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Research Article

Effects of Time-Since-Fire on Vegetation Composition and Structures in Semi-Arid Perennial Grassland on the Loess Plateau, China

Although there is an increased understanding of fire's role in maintaining grassland ecosystems, few studies on vegetation develops after a fire disturbance has been reported in arid perennial grasslands on the Loess Plateau. To understand how vegetation recovers after a fire disturbance, we studied three grassland sites with different times since last fire in arid steppe on the Loess Plateau, China. Results showed that 2 years after a fire, total cover, species abundance, and diversity rapidly recovered and increased to higher than unburned grasslands. Rapid recovery after a fire disturbance was mainly attributed to the removal of litter which provided better microhabitats for lower dominance species and the vegetative regeneration of perennial species following fire. Fire has little effects on the composition of grassland species in the long run if the grasslands were dominated by perennial species because asexual recruitment plays an important role in the vegetation recovery after fire. The accumulated litter seems not a major reason explaining why fire does not significantly alter vegetation composition in studied grasslands. Low frequency fire is helpful to the renewal of grassland. Our results suggested that opportune fire is an effective regulator of plant composition and maintenance in arid grassland.

Keywords: abundance; arid grassland; cover; diversity; post-fire vegetation dynamics

Received: December 11, 2012; *revised:* January 7, 2013; *accepted:* January 24, 2013

DOI: 10.1002/clen.201200678

1 Introduction

Fire, an important component of disturbance in grassland, plays an important role in vegetation dynamics and succession [1–3]. Fire affects plants directly, by injury and mortality, and indirectly, by changing resource availability. The effects of fire on vegetation composition and process vary with intensity [4], severity [5], frequency [6], and season [7]. In general, fire management plays an important role in impacting on the vegetation structures [8] and regeneration [9], composition, diversity [10], and productivity [11]. In addition, fire also changed the microhabitat conditions in grassland communities. The removal of aboveground litter, vegetation, and the topsoil initially increased soil temperature, pH, and available mineral nitrogen [8].

Although the relative importance of fire management for biodiversity conservation is increasingly being recognized, fire exclusion policy and the policy of putting out fires immediately after ignition are widespread in many countries, especially in China. Most managers believe that fire can be a very destructive force to grassland ecosystems, and would lead to plant productivity reduction, vegetation degradation, and soil erosion. Therefore, many previous studies on disturbance in semi-arid sub-alpine perennial grassland have mainly focused on the effects of grazing, restoration management, and fertilizer on vegetation composition, diversity, and succession. Very few studies are available from Chinese grasslands that report the effects of fire on vegetation composition and diversity. The length of time since last fire is also an important topic of fire ecology, which affects the community composition and structure [12, 13]. However, the effects of the time-since-fire on community composition and structures in perennial semi-arid grassland are generally less well documented. Clearly there remains the need for further research into the effects of fire disturbance on grassland dynamics.

In Yunwu Mountain, grazing was the most frequent disturbance that induced serious grassland degradation and soil erosion many years ago. In order to prevent further deterioration of the existing conditions, livestock grazing was completely removed from the entire site after management changed to the reserve in 1982. However, extensive fires in Yunwu Mountain Pastoral Preservation Station are known to have occurred on two occasions in 1999 and 2008, due to accidental ignitions by local people. These fires provide an opportunity to study how vegetation develops after a fire disturbance in semi-arid grassland in the absence of grazing. Furthermore, we investigate how time since last fire affects the aboveground vegetation composition and diversity. The ultimate aim of this study is to provide more information for effective vegetation management of grassland ecosystems.

