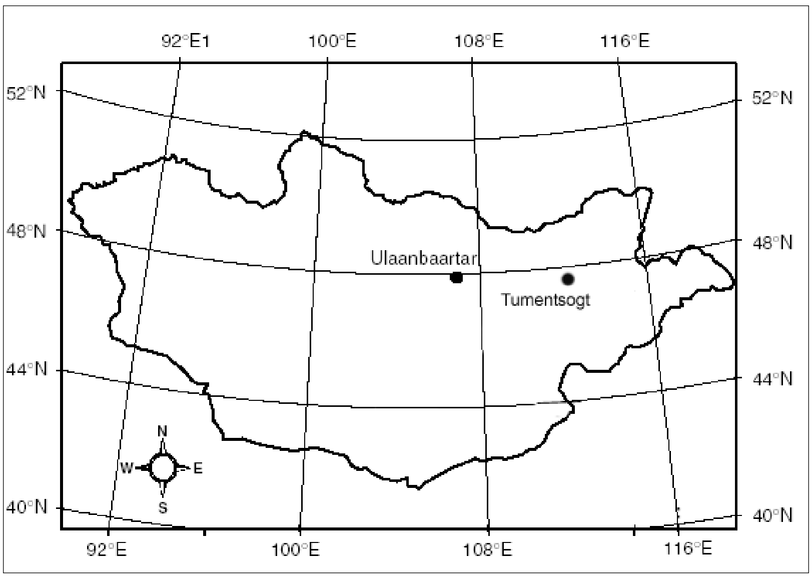


Figure 2. Location of the study site

There are many studies on the effects of grazing on grassland ecosystems. However, so far the fire effects on steppe grasslands of Mongolia had not yet been investigated. In other countries the effect of grazing and fire has been studied on grassland communities (Waser and Price, 1981; Kelt and Valone, 1995; Valone and Kelt, 1999; Ward et al., 2000; Drewa and Havstad, 2001; Westbrooke et al., 2005).

The role of prescribed fire and / or wildfire in promoting grass growth at the expense of woody vegetation has been well documented worldwide (e.g., Cook et al., 1994). A model was recently developed to predict the direct consequences of prescribed fire for most forest and rangeland types in the United States (Reinhardt et al., 1997). Generalizations about the response of herbaceous vegetation to fire are difficult to make because the fire environment and the vegetation are highly variable, as is their degree of interaction, i.e. vegetation production determines fuel loads which affects fire behaviour. Conversely, it appears that herbaceous vegetation production is related to fire behaviour (Bidwell and Engle, 1992).

Most rangeland communities are resilient to fire but significant changes in structure and composition may occur. Such changes are not due to fire alone because the interaction of grazing pressure and the rainfall regime before and after the fire determines the overall ecological impact. Grazing pressure can both affect and interact with the fire regime by reducing the quantity of fuel and by changing the plant species composition (Noble et al., 1986). Because fire is often deliberately applied to increase nutritious grass production, the grazing treatment applied immediately after fire might be critical in determining the path of plant succession in these situations (Danckwerts and Adams, 1992).

Therefore, it is necessary to conduct detailed research to determine the specific fire effects on the Mongolian steppe grasslands. This paper addresses the fire effects and the combined fire and grazing effects on steppe vegetation structure and composition, and the aboveground community biomass in Mongolia.

2. Materials and Methods

The objective of the study was to determine the fire effects on the steppe vegetation.

2.1 Study Site and Field Sampling

The study site is located in Tumentsogt soum, Sukhbaatar province (112°24’187’’N, 47°40’788’’E), which is 500 km south-east from Ulaanbaatar at an altitude of 927 m a.s.l.. This is site has most preserved eastern Mongolian steppe features with its high grass and high frequency of fires.

The region is characterized by temperate semi-arid continental monsoon climate. Annual mean precipitation is 230 mm, mainly from June to September. The annual mean temperature in this area is 0.5-0.6°C and the average annual wind speed is 3-4 m/sec (Batdelger et al., 2001). The soil type is chestnut. The vegetation in the study area is a typical tallgrass steppe, dominated by *Stipa grandis* – the most widely distributed grassland community in the eastern Eurasia steppe region. Subdominants are this community are *Leymus chinensis, Cleistogenes squarrosa* and *Stipa sibirica.* In the study site 72 vascular plant species in 54 genera and 26 families are found.

