INFLUENCE OF DIFFERENT LONGITUDINAL DUNE POSITIONS IN THE GURBANTUNGGUT DESERT ON THE REPRODUCTION OF *HALOXYLON AMMODENDRON* SEEDLINGS

CHAOBIN ZHOU – YUYANG SONG*

Department of Forestry, Agricultural College, Shihezi University
Road of North 4th, Shihezi City, Xinjiang 832003, China

** Corresponding author*
e-mail: syy.agr.edu@126.com

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Abstract: Field observations have been conducted on the survival mechanism of Haloxylon ammodendron seedlings in different longitudinal dune positions in the Gurbantunggut Desert for six consecutive years. In addition, the relationship between seedling settlement and environmental factors has been analyzed. *Haloxylon ammodendron* seedlings on windward slopes exhibit good natural reproduction, which is significantly higher than those on dune crests and leeward slopes (P=0.002). Wind erosion and sand burial impose restrictions on the natural production of *Haloxylon ammodendron* seedlings on dune crests and leeward slopes. Soil water content is the most important factor that influences the survival of seedlings. The other factors are herbaceous coverage, accumulated temperature at 30 cm aboveground from April to June, and vapor pressure deficit. Seedlings planted artificially and through afforestation can better adapt to wind erosion and sand burial. The average preserving rates of seedlings on windward slopes, leeward slopes, and dune crests are 35.67%, 29.6%, and 32.44%, respectively, which are significantly higher than that of naturally reproduced *Haloxylon ammodendron* seedlings (P<0.01). In afforestation, snow entropy combined with a water-retaining agent is applied during spring on 2-year-old seedlings artificially planted on dune crests and leeward slopes to increase the survival rate of seedlings.
Key words: *Gurbantunggut Desert; Haloxylon ammodendron; seedling reproduction;longitudinal dune position; soil water content*

Introduction

Haloxylon ammodendron, which belongs to genus *Haloxylon*, is an important component of the Tethys flora. This plant formation, which has the widest distribution of vegetation in the Asian desert region, consists mainly of *Haloxylon ammodendron* (Wu, 1995; West, 1983). In the Xinjiang Province in China, the distribution area of *Haloxylon ammodendron* is approximately 81.44 million km^2, occupying 68% of the total area with *Haloxylon ammodendron* in China. The distribution area of *Haloxylon ammodendron* in the Gurbantunggut Desert is approximately 71.95 million km^2, occupying 94% of Xinjiang. This area represents the most centralized distribution of *Haloxylon ammodendron* in China. However, the area of natural *Haloxylon ammodendron* forest is decreasing because of land development, groundwater mining,

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excessive deforestation, and overgrazing. Hence, *Haloxylon ammodendron* has been listed as a national grade 3 endangered plant in China (Guo et al., 2005).

Wind power, terrain, hydrology, vegetation, and sand dune types have various influences in the Gurbantunggut Desert (Wu, 1997). Along the prevailing wind direction, sand dunes can be divided into different longitudinal positions as windward slopes, leeward slopes, and dune crests. Windward and leeward slopes are stable or semi-stable sand dunes, respectively, whereas dune crests are moving at a width of 10 m to 40 m (Wang et al., 2005). As the dominant vegetation species in the Gurbantunggut Desert, *Haloxylon ammodendron* has high drought endurance and saline–alkaline tolerance (Zhou and Xu, 2002). This plant is commonly used as a pioneer greening tree species in desert regions (Bedunah and Schmidt, 2000), and has a significant role in maintaining the stability of desert sand dunes. Investigation on permanent sample plots in the Gurbantunggut Desert for six consecutive years (2006 to 2011) showed that the reproduction methods of *Haloxylon ammodendron* seedlings in different longitudinal dune positions exhibit significant differences. The reproduction rate of *Haloxylon ammodendron* seedling on windward slopes is higher than those on leeward slopes and dune crests. Vegetation on leeward slopes and dune crests is sparse, whereas the bare areas of sand dunes have high vegetation proportion, which causes wind erosion.

The established study indicates that different longitudinal positions of desert dunes exhibit significant differences in parameters such as soil moisture (Wang et al., 2006), ephemeral plant coverage (Wang et al., 2004), activity intensity of the sand surface (Guo et al., 2010), wind erosion, and sand burial (Wang and Lei, 1998), among others. Wind erosion in desert areas is not favorable to capturing seeds on the ground surface, whereas extreme sand burial thickness is not beneficial to seedling emergence (Wang and Lei, 1998; Li et al., 2011; Al-khalifah and Shanavaskhan, 2007). *Haloxylon ammodendron* has winged fruits and disperses mainly by wind. The ephemeral plant coverage on windward slopes is well-developed, thus creating conditions that allow the ground surface to capture *Haloxylon ammodendron* seeds. Appropriate sand burial thickness guarantees smooth emergence of *Haloxylon ammodendron* seedlings (Wang and Lei, 1998; Li et al., 2011), thus resulting in more *Haloxylon ammodendron* plants growing through natural reproduction on windward slopes. Wind deposition leads to excessively deep sand burial on leeward slopes (Wang and Lei, 1998), thus inhibiting the germination of seeds and the emergence of seedlings. Wind erosion on dune crests is excessive, and vegetation is sparse, which makes it difficult for the ground surface to capture seeds. Therefore, few seedlings grow on leeward slopes with deep sand burial and on dune crests with excessive wind erosion. The combined actions of biotic (e.g., ephemeral plant coverage) and abiotic (e.g., sand burial, wind erosion, and soil moisture) factors in different longitudinal dune positions influence capturing of *Haloxylon ammodendron* seeds. The successful settlement link of seedlings is also important in natural plant reproduction. However, reports on the influence of biotic and abiotic factors on different longitudinal dune positions on the settlement process of *Haloxylon ammodendron* seedlings are few.

