



# 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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**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 at breast height (DBH) classes in both grazed and fenced plots, which were established in Horqin Sandy Land of northeastern China. The results showed that, in the grazed plot, the distances where transformation between random and clustered patterns occurred in class 1 ( $10\text{ cm} \leq \text{DBH} \leq 15\text{ cm}$ ) and class 2 ( $15\text{ cm} < \text{DBH} \leq 20\text{ cm}$ ) were 2.27 and 2.37 m, respectively. Meanwhile, in the fenced plot, the distances between random and aggregated patterns that occurred in classes 1, 2 and 3 ( $\text{DBH} > 20\text{ cm}$ ) were 3.13, 3.13 and 7.85 m, respectively. In the fenced plot, at distances larger than 67.72 m there was a negative association between classes 1 and 2, which was also the case between classes 2 and 3 and between classes 1 and 3 for distances greater than 104.09 and 128.54 m, respectively. Meanwhile, negative associations occurred only at distances larger than 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

Vegetation and soil are key parts of the Earth system that sustain societies with services, goods and resources (Berendse et al., 2015; Brevik et al., 2015). The grazing impact on soils and vegetation causes some ecosystems to be affected by land degradation processes (Cerdà and Lavee, 1999; Mekuria et al., 2013; Tarhouni et al., 2015). Desertification, one of the most important types of land degradation, occurs widely in the world, especially in China (Izzo et al., 2013; Jafari et al., 2013; Salvati et al., 2013; Wang et al., 2013; Bisaro et al., 2014; Fleskens and Stringer, 2014).

In arid and semiarid land of northern China, grazing is considered as a key driving force behind desertification, as it affects vegetation and soil (Deregibus et al., 1994; Kraaij and Ward, 2006; Wang et al., 2015). Therefore, exploring the effects of grazing on vegetation, especially original vegetation, is helpful for understanding the desertification process.

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 steppes play 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 has 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 popula-

tion density (Li et al., 2003). Few studies have focused on the spatial pattern of elm distribution in these areas. Plant spatial patterns provide fundamental information for understanding the regeneration processes 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 a density- or distance-dependent factor, such as host-specific predators or pathogens. Therefore, exploring the effects of grazing on the spatial pattern of elm in a sparse woodland steppe is helpful for explaining the formation of spatial structure in a sparse elm steppe and is also important for protecting biodiversity and promoting vegetation restoration.

To our knowledge, few studies have been carried out on the spatial pattern of elm distribution. This is primarily due to the large-scale experimental region required to explore sparse space structure. In the 1980s, 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 steppes. This study provided experimental evidence of grazing effects on the spatial pattern of sparse elm steppes in a large-scale region. The main aims of this study were (1) to study the effects of grazing on the spatial pattern of elm in sparse woodland steppes, (2) to investigate the change in spatial patterns at a large scale and (3) to identify the associations of spatial pattern between different scaled groups. Our findings could contribute to the understanding of the formation of the spatial pattern of elm population in a 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 prohibits grazing from May to September, has prevailed in recent years. The study area belongs to a semiarid climate. Mean minimum temperature is  $-14.0^{\circ}\text{C}$  in the coldest month (January) and  $23.0^{\circ}\text{C}$  in the warmest month (July). The mean annual precipitation is 340 mm, 70 % of which falls between June and August (Li et al., 2006; Yan and Liu, 2010). Annual mean wind velocity is

$4.4\text{ m s}^{-1}$  and the number of gale days ( $> 16\text{ m s}^{-1}$ ) 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. The landscape of the study area is characterized by a mosaic of active sand dunes, stabilized dunes and dune slacks (Cao et al., 2011). Soil of the sand dunes and the dune slacks was aeolian sandy soil and meadow soil, respectively (Liu et al., 2012).

