

Effects of vegetation cover on recruitment of *Ulmus pumila* L. in Horqin Sandy Land, northeastern China

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Abstract: Understanding the effects of vegetation cover on seedling survival is helpful for promoting vegetation restoration in environmentally fragile zones. This study was conducted in the desertified, moving sand dunes of Horqin Sandy Land, Inner Mongolia, northeastern China. We hypothesized that (1) seed density (i.e., number/m²) increases as vegetation cover increases, and (2) there will be more surviving seedlings in locations with higher vegetation covers. Total vegetation cover and initial densities of seeds, germinated seeds and surviving seedlings of *Ulmus pumila* were evaluated under various vegetation covers in trying to clarify the effects of vegetation cover on the early stages of the plant life history. In agreement with the first hypothesis, initial seed densities were greater ($P < 0.05$) under higher vegetation covers. The relationship between vegetation cover and initial seed density was represented by a quadratic regression, where a threshold occurred with a vegetation cover of 36% ($P < 0.05$). The higher total vegetation covers, however, did not result in increased densities of germinated seeds ($P > 0.05$), which on average represented 16.7% of initial seed densities. Even more, three months after the study initiation, total vegetation covers were similar ($P > 0.05$) at all positions in the dunes, and they determined a similar number ($P > 0.05$) of surviving seedlings at those positions (i.e. the second hypothesis had to be rejected). The mean number of seedlings that survived at all positions was only 4.5% of germinated seeds. The number of surviving elm seedlings (0 to 1.7 seedlings/m²) under various vegetations covers (12.2% to 20.8%) at all dune positions by late summer would most likely not contribute to vegetation restoration in the study area.

Keywords: arid and semiarid zones; elm; seed dispersal; seed germination; seedling survival

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The relationship between seed density (i.e. number/m²) and vegetation cover is little mentioned in the literature. This might be because (1) species might have enormous differences in seed morphology, which affects both seed dispersal and falling on the ground (Bekker et al., 1998), and (2) water movement and animal agents can change the spatial pattern in seed density (Ingle, 2003). Moreover, the spatial pattern of seed density largely determines seedling survival, which is the subsequent stage of seed dispersal in the plant life history (McAlpine and Jesson, 2008). Seed density has been positively correlated with surviving

seedling density (Houle, 1998).

Aguiar and Sala (1999) reported that seeds tend to accumulate near vegetation patches, and have low density in bare-soil areas. Although, in some cases, the seed rain is uniform, abiotic redistribution and differential predation generally result in a higher concentration of seeds underneath, or close to, vegetated patches (Aguiar and Sala, 1999).

Understanding the effects of vegetation cover on seedling survival is helpful for promoting vegetation restoration in environmentally fragile zones (Dupuy and Chazdon, 2006). Seedling establishment has

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important effects in determining plant population and community patterns (Yu et al., 2009), and it also has a major role in maintaining plant recruitment (Queenborough et al., 2007). Sexual reproduction in the Patagonian arid steppe, where bare soil patches account for 36% of the total area, not only represents a mere reproduction pathway, but it is the major pathway for recruitment of new individuals in the existing plant community (Soriano and Sala, 1986). These authors reported that recruitment would be maximum very close to young shrubs, which have not developed a complete and dense peripheral ring of grasses, and would decrease with distance.

Elm (*Ulmus pumila* L.) trees spread widely in arid and semi-arid regions, especially in Horqin Sandy Land, one of the largest sandy lands in China (Liu and Cui, 2009). These trees are the main constituents in forming sparse woodland steppes, which are considered climax communities in Horqin Sandy Land (Shi et al., 2004). Elm seeds, which belong to wind-dispersed seeds, can be dispersed far away from their parents during the windy season (Li et al., 2004).

The main objective of this study was to test the hy-

potheses that (1) seed density increases as vegetation cover increases, and (2) there will be more surviving seedlings in locations with higher vegetation covers.

1 Materials and methods

1.1 Study area

This study was conducted in the Wulanaodu region (42°29'–43°06'N, 119°39'–120°02'E; 480 m asl), which is located in Horqin Sandy Land, northeastern China. The region has a semi-arid climate. The long-term (50 years) average annual precipitation is 350 mm. Daily mean temperature is –14.0°C in January and 23.0°C in July. The windy season starts from March to May, and mean wind velocity is 4.4 m/s (Li et al., 2006). Climate information during the study year is presented in Fig. 1.