Sand burial and wind erosion inhibit the natural reproduction of *Haloxylon*

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ammodendron. Vegetation on leeward slopes and dune crests in desert regions is particularly sparse, and thus, these areas become sources of dust. The established study demonstrates that because of insufficient “seedling banks” on leeward slopes and dune crests, the natural reproduction of *Haloxylon ammodendron* in microhabitats becomes challenging. Single prohibition measures have difficulty realizing the natural reproduction of seedlings on leeward slopes and dune crests. Thus, whether such measures can promote seedling reproduction in regions with wind erosion and sand burial by creating “seedling banks” of *Haloxylon ammodendron* through artificial recovery remains unanswered.

The distribution area of natural *Haloxylon ammodendron* and its coverage degree are decreasing because of excessive development and increasing environmental degradation. Some areas of moving sand dunes are gradually extending, whereas several fixed dunes tend to become moving sand dunes. Therefore, specifying the reproduction structure and formation mechanism of *Haloxylon ammodendron* in different longitudinal dune positions as well as investigating the feasibility of artificial recovery of *Haloxylon ammodendron* on dune crests and leeward slopes have significant implications in recovering *Haloxylon ammodendron* population. By focusing on the aforementioned phenomena, this study addresses the following issues: (1) exploring the reproduction mechanism of *Haloxylon ammodendron* in different longitudinal dune positions; (2) specifying the influences of biotic and abiotic factors in different longitudinal dune positions on the reproduction of *Haloxylon ammodendron* seedlings; (3) probing into the recovery feasibility of artificial vegetation in areas with wind erosion and sand burial (i.e., leeward slopes and dune crests), and providing a reference to recover *Haloxylon ammodendron* population and to practice wind erosion prevention and sand fixation.

Materials and methods

Study site

The Gurbantunggut Desert is located in the hinterland of the Junggar Basin in northwest China (44°11′ to 46°20′ N, 84°31′ to 90°00′ E), with an area that reaches 48,800 km^2. The Gurbantunggut Desert is the second largest desert in China. Located far from the ocean, it has a temperate arid desert climate. The annual precipitation is 80 mm to 190 mm. The annual average temperature is 5.0 °C to 5.7 °C. The annual evaporation capacity is 2,000 mm to 2,800 mm. The annual average wind velocity is 2.0 $m.s^{-1}$ to 3.6 $m.s^{-1}$. The annual windy days are 174, and the prevailing wind direction is northwest. Compared with other arid regions, the Gurbantunggut Desert has 95 d to 110 d of stable snow-covered period each year, with a snow depth of 10 cm to 30 cm. *Haloxylon ammodendron* is the dominant species in this desert, and the ephemeral plant layer is well-developed. The vegetation coverage rate in the internal desert is 20% to 30%. Approximately 80% of the study area remains stable under good vegetation conditions (Wang et al., 2005). *Table 1* lists the characteristics of the longitudinal

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positions of sand dunes in different locations. These characteristics include gradient, aspect, soil water content, vegetation coverage, organic content, soil total salt, wind velocity, and precipitation.

Table 1. *Data on environmental factors in each location*

Location	Ter	Slope gradient (°)	Slope aspect	SWC (%)	Cov (%)	Org (%)	TSC (%)	Win ($m.s^{-1}$)	Pre (mm)	EVA (mm)
Kuitun	Windward slope	13	West	8.10	38.8	0.69	0.58	3.07	192	2096
	Leeward slope	27	East	8.20	15.3	0.65	0.46	2.15		
	Dune crest	/	/	6.50	12.2	0.72	0.53	3.62		
Shihezi	Windward slope	14	Northwest or North	6.50	24.4	0.85	0.64	3.21	117	2042
	Leeward slope	29	South or Southeast	6.1	10.3	0.88	0.55	2.21		
	Dune crest	/	/	4.9	7.7	0.73	0.56	3.75		
Jinghe	Windward slope	9	South	3.9	7.0	0.64	0.72	4.74	144	2100
	Leeward slope	25	North	4.3	5.7	0.48	0.65	3.29		
	Dune crest	/	/	3.8	3.9	0.54	0.63	3.94		

Note: Annual precipitation was based on the years 1999 to 2008. Climate data (Pre and EVA) come from weather station sites of state-owned farms. The farms where the sampling sites were located ran deeply into the desert. Each sampling site was 10 km to 20 km from the weather station.