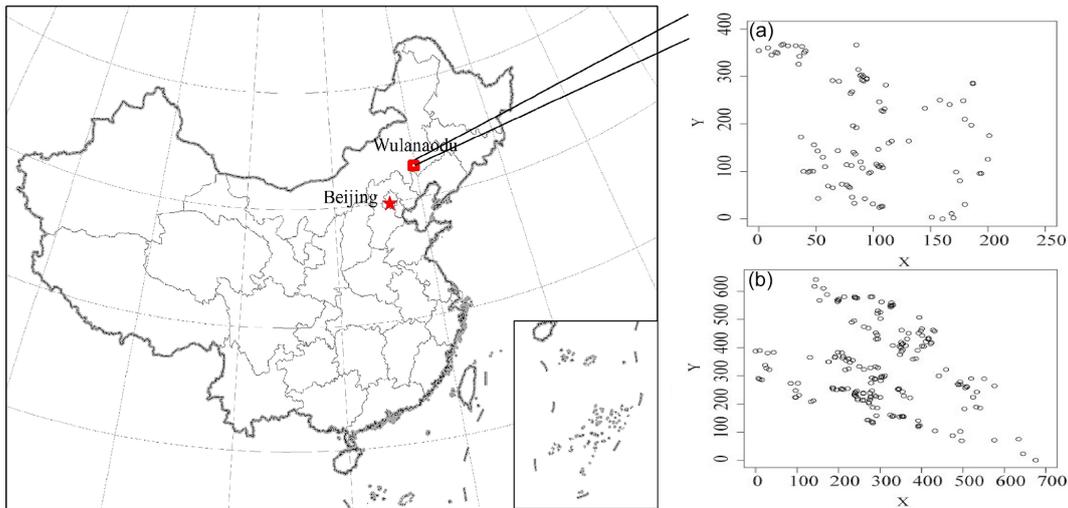
Two permanent plots, one of 44.2 ha ( $650\text{ m} \times 680\text{ m}$ ) that was fenced in 1998, and another of 10.5 ha ( $300\text{ m} \times 350\text{ m}$ ) that was grazed, were included in the test area. The slopes in the two regions were 3–5° on average. The fenced plot was almost the same as the grazed plot in terms of soil physical and chemical characteristics and microtopography before it was fenced. For example, pH, soil bulk density, total N, and total P were 7.75–7.87,  $1.55\text{--}1.58\text{ g m}^{-3}$ , 0.045–0.051 and  $0.29\text{--}0.54\text{ g kg}^{-1}$  respectively in the fenced plot (Han, 2012). In the grazed plot, pH, soil bulk density, total N, and total P were 7.7,  $1.65\text{--}1.72\text{ g m}^{-3}$ , 0.046–0.080 and  $0.26\text{--}0.30\text{ g kg}^{-1}$  respectively (Cao, 1990). The species included elm and the following other species: *Caragana microphylla* Lam., *Setaria viridis* (Linn.) Beauv. 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

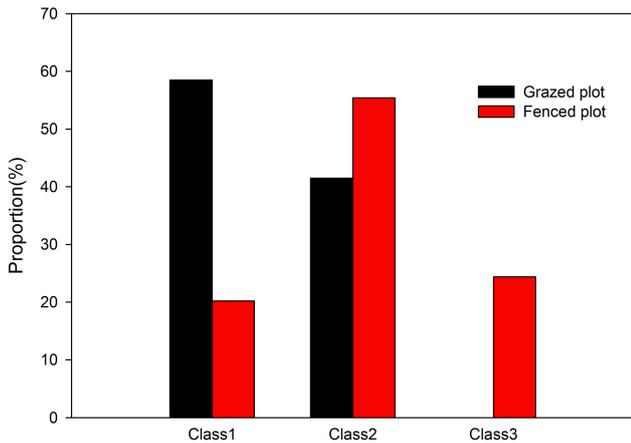
Within the two plots mentioned above, the diameter at breast height (DBH) was measured and the number of trees with  $\text{DBH} \geq 10\text{ cm}$  was recorded. As superior competitive ability requires a relatively large plant body size, we thought that 10 cm DBH is enough to avoid the potential effects of interspecific competition between elm and other species in the study area. According to the DBH, elm trees were divided into three groups: class 1 ( $10\text{ cm} \leq \text{DBH} \leq 15\text{ cm}$ ), class 2 ( $15\text{ cm} < \text{DBH} \leq 20\text{ cm}$ ) and class 3 ( $\text{DBH} > 20\text{ cm}$ ) (Li et al., 2011).

To estimate the spatial pattern of elm trees, coordinates of trees with  $\text{DBH} \geq 10\text{ cm}$  were recorded using GPS (Global Position System; the accuracy is 0.5 m at a maximum). 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 clustered pattern, while  $L(r) < 0$  for uniform pattern. To assess the significance level of non-CSR, Monte Carlo simulation ( $n = 99$ ) was used.

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



**Figure 1.** The location of the study area and relative coordinates of elm trees in grazed plots (a) and fenced plots (b).