1.2 Soils

The typical landscape includes active sand dunes, stabilized sand dunes, and inter-dune lowlands. The soil is sandy, loose in structure, light yellow in color, and susceptible to wind erosion (Zhou et al., 2012).

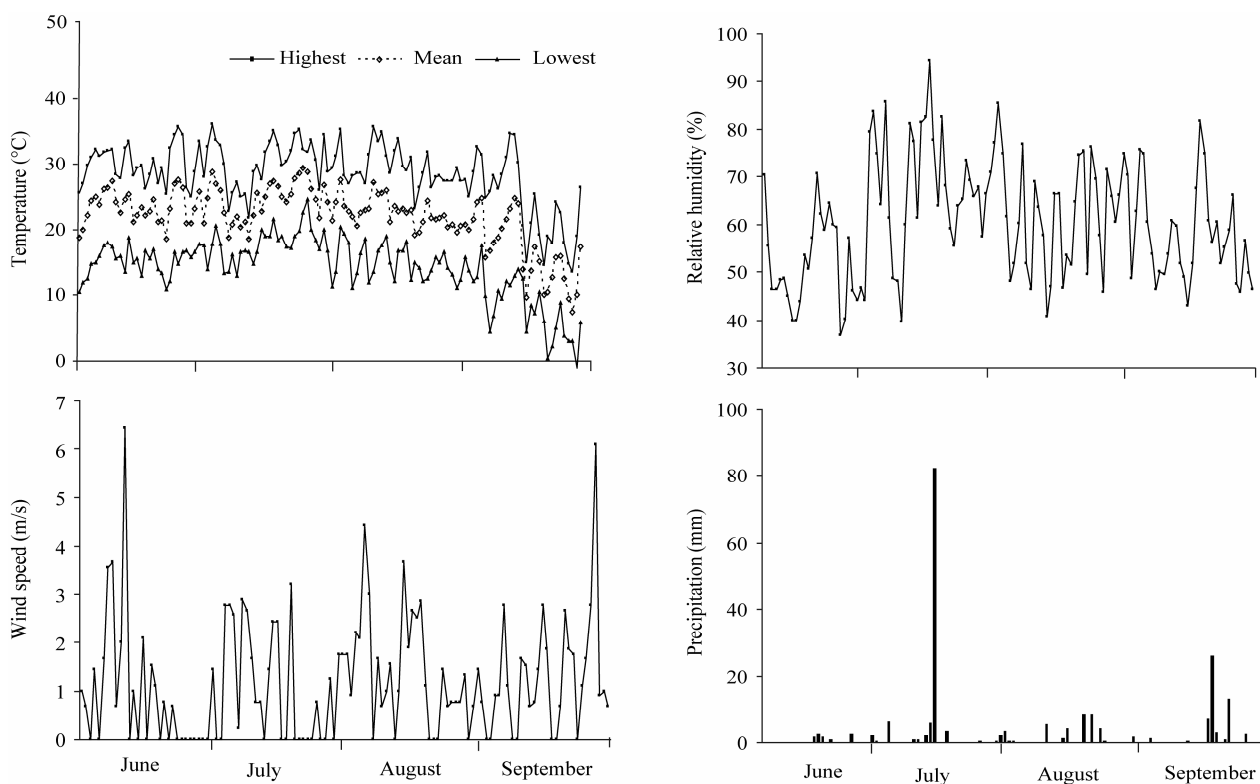


Fig. 1 Climate variables during 2010 at Horqin Sandy Land in Inner Mongolia, China

1.3 Vegetation

The original vegetation is sparse elm woodland, which has been altered in the past several decades because of continued overcutting and overgrazing (Cao et al., 2011). The present vegetation is mainly dominated by some shrubs, such as *Salix gordejievii* and *Artemisia halodendron*, and perennial and annual herbs, such as *Aristida adscensionis*, *Agriophyllum squarrosum* and *Setaria viridis* (Cao et al., 2011).

1.4 Experimental procedures

Vegetation cover has a spatial heterogeneity in sand dunes (Luisa et al., 2001), especially along the direction of their movement. In Horqin Sandy Land, we determined 7 typical positions during 2010 along the direction of sand dune movement: (1) grassland, (2) transition between grassland and mobile dune, (3) bottom of leeward slope, (4) middle of leeward slope, (5) top of mobile dune, (6) middle of windward slope, and (7) bottom of windward slope (Fig. 2; Ma and Liu, 2008). Plots used in this study were established to represent different vegetation covers. Six transects were established along the direction of sand dune movements; each of them was at least 10 m from each other. In each transect, 7 plots (1 m×1 m) were established, one for each of the 7 typical positions along the direction of sand dune movement (Fig. 2). In each plot, total vegetation cover, initial seed density, germinated seed density and the number of surviving seedlings of *U. pumila* were determined. The following species determined the total vegetation cover: *Artemisia wudanica*, *Chloris virgata*, *Eragrostis pilosa*, *Setaria viridis*, *Chenopodium glaucum*, *Ch. acuminatum*, and *Ch. aristatum*. Total vegetation cover was estimated each time the other variables were measured. Each 1 m×1 m plot was divided into four 0.50 m×0.50 m sectors to better estimate total vegetation cover within the

whole plot.

To quantify the initial seed density (seeds/m²) of *U. pumila* at each position, seeds were counted in each plot on 1 June 2010, after the end of the seed rain period (i.e. end of May; Liu et al., 1985). The number of these seeds could reliably be assumed to be initial seed density, because seeds coming from previous years are not viable (Liu et al., 2009). Seed dormancy as well as the effects of predators and pathogens on seeds, were not considered in this study. The germinated seed density was investigated on 20 June, because the most viable elm seeds germinate in a relatively short period after falling on the ground. The number of surviving seedlings was monitored in each plot on 1 September. Meanwhile, dead seedlings were removed from each plot.

Soil moisture was measured at all study dune positions at 0–10, 10–20 and 20–30 cm soil depths with a Time-Domain Reflectometer (TDR meter, China). Measurements were conducted on 20 June and 1 September, 2010, and at the same time germinated seed density and surviving seedling density were determined.

1.5 Statistical analysis

The differences in vegetation cover, seed density, germinated seed density and surviving seedling density among positions were tested using one-way ANOVA followed by Tukey's test. Spearman rank correlation analysis was used to analyze the relationships between vegetation cover versus densities of initial seeds, germinated seeds, and surviving seedling. The regressions representing vegetation cover versus initial seed and germinated seeds densities are reported with the highest adjusted R^2 . Soil moisture data were analyzed using three-way ANOVA (7 sand dune positions×3 soil moisture depths×2 sampling dates).

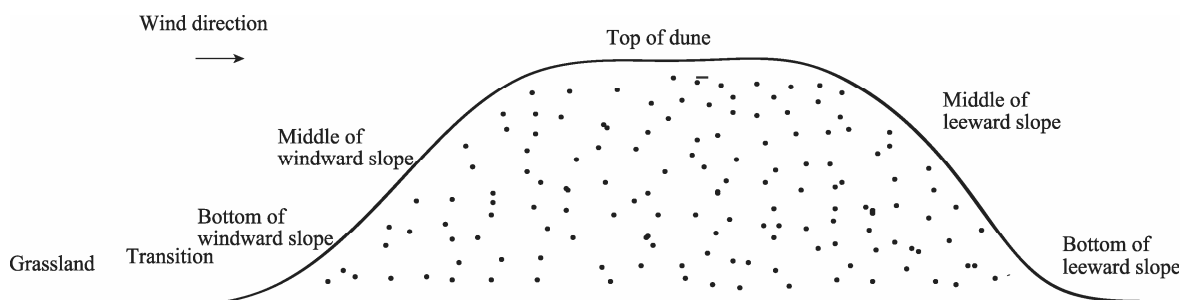


Fig. 2 Diagram indicating the various study positions in the dune

Percentage soil moisture data were at an arcsine transformed before analysis to comply with the assumptions of homogeneity and homocedasticity of variance. Untransformed values are used in the text. Probability values <0.05 were considered significant for all tests. All statistical analyses were performed with SPSS software (version 14.0).