Data collection during the steppe research was conducted in 2001-2003. Two study sites were established, each 100x100 m. One site was been fenced in June 2001 for evaluating fire effects only. The other site was not fenced in order to evaluate fire and grazing effects. Within each site 5 sub-plots were established. In summer 2001 data were collected on all 10 plots that were subjected to moderate grazing. The plots were not burned, i.e. all plots were in the same condition (Figure 2).

In the following spring and autumn fire seasons experimental fires were ignited to burn all plots.

Table 1. Study plots by different variations of grazing and burned

Plot Designation	Situation of grazing	Situation of burned	Plot Designation	Situation of grazing	Situation of burned
NGS-1	none	burned in the spring 2002	GS-1	grazing	burned in the spring 2002
NGA-1	none	burned in the autumn 2001	GA-1	grazing	burned in the autumn 2001
NGS-2	none	burned in the spring 2002 and 2003	GS-2	grazing	burned in the spring 2002 and 2003
NGA-2	none	burned in the autumn 2001 and 2002	GA-2	grazing	burned in the autumn 2001 and 2002
NGC	none	none	GC	grazing	None

We collected data between 1 and 10 July in 2001 and 2003 using the line-point transect method (three 25-m line transects for each plot). Every 25 cm data were taken and the coverage of species was determined every 5 m along the transect. Aboveground biomass was sampled during 10-15 July each year by clipping all plants within a 0.25 m^2 quadrate, dried and weighed. The dry mass per quadrate averaged over the eight blocks was used to estimate the aboveground community biomass.

2.2. Data analysis

The differences in total vegetation coverage, litter, bare ground, aboveground biomass of community, coverage of three-year-old dominant species were compared on 10 plots using the Microsoft Access programme.

3. Results

3.1 Coverage

Figure 4 shows that in 2001 when all plots were in the same condition (grazing and unburned) vegetation coverage was higher in GC and GA-2 plots. In 2002, after one site was fenced and plots were burned by different treatments (Table 1) the situation changed. Vegetation coverage was higher in the fenced site than on the grazed site. In the fenced site vegetation coverage was 65.1% of the control plot. In the burned plots the vegetation coverage was 53.1-56.1%. Also in the grazed site vegetation coverage was higher on the control plot than on the burned plots. Highest vegetation coverage was found in the NGC plot (no grazing and no fire).

In 2003, the vegetation coverage decreased in all plots. The main reason for this was that this year was dryer than 2002.

The following results show the comparison of plots in 2003. In the fenced site the vegetation coverage was lower than the NGS-2 and NGA-2 plots that had been burned twice, and higher in the NGC, NGS-1 and NGA-1 plots that were either unburned or burned once. In the grazing site vegetation coverage was lower than on the fenced site. However, the same principles were found when comparing to the other plots. Figure 4 shows that the coverage of the GC plot was lower than NGC, but similar results in the NGS-2 and NGA-2 plots.

Our results show an inverse correlation between litter coverage and bare ground. After fire the litter disappeared and the bare ground cover increased. The lowest mean of bare ground is 13.6% in the NGC plot and the highest mean is 59.1% in the GS-2 and GA-2 plots (grazing and burned twice). Bare ground was increased 3-fold after burning once and 3.8 fold after burning twice. Comparing bare ground of control plots in non grazing sites with grazing showed a 1.3 fold increase. In the grazing site bare ground was increased 2-fold after burned once and 2.6 fold after burning twice. Litter was highest in the NGC plot (32.4%), i.e. 1.3-fold higher than in the GC plot and 2-fold higher than the NGS-1 and NGA-1 plots.