2 Materials and methods

2.1 Study area

This study was conducted in semi-arid grasslands in Yunwu Mountain Pastoral Protection Area (36°13′–36°19′N, 106°24′–106°28′E), which is

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located 45 km northeast of Guyuan County, Ningxia Autonomous Region, P. R. China (Fig. 1). The region has a semi-arid continental climate with hot summers and cold winters. It has an altitude range of 1800–2100 m, an average temperature of 6.7°C, and an average total annual evapotranspiration of 1400 mm. Mean annual precipitation is 400–450 mm with great inter-annual variability, and rainfall of July to September each year accounts for 65–85% of the annual precipitation. The study area's annual ≥10°C accumulated temperature is 2259.7°C, and the annual average frost-free period is 112–140 days [14]. The soil type of the study area is loessial with silt content ranging from 64 to 73% and clay content varying from 17 to 20%. The water in soil is mainly from atmospheric rainfall, and the soil is weakly resistant to erosion. The vegetation is semi-arid grassland and is dominated by *Stipa* spp. [14].

2.2 Experiment design and sampling

In July 2010, three 500 × 500 m^2 blocks were randomly established for sampling in burned 1999 sites, burned 2008 sites, and unburned sites, respectively. This resulted in a total of nine blocks for the study. The unburned sites, located in the vicinity of the fire area, were chosen for comparison, which have been free of fire for at least 30 years. The elevation range is 2063–2080 m in burned 2008 sites, 2055–2075 m in burned 1999 sites, and 2043–2073 m in unburned sites. These three study sites are on the same geological material and located very near to each other. Since 1982, they were under the same management regimes, which completely excluded livestock grazing. Before being burned, the vegetation in the burned 2008 sites and burned 1999 sites were similar with the unburned sites, and all

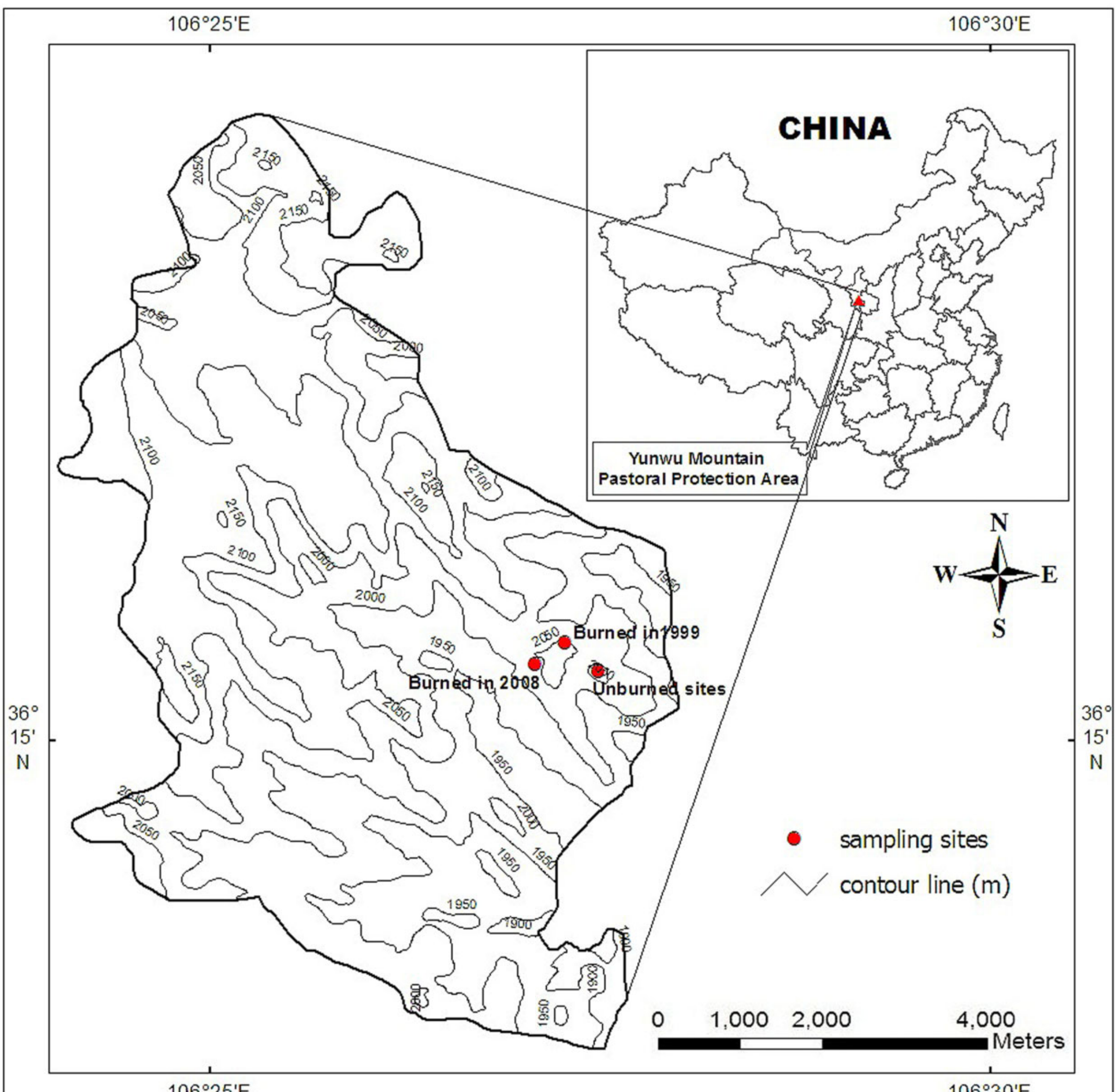

Figure 1. Map of study site, the Yunwu Mountain Pastoral Protection Area showing the location of the study sampling sites. It is located in the northeast of Guyuan County, Ninxia Hui Autonomouse Region, China.

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belonged to *Stipa bungeana* community. Three sampling plots (50 m × 50 m) were selected at random within each block, and three 0.25 m^2 quadrats (50 cm × 50 cm) were set 15 m apart in each plot. A total of 27 quadrats in each block were sampled.

The vegetation investigation was conducted from July to August in 2010, when above-ground vegetation reached its greatest biomass. In each quadrat, the total plant cover and litter biomass were measured. Meanwhile, the presence of all species was recorded, and cover and abundance for each species were measured. Species cover was measured with a visual estimate, and abundance was measured by counting species numbers in each quadrat. Plant nomenclature and assignment to families follows Wu [15].

2.3 Statistical analysis

Species richness S (the total number of species) and the Shannon–Wiener diversity index were calculated for community diversity analysis. Shannon–Wiener's index of diversity:

$$H = -\sum (P_i \ln P_i)$$

where $P_i = N_i/N$, N_i is the number of individuals of species i and N is the total individuals of all species present.

A two-way analysis of variance (ANOVA) was performed to examine the influence of the random factor blocks and the fixed factor treatment (two post-fire treatments), and interaction on the univariate measures (total cover, abundance, species richness, species diversity index, and litter biomass). To meet the requirement of variance homogeneity, the data were logarithmically transformed prior to analysis. Tukey post hoc comparison test was used to compare the difference between the two post-fire treatments when an *F*-test indicated significant treatment effects. For all ANOVA analyses, results in which $p < 0.05$ were reported as significant. All data were expressed as mean ±1 standard error of mean. Untransformed mean values for sites of management types were obtained by averaging the values of the respective three blocks. For all analyses described in this study, quadrats of 0.25 m^2 were used, as this should give a finer resolution. All statistical analyses were performed using the software program SPSS, ver.16.0 (SPSS, Chicago, IL, USA).

The changes in the community were evaluated using the detrended correspondence analysis (DCA). It was used to analyze variation among sites, show community level response to a fire disturbance and analyze the relationship between species abundance and different sites, based on the percent cover and the species abundance of each plant species at each plot, respectively. Prior to analysis, original cover values of each species were standardized by the maximum value modification for preventing any bias to the species with high values. By this adjustment, species cover values were transformed in the range of 0–1. Only for common species (≥5% frequency) were included in the DCA analysis. Data were analyzed using CANOCO for Windows 4.5 software [16].

3 Results

3.1 Species diversity conservation after fire

The analysis of variance (two-way ANOVA) revealed statistically significant differences in species richness ($F_{2.42} = 3.872$, $p < 0.05$), but non-significant in species diversity ($F_{2.42} = 3.837$, $p > 0.05$) among blocks. Fire significantly affected species richness and species diversity among three sites. There were significant differences for species richness (*S*) ($F_{2.42} = 4.935$, $p < 0.05$) and Shannon–Wiener's index (*H*) ($F_{2.42} = 11.525$, $p < 0.05$) among three sites. The block and fire interaction was not significant in both species richness and species diversity. Species richness and Shannon–Wiener's index were significantly higher at burned 2008 sites in comparison with control unburned sites. However, there were no significant differences for species richness and diversity index between burned 1999 sites and unburned sites. The species diversity significantly increased for sites of two years since last fire compared with unburned sites, but the effects disappeared 10 years since the last fire (Fig. 2).

3.2 Plant cover and abundance after fire

Two-way ANOVA indicated that different sites had significantly different plant cover ($F_{2.42} = 17.800$, $p < 0.001$). There was no significant difference for plant cover between blocks. Plant cover greatly increased after 2 years since last fire in studied grassland communities. Although the effects diminished 10 years since the last fire, the plant cover was also significantly higher than unburned sites. Two-way ANOVA recognized no significant difference for the species abundance between three sites.

Although no significant increase in species abundance, the total cover rapidly increased and even was greater than the unburned sites in the first 2 years after the fire. The dominant species *Stipa bungena*, *Artemisia sacrorum*, and *Carex rigescens* made important contributions to the significant increase in total cover 2 years after a fire. Two-way ANOVA performed on the litter biomass revealed a significant difference between sites ($F_{2.42} = 9.664$, $p < 0.05$) and blocks ($F_{2.42} = 4.105$, $p < 0.05$), but no significant difference in the interaction between the block and fire. The fire disturbance significantly reduced the litter biomass in burned 2008 sites, but the effects diminished 10 years after last fire. There was no significant difference in the litter biomass between the burned 1999 sites and the unburned sites (Fig. 2).

3.3 Relationship between communities

In the context of this study 48 species were recorded, 43 species occurred at burned 2008 sites, 42 species occurred at burned 1999 sites, and 38 species occurred at unburned sites. Thirty-two species were all recorded in these three sites. DCA on each species cover in each plot was presented in Fig. 3a. The distribution of plots in DCA ordination diagram showed a separation between burned and unburned sites, especially between burned 2008 sites and unburned sites, however, some plots in burned 1999 sites and unburned sites were not distributed separately from each other. The results supported that the similarity in the vegetation composition between burned 2008 sites and burned 1999 sites was more than between burned 2008 sites and unburned sites. DCA results for analyses with species abundance in each plot are presented in Fig. 3b. There was greater overlap in dominant and common species. These three sites were all dominated by perennial species, such as *Stipa* species (*Stipa bungeana*, *Stipa capillata*, and *Stipa grandis*), *Artemisia* species (*Artemisia sacrorum* and *Artemisia giraldii*), *Carex rigescens* and *Heteropappus altaicus*. Species *Bupleurum chinese* and *Carduus nutans* which were away from other species only appeared in the burned sites. Some rare species *Androsace umbellate*, *Artemisia capillaries*, *Euphorbia pekinensis*, and *Artemisia frigida* only occurred in the burned sites, and species *Potentilla freyniana*, *Thalictrum aquilegifolium*, and *Torularia humilis* only occurred in unburned sites (≤5% frequency, not shown in Fig. 3).

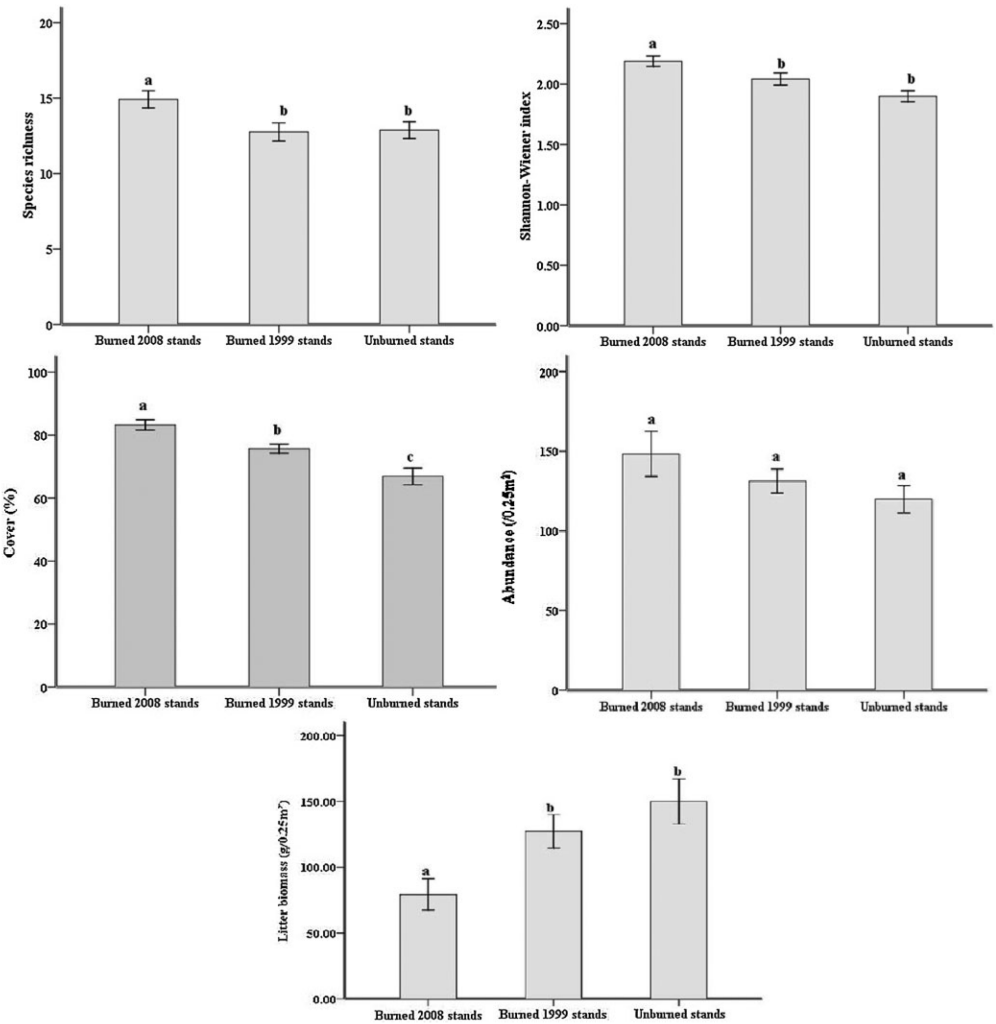

Figure 2. Vegetation parameters changes under the different time since last fire in semi-arid grasslands on the Loess Plateau; burned 2008 sites (2 years since last fire), burned 1999 sites (10 years since the last fire), and unburned sites (no fire history at least 30 years). Values (±SE) are means of 27 squares. Means with the same letter are not significantly different, $p > 0.05$, by the Tukey tests.

4 Discussion

Although site difference of investigation may be part of the reason why there is the difference in total cover, species richness, and diversity, it does not significantly affect the results got in this study. Before the fire event, these three sites were dominated by *Stipa bungeana* and had the same management history. Since 1982, the reserve was fenced by wire netting to completely excluded livestock grazing. Some units organized researchers to conduct a survey of vegetation in the reserve in 1983. Zhou and Cheng proposed that *Stipa bungeana* community was the most widely distributed community and mainly located in the center, south, north, and east of the reserve [17]. The site in this study is the main distribution area for *Stipa bungeana* community. Therefore, we consider the difference in total cover, species richness and diversity between these three areas is mainly caused by fire disturbance in this study.

Clearly, the perennial grasslands could quite rapidly recover from a fire disturbance, and even thrive for 2 years after a fire in this area. Rapid recovery of vegetation after fire in grassland ecosystems has been observed in other studies [18–20]. There are several mechanisms to explain this phenomenon. Firstly, the rapid recover of vegetation after fire is attributed to the removal of accumulated litter, which improve growing environment for lower dominance species following fire, such as removal of light limitation and coincident increases of soil nutrients. Secondly, competitive interactions are reduced and recruitment possibilities are high in early post-fire vegetation development. Eggers and Porto suggested that vegetation would quickly recover to its pre-burn species composition after a burn as the majority of species re-sprout shortly after the fire [21]. Our studies also find that asexual recruitment play an important role in the grasslands recovery after a fire in this area [21]. Thirdly, the other main reason is that the semi-arid grasslands are dominated by the perennial plants. Recovery of tall-tussock grassland after fire depends on the ability of the surviving tussocks to regain their former dominance. Finally, the grassland after a fire event is also fenced by wires and completely excluded grazing, which may accelerate grassland recovery after fire. However, change of vegetation structure caused by fire is rather transient, and the effects would gradually decrease and even disappear with the time increasing. This is consistent with the results of Imanuel which showed that the

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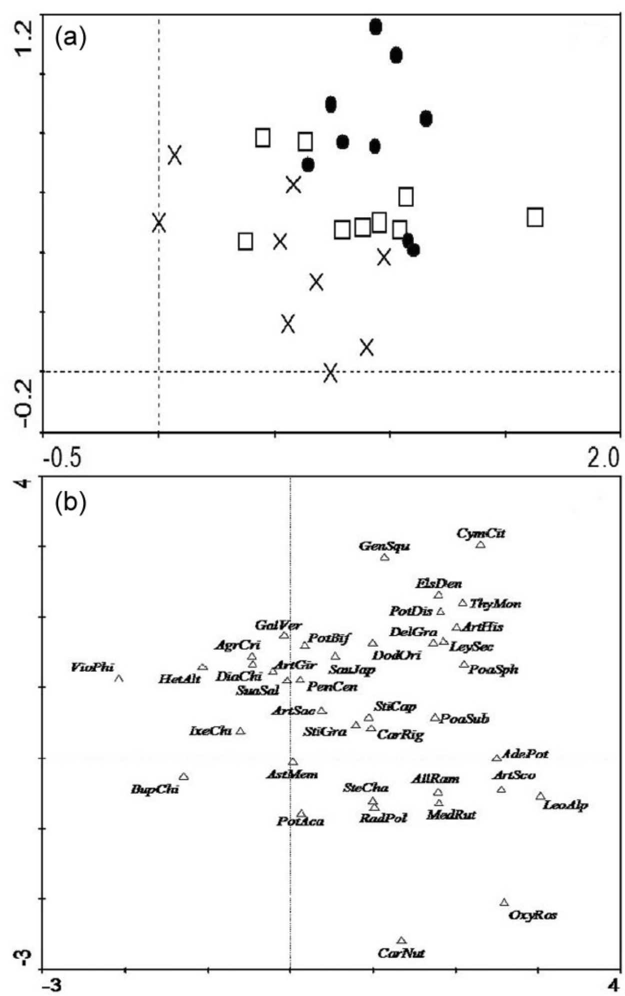

Figure 3. Detrended correspondence analysis of floristic data; (a) DCA plot ordination of vegetation data (percent cover by species). Number represents plots, and symbols indicate community type identification. ×: burned 2008 sites; □: burned 1999 sites; ●: unburned sites. (b) DCA species ordination of vegetation data (abundance by species). *StiCap* = *Stipa capillata*; *StiGra* = *Stipa grandis*; *ArtHis* = *Arthraxon hispidus*; *PoaSub* = *Poa subfastigiata*; *PoaSph* = *Poa sphondylodes*; *AgrCri* = *Agropyron cristatum*; *LeySec* = *Leymus secalinus*; *CymCit* = *Cymbopogon citratus*; *PenCen* = *Pennisetum centrasiati*; *CarRig* = *Carex rigescens*; *PotBif* = *Potentilla bifurca*; *PotDis* = *Potentilla discolor*; *PotAca* = *Potentilla acaulis*; *SuaSal* = *Suaeda salsa*; *LeoAlp* = *Leontopodium alpinum*; *ArtSac* = *Artemisia sacrorum*; *ArtSco* = *Artemisia scoparia*; *ArtGir* = *Artemisia giraldii*; *SauJap* = *Saussurea japonica*; *HetAlt* = *Heteropappus altaicus*; *CarNut* = *Carduus nutans*; *IxeChi* = *Ixeris chinensis*; *DiaChi* = *Dianthus chinensis*; *SteCha* = *Stellera chamaejasme*; *AllRam* = *Allium ramosum*; *GenSqu* = *Gentiana squarrosa*; *OxyRos* = *Oxytropis rosea*; *MedRut* = *Medicago ruthenica*; *AstMem* = *Astragalus membranaceus*; *VioPhi* = *Viola philippica*; *RadPol* = *Radix polygalae*; *GalVer* = *Galium verum*; *ThyMon* = *Thymus mongolicus*; *DodOri* = *Dodartia orientalis*; *ElsDen* = *Elsholtzia densa*; *AdePot* = *Adenophora potaninii*; *BupChi* = *Bupleurum chinense*; *DelGra* = *Delphinium grandiflorum*.

effect of fire were considerably attenuated in the second growing season after the fire, and had disappeared in the third winter after the fire [22]. In addition, the increase of ash fertilization through ash deposition previously contained in vegetation and transient increase of pH are also important to the post-fire recovery [23, 24]. In all, these factors all contribute to physiological modifications, greater photosynthetic capacity and higher nitrogen use efficiency [25], leading to rapid recovery of vegetation from fire in perennial semi-arid grasslands. In this study, only the influence factor of the litter is measured, and other abiotic variables are not measured, which limits analysis of the main driving factor. In short, when fire is not very frequent in perennial grasslands, the recovery after fire is rapid.

The largest impact of fire on the vegetation composition is on the abundance of species *Stipa bungeana*, *Carex rigescens*, and *Artemisia sacrorum*. Two years after fire, fire significantly causes an increase of the growth of the dominant species. Some other studies stated that dominant species may be favored by fire [26, 27]. Before fire, the thick litter buildup by the dead biomass of grasses and the dense growth of *S. bungeana* seriously inhibits their own growth and suppress the growth of other species in the grassland community. Fire reduces the competitive vigor of *S. bungeana*, and allows other species to co-exist. Some species, e.g., *Bupleurum chinense*, have disappeared form the unburned perennial grasslands. However, Fire provides an opportunity for the emergence of these rare species and shade-intolerant species. The plants that emerge in burned areas experience considerably higher light intensities than those in unburned sites at germination and during establishment and early vegetative growth [22]. At the same time, the higher spatial heterogeneity by fire is advantage to the tiller growth and tussock development of *Stipa bungeana*, rhizomous growth of *Carex rigescens*, and root sucker growth of *Artemisia sacrorum*. With time increasing after fire, the growth of species *Stipa bungeana*, *Carex rigescens*, and *Artemisia sacrorum* are suppressed due to grazing exclusion. Therefore, grassland communities may restore to the status of the unburned site for 10 years after a fire.

Fire disturbance alters the community composition and structures in the semi-arid grasslands, which were inconsistent with the results of Knops which showed that vegetation composition did not obviously change after fire [28]. Knops proposed that the little change in vegetation was important because the primary productivity was low and litter did not accumulate in American infertile prairie [28]. In our study, litter was also much greater in the undisturbed area and covered all the inter-tussock spaces. Therefore, the accumulated litter or not may be a major reason explaining why fire significantly alters vegetation composition in the semi-arid grasslands. Overall, the time since last fire alters the vegetation composition and structures, but the change in vegetation structure caused by fire is rather transient, and the effects would gradually decrease and even disappear with the time increasing in perennial grasslands.

Acknowledgments

This work was supported by the "Strategic Priority Research Program – Climate Change: Carbon Budget and Related Issues" of the Chinese Academy of Sciences (grant no. XDA05050403), "100-Talents Program" to Shi Zhi-Hua, West Light Foundation to Wu Gao-Lin and Northwest A&F University (QN2011039).

The authors have declared no conflict of interest.

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