2 Results

2.1 Soil moisture content

Sampling date interacted with soil sampling position along transect ($F_{6, 210}=5.38$, $P=0.000$) and soil sampling depth ($F_{2, 210}=5.48$, $P=0.0005$). In June and September, soil moisture contents in the grassland and transition zones were greater ($P<0.05$) than those at any one of the five positions within the dune (Table 1). In September all positions within the dune showed a similar ($P>0.05$) soil moisture content (Table 1). However, soil moisture content at the bottom of the windward slope was greater ($P<0.05$) than that at the bottom of the leeward slope in June (Table 1). At all soil sampling positions along the transect, soil moisture contents were greater ($P<0.05$) in June than in September (Tables 1). Soil moisture content increased ($P<0.05$) with soil depth in June and September (Table 2), and once again soil moisture contents were greater ($P<0.05$) in June than in September (Table 2).

2.2 Vegetation cover

On 1 and 20 June, vegetation cover was significantly different ($F=19.840$ and $F=12.746$, respectively;

$P=0.000$) among positions. During the whole study, vegetation cover was more similar ($P>0.05$) at the grassland than at the transition (Table 3). However, vegetation cover values on 1 and 20 June were more than 3 times greater ($P=0.000$) at the grassland and transition than at the other five positions in the dune. On 1 September, however, vegetation cover was similar ($P=0.115$) at all positions in the dune (Table 3).

2.3 Densities of initial seeds, germinated seeds and surviving seedlings

On 1 June, the initial seed density was significantly different among positions ($F_{6, 35}=11.007$, $P=0.000$). It was significantly greater ($P<0.05$) at the grassland than at the remaining positions but at the transition (Table 3). Initial seed densities were similar ($P>0.05$) among the bottom and middle of windward slopes, the top, and middle and bottom of leeward slopes (Table 3). The mean density among all positions was 66 seeds/m².

The germinated seed densities were significantly different among positions ($F_{6, 35}=3.223$, $P=0.013$). The descending order of the number of germinated seeds per square meter was as follows: middle of windward slope>grassland>top of dune>bottom of windward slope>transition>bottom of leeward slope>middle of leeward slope (Table 3). However, there were only significant differences ($P<0.05$) between the middle of windward slope and the middle of leeward slope (Table 3). The mean density of germinated seeds among all positions was 11 seeds/m², 16.7% of initial seed density.

Table 1 Soil moisture contents at the sampling positions within transects during June and September 2010

Sampling date	Soil moisture content (%)						
	Grassland	Transition zone	Bottom of windward dune slope	Middle of windward dune slope	Top of dune	Middle of leeward dune slope	Bottom of leeward dune slope
20 June	12.8 ^{a,a}	12.8 ^{a,a}	9.9 ^{b,a}	9.1 ^{bc,a}	9.6 ^{bc,a}	9.2 ^{bc,a}	8.9 ^{c,a}
1 September	8.2 ^{a,b}	8.6 ^{a,b}	7.2 ^{b,b}	6.9 ^{b,b}	6.7 ^{b,b}	7.0 ^{b,b}	7.0 ^{b,b}

Note: each value is the mean of $n=18$. Different letters indicate significant differences among positions within the transect (first letter) or between sampling dates (second letter).

Table 2 Soil moisture contents at various soil depths in June and September 2010

Sampling date	Soil moisture content (%)		
	0–10 cm	10–20 cm	20–30 cm
20 June	9.1 ^{a,a}	10.6 ^{b,a}	11.3 ^{c,a}
1 September	6.5 ^{a,b}	8.1 ^{b,b}	7.5 ^{c,b}

Note: each value is the mean of $n=42$. Different letters indicate significant differences among soil depths (first letter) or between sampling dates (second letter).