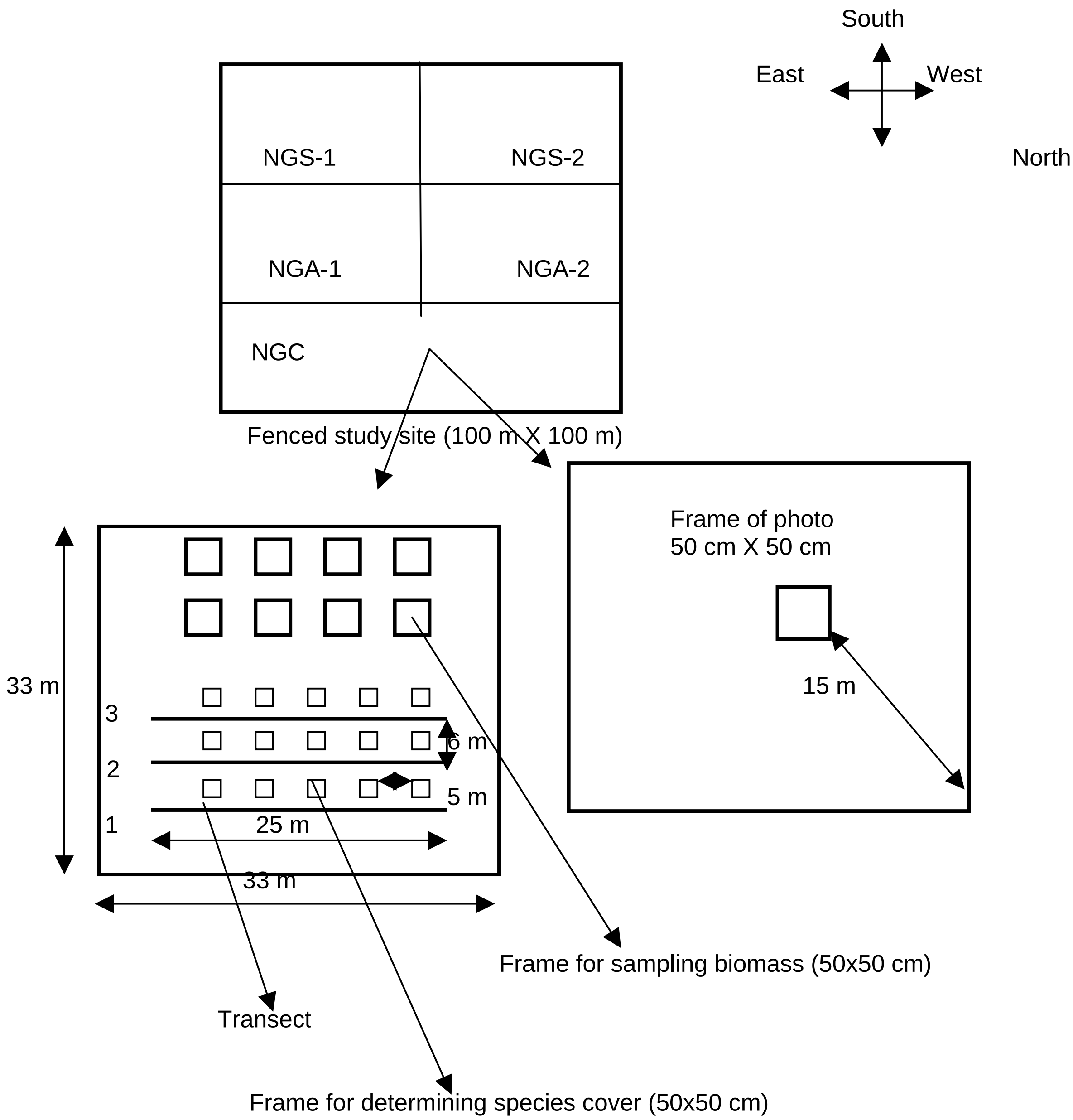
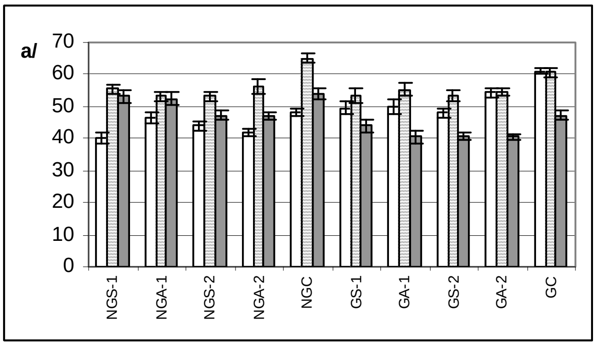
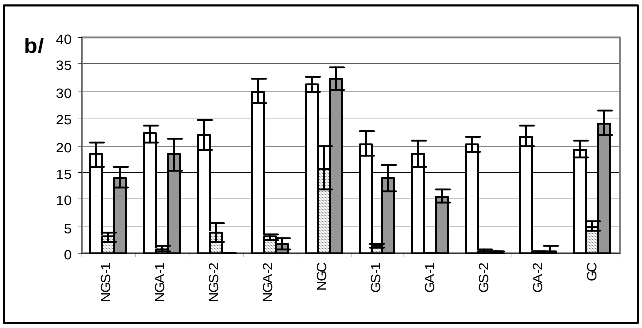