Experimental design

Investigating the survival dynamic condition of Haloxylon ammodendron through natural reproduction

Sample regions with representative *Haloxylon ammodendron* growth and climate in the Gurbantunggut Desert, such as Jinghe (44°34.747′ N, 83°16.162′ E), Kuitun (44°47.739′ N, 84°59.897′ E), and Shihezi (45°1.681′ N, 86°18.294′ E), were selected. Three longitudinal dune positions, namely, dune crests, windward slopes, and leeward slopes, were also chosen in each location. The soil in all areas was sandy soil. Sample regions measuring 10 m × 10 m for each longitudinal dune position were randomly set, thus giving a total of 90 sample regions. The first investigation was conducted in September 2006. The survival conditions in each sample region of the three microhabitats of one-year-old *Haloxylon ammodendron* grown under the shrub crown, under the herb layer, and on open space were investigated. (In general, *Haloxylon ammodendron* blossoms and yields fruits after 5 years to 6 years of being planted. This study defines the growth of *Haloxylon ammodendron* seedlings from 1 year to 6 years). During the investigation, *Haloxylon ammodendron* appeared under the projection of the shrub crown, with renewed seedlings after falling under shrub crown. *Haloxylon ammodendron* appeared within the projection range of the herbaceous layer, with renewed seedlings after falling under the layer. The remaining seedlings were renewed after falling on open space. The one-year old seedlings grown on the sample regions were marked and their survival condition was recorded. During the same period, the

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survival condition of the marked *Haloxylon ammodendron* seedlings was tracked and investigated from 2007 to 2011.

Investigating the survival condition of Haloxylon ammodendron seedlings through artificial reproduction

To explore the artificial reproduction potential of *Haloxylon ammodendron* on windward slopes, leeward slopes, and dune crests, other longitudinal dune positions in the spring of 2007 were set in Jinghe, Kuitun, and Shihezi. Snow entropy was combined with a water-retaining agent to plant two-year-old *Haloxylon ammodendron* seedlings. Ten sample regions measuring 10 m × 10 m were randomly set in each longitudinal dune position, thus giving a total of 90 sample regions. Trenching specification was 0.3 m × 0.3 m × 0.3 m. Transplant density was 2 m × 2 m, and the dosage of the water-retaining agent was 60 g per plant. Water was fully absorbed by the water-retaining agent (polyacrylamide and granulate; the highest water-absorbent rate was 312.5 times) to a completely saturated state (water was absorbed for 1 h) before planting and emphatically act on the bottom. A minimum distance of 2 m was maintained from mature *Haloxylon ammodendron* trees when planting. The investigation on the survival rate of *Haloxylon ammodendron* and its growth height was conducted for five consecutive years from September 2007 to September 2011.

Investigating the sample region and determining the indicators

It conducted in the artificially planted sample region. In June 2007, the first survey on indicators, such as the individual number of shrub and crown width [coverage was calculated by using the formula of elliptical areas, i.e., $C = \pi XY/4$, where X and Y refer to the major and minor axis lengths of each crown, respectively (Phillips and MacMahon, 1981)], was made. Three small quadrats measuring 1 m × 1 m were set in each quadrat. The coverage degree of the herbaceous plant in each small quadrat (Causton, 1988) was determined. The coverage degree in each 10 m × 10 m quadrat was also calculated. The indicators in each sample region, such as soil water content (SWC), wind velocity (Win), accumulated temperature at 30 cm aboveground from April to June (ATA), and vapor pressure deficit (VPD), were successively observed in 7 d intervals from April to September 2007 (actual observations were conducted 24 times). Meanwhile, automatic weather stations (Campbell® Scientific, Australia) observed the meteorological factors of Win, ATA, and VPD from 8:00 to 20:00 on the aforementioned days. The numerical values of the meteorological factors were recorded in 30 min intervals.

Soil samples from the four corners and the center were collected from depths of 0 cm to 10 cm and 10 cm to 30 cm to perform blending analysis in each sample region. The wet and dry weights of all soil samples were used to calculate SWC. pH was determined in a 1.0:2.5 (w:v) suspension of soil in water by using a pH/ORP/EC/°C field meter (Hanna® Instruments, USA). Total salt content (TSC) was determined by using an EC/TDS/°C meter (Hanna® Instruments, USA). Organic matter content (Org) was

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determined through the Tyurin method. The thickness of sand burial (SBD) was determined by adopting a drilling method, in which 9 iron bars were evenly inserted in each sample region. Wind erosion and SBD were measured from April to September. The measurement results are shown as *Table 2*.

Table 2. *Sand burial or wind erosion characteristics in each location*

Location	Ter	Microhabitats	Status	Maximum depth (cm)
Kuitun	Windward	On open space (Exposed land without vegetation)	Wind erosion	3.1
		Under the herb layer	Sand burial	0.8
	Leeward slope	On open space (Exposed land without vegetation)	Sand burial	4.2
		Under the herb layer	Sand burial	4.4
	Dune crest	On open space (Exposed land without vegetation)	Wind erosion	4.9
		Under the herb layer	Sand burial	1.1
Shihezi	Windward	On open space (Exposed land without vegetation)	Wind erosion	3.8
		Under the herb layer	Sand burial	1.5
	Leeward slope	On open space (Exposed land without vegetation)	Sand burial	5.6
		Under the herb layer	Sand burial	5.9
	Dune crest	On open space (Exposed land without vegetation)	Wind erosion	5.8
		Under the herb layer	Sand burial	1.4
Jinghe	Windward	On open space (Exposed land without vegetation)	Wind erosion	4.8
		Under the herb layer	Sand burial	1.7
	Leeward slope	On open space (Exposed land without vegetation)	Sand burial	7.9
		Under the herb layer	Sand burial	8.1
	Dune crest	On open space (Exposed land without vegetation)	Wind erosion	12.3
		Under the herb layer	Sand burial	0.8