Table 3 Vegetation cover, and densities of initial seeds, germinated seeds and surviving seedlings of *U. pumilia* at different dune positions during 2010

Position	1 June 2010		20 June 2010		1 September 2010	
	Cover (%)	Initial seeds (seeds/m ²)	Cover (%)	Germinated seeds (seedlings/m ²)	Cover (%)	Surviving seedlings (seedlings/m ²)
Grassland	32.5±8.2 ^a	184.8±105.2 ^a	32.8±11.1 ^a	25.8±13.4 ^{ab}	20.8±9.2 ^a	0.0±0.0 ^a
Transition zone	24.2±6.7 ^a	117.5±54.3 ^{ab}	30.8±14.3 ^a	4.3±1.9 ^{ab}	18.3±4.1 ^a	0.2±0.4 ^a
Bottom of windward slope	7.7±6.6 ^b	51.7±14.0 ^{bc}	8.5±6.2 ^b	6.8±3.2 ^{ab}	13.3±5.2 ^a	0.0±0.0 ^a
Middle of windward slope	12.5±4.2 ^b	33.5±16.4 ^c	13.3±5.2 ^b	29.8±9.7 ^a	20.0±6.3 ^a	1.7±1.6 ^a
Top of dune	11.3±4.3 ^b	32.0±19.8 ^c	13.3±5.2 ^b	7.2±3.8 ^{ab}	15.8±4.9 ^a	0.7±1.6 ^a
Middle of leeward slope	7.3±3.4 ^b	31.8±11.5 ^c	8.2±4.6 ^b	0.5±0.5 ^b	19.2±4.9 ^a	0.2±0.4 ^a
Bottom of leeward slope	6.2±2.9 ^b	8.2±7.9 ^c	6.5±4.0 ^b	2.0±1.29 ^{ab}	12.2±6.3 ^a	1.0±1.7 ^a
<i>F</i> -value	19.840	11.007	12.746	3.223	1.867	1.949
<i>P</i> -value	0.000**	0.000**	0.000**	0.013*	0.115	0.1

Note: each value is the mean±SD of $n=6$. Different letters within the same column indicate significant differences at the indicated P value.

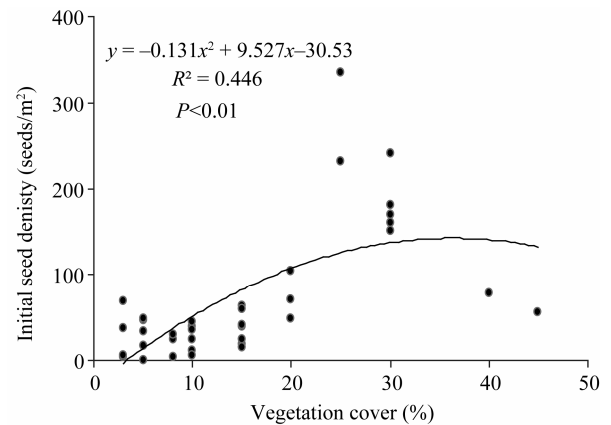
Densities of surviving seedlings were not significantly different among positions ($F_{6, 35}=1.949$, $P>0.05$). The number of surviving seedlings per square meter among all positions, although not significantly different ($P>0.05$), decreased in the following order: middle of windward slope>bottom of leeward slope> top of dune>transition=middle of leeward slope>bottom of windward slope=grassland (Table 3). There were no surviving seedlings at the grassland or at the bottom of windward slope. The mean density of surviving seedlings was 0.5/m², approximately 0.76% of initial seed density, and 4.5% of germinated seed density.

2.4 Relationships between vegetation cover and densities of initial seeds, germinated seeds and surviving seedlings

The initial seed density showed a significant correlation ($P<0.01$) with vegetation cover (Fig. 3). Highest seed densities were found when vegetation cover was about 36% (Fig. 3). The germinated seed density (y) showed a significant correlation with vegetation cover (x) ($y=5.47+1.79x-0.03x^2$; $R^2=0.101$; $P<0.05$). The correlation between vegetation cover and surviving seedlings density was not significant ($P>0.05$).

3 Discussion

The highest initial seed density was found under the highest vegetation cover (i.e. grassland and transition). This supports the hypothesis that seed density

**Fig. 3** Relationship between initial seed density and vegetation cover

increases with increases in vegetation cover. Our results agree with those of Aguiar and Sala (1999) who reported that seeds tend to accumulate near vegetation patches, and have low density in bare-soil areas. The high temperatures and low precipitations during the end of June must have contributed to the low number of germinated seeds with respect to the initial seed density. Went (1949) reported that low precipitation constrained seed germination of desert plants. Bellairs and Bell (1990) also showed that temperatures greater than 20°C reduced germination percentages in various arid-zone woody species. Furthermore, Zheng et al. (2004) found that germination was greatly reduced at high temperatures in *Caragana korshinskii* under water stress conditions. A greater seed density did not determine greater seedling survival in our

study. These results contrast with those of Houle (1998) who found a positive correlation between seed density and surviving seedling density.

