Differences in species composition of the soil seed banks among degraded patches in an agro-pastoral transition zone in Inner Mongolian steppe

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Abstract. Degraded grasslands were distributed in patches characterized by fringed sagebrush (*Artemisia frigida*), narrowleaf stellera (*Stellera chamaejasme*), shining speargrass (*Achnatherum splendens*), or white swordflag (*Iris lactea*) at an agro-pastoral transition zone of the south Inner Mongolian steppe, which have been retrogressive from a *Leymus chinensis* steppe. A control patch (undegraded) was located close to the four degraded patches. We investigated the size, composition, species richness of soil seed banks, and its relation to the aboveground vegetation. The density of soil seed banks was highest in the white swordflag patch, intermediate in the shining speargrass and undegraded patches and lowest in the fringed sagebrush and narrowleaf stellera patches. The percentage of the persistent seed bank in the undegraded patch was higher than those in the four degraded patches. Similarities between the soil seed bank of the undegraded patch and degraded patches and between soil seed banks and standing vegetation of the undegraded patch were all low. The potential for in situ regeneration of the established vegetation of the undegraded patch from the soil seed bank is low in all of these four patches. We can assume that restoration of these habitats can not rely on seed banks alone.

Keywords: Revegetation, seed bank strategies, degraded steppe.

Introduction

Soil seed banks play an important role in plant community dynamics, vegetation regeneration and maintaining floristic diversity (Bossuyt and Honnay 2008). The density of the seed banks, similarities between the established vegetation and the seed banks, and the persistence seed bank are relevant in the revegetation of plant community (Funes *et al.* 2001; Li *et al.* 2007; Thompson *et al.* 1997).

The Inner Mongolian steppe at the agro-pastoral transition zone became degradation seriously by heavy grazing (Wang 1996; Zhao *et al.* 2005; Zhao and Li 2009). Restoration of degraded grassland vegetation should be immediately enhanced (Liu *et al.* 2009). Degraded patches, which were dominated by one species - *L. chinensis* before degradation, were now invaded in patches by *A. frigida*, *S. chamaejasme*, *A. splendens*, *I. lactea*, or *Cleistogenes squarrosa* as the result of heavy grazing in general (Wang 1996, Zhao *et al.* 2005). In order to estimate the potential for *in situ* regeneration of plant community, composition of soil seed banks has been widely studied in *Stipa krylovii* steppes (Zhan *et al.* 2005; Li *et al.* 2007). However, relatively little is known about the soil seed bank in *Leymus chinensis* steppes. This study investigated soil seed banks in degraded and undegraded *L. chinensis* steppes to guide conservation actions in similar ecosystems.

Our specific goals were to: (1) Compare the soil seed banks of undegraded and degraded grassland to ensure whether soil seed banks have changed as aboveground vegetation composition changed from the original dominants of *L. chinensis*; (2) Compare the composition of established vegetation and seed banks within patches to evaluate the potential of soil seed bank contribution to the regeneration of vegetation in this region.

Methods

The study was conducted in the south Inner Mongolian steppe. The mean annual temperature is 1.4°C, and monthly mean temperature ranges from -17.5°Cin January to 18.9°C in July. The mean annual total precipitation is about 350 – 400 mm with 70% rainfall during July, August and September. Undegraded grasslands are dominated by *L. chinensis*, and degraded grasslands were distributed in patches characterized by *A. frigida*, *S. chamaejasme*, *A. splendens or I. lactea*. Soil and plant community properties were shown in Table 1.

Table 1. Soil and plant community properties of the five different communities of degraded and undegraded patches.

	L. chinensis patch	*A. splendens* patch	*I. lactea* patch	*A. frigida* patch	*S. chamaejasme*
Soil organic matter	4.38	3.00	4.08	3.44	5.36
Available	8.07	2.16	5.24	3.32	4.39
Total nitrogen (%)	0.31	0.21	0.28	0.25	0.38
Available	115.0	89.9	82.3	86.8	100.5
Water condition	Intermediate	moist	moist	dry	dry
Vegetation cover	100	100	90	77	90

Table 2. Sørensen coefficient of the five degraded and undegraded patches. Sørensen coefficient A is similarity in species composition between total soil seed banks and established vegetation in the respective patch; Sørensen coefficient B is similarity in species composition between total soil seed banks and standing vegetation in the undegraded patch.

	L. chinensis patch	*A. splendens* patch	*I. lactea* patch	*A. frigida* patch	*S. chamaejasme* patch
Sørensen coefficient A	32%	47%	42%	23%	20%
Sørensen coefficient B	32%	27%	18%	27%	20%

Table 3. Number of species (percentages indicated in parentheses) showing different seed banks strategies in the five degraded and undegraded patches.

	L. chinensis patch	*A. splendens* patch	*I. lactea* patch	*A. frigida* patch	*S. chamaejasme* patch
Transient	3(25)	8(47)	7(50)	6(55)	6(60)
Short term persistent	5(42)	3(18)	3(21)	1(9)	2(20)
Long term persistent	4(33)	6(35)	4(29)	4(36)	2(20)

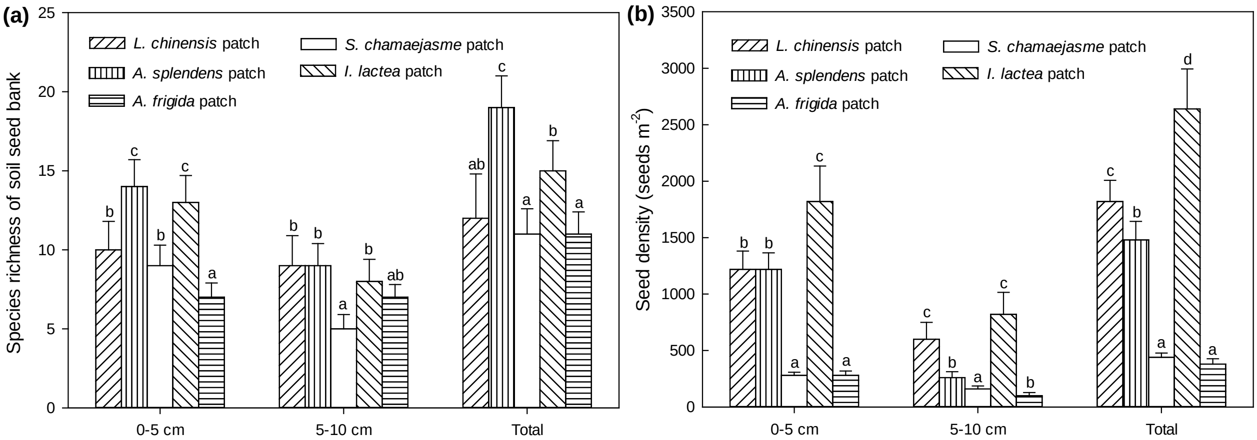

Figure 1. (a) Species richness (a) and density of soil seed bank (b) at two soil depths and through the total soil profile in the five degraded and undegraded patches. Different letters indicate significant differences (*P*<0.05).

The germinable soil seed banks were investigated in the four degraded and one undegraded patches with ten random plots (1 × 1 m) in each patch. Plant coverage, density and frequency were measured twice during the entire growing season, and soil samples (10 × 10 cm) were taken at two depths (0 – 5 cm and 5 – 10 cm) after the plant community had set seed in the 50 plots. The soil samples were sieved through 2 mm mesh sieves to remove larger stones and plant fragments, and then were spread over a 10 cm thickness of vermiculite in plastic pots (20 cm in diameter;15 cm in depth) to do soil seed bank germination in a greenhouse (Funes *et al*. 2001).

Similarity in species composition between seed bank and standing vegetation was assessed by the Sørensen coefficient (Peco *et al.* 1998). Sørensen coefficient: $SC=2Jn/(An+Bn)$, where SC = similarity coefficient; An = total number of species in the seed banks; Bn = total number of species in the established vegetation, and Jn = number of species present both in the soil seed bank and standing vegetation. The Sørensen coefficient was also used to evaluate the similarity between the soil seed bank of the undegraded patch and the soil seed banks of the degraded patches.

The soil seed banks were classified as transient, short term persistent, long term persistent, according to Funes *et al*. (2001) and Thompson *et al.* (1997). Transient seed banks were those where species were present in the aboveground vegetation and absent from the seed bank or present only in the upper soil layer. If viable seeds of most species were present in the 5 – 10cm soil layer, or equal in the two soil depths, the seed bank of the species was classified as long term persistent. If viable seeds were found more frequently in the upper soil layer, the soil seed bank of a species was considered to be short term persistent. One-way ANOVA followed by Duncan's Multiple-Range Test was used to analyze the differences among the density and species richness of the seed bank.

Results

Similarity coefficient between total soil seed banks and established vegetation respective patches was lowest in the *A. frigida* and *S. chamaejasme* patches with dry growing condition, intermediate in the undegraded patch with intermediate water condition, and highest in the *A. splendens* and *I. lactea* patches (Table 2). Percentage of the persistent seed bank in the *L. chinensis* patch was higher than those in the four degraded patches (Table 3). Species richness of the seed bank was high in the *A. splendens* patch, intermediate in the *I. lactea* patch, and low in the *L. chinensis*, *S. chamaejasme*, and *A. frigida* patches (P< 0.05, Fig. 1a).The density of soil seed banks was high in the *I. lactea* patch, intermediate in the *A. splendens* and *L. chinensis* patches, and low in the *A. frigida* and *S. chamaejasme* patches (P<0.05, Fig. 1b).