Redundant variables analysis (RDA)

Monte Carlo testing was performed in the sample region to select the significant variables ($P<0.05$). The environmental factors that significantly affects *Haloxylon ammodendron* density are SWC, pH value (pH), Org, TSC, ATA, VPD, SBD, soil evaporation (EVA), annual precipitation (Pre), terrain (Ter), herbaceous layer cover degree (Cov), and Win. Other environmental factors are not significant, thus RDA is not analyzed (*Table 3*). The density of artificially planted *Haloxylon ammodendron* seedlings was determined for each sample region in September 2011. The matrix of [seedling density × sample region]$_{10\times9}$ was established; the selected 12 environmental factors were SWC, pH, Org, TSC, ATA, VPD, SBD, EVA, Pre, Ter, Cov, and Win. These factors constituted the matrix of [environment × sample region]$_{12\times9}$ and were used in the multiple quantity analysis of the relationship between vegetation and environment (ter Braak and Šmilauer, 2002) (*Table 3*).

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Table 3. *Forward selection analysis and Monte Carlo test of the environmental factors that affect seedling density of Haloxylon ammodendron*

Environmental factor	Seedling density	
	P-value	*R*-value
SWC (%)	0.001	0.51
pH	—	
Org (g/kg)	0.04	0.02
TSC (g/kg)	0.02	0.03
ATA (°C)	0.002	0.08
VPD	0.002	0.06
SBD (mm)	0.47	
EVA (mm)	—	
Pre (mm)	0.02	0.01
Ter	0.08	
Cov (%)	0.002	0.25
Win (m/s)	0.17	

$P<0.01$ indicates that the influence of environmental factors on the seedling density of *Haloxylon ammodendron* is significant at the 0.01 level. $P<0.05$ indicates that the influence of environmental factors on the seedling density of *Haloxylon ammodendron* is significant at the 0.05 level. "—" indicates that a collinearity relationship exists between environmental factors and other environmental factors. The *R*-value represents relative percentage. Terrain is evaluated by an artificial method: windward slope: 0, leeward slope: 0.5, dune crest: 1.

Data analysis

Data analysis was conducted via SPSS 15.0 (SPSS Inc., USA). The quantity variance of *Haloxylon ammodendron* with respect to different longitudinal dune positions, microhabitats, and reproduction manner (natural reproduction and artificial reproduction) adopted one-way ANOVA.

Results

Natural reproduction of Haloxylon ammodendron seedlings in different longitudinal dune positions

The survey results of the natural reproduction of *Haloxylon ammodendron* seedlings from 2006 to 2011 shows that the windward slopes in the three areas has the largest number of *Haloxylon ammodendron* seedlings, accounting for 72.39% ± 2.24% of the total number of seedlings and obviously exceeding those on dune crests and leeward slopes (P=0.002, F=8.07 F_{crit}=5.61). The difference between dune crests and leeward slopes is not significant, i.e., 13.70% ± 1.06% and 13.91% ± 1.29%, respectively (*Fig.*

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1). In Kuitun and Shihezi, the distribution patterns exhibit that the seedlings under the herb layer has the largest number, followed by the seedlings on open space, and then the seedlings under the shrub crown (*Table 4*). In Kuitun, the number of seedlings under the herb layer, on open space, and under the shrub crown accounts for 66.49%, 21.40%, and 12.11%, respectively. In Shihezi, the number of seedlings under the herb layer, on open space, and under the shrub crown accounts for 66.49%, 21.40%, and 12.11%, respectively. In Jinghe, the seedlings under the shrub crown have the largest number (72.75%), followed by the seedlings under the herb layer (19.14%), and then the seedlings on open space (8.12%) (*Table 4*).

