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# The effects of grazing on the spatial pattern of elm (*Ulmus pumila* L.) in the sparse woodland steppe of Horqin Sandy Land in Northeastern China

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7, 3339–3357, 2015

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## Abstract

The aim of this study was to explore the effects of grazing on the formation of the spatial pattern of elm growth in a sparse woodland steppe. We used a point pattern method to analyze the elm trees within different diameter classes in both grazed and
5  fenced plots, which were established in Horqin Sandy Land, northeastern, China. The results showed that, in the grazed plot, the distances where transformation between random and aggregated patterns occurred in class 1 (10 cm ≤ DBH ≤ 15 cm) and class 2 (15 cm ≤ DBH ≤ 20 cm) were 2.27 and 2.37 m, respectively. Meanwhile, in the fenced plot, the distances between random and aggregated patterns that occurred in class
10  1, class 2 and class 3 (DBH > 20 cm) were 3.13, 3.13 and 7.85 m, respectively. In the fenced plot, in distances larger than 67.72 m there were a negative association between class 1 and class 2, which was also the case between class 2 and class 3 and between class 1 and class 3 for distances greater than 104.09 and 128.54 m, respectively. Meanwhile, negative associations occurred only with distances larger than
15  29.38 m in the grazed plot. These findings suggest that grazing reduced the competition intensity between elm trees; and therefore, grazing management could be an effective strategy used to regulate the elm population in the degraded sandy land of Northern China.

## 1  Introduction

20  Vegetation and soil as the key parts of the Earth system that sustain the human societies with services goods and resources (Berendse et al., 2015; Brevik et al., 2015). Besides that, soils and vegetation are the key part of the hydrological, geological, chemical and biological Earth systems (Davidson and Artaxo, 2004; Metcalfe et al., 2011). The grazing impact on soils and vegetation determines that some ecosystems
25  are affected by land degradation processes (Cerdà and Lavee,1999; Mekuria et al., 2013). The desertification, one of the most important types of land degradation, occurs

widely in the world, especially in China (Izzo et al., 2013; Wang et al., 2013; Bisaro et al., 2014; Fleskens and Stringer, 2014).

In arid and semi-arid land of northern China, the grazing is considered as a key driving force deducing desertification, as its effects on vegetation and soil (Deregibus et al., 1994; Kraaij and Ward, 2006; Wang et al., 2015). Therefore, exploring the effects of grazing on vegetation, especially origin vegetation is helpful for understanding the desertification procession.

Elm (*Ulmus pumila* L.) trees are the main constituents in forming sparse woodland steppes, which is considered the original vegetation type and is the focus of the vegetation restoration efforts in Horqin Sandy Land, one of the largest sandy lands in China (Yu and Chen, 2007; Tang et al., 2014). Sparse elm steppe plays an important role in promoting vegetation restoration (Jiang et al., 2003), reducing wind erosion (Jin et al., 2009), and increasing carbon storage (Zeng et al., 2009).

The effect of grazing on elm trees raised great attention recently (Dulamsuren et al., 2009). Previous reports have documented an increase in seed production in grazed pastureland (Tang et al., 2014) and a reduction in elm population density (Li et al., 2003). Few studies have focused on the spatial pattern of elm distribution in these areas. Plant spatial pattern provides fundamental information for understanding regeneration process of species and for inferring mechanisms resulting in species coexistence in communities (Leps and Kindlmann, 1987; Ward et al., 1996). For instance, Hubbell (1979) studied the trees dispersal in a deciduous forest to explain the high species diversity in tropical forests. Janzen (1970) predicts that the spatial pattern of seedlings recruitment is influenced by density-or distance-dependent factor, such as host-specific predators or pathogens. Therefore, to explore effects of grazing on spatial pattern of elm in sparse woodland steppe is helpful for explaining the formation of spatial structure in the sparse elm steppe and is also important for protecting biodiversity and promoting vegetation restoration.