Figure 3. Scheme of the fenced study site





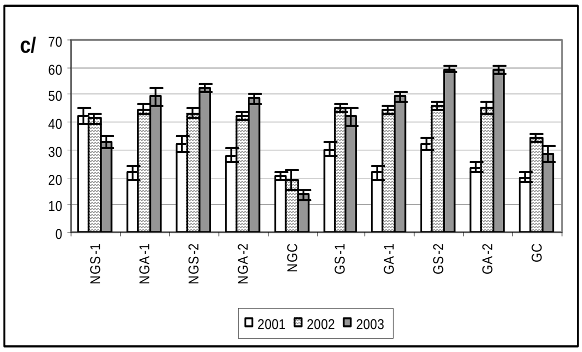


Figure 4. Total coverage of *Stipa grandis* community (a) vegetation cover (%), (b) litter cover (%), (c) bare ground (%).

We determined the coverage of all species of this community. In this paper we considered dominant species. We found fire effect on the coverage of species steppe community.

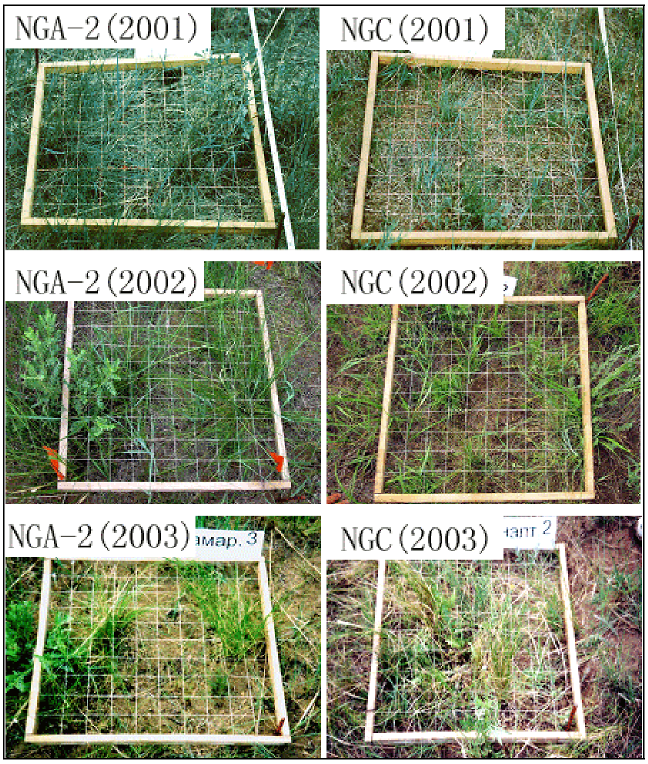
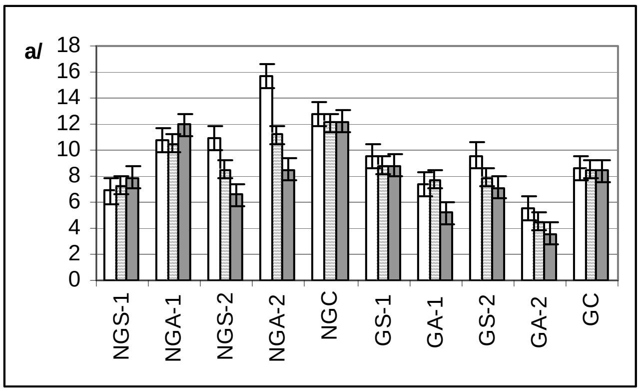
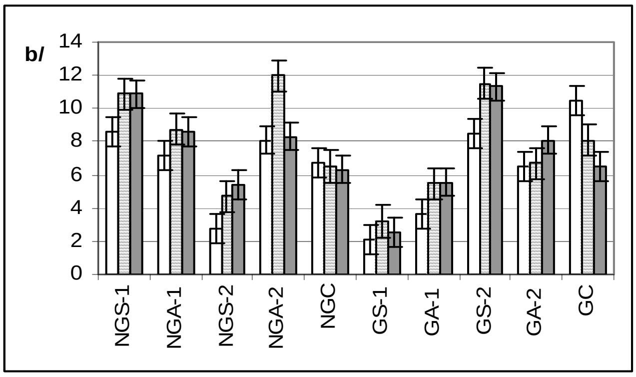