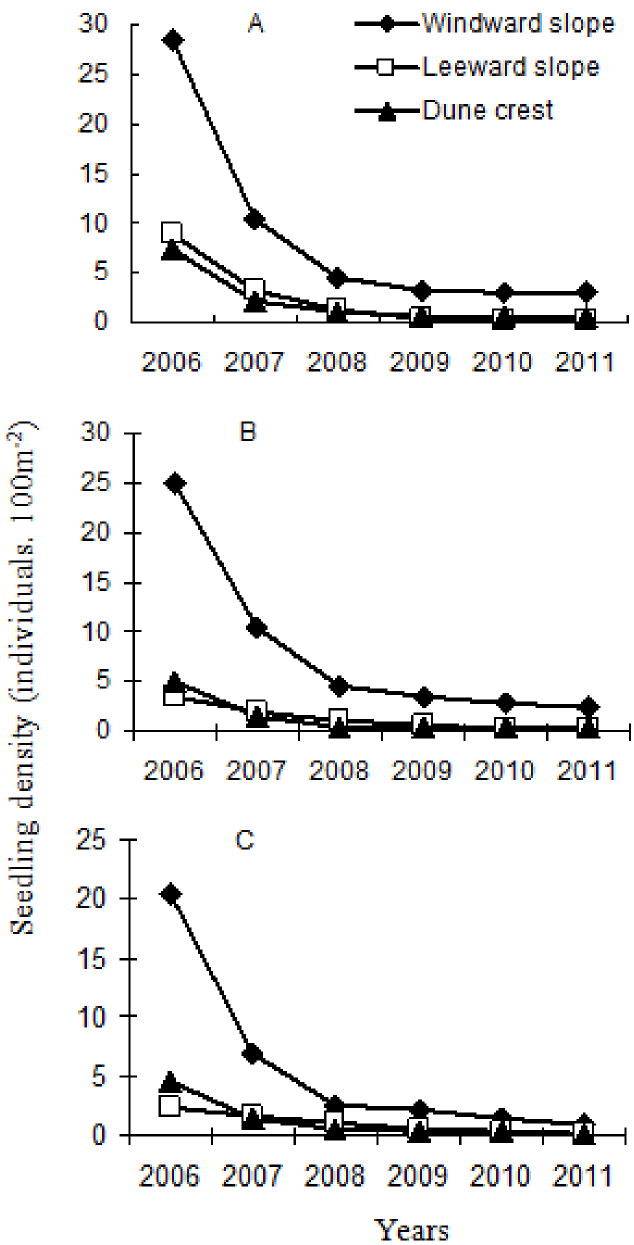

Figure 1. *The survival of naturally regenerated seedlings of Haloxylon ammodendron. Seedling density in A: Kuitun, B: Shihezi, and C: Jinghe*

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Table 4. *The ratio of seedling numbers in each microhabitat*

Microhabitats	Kuitun	Shihezi	Jinghe
On open space (Exposed land without vegetation)	30.64%	21.40%	8.12%
Under the herb layer	59.41%	66.49%	19.14%
Under the shrub crown	9.95%	12.11%	72.75%

The death rate of *Haloxylon ammodendron* seedlings is higher during the first stage than in the latter stages. The average death rate in 2007 reached 58.9% ± 4.48%. The root system becomes stronger and deeper with the increasing age of *Haloxylon ammodendron* seedlings. Consequently, the growth condition and stress resistance of the plants also become stronger, and thus, the death rate gradually decreases. The average death rate in 2011 was only 22.08% ± 8.54%. Based on the statistics on the final survival rate of the seedlings in 2011, each sample region present the pattern in which windward slopes has the highest survival rate (8.31% ± 1.96%), followed by dune crests (6.81% ± 1.19%), and then leeward slopes (4.46% ± 0.69%).

Artificial reproduction of Haloxylon ammodendron seedlings in different longitudinal dune positions

For the 2-year-old seedlings of *Haloxylon ammodendron* which were artificially planted on different locations, i.e., windward slopes, leeward slopes, and dune crests, the 5-year consecutive surveys show that the average survival rate of the seedlings during the fifth year on windward slopes, leeward slopes, and dune crests are 24.4% ± 9.04%, 17.47 ± 6.9%, and 14.67 ± 6.08%, respectively (*Fig. 2*). The seedling survival rate for artificial reproduction is obviously higher than that for natural reproduction (P=0.008, F=9.06, F_{crit}=4.49).

The relationship between the survival of Haloxylon ammodendron seedlings and environmental factors

Among the environmental factors that affect the density of *Haloxylon ammodendron* seedlings, SWC is the most important, followed by Cov, ATA, and VPD. Other factors do not have a significant influence (*Fig. 3*). Kuitun has the highest SWC, followed by Shihezi, and then, Jinghe. Thus, the density of *Haloxylon ammodendron* seedlings presents a corresponding varying pattern.

Discussion

Restoring vegetation cover is significant in recovering ecosystem function (O'Brien and Zedler, 2006). However, vegetation cannot thrive through natural reproduction under harsh environmental conditions (Lindig–Cisneros and Zedler, 2002). Our research shows that wind erosion and sand burial are serious problems on leeward slopes and

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dune crests, which make these areas not suitable for *Haloxylon ammodendron* reproduction. *Haloxylon ammodendron* have winged fruits and they mainly rely on the wind for dispersal. Hence, surface substrate characteristics determine the distribution pattern of the seeds. The investigated sample regions in the Gurbantunggut Desert are not advantageous for surface capturing of *Haloxylon ammodendron* seeds because of low SWC, strong wind, unstable substrate characteristics, and other conditions on dune crests. Moreover, among the three longitudinal dune positions, uncovered dune crests result in wind-blown sand movements under the action of wind and sand (Wang et al., 2004), thus exhibiting wind erosion. After crossing a dune crest, wind-drift sand is obstructed by the dual effects of vegetation block and whirly vortex, and thus, wind velocity decreases sharply on leeward slopes, which causes eolian deposits (sand burial).

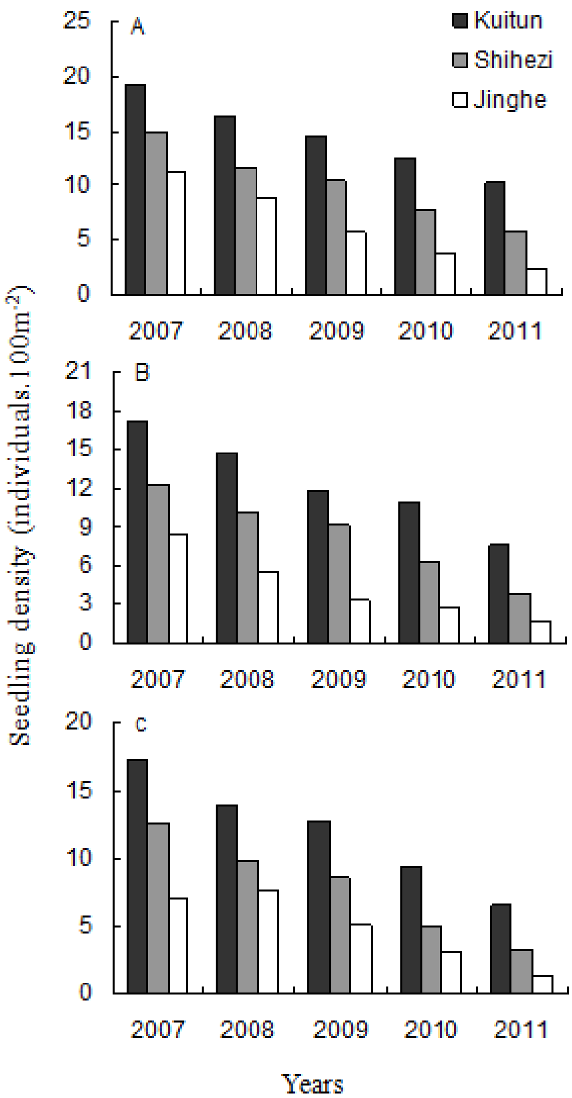

Figure 2. *The survival rate of planted Haloxylon ammodendron seedlings. A: Windward slope, B: Leeward slope, and C: Dune crest*

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Among the three positions, the SBD on leeward slopes is the highest, exceeding 4.2 cm (*Table 4*), thus leading to the inhibition of *Haloxylon ammodendron* seed germination and seedling emergence (Li et al., 2011). This result indicates that longitudinal dunes affect natural reproduction by influencing ephemeral coverage, wind erosion, and sand burial (Maun, 1996; Huang and Gutterman, 1998), which is consistent with the research results of Jansen and Ison (1995) and Huang et al. (2004).

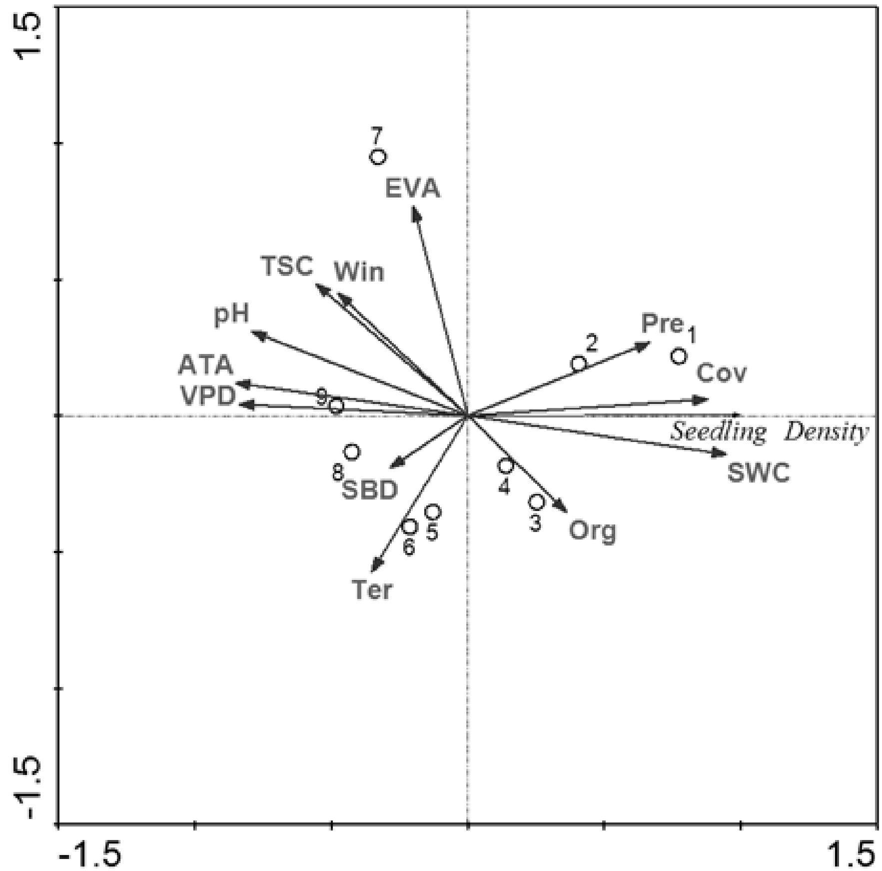

Figure 3. *RDA of the seedling density with environmental factors. The Hindu-Arabic numerals refer to the plots.*

Therefore, natural reproduction of *Haloxylon ammodendron* seedlings on dune crests and leeward slopes will be slow. Through afforestation, “seedlings banks” of *Haloxylon ammodendron* can be built, thus significantly improving the success rate of *Haloxylon ammodendron* reproduction. The results of our research show that artificially planting *Haloxylon ammodendron* seedlings have growth potentials, with full-grown root systems enabling the plants to absorb deep soil water (Marushia and Holt, 2008), thus allowing them to survive on sand dunes. The survival rate of artificially planted seedlings on windward slopes, dune crests, and leeward slopes are respectively 1.94, 2.91, and 1.15 times higher than that of naturally reproduced seedlings (*Figs. 1* and *2*), which further confirms that promoting the stable recovery of flowing sand surface by artificially building "seedlings banks" of *Haloxylon ammodendron* on dune crests and leeward slopes where natural reproduction is difficult is feasible.

Meanwhile, the harsh environmental conditions in deserts, such as drought, high temperature, and so on, result in high death rates. For example, the survival rate of *Eremosparton songoricum* (Fabaceae) in the Gurbantunggut Desert is only 2% (Liu et al., 2011). *Haloxylon ammodendron* is the dominant species in the Gurbantunggut Desert. However, its seedling death rate during the first year is still higher than 80% (Huang et al., 2009). The results of the research on seedling natural reproduction indicate that the final survival rates of the seedlings in their sixth year on the longitudinal dune positions of windward slopes, leeward slopes, and dune crests are 8.31%, 4.46%, and 6.81%, respectively, which are higher than the reproduction success rates of perennial plants in the Sonoran Desert (Ackerman, 1979) and the Mojave Desert (Bowers et al., 2004). Meanwhile, the 2-year-old artificially planted seedlings effectively avoid the high death rate during the initial growth stage. The final survival rate of artificially planted *Haloxylon ammodendron* seedlings in the first year is higher than 49.07%. During the fifth year, the final survival rates of the seedlings on windward slopes, leeward slopes, and dune crests are 24.40%, 17.47%, and 19.40%, respectively, thus exhibiting the advantages of artificially planting seedlings.

This research adopts RDA to investigate the influences of environmental factors on the survival of *Haloxylon ammodendron* seedlings. In the wilderness (desert) ecosystem, water is the most important factor that affects the survival of plants. Rainfall is the only source of SWC in the Gurbantunggut Desert. The high SWC that corresponds to more rainfall in Kuitun compared with in Jinghe and Shihezi also proves this statement. However, the SWC in Jinghe is generally lower than that in Shihezi even if rainfall in Jinghe is more abundant in Shihezi because the wind is strong in Jinghe and the soil, which is mainly coarse sand, has poor water-retaining property. At different longitudinal dune positions, soil water exhibit sideway movements along the slopes during vertical infiltration because of the short-term concentrated ablation of winter snow cover in early spring as well as the presence and downward movement of confining beds (tjaele). As a result, soil water in the sample plots forms a spatial distribution pattern in which windward and leeward slopes have higher SWCs than dune crests (Wang et al., 2006). A pattern in which the density of *Haloxylon ammodendron* seedlings increases with increasing SWC is also observed (Fig. 3). As the direct driving force of water evaporation, atmospheric drought can cause the death of plants as frequently reported (Yarranton and Yarranton, 1975). VPD indicates that the degree of atmospheric drought also controls the evaporation of surface soil water and the transpiration rate of vegetation. When atmospheric drought is severe, water evaporation loss on the surface soil of longitudinal dunes and water consumption of vegetation transpiration are higher (Liu et al., 2011). Consequently, the death rate of *Haloxylon ammodendron* seedlings will also be higher (Fig. 3). In addition to drought, high temperature also inhibits seedling survival (Callaway, 2007). On one hand, high temperature directly causes an increase in surface temperature that leads to burning the part of the stem closest to the

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ground. On the other hand, high temperature aggravates soil water stress and then reduces the vitality of *Haloxylon ammodendron*. Assimilating shoots wilt, thus significantly affecting the survival of *Haloxylon ammodendron* seedlings. Our study found that the density of *Haloxylon ammodendron* seedlings at each sample plot has a significant negative correlation with ATA (*Fig. 3*). By contrast, the presence of the herb layer relieves high temperature and reduces soil evaporation on microhabitats (Gong et al., 2008), thus promoting the survival of the seedlings. In the present research, coverage has a significant positive correlation with the density of *Haloxylon ammodendron* seedlings (*Fig. 3*). However, its specific mechanism still needs further study.

Conclusion

(1) The most important environmental factor that influence the survival rate of *Haloxylon ammodendron* seedlings is SWC, followed by Cov, ATA, and VPD.

(2) The main factors that cause poor reproduction of *Haloxylon ammodendron* seedlings on dune crests and leeward slopes are wind erosion and sand burial, whereas artificial seedling afforestation can promote reproduction success rate of *Haloxylon ammodendron* seedlings on dune crests and leeward slopes.

(3) In the Gurbantunggut Desert, water is the most significant factor that affects the survival of *Haloxylon ammodendron* seedlings (*Fig. 3*). Therefore, in some key areas such as the edges of an oasis, dune crests, and the longitudinal dunes on the leeward slopes on both sides of a desert road, water can effectively improve the survival rate of *Haloxylon ammodendron* seedlings by conducting seedling afforestation during early spring, which is the best period of SWC, and by taking advantage of water-retaining agents with excellent water-retention capacity.

(4) With better conditions on windward slopes, *Haloxylon ammodendron* seedlings have high survival rate on these positions. These plants can be protected by closing hillsides for afforestation to promote natural reproduction.