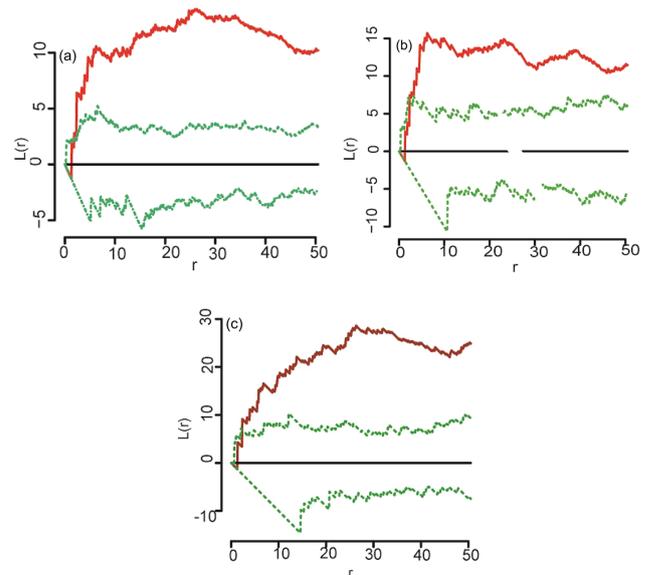
**Figure 2.** The proportion of elm tree classes in grazed and fenced plots. Class 1 consists of elm trees with  $10\text{ cm} \leq \text{DBH} \leq 15\text{ cm}$ ; class 2 elm trees with  $15\text{ cm} \leq \text{DBH} \leq 20\text{ cm}$ ; class 3 elm trees with  $\text{DBH} > 20\text{ cm}$ .

in the R statistical programming software (Baddeley et al., 2005).

### 3 Results

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

Within the grazed plot, the density of elm trees ( $\text{DBH} > 10\text{ cm}$ ) was  $8.95\text{ individual ha}^{-1}$ . The proportion of trees in classes 1 and 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 density of elm trees ( $\text{DBH} > 10\text{ cm}$ ) was  $4.37\text{ individual ha}^{-1}$ . The



**Figure 3.** Ripley's  $L(r)$  functions and Monte Carlo intervals for elm trees in different classes. Observed patterns (red color, straight line) fell above, below and within 95 % Monte Carlo intervals (green color, dashed line). The spatial pattern of all elm trees with  $\text{DBH} \geq 10\text{ cm}$  in the grazed plot was shown in (a). The spatial patterns of elm with two classes in the grazed plot were shown in (b)  $10\text{ cm} \leq \text{DBH} \leq 15\text{ cm}$  and (c)  $15\text{ cm} < \text{DBH} \leq 20\text{ cm}$ .

proportion of trees in classes 1, 2 and 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 a clustered pattern at a distance of 1.87 m

(Fig. 3a). For elm trees in class 1, the transformation of a random to a clustered 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 clustered 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 clustered 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 clustered 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 clustered pattern occurred within greater distances (Fig. 4d).

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

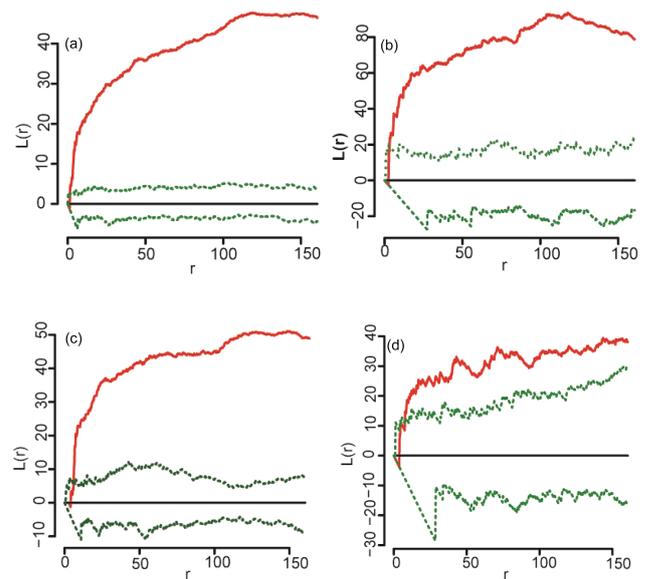
Within the grazed plot, trees designated in classes 1 and 2 had distribution patterns that were positively associated within a range from 4.54 to 6.11 m but had a negative association when the distance was larger than 29.38 m. The association correlation did not show a significant effect with a distance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

The negative and positive associations appeared alternately within the fenced plot. For elm trees in classes 1 and 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 of a distance larger than 67.72 m (Fig. 5b). The association of elm trees in classes 1 and 3 was positive at a distance of 8.16–20.07 m, and negative at distance larger than 128.54 m (Fig. 5c). Meanwhile, the association of elm trees in classes 2 and 3 was negative at larger distances greater than 104.09 m (Fig. 5d).

## 4 Discussion

According to our results, the transformation between random and clustered 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 classes 1, 2 and 3 occurred over distances of 3.13, 3.13 and 7.85 m, respectively. This suggested that the distance between random and clustered patterns was larger in the fenced plot than that in the grazed plot.