Discussion

The diversity of seed banks of degraded patches often decreases with grassland degradation (Zhang *et al.* 2005). In contrast, our findings indicated species richness of the soil seed bank of the undegraded patch was significantly ($P \leq 0.05$) lower than of other two degraded patches (*A. splendens* - shining speargrass and *I. lactea* - white swordflag). It was mainly the large contribution of forbs and annual grasses that occurred at a high frequency (80%) in the *A. splendens* and *I. lactea* patches. Grassland degradation has led to a decline in dominance of *L. chinensis* and an increase in plant species of low height, such as *Digitaria sanguinalis*, *Herba Taraxaci*, *Potentilla ansrina*, *Kochia scoparia* and *Lepidium apetalum* (Chen *et al.* 2008; Chen *et al.* 2007; Liu *et al.* 2008), which compete more effectively for light and soil nutrients in patches of low crown density. These species mainly exist in the *A. splendens* and *I. lactea* patches with moist growing conditions, producing large amounts of seeds which were dispersed into the soil of degraded patches. As a result, the soil seed bank density of the undegraded patch was lower than that of degraded *I. lactea* patch. This finding is in agreement with previous studies (Sudebilige *et al.* 2000; Zhang *et al.* 2005).The soil seed bank density of the undegraded patch was higher ($P \leq 0.05$) than that of the degraded *S. chamaejasme* and *A. frigida* patches, and in agreement with the results described by (Shao *et al.* 2005). The reason is that undesirable growing conditions led to deterioration of soil physical and chemical properties which limit plant growth, and it was difficult for plants to produce seeds. However, soil seed bank species richness was not significantly different between the undegraded patch and the degraded *S. chamaejasme* and *A. frigida* patches in our study.

The undegraded patch was dominated by perennial grasses, which reproduce by tillering and produce a small number of seeds. In addition, perennial grasses with high height and coverage keep sunlight above the canopy, affecting species of low height restraining seed production. Their small contribution to the soil seed bank led to a low seed bank-vegetation similarity. Degraded patches with moist growing condition were dominated by species of low height (*Potentilla ansrina*, *Herba Taraxaci*, *Kochia scoparia*, *Atriplex patens*, *Chenopodium glaucum*). Because perennial grasses in degraded patches are inhibited by heavy grazing (Zhao *et al.* 2005), species of low height compete more effectively for light and soil nutrients, producing a large number of seeds. Their large contribution to the soil seed bank led to a high seed bank-vegetation similarity. Unpredictable growing conditions limit plant growth. Therefore, *S. chamaejasme* and *A. frigida* patches lack both perennial grasses and species of low height. This led to a low seed bank-vegetation similarity (Shao *et al.* 2005, Tong *et al.* 2009).

The Sørensen coefficients comparing the soil seed banks of the undegraded patch and soil seed banks of degraded patches were low, indicating that soil seed banks of degraded patches have changed with degradation. Moreover, similarity coefficients between soil seed banks and standing vegetation of the undegraded patch is still low. These findings illustrate that the potential for *in situ* regeneration of the undegraded vegetation is low. This result is in accordance with previous studies (Jiang *et al.* 2004, Shao *et al.* 2005, Zhan *et al.* 2005).

Species of above-ground dominants in degraded patches and undegraded patch were all transient (*e.g. L. chinensis*, *A. splendens*, *I. lactea*, *A. frigida* and *S. chamaejasme*). These species were perennial, reproduced vegetatively and produced few and in some cases dormant seeds (*e.g. I. lactea*). Species with persistent seed banks were mostly present in the established vegetation of degraded patches. But these species were always annual, reproducing by seeds (*e.g. D. sanguinalis*, *Artemisia capillaris*, *Potentilla acaulis*). Species with persistent seed banks (long term and short term) are important for community persistence and regeneration following disturbance (McDonald *et al.* 1996). Percentage of persistent seed banks in the undegraded patches was 75%, higher than that in the degraded patches (about 45%). On this point, soil seed banks of the undegraded patch are in better condition than that of the degraded patches. This result is in accordance with results obtained in similar communities (Tong *et al.* 2009).

Conclusion

On the basis of seed bank-vegetation similarity, seed-bank density and persistence of seeds, the potential for *in situ* regeneration of the established vegetation of the four degraded patches to the undegraded patch from the soil seed bank is low. Emerging vegetation of these patches cannot rely on seed banks alone. Successful grassland restoration on such sites may require seeds of target species absent in the seed bank to be introduced artificially.

Acknowledgments

This project was supported by the earmarked fund for Modern Agro-industry Technology Research System (CARS-35) and National Natural Science Foundation of China (31270375). Many thanks to all those who were involved in this work, with particular gratitude to Xu Xin,Tian Jingyang, Tu Yin, and Chen Chao for their assistance in the greenhouse portion of this project, Dr Marshall Haferkamp and Lijun Lin for his helpful comments in the preparation and review of the manuscript.

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