REFERENCES

[1] Ackerman, T. L. (1979): Germination and survival of perennial plant species in the Mojave Desert. – Southwest Nat. 24: 399–408.

[2] Al-khalifah, N. S., Shanavaskhan, A. E. (2007): On the distribution, status and phenology of Ghada (Haloxylon persicum Bunge) in the Arabian Peninsula. – Trop. Ecol. 48: 51-60

[3] Bedunah, D. J., Schmidt, S. M. (2000): Rangelands of Gobi Gurvan Saikhan national conservation park, Mongolia. – Rangelands 22: 18–24.

[4] Bowers, J. E., Turner, R. M., Burgess, T. L. (2004): Temporal and spatial pattern in emergence and early survival of perennial plants in the Sonoran Desert. – Plant Ecol. 172: 107–119.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1301_099113

[5] Callaway, R. M. (2007): Positive interactions and interdependence in plant communities. – Springer, Dordrecth, The Netherlands.

[6] Causton, D. R. (1988): An introduction to vegetation analysis: principles, practice and interpretation. – Unwin Hyman, London.

[7] Gong, X., Brueck, H., Giese, K. M., Zhang, L., Sattelmacher, B., Lin, S. (2008): Slope aspect has effects on productivity and species composition of hilly grassland in the Xilin River basin, Inner Mongolia, China. – J. Arid Environ. 72: 483–493.

[8] Guo, H. X., Wang. X. Q., Gai, S. G., Wu, T., Hu, Y. F. (2010): Wind blown sand movement on the top of semi-fixed longitudinal dune in the hinterland of Gurbantunggut Desert. – Arid Land Geography 33: 954-961(in Chinese).

[9] Guo, Q. S., Guo, Z. H., Yan, H., Wang, C. L., Tan, D. Y., Ma, C., He, Y. H. (2005): Study on potential distribution of Haloxylon plants dominated desert vegetation in China. – Acta Ecologica Sinica 25: 848–853 (in Chinese).

[10] Huang, P. Y., Xiang, B., Li, Q. J., Xu, Z. H. (2009): Relationship between Haloxylon ammodendron seedling dynamics and habitat before summer. – Journal of Desert Research 29: 87-94 (in Chinese).

[11] Huang, Z. Y., Gutterman, Y. (1998): Artemisia monosperma achene germination in sand: effects of sand depth, sand/water content, cyanobacterial sand crust and temperature. – J. Arid Environ. 38: 27–43.

[12] Huang, Z. Y., Dong, M., Gutterman, Y. (2004): Factors influencing seed dormancy and germination in sand, and seedling survival under desiccation, of Psammochloa villosa (Poaceae), inhabiting the moving sand dunes of Ordos, China. – Plant Soil 259: 231–241.

[13] Jansen, P. I., Ison, R. L. (1995): Factors contributing to the loss of seed from the seed bank of Trifolium balansae and Trifolium resupinatum over summer. – Aust. J. Ecol. 20: 248–256.

[14] Li, H., Li, Y., Fan, L. L. (2011): Response of seedling emergence of two Haloxylon species to the interchanging of soil matrix in habitants and sand burial depth. – Arid Zone Research 28: 780-788 (in Chinese).

[15] Lindig-Cisneros, R., Zedler, J. B. (2002): Halophyte recruitment in a salt marsh restoration site. – Estuaries 25: 1174–1183.

[16] Liu, H. L., Shi, X., Wang, J. C., Yin, L. K., Huang, Z. Y., Zhang, D. Y. (2011). Effects of sand burial, soil water content and distribution pattern of seeds in sand on seed germination and seedling survival of Eremosparton songoricum (Fabaceae), a rare species inhabiting the moving sand dunes of the Gurbantunggut Desert of China. – Plant Soil 345: 69–87.

[17] Marushia, R. G., Holt, J. S. (2008): Reproductive strategy of an invasive thistle: effects of adults on seedling survival. – Biol. Invasions 10: 913–924.

[18] Maun, M. A. (1996): The effects of burial by sand on survival and growth of Calamovilfa longifolia. – Ecoscience 3: 93–100.

[19] O'Brien, E. L., Zedler, J. B. (2006): Accelerating the restoration of vegetation in a southern California salt marsh. – Wetl. Ecol. Manag. 14: 269–286.

[20] Phillips, D. L., MacMahon, J. A. (1981): Competition and spacing patterns in desert shrubs. – J. Ecol. 69: 97-115.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1301_099113

[21] ter Braak, C. J. F., Šmilauer, P. (2002): CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). – Microcomputer power, Ithaca, New York.

[22] Wang, X. Q., Lei, J. Q. (1998): Sand deposit and erosion characteristics of semi-fixed linear dune in Gurbantunggut desert. – Arid Zone Research 15: 35-39 (in Chinese).

[23] Wang, X. Q., Jiang, J., Lei, J. Q., Zhao, C. J. (2004): Relationship between ephemeral plants distribution and soil moisture on longitudinal dune surface in Gurbantonggut desert. – Chin. J. Appl. Ecol. 15: 556-560 (in Chinese).

[24] Wang, X. Q., Wang, T., Jiang, J., Zhao, C.J. (2005): On the sand surface stability in the southern part of Gurbantunggