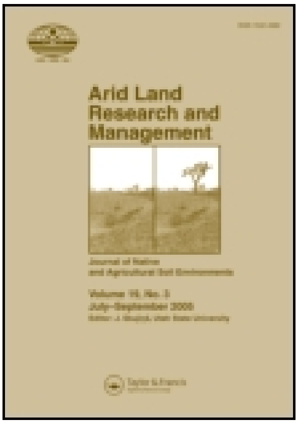

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Effects of Exclosure Management on Elm (*Ulmus Pumila*) Recruitment in Horqin Sandy Land, Northeastern China

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Effects of exclosure management on the plant recruitment are not clear yet. To assess the effects of exclosure management on the recruitment of elm, population structure, seed production, and densities of seeds and seedlings of elm were investigated in fenced and grazed pastures in Horqin Sandy Land, northeastern China. The results showed that seed biomass per branch of elm in the grazed plot was significantly higher than in fenced pasture (0.85 ± 0.27 g vs. 0.55 ± 0.36 g, $p < 0.05$), and seed density was higher in grazed pasture (845 ± 370 seedsm^{-2}) than that in fenced pasture (558 ± 241 seedsm^{-2}), indicating that grazing would improve reproductive allocation of elm. However, there was no significant difference of seedling density between grazed and fenced pastures. More important, the elm trees with a height less than 0.5 m appeared in the fenced pasture but disappeared in the grazed pasture, indicating the positive effects of exclosure management on the elm recruitment. Our results suggested that the exclosure would favor recruitment of elm through its protection of saplings instead of through increased seed production. This study improves our understanding of the effects of grazing on population dynamics of elm and would contribute to the restoration of degraded sandy land in northern China.

Keywords elm recruitment, grazing, seed production, seed supply, seedlings survival

Introduction

Ulmus pumila L. is the dominant tree species in the sandy lands and Gobi desert of Mongolian Plateau (Dulamsuren et al., 2005; Dulamsurenet al., 2009a; Wesche et al., 2011). In China, Savanna-like elm woodland occurs mainly in Inner Mongolia, especially in Horqin Sandy Land, where Savanna-like elm woodland is an original vegetation type. It plays an important role in reducing wind erosion (Jin et al.,

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2009), increasing carbon storage (Zeng et al., 2009), and accelerating vegetation restoration (Jiang et al., 2003). In recent years, the area of sparse elm woodland decreases sharply, which is attributed to the heavy grazing (Li et al., 2004). However, the underlying mechanism for the negative effects of grazing by large animals on elms is still unclear. Furthermore, to determine the major factor, which limits elm recruitment is an important step in providing guidelines to vegetation restoration.

Many factors, both abiotic and biotic, may play an important role in the recruitment of elm. Abiotic factors include microhabitats (Dulamsuren et al., 2009b; Janišová et al., 2012), disturbance of sand burial (Shi et al., 2004), and drought stress (Dulamsuren et al., 2009a). The biotic factors include human behavior (Li et al., 2003) and grazing activity (Dulamsuren et al., 2009a). For instance, grazing activity affects numerous processes associated with seedling recruitment, including reducing allocation of biomass to seed production, altering seed rain by seed consumption, and directly damaging seedlings (Cooper, 2006; Lenoir and Pihlgren, 2006).

Lack of elm recruitment is supposed to be related to intensive grazing since the mid-1980s (Lindeman et al., 1994). Consequently, exclosure management is considered to be a superior choice to promote elm recruitment (Katoh et al., 1998). Exclosure management may influence seedling recruitment through promoting reproductive allocation and seed production (Pratt et al., 2005). In the previous practices, however, elm seedlings are generally detected in fenced lands but not in the adjacent grazing lands. The empirical evidence from comparison between paired grazed and fenced plots is really scarce.

With the aim to understand the effects of exclosure management on the recruitment of elm, we carried out a field experiment in the sandy land of northern China. We hypothesized that 1) elm trees in fenced land would produce more seeds than in grazed land, and, consequently, 2) elm seedling density in fenced land would be higher than in grazed land. By evaluating the effects of exclosure management on elm recruitment, this study would contribute to the vegetation restoration in arid and semi-arid lands in northern China.

Materials and Methods

Study Site

The study was conducted in the Wulanaodu region (119°39′–120°02′E, 42°29′–43°06′N, 480 m a.s.l.), western part of the Horqin Sandy Land. The Horqin Sandy Land, with an area of 51000 km^2, is located in the eastern Inner Mongolia of northern China. Mean annual temperature is 6.3°C. Mean daily temperatures in the coldest (January) and warmest (July) month are −14.0°C and 23.0°C, respectively. The average annual precipitation is 340 mm, 70% of which is received between June and August. The major wind direction during the period of March–May is from the northwest and the secondary wind during the period of June–September is from the southwest (Li et al., 2006; Liu et al., 2007).

Experimental Design and Plant Sampling

The present study was restricted to two neighboring pastures with each 5 ha in size. One pasture had been under exclosure management and the other had been continuously grazed since 2005 (Figure 1). Exclosure management prohibited the entering

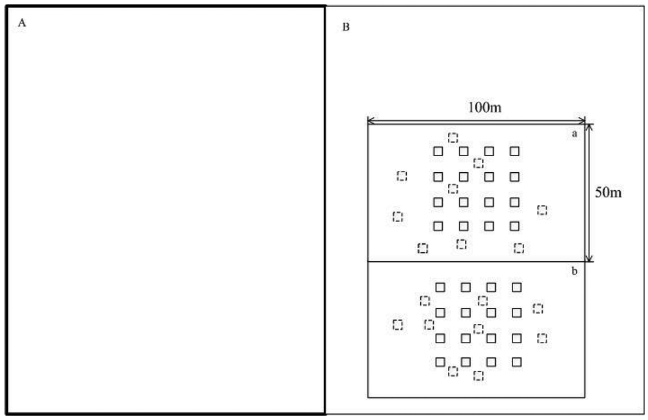

Figure 1. Experimental design. One pasture (A) had been under exclosure management and the other (B) had been continuously grazed since 2005. The area of these two pastures was 5 ha respectively. The fenced land (A) and grazed land (B) were established in 2007. In grazed land, subplots for monitoring seed density and surviving seedling density were represented with continuous line and dotted line respectively.

of large herbivores, that is, sheep and cattle. Pastures were dominated by elm trees and annual herbs, that is, *Setaira viridis* (L.) Beauv, *Chloris virgata* Swartz, and *Corispermum hyssopifolium* (L.).

The population structure and seed production of elm were examined in these two pastures (A and B in Figure 1). To assess elm population structure, 10 quadrats ($10\,m \times 10\,m$) were randomly selected in each pasture (5 ha) in April, 2009. We recorded the height and diameter at breast height (DBH) of elm trees in each plot. Elm trees were divided into five groups according to their heights, that is, class 1: height < 0.5 m; class 2: $0.5\,m < \text{height} \leq 1\,m$; class 3: $1\,m < \text{height} \leq 2\,m$; class 4: $2\,m < \text{height} \leq 3\,m$; class 5: height > 3 m. Classes 1–5 represented stages of seedling, saplings, young tree, medium tree, and aged tree, respectively. To estimate the individual-level seed production, 12 fertile trees with similar height and DBH were selected in each pasture and the number of branches in each tree was recorded. In each tree, 3 branches with medium size were clipped and seeds on them were collected on 20 May 2009, when matured seeds did not fall off. The seeds were dried for 24 h at 85°C and weighted. In the grazed pasture, two plots ($50\,m \times 100\,m$) were established in 2007 and one of them was fenced with meshed wire. The lowest height of wire mesh was 40 cm, which prohibited the entering of large herbivores and permitted the entering of small mammals, such as rodents. These two plots were adjacent each other and had similar environmental characteristics (Figure 1). The predominant aspect in fenced and grazed plots was east and slope in these plots was 3–5 degree in average, respectively. Within each plot, there were 12 elm trees, 7–10 m in height, and 15–20 cm in breast diameter.

To estimate seed density during seed rain period (from 11 to 23 in May 2009), 16 subplots ($1\,m \times 1\,m$) were sampled in the aforementioned plot ($50\,m \times 100\,m$) following the systematic sampling method (Gomez-Aparicio, 2008). To avoid seed transfer from one subplot to another through seed secondary dispersal, subplots were at least 10 m apart in distance, as more than 95% of seeds has dispersal distance less than 9 m (Yang et al., 2012). Seeds were directly collected from the ground every 2 days.

Collected seeds were brought to laboratory and their number was recorded. The observation lasted from 11 May to 23 May in 2009.

To examine the dynamic of seedlings survival, 9 subplots (1 m × 1 m) were randomly established in the plots (50 m × 100 m), which were different subplots from those used for the measurement of seed density (Figure 1). The number of living seedlings was recorded and dead ones were removed. The observation was conducted every 5 days from 18 June to 23 July in 2009.

Data Analysis

The individual-level seed production was estimated with the number of branches per tree and seed biomass per branch, which was calculated according to the equation, that is, seed biomass per branch = total seed biomass/the number of shoots ($n = 3$).

Seed biomass per branch, densities of seeds and surviving seedlings, and density of elm trees in grazed and fenced plots were compared with unequal variance *t*-tests. Probability values <0.05 were considered significant for all tests. All statistical analyses were performed with SPSS14.0 (Chicago, USA). Data were presented as means ± standard deviations.

Results

There was significant difference in seed biomass per branch between grazed and fenced pasture (*t*-test, $F = 0.845$, $p = 0.03$), with 0.85 ± 0.27 g in grazed pasture and 0.55 ± 0.36 g in grazed pasture (Figure 2).

The accumulated seed density was significantly higher in grazed pasture than in fenced pasture (*t*-test, $F = 1.491$, $p = 0.017$), with 558 ± 241 seeds m^{-2} in fenced pasture and 845 ± 370 seeds m^{-2} in grazed pasture (Figure 3). The density of surviving seedlings decreased with the growing season in both grazed and fenced pastures. There was no significant difference in the density of surviving seedlings between grazed and fenced pasture within each observation day (all $p > 0.05$; Figure 4).

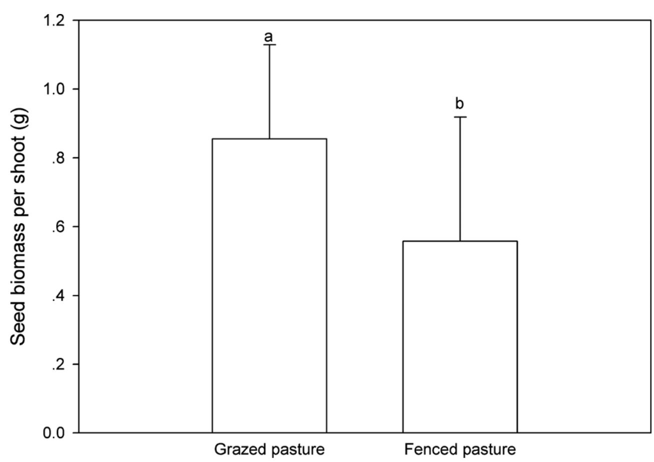

Figure 2. Seed biomass per branches (g) in grazed and fenced pastures. Vertical bars indicate standard deviation of means. Different letters indicate significant difference ($p < 0.05$).

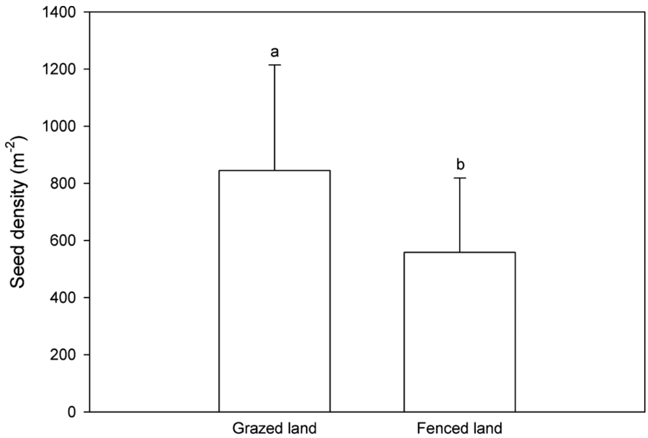

Figure 3. Seeds densities in grazed and fenced lands (m^{-2}). Vertical bars indicate standard deviation of means. Different letters indicate significant difference ($p < 0.05$).

In the fenced pasture, all classes (from 1 to 5) occurred except class 2. With an increase in height, the density of elm trees decreased gradually. Both class 1 and 2 did not appear in the grazed pasture (Figure 5). The density of elm trees in class 1 was significantly higher in fenced land than in grazed pasture (*t*-test, $F = 9.577$, $p = 0.006$).

Discussion

Contrary to expectations, we found that seed production and seed density in fenced pasture were significantly lower than in grazed pasture. We supposed that the changes of inter-specific interactions following grazing would account for these differences between grazed and fenced pasture. In sparse elm woodland, elm trees

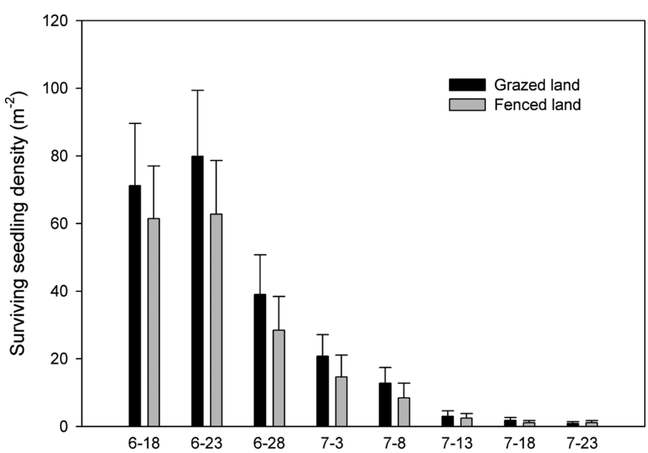

Figure 4. Densities of surviving seedlings (m^{-2}) in the grazed and fenced lands. Vertical bars indicate standard deviation of means. All differences between densities in grazed and fenced lands in investigations were not significant, according to t-tests.

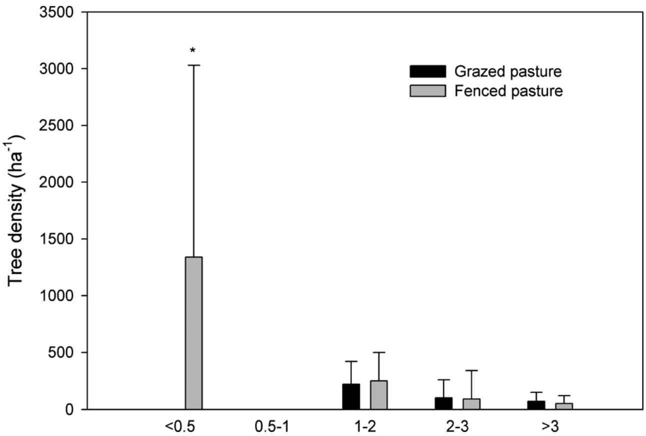

Figure 5. Elm tree density (ha^{-1}) in grazed and fenced lands. Vertical bars indicate standard deviation of means. *indicates significant difference between grazed and fenced lands ($p < 0.05$).

obtain resource, such as water and nutrient, through competing with annual and perennial herbs (Li et al., 2002). Grazing damages herbs through browsing and trampling, and thus alters the inter-specific competition between elm trees and herbs (Skarpe, 1991). Plant resource availability, such as total soil N, would not vary between grazing and fenced ecosystems (Ritchie et al., 1998; Kraaij and Ward, 2006). As the resource obtained by herbs is reduced in the grazed plots due to the grazing of herbs by large animals, more resource can be used by elm trees. Therefore, grazing improves resource availability in elm trees, indicating that more resources can be devoted to elm seed production.

Our result that seed production increased in grazed pasture was consistent with previous studies (Lenoir and Pihlgren, 2006). The seed production under grazing disturbance is closely related to how grazing influences plants (Cierjacks and Hensen, 2004). It is suggested that grazing would result in an increase in seed production of plants through inhibiting their competitors. Seed supply is a key factor influencing plant recruitment and an increase in seed supply would lead to increases in seedling recruitment (Shaw and Antonovics, 1986). Lack of seed supply limits recruitment of plants in forest and grassland (Holl, 1999; Gulias et al., 2004; Dalling et al., 2002). Moreover, in sand dunes ecosystems, seed supply limits the recruitment of *Rosa rugosa* (Kollmann et al., 2007). However, seed densities were 558 m^{-2} and 845 m^{-2} in fenced and grazed lands, respectively, indicating seed supply would not be the limitation for the elm recruitment in both grazed and fenced ecosystems. This result is inconsistent with previous studies on *Ulmus glabra* in a mixed-species forest, within which Götmark et al. (2005) found that seed supply limits the recruitment of *Ulmus glabra*. The differences between result from the present study and that from Götmark et al. (2005) suggest that the effects of seed supply on plant recruitment would be species-specific. Hence, we suggest that increasing the seed supply to promote vegetation restoration is not suitable for elm recruitment in Horqin Sandy Land.

According to this study, elm seedling densities in fenced and grazed pastures were not significantly different, which did not support our hypothesis that elm seedling density in fenced pasture would be higher than in grazed pasture. Elm seedling survival is reduced due to mortality in the first weeks, which is consistent with previous studies (Dulamsuren et al., 2009b). It is well-known that elm seedlings usually suffer from several biotic and abiotic factors, including herbivory by insects, drought stress, and nutrient depletion (Dulamsuren et al., 2009b). Although elm seedlings can use deep-distributed-roots to survive in severe drought (Dulamsuren et al., 2009b), the seeding survival rate can also be reduced by extreme precipitation events. For instance, the elm seedlings survival rate was much lower in the condition with 50% reduction of mean annul precipitation than with normal mean annual precipitation (Tang, unpublished data). The total precipitation in 2009 was 170 mm, only half of the long-term mean annual precipitation in the area. Thus, low water availability would be one of the probable reasons for the high mortality of seedlings in this study.

Elm trees with height less than 0.5 m occurred in fenced pasture but disappeared in grazed pasture, indicating that exclosure management had positive effects on elm recruitment. Young seedlings would be damaged by browsing and trampling of large livestock, indicating that grazing is a negative factor on seedling survival. Exclosure management can prevent elm seedlings from grazing, which is helpful for maintaining elm seedlings survival. It must be pointed out that, however, many other factors can lead to death of seedlings, such as drought stress (Watt and Gibson, 1988; Goergen and Daehler, 2002; Vieira et al., 2007). Although exclosure management protects elm seedlings from grazing, not all of elm seedlings have chance to live through the bottle-neck period, which is supported by the fact that elm trees with a height in the range of 0.5 m and 1 m do not occur in fenced and grazed lands. This suggests more factors should be considered in further studies.

In conclusion, grazing would favor the reproduction of elm in this sandy land, probably due to the alteration of resource competition between tree and herb species. However, grazing showed negative effects whereas fencing showed positive effects on the survival of saplings. Together, results from this study showed that exclosure management would favor the growth of elm population through its protection of the survival of saplings but not through higher reproductive allocation. We suggest that exclosure management would be an effective strategy to restore the elm population in the degraded sandy land of northern China.

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