Figure 5. Plots NGA-2 (burning) and NGC (no burning), in different variation of burned

Stipa grandis P. Smirn. is a perennial firm-bunch grass of Gramineae that is dominating the typical steppe ecosystems of Mongolia. Coverage of *Stipa grandis* was reduced 1.5- to 2-fold after burning twice (NGS-2, NGA-2); coverage increased one year after burning once (NGS-1, NGA-1) in the fenced site (Figure 6a). In the grazing site coverage of *Stipa grandis* decreased in all plots. However, after fire the population of *Stipa grandis* recovered. The fire reduced senile plants, and newly sprouting plants increased (Tuvshintogtokh, 1997).

Leymus chinensis (Trin.) Tzvel is a perennial rhizome-grass and subdominant in this community. Its vegetative buds are located deep in the soil and are not damaged by fire. The vegetative regeneration is good. Figure 6 (b) shows that the coverage of *Leymus chinensis* increased after fire. In 2002, the coverage increased in all burned plots and not in unburned plots (NGC, GC).





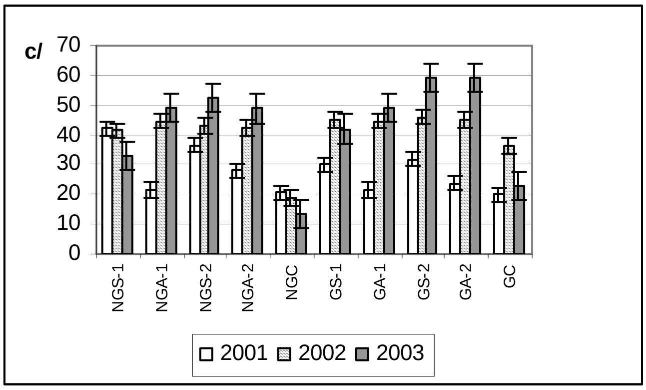


Figure 6. Coverage of dominant species
(a) *Stipa grandis* (%)
(b) *Leymus chinensis* (%)
(c) *Cleistogenes squarrosa* (%)

Cleistogenes squarrosa (Trin.) Kehg. is a loose-bunch grass and subdominant in this community. A recent study is indicating that the coverage of *Cleistogenes squarrosa* increased after fire (Figure 6c). In 2003, coverage of *Cleistogenes squarrosa* increased in NGS-2, GS-2, GA-2 plots, decreased in NGC, GC plots and almost was not changed in the NGA-1, GS-1, GA-1 plots. The observations show that *Cleistogenes squarrosa* quickly regenerated by a large number of vegetative buds, although it is easily damaged by fire too.

3.2. Biomass

Our results show that in 2002 control plots (unburned) has high biomass compared to burned plots. On the contrary were comparing control plots each other biomass of no grazing plot has higher 1.5 times than grazing plot. In 2003, in the fenced site highest biomass is in the NGS-1 plot (1890 kg ha^{-1}) and NGC plot (1720 kg ha^{-1}). Biomass increased in plots that were burned once and not grazed (NGS-1, NGA-1). Biomass decreased in other all plots. In the non-fenced site biomass of all plots are lower than in non-grazed plots and lowest (770 kg ha^{-1}) of them is in the plots burned twice (GA-2) (Figure 7).

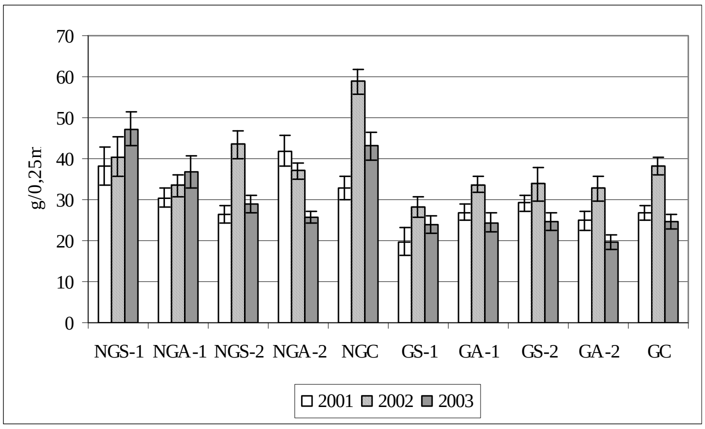


Figure 7. Total biomass of *Stipa grandis* community

4. Discussion

The effect that fire has on the soil and vegetation depends on the intensity of the fire. This intensity (*I*), in turn, depends on the heat yield (*H*), the availability of fuel (*W*), and the rate of spread (*R*) of the fire. This relationship is expressed by $I=H \times W \times R$ (Byram, 1959). The rate of spread of the fire depends on wind speed, nature of the fuel, humidity, and temperature.