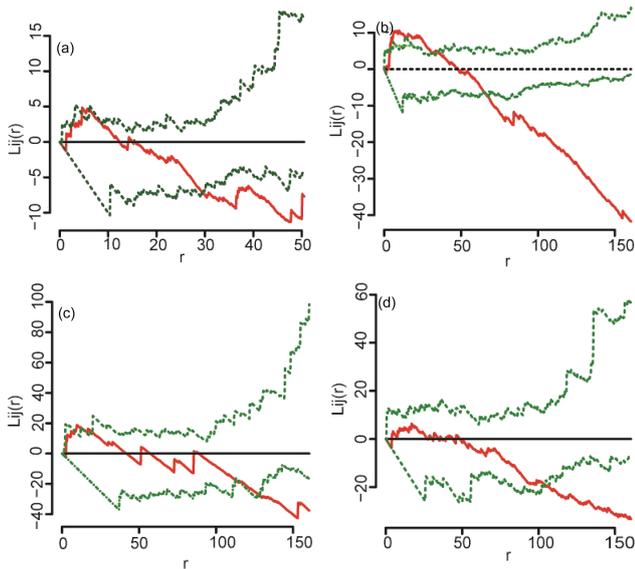
The initial spatial pattern of elm population is formed during the seed rain stage, and results in a clustered pattern (Yang et al., 2012, 2013). In conjunction with the growth of the plant population, the spatial pattern of all trees (not just elm trees) shows a shift from a clustered pattern to one of uniform distribution (Weiner et al., 2001; Stoll and Bergius,



**Figure 4.** Ripley's  $L(r)$  functions and Monte Carlo intervals for elm trees in different classes. Observed patterns (red color, straight line) fell above, below and within 95% Monte Carlo intervals (green color, dashed line). The spatial pattern of all elm trees with  $\text{DBH} \geq 10$  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)  $10 \text{ cm} \leq \text{DBH} \leq 15 \text{ cm}$ , (c)  $15 \text{ cm} < \text{DBH} \leq 20 \text{ cm}$  and (d)  $\text{DBH} > 20 \text{ cm}$ .

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 a clustered to a uniform pattern is a process, and 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 clustered pattern, compared with that of the clustered pattern of young trees. If competition led to the change in spatial pattern, i.e., transformation from a clustered pattern to a uniform pattern, then the larger distance between the clustered and uniform pattern suggests greater competition intensity. Thus, grazing may reduce the competition intensity in the sparse elm steppe, given the shorter distance between clustered and uniform patterns noted here.

Our results suggest that grazing regulates the spatial pattern of the 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 clustered and uniform patterns within grazed and fenced plots was 1.87 and 1.58 m, respectively. This was consistent with work by Lin et al. (2010), who 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



**Figure 5.** Associations between different classes. Observed patterns (red color, straight line) fallen below and above 95 % Monte Carlo intervals (green color, dashed line) stood for the significant difference. The associations between class 1 ( $10 \text{ cm} \leq \text{DBH} \leq 15 \text{ cm}$ ) and class 2 ( $15 \text{ cm} < \text{DBH} \leq 20 \text{ cm}$ ) in the grazed plot was shown in (a). The associations between class 1 ( $10 \text{ cm} \leq \text{DBH} \leq 15 \text{ cm}$ ) and class 2 ( $15 \text{ cm} < \text{DBH} \leq 20 \text{ cm}$ ) in the fenced plot was shown in (b). The associations between class 1 ( $10 \text{ cm} \leq \text{DBH} \leq 15 \text{ cm}$ ) and class 3 ( $\text{DBH} > 20 \text{ cm}$ ) was shown in (c). And the associations between class 2 ( $15 \text{ cm} < \text{DBH} \leq 20 \text{ cm}$ ) and class 3 ( $\text{DBH} > 20 \text{ cm}$ ) was shown in (d).

distance between the random and clustered pattern occurred in an orderly way, rather than the clustered patterns appearing on a fine scale and random patterns occurring on a relatively large scale as reported previously (Niu et al., 2008; Ren and Zhao, 2013).

In the fenced plot, negative associations appeared between classes 1 and 2 in distances larger than 67.72 m, between classes 2 and 3 in distances larger than 104.09 m and between classes 1 and 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 perfor-

mance 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-occurrence of intra-specific and inter-specific competition is 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 the sparse elm steppe. In the sparse woodland steppe, the size of elm trees is far larger than shrubs and herbs, and allows them to have a competitive advantage over smaller plants (Freckleton and Watkinson, 2001). Thus, we believed that the effects of intra-specific competition played a more important role than inter-specific competition in regulating the 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.

## 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 the spatial pattern in elm populations through its role in reducing intra-specific competition. 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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