The greater cover of *U. pumilia* at the grassland and transition zones than at the other positions in the dune on 20 June might partially be attributed to the greater soil moisture contents at those locations than at any other dune position. The cover of this species, however, was similar at all study positions on 1 September. This might have been partially the result of the greater reduction in soil moisture content at the grassland and transition areas (mean=34.4% reduction) than at any other study positions in the dune (mean=25.4% reduction). The number of seedlings which survived from the germinated seed stock under a similar vegetation cover at all positions was very low in the sand dunes. This might be attributed, at least in part, to the low precipitations, relatively high winds, and high maximum air temperatures which occurred from mid-July to early September during the study period (see Fig. 1). Soil moisture contents were reduced by at least 21.4% in all dune positions between 20 June and 1 September. This reduction in soil moisture content might have contributed to the seedling mortality of *U. pumilia* in all study locations. Even more, the lowest soil moisture contents on 20 June and 1 September occurred within the first 0–10 cm soil depth, where most likely it is a great portion of the root system of the *U. pumilia* seedlings. In arid systems, juvenile mortality during summer drought is thought to be a major limitation to recruitment. For example, Pyke (1990) found mortality of seedlings during spring ranged between 8% and 14%, but mortality during the first summer reached up to 86%. Similarly, Salihi and Norton (1987) reported 30% seedling mortality during the first spring but 85% mortality over the first seasonal drought cycle. It is suggested that those high temperatures were most likely the major constraint to seedling establishment in the patch interspaces in years of scanty precipitation during late spring and summer. This occurred in soils which have an average of 80% total coarse fraction (sand), as in an arid zone in central-western Argentina, where maximum air temperatures during summer are similar to those in our study area and soil temperatures

in the upper soil surface were up to 50°C in the patch interspaces among vegetation patches (Busso et al., 2012). On the open sand dunes, maximum surface temperatures are essentially similar to those of the desert environment. The seedlings of *Calamovilfa longifolia* exhibited high mortality at a young age (7–12 days) which coincided with a heat wave (Maun, 1981). The high air temperatures (28°C–30°C) on a bright sunny day raised surface sand temperatures to about 48°C–53°C (Maun, 1981). A large number of young seedlings died because of girdling of the first internode at the point of its contact with hot sand. The phloem of seedlings is killed by high temperatures (Maun, 1981). Exposure to temperatures over 45°C during at least 30 min can cause severe damage to plants from a wide range of climatic regions (Fitter and Hay, 1983). If temperatures remain high for several hours per day during several weeks, it is likely that seedling death will occur. Heat causes death of plant tissues damaging membranes and particularly denaturalizing proteins (Larcher, 2003). Hubbard (1957) also showed that *Eurotia lanata* seedlings developed best in full sunlight, but not on bare soil because the late spring-early summer high soil surface temperatures were very likely lethal to the young, tender plants. Thus, the low soil surface moisture contents, and very likely high soil surface temperatures, might have combined to cause such high seedling mortality in *U. pumilia* at all study locations on 1 September.

Sand movement is a regular feature in dune systems where seeds, seedlings and adult plants experience regular burial in sand to various depths because of wind effects (Maun, 1994). Sand accretion alters the normal microenvironment of plants. Maun (1994) reported that plants are unable to survive on eroding surfaces owing to desiccation of their root systems. The response of seedlings to burial is similar to that of adult plants but owing to limited nutrient reserves their rate of survival is significantly lower (Maun, 1994).

Although the death of seedlings might be partially correlated with low precipitation, it is not clear whether water shortage in the plant is a direct or an indirect cause of mortality. Seedlings may die from desiccation, heat damage, or from another cause. After

dry periods, sand becomes more loose and hydrophobic, so that wind may lead to superficial erosion and exposure of the seedling root systems to the air. During August 2010, monthly mean and maximum wind speeds reached 1.38 and 4.38 m/s, respectively. Thus, wind speed might have contributed to the reduced survival of *U. pumilia* seedlings. Also, by late August and early September, the vegetation cover and seedling survival rate at all positions in the sand dunes were similar. Shade has been shown to be closely correlated with tree seedling establishment (i.e. there would be a primary role of shade in facilitating tree seedling establishment beneath tree canopies: Kellman and Kading, 1992). However, these authors attributed the failure of trees to continue recruiting successfully beneath facilitating trees to intraspecific competition among recruiting tree individuals.

The quadric expression, with a threshold between vegetation cover and initial seed density, was consistent with the results of Liu et al. (2009). However, this threshold, which was observed at 36% vegetation cover, was lower than that reported in other studies (Liu et al., 2009). The discrepancy in thresholds might be partially attributed to land use types. The study of Liu et al. (2009) was conducted under a fenced grassland, where vegetation cover ranged from 0 to 100%. This investigation was conducted in a mobile sand dune, where vegetation cover was commonly less than 60% in Horqin Sandy Land. The threshold in seed density might be closely related to land use types, indicating spatial heterogeneity in vegetation cover as a key factor in regulating seed dispersal by wind.

The correlation between vegetation cover and surviving seedling density was not significant, which does not support the hypothesis that increased seedling survival would appear in positions with higher vegetation covers. Flemmer et al. (2003) found that survival of livestock-desirable perennial grass individuals declined as vegetation cover of undesirable perennial grasses increased in an arid region; when individuals of desirable perennial grass grew under the severe shade produced by the very high biomass of undesirable perennial grass individuals, there was no survival of the desirable perennial grass; photosynthetic photon flux density

was too low to allow survival of the individuals of these species (Flemmer et al., 2003). On the other hand, Franks (2003) found that vegetation cover had positive effects on seedling survival. This facilitation effect of tree (e.g. *U. pumilia*) seedling establishment under the canopy of vegetation was reported by Kellman and Kading (1992) in a sand dune succession. These authors showed that shade (i.e. increasing vegetation cover) was the only factor showing a pattern closely corresponding to that of seedling establishment; i.e. shade facilitated pine seedling establishment beneath pre-established trees of *Quercus rubra*. However, these authors also reported that failure of pine to continue recruitment successfully beneath facilitating oak trees was tentatively attributed to intraspecific competition among pine individuals as a result of increasing seedling density. The results of De Jong and Klinkhamer (1988) on the seedling establishment of the biennial *Cynoglossum officinale* in a sand dune area are also relevant. They found that soil water content and cover of woody plants explained 74% of the variance in the early mortality of *Cynoglossum* seedlings. They suggested that variation in rainfall might cause yearly differences in survival and growth of the biennial species, and affect its distribution over shaded and exposed habitats.

Many abiotic factors, such as light (Tognetti et al., 1998), soil temperature (Busso et al., 2012), nutrients (Hawkins et al., 1998), drought (Welander and Ottosson, 2000), soil moisture and hardness (Cao et al., 2011) and biotic factors, such as predators (Grant-Hoffman et al., 2010), inter-specific competition (Florentine and Fox, 2003) and pathogens (Bell et al., 2006) might act either in combination or isolation to determine the effects of vegetation cover on seedling survival. Further research should be focused on evaluating the impacts of these various abiotic and biotic factors on vegetation cover of elm seedling survival.

4 Conclusions

By early June, the greater vegetation cover in the grassland and transition zone than in the other positions in the sand dune determined a greater elm initial seed density. However, by late June, those greater vegetation covers were unable to increase the germinated seed density at most positions in the dune. Even more, by

early September, all positions in the dune showed a similar vegetation cover, which indicated a similar, very low survival of elm seedlings (0 to 1.7 seedlings/m²). This study suggests that elm recruitment under the study vegetation covers (12.2% to 20.8%) by early September in the different dune positions would most likely not be helpful to improve dune stabilization in Horqin Sandy Land in Inner Mongolia, northeastern China. Various other measures appeared to be helpful for stabilizing these sand dunes, thereafter contributing to vegetation restoration: (1) building corn straw fences, (2) placing wheat straw checkerboard, and (3) planting *Artemisia halodendron* on the dunes (Zhang et al., 2004). These practices would significantly increase plant species diversity, vegetation cover, and above- and below-ground biomasses on the moving sand dunes, thereafter contributing to vegetation restoration (Zhang et al., 2004).

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