Our results indicate that after fire vegetation the coverage and biomass density of the steppe community decreased. In the following year the vegetation regenerated quickly. However, consecutive fires resulted in a constant decrease of vegetation coverage. It is observed that bare ground increased and soil moisture is due to this influence of fire. Water holding capacity is lower and evaporation is higher on burned plots than on unburned ones. Burned sites also have higher temperatures than unburned sites, due to the increased absorption of sunlight by the blackened soil surface. This is especially true in grasslands (Barbour, 1987).

After the fire plant species react differently regarding their regeneration, and this is caused by their specific bio-morphological types. Vegetative buds are of pivotal importance for branching and growth of sprouting plants (Munier-Jolain et al., 1996). The location of their root system, vegetative buds and their number were dependent on the increase or reduction of vegetation coverage. Soil surface temperatures in grassland fires reach about 120°C, and in soil 1-5 cm deep, there is a temperature increase of only 10-15°C above ambient soil temperatures (Barbour, 1987). So vegetative buds on the ground easily damaged by fire and vegetative buds under ground do not damaged. Our results show that *Stipa grandis* decrease and *Leymus chinensis* and *Cleistogenes squarrosa* increase after fire.

The root system of *Stipa grandis* is located near the surface and some vegetative buds are located near the surface too (Gorshkova, 1966). Thus, vegetative buds are easily damaged by fire. The difference between *Stipa grandis* and *Cleistogenes squarrosa* is the quantity of vegetative buds. *Cleistogenes squarrosa* has a large number of vegetative buds some of which are damaged by fire too. However, by virtue of their high number *Cleistogenes squarrosa* can regenerate quickly. Therefore the photosynthetic pathway of *Cleistogenes squarrosa* is C_4. Pyankov et al. (2000) proved that the combination of C_4 species is favourable to occupy very arid conditions (Pyankov et al., 2000).

Leymus chinensis has long, strong rhizomes and vigorous vegetative propagation. Its rhizomes lie horizontally about 10 cm below the soil surface and are highly branched. Reproduction is mainly by clonal propagation (Wang et al., 2004). Thus, vegetative buds of *Leymus chinensis* are not damaged by steppe fire and its vigorous vegetative propagation contributes to an increase of coverage.

Thus, there is a structural change the steppe plant community. A large number of *Leymus chinensis* grow instead of *Stipa grandis* under frequent fires every year. And by grazing effect *Stipa grandis* was decreased and *Leymus chinensis* and *Cleistogenes squarrosa* were increased too. As a result, the *Stipa grandis* community may change towards a *Leymus chinensis*-*Cleistogenes squarrosa* community as consequence of the effects of frequent fires and grazing in the Eastern Mongolia.

Our study evinced that the adaptations of grassland plants, most of with are hemicryptophytes, allow them to survive and even thrive in the presence of periodic fire. The fire environment provides a very powerful selective force in the grassland. Mechanisms for survival in grasslands include increased reproduction from seeds as well as resprouting from perennial buds, which are protected at below the surface of the soil.

Besides this observation it has been noted that forests and meadow steppes were drying after fire and changing towards typical steppe ecosystems (Ochir, 1967). The succession stages of a burned pine forest include the *Hamenerion angustifolium* community, followed by birch forest (*Betula* spp.) and the pine forest climax community. If fires are tooo frequent (annually) the *Pinus sylvestris* forest will be develop to a meadow steppe community (Zoyo, 2000). Altogether it is evident that the long-term effects of frequent fires result in a xerophytic vegetation cover in which C_4 species are becoming dominant.

Our results demonstrate that the combined effects of fire and grazing are effecting the grassland negatively. Consecutive fire had more negative effects on the steppe community as compared with grazing. Without grazing impact a single fire has positive effects on the steppe vegetation.

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