The lack of studies focused on the spatial pattern of elm distribution is primarily due to the large-scale experimental region required to explore sparse space structure. In

the 1980's, a 13 ha area was considered a large-scale experiment (Hubbell, 1979); yet, in recent years 20–25 ha is now the norm (Li et al., 2009). The increasing standard of area in large-scale experiments reflects the growing appreciation of spatial scale-dependence. Spatial scale-dependence reflects how the plant spatial pattern differs for each measured scale (Picard et al., 2009). In sparse forests, the average distance between elm trees is larger than what is found for plants in a rainforest. Thus, a large-scale experimental region is necessary to explore effects of grazing on spatial pattern of elm in sparse woodland steppe. The main aims of this study were: (1) to reveal the effects of grazing on spatial pattern of elm in sparse woodland steppe, (2) to investigate the change in spatial patterns at a large scale, and (3) to test the associations of spatial pattern between different scaled groups. Our findings significantly contributed to the understanding of the formation of spatial pattern of elm population in sparse woodland steppe.

## 2   Materials and methods

### 2.1   Study area

The study was conducted in the Wulanaodu region in Horqin Sandy Land in northeastern China (119°39′–120°02′ E, 42°29′–43°06′ N, 480 m a.s.l.). In the region the seasonal grazing regime, which prohibited grazing from May to September, has prevailed in recent years. The study area belongs to a semi-arid climate. Mean daily temperature was −14.0 °C in the coldest month (January) and 23.0 °C in the warmest month (July). The mean annual precipitation is 350 mm, 70 % of which falls between June and August (Li et al., 2006; Yan and Liu, 2010). Annual mean wind velocity is 4.4 m s$^{-1}$ and the number of gale days (> 16 m s$^{-1}$) is 21–80. The windy season is from March to May, and the growing season begins in late April and ends in late September. The prevalent wind direction is northwest, and the second prevalent wind direction is southwest.

Two permanent plots, with one of 44.2 ha (650 m × 680 m) that was fenced, and another of 10.5 ha (300 m × 350 m) that was grazed, were included in the test area. The slopes in the two regions were 3–5° in average. The species included elm and the other species: *Caragana microphylla* Lam., *Setaria viridis* (Linn.) Beauv.
5 subsp. viridis, *Bassia dasyphylla* (Fisch. et Mey.) O. Kuntze, *Chenopodium acuminatum* Willd., *Chenopodium glaucum* Linn., *Chenopodium aristatum* Linn., *Lespedeza davurica* (Laxm.) Schindl., and *Pennisetum centrasiaticum* Tzvel.

## 2.2 Data collection and analysis

Within the two plots mentioned above, the diameter at breast height (DBH) was mea-
10 sured and the number of trees with DBH ≥ 10 cm was recorded. We thought that 10 cm DBH is enough to avoid the potential effects of inter-specific competition between elm and other species in the study area. According to theDBH, elm trees were divided into three groups: class 1(10 cm ≤ DBH ≤ 15 cm), class 2 (15 cm ≤ DBH ≤ 20 cm), and class 3 (DBH > 20 cm) (Li et al., 2011).
15 To estimate the spatial pattern of elm trees, coordinates of trees with DBH≥ 10 cm were recorded using GPS (Global Position System). The GPS coordinates were transformed into a relative $x$–$y$ axis (Fig. 1). Point patterns of trees were analyzed using Ripley's $L(r)$ function (Gray and He, 2009). $L(r) = 0$ for completely spatial randomness (CSR), $L(r) > 0$ for aggregated pattern, while $L(r) < 0$ for regular pattern. To assess the

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significance level of non-CSR, Monte Carlo simulation ($n = 99$) was used.

$$K(r) = A \sum_{\substack{i=1 \\ i \neq j}}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} w_{ij} I(u(i,j))/n^2 \tag{1}$$

$$L(r) = \sqrt{K(r)/\pi} - r \tag{2}$$

$$K_{12}(r) = A \sum_{i=1}^{n1} \sum_{j=1}^{n2} I(u_{ij}) w_{ij}/n_1 n_2 \tag{3}$$

$$L_{12}(r) = \sqrt{K_{12}(r)/\pi} - r \tag{4}$$

$n$ was the total number of trees in study area $A$. $u_{ij}$ denoted the distance between the $i$th tree and the $j$th tree. $I(u_{ij})$ was an indicator function and $w_{ij}$ was included to correct edge-effect. $n_1$ and $n_2$ were the total number of trees of class 1 class 2 that occurred in area $A$.

The second order bivariate estimator of the Ripley's $L$ function was used for detecting associations between the three classes mentioned above. The $L$ functions and Monte Carlo simulations were calculated using the "spatstat" package in the R Statistical Programming Software (Baddeley et al., 2005).

## 3 Results

### 3.1 Number of elm trees in grazed and fenced plots

Within the grazed plot, the number of elm trees (DBH > 10 cm) was 94 in total. The proportion of trees in class 1 and class 2 was 58.5 and 41.5 %, respectively. The elm trees in class 3 were not found in the grazed plot (Fig. 2). Meanwhile, within the fenced

plot, the number of elm trees (DBH > 10 cm) was 193 in total. The proportion of trees in class 1, class 2 and class 3 was 20.2, 55.4 and 24.4 %, respectively (Fig. 2).

## 3.2 Spatial patterns of elm trees in grazed and fenced plots

Within the grazed plot, the random pattern of elm distribution transformed into an aggregated pattern at a distance of 1.87 m (Fig. 3a). For elm trees in class 1, the transformation of a random to an aggregated pattern occurred at a distance of 2.27 m (Fig. 3b). When the distance was over 3.27 m, a random spatial pattern appeared for trees in class 2, and then an aggregated pattern was present (Fig. 3c).

The random pattern transformed into the aggregated pattern at the distance of 1.58 m in the fenced plot (Fig. 4a). The intensity of aggregation was positively correlated to an increase in distance. For elm trees in class 1, the transformation of the random pattern to the aggregated pattern appeared at the distance of 3.13 m (Fig. 4b). If the distance was over 3.13 m, a random pattern appeared for trees in class 2 and then the aggregated pattern occurred (Fig. 4c). For trees in class 3 (DBH > 20 cm), the random pattern appeared over a distance of 7.85 m and the aggregated pattern occurred in greater distances (Fig. 4d).

## 3.3 Associations between elm groups in grazed and fenced plots

Within the grazed plot, trees designated in class 1 and class 2 had distribution patterns that were positively associated within a range from 4.54 to 6.11 m but had a negative association when the distance was larger than 29.38 m. The association correlation did not show a significant effect with a distance of zero (Fig. 5a).

The negative and positive associations appeared alternately within the fenced plot. For elm trees in class 1 and class 2, a positive association was evident between them within a range of 3.78 to 35.12 m, and a negative association observed when in a range with a distance larger than 67.72 m (Fig. 5b). The association of elm trees in class1 and class 3 was positive at a distance of 8.16 to 20.07 m, and negative at distance larger

than 128.54 m (Fig. 5c). Meanwhile, the association of elm trees in class 2 and class 3 was negative at larger distances greater than 104.09 m (Fig. 5d).

## 4   Discussion

According to our results, the transformation between random and aggregated patterns that were observed in the grazed plot between classes 1 and 2 occurred over a distance of 2.27 and 2.37 m, respectively. Meanwhile, in the fenced plot, the transformation between these patterns for in class 1, class 2 and class 3 occurred over distances of 3.13, 3.13 and 7.85 m, respectively. This demonstrated that the distance between random and aggregated patterns was larger in the fenced plot than that in the grazed plot.

The initial spatial pattern of elm population is formed during the seed rain stage, and results in an aggregated pattern (Yang et al., 2012, 2013). In conjunction with the growth of the plant population, the spatial pattern of all trees (not just elm trees) shows a shift from a clustered pattern to one of regular distribution (Weiner et al., 2001; Stoll and Bergius, 2005; Picard et al., 2009). Previously, Barbour (1973) proposed that, statistically, the most likely dispersal of shrubs is uniform in pattern, which is largely determined by the competition for resources (Toft and Fraizer, 2003). However, an important consideration is the fact that the transformation from an aggregated to uniform pattern is a process, and at midway during this process, the spatial pattern appears random. For example, Barot et al. (1999) found that the spatial pattern of adult savanna palm trees had a random pattern or loosely aggregated pattern, compared with that of the aggregated pattern of young trees. If competition led to the change in spatial pattern, i.e. transformation from aggregated pattern to uniform pattern, then the larger distance between the aggregated and uniform pattern suggests greater competition intensity. Thus, grazing may reduce the competition intensity in the sparse elm steppe given the shorter distance between aggregated and uniform patterns noted here.

Our results suggest that grazing regulates the spatial pattern of sparse woodland steppe, and by doing so, represents one of the underlying mechanisms that govern the formation of plant spatial pattern. Here, the distance between the aggregated and uniform patterns within grazed and fenced plots was 1.87 and 1.58 m, respectively. This was consistent with work by Lin and colleagues (2010), where they found that grazing altered the fine scale (< 2 m) processes in a desert steppe in Inner Mongolia, China. However, in our study the increase in distance between the random and aggregated pattern occurred orderly, rather than the aggregated patterns appearing in a fine scale and random patterns occurring in a relatively large scale as reported previously (Niu et al., 2008; Ren and Zhao, 2013).

In the fenced plot, negative associations appeared between class 1 and class 2 in distances larger than 67.72 m; between class 2 and class 3 in distances larger than 104.09 m; and between class 1 and class 3 in distances larger than 128.54 m. Thus, as the diameter increases, negative associations of elm trees groups tend to appear in larger distances. Individuals with large sizes need more resources to live and the competition intensity between them may be more severe than that between individuals with smaller sizes (Weiner et al., 2001). Therefore, competition intensity is related to the distance where negative association appears and when negative associations appear in the larger distances, which results in more competition intensity. In the grazed plot, the negative association occurred in a distance larger than 29.38 m, which is far less than that in the fenced plot. Thus, the competition intensity was reduced in the grazed plot, suggesting that grazing may be a useful factor to regulate population structure and promote vegetation restoration in Horqin Sandy Land. In Horqin Sandy Land, a lack of resources, especially water supply, limits the performance of individuals and hampers the recruitment in populations (Chesson et al., 2004). Importantly, these findings offer an alternative to the prevailing view that suggests that enclosure management is an effective measure to promote vegetation restoration (Jiang et al., 2003).

The co-occurrences of intra-specific and inter-specific competitions are common in nature (Packer and Clay, 2000; Condit et al., 2002) and it is difficult to separate the

effects of these on spatial distribution. The inter-specific competition is not considered here, which is mainly due to asymmetric competition between elm trees and other plants in sparse elm steppe. In the sparse woodland steppe, the size of elm trees is far larger than shrubs and herbs, and allow for them to have a competitive advantage over

5    smaller plants (Frecketon and Watkinson, 2001). Thus, we believed that the effects of intra-specific competition played a more important role than inter-specific competition in regulating spatial pattern of elm trees (Schwinning and Weiner, 1998). The communities with single dominant species, as observed in this study, are more suitable for detecting specific competition.

## 10    5    Conclusions

Our study suggests that grazing regulates the spatial pattern of elm trees in a sandy land, and this is likely due to the reduction of intra-specific competition between elm trees. Given this, we believe that grazing management would favor the optimization of spatial pattern in elm populations through its role in reducing intra-specific competition.

15    In particular, grazing management would be an effective strategy to regulate growth distribution of the elm population in the degraded sandy land of northern China.

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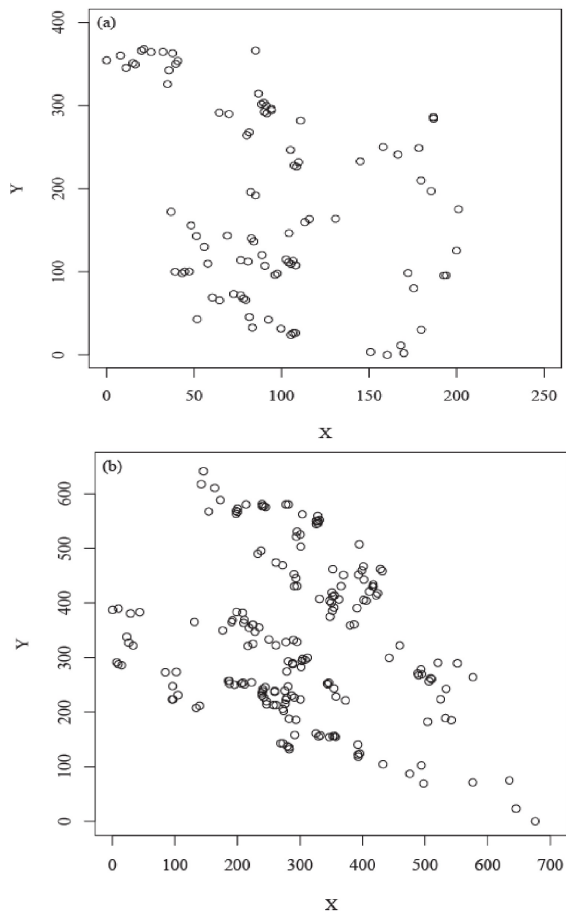
**Figure 1.** The relative coordinates of elm trees in grazed plots **(a)** and fenced plots **(b)**.
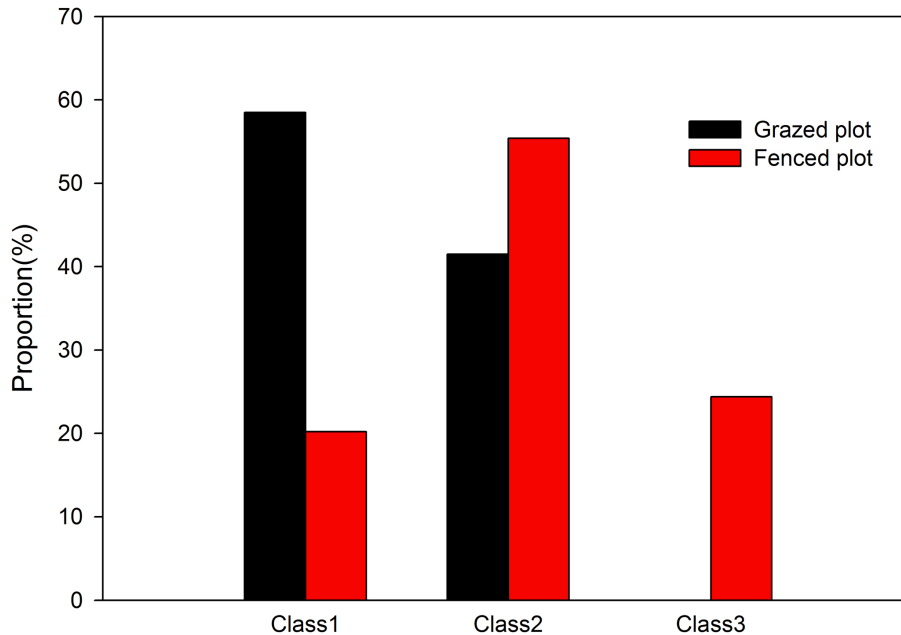
**Figure 2.** The proportion of elm trees classes in grazed and fenced plots. Class1 means elm trees in 10 cm ≤ DBH ≤ 15 cm; Class2 means elm trees in 15 cm ≤ DBH ≤ 20 cm; Class3 means elm trees in DBH > 20 cm.
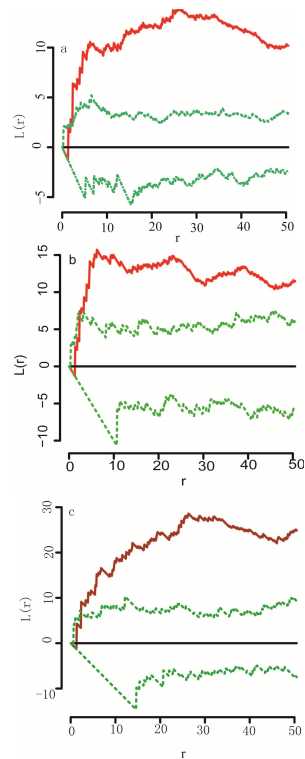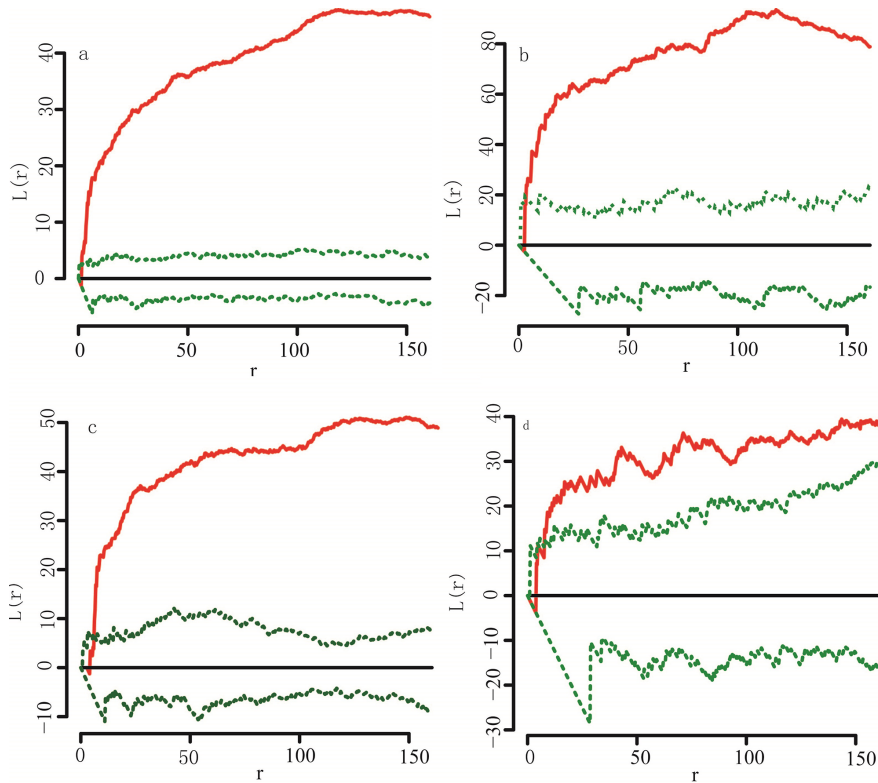
**Figure 3.** It was showed in the graphs that the Ripley' $L(r)$ functions and Monte Carlo intervals for elm trees in different classes. Observed patterns (red colour, –) fell above, below and within 95 % Monte Carlo intervals (green colour, - - -). The spatial pattern of all elm trees with DBH ≥ 10 cm in the grazed plot was shown in **(a)**. The spatial patterns of elm with two classes in the grazed plot were shown in **(b)** (10 cm ≤ DBH ≤ 15 cm), **(c)** (15 cm ≤ BH ≤ 20 cm).

**Figure 4.** It was showed in the graphs that the Ripley' $L(r)$ functions and Monte Carlo intervals for elm trees in different classes. Observed patterns (red colour, –) fell above, below and within 95 % Monte Carlo intervals (green colour, - - -). The spatial pattern of all elm trees with DBH $\geq$ 10 cm in the fenced plot was shown in **(a)**. The spatial patterns of elm with three classes in the fenced plot were shown in **(b)**: 10 cm $\leq$ DBH $\leq$ 15 cm, **(c)**: 15 cm $<$ DBH $\leq$ 20 cm and **(d)**: DBH $>$ 20 cm.

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**Figure 5.** It was showed in the graphs that the associations between different classes. Observed patterns (red colour, –) fallen below and above 95 % Monte Carlo intervals (green colour, - - -) stood for the significant difference. The associations between class 1 (10 cm ≤ DBH ≤ 15 cm) and class 2 (15 cm ≤ BH ≤ 20 cm) in the grazed plot was shown in **(a)**. The associations between class 1 (10 cm ≤ DBH ≤ 15 cm) and class 2 (15 cm ≤ BH ≤ 20 cm) in the fenced plot was shown in **(b)**. The associations between class 1 (10 cm ≤ DBH ≤ 15 cm) and class 3 (DBH > 20 cm) was shown in **(c)**. And the associations between class 2 (15 cm ≤ BH ≤ 20 cm) and class 3 (DBH > 20 cm) was shown in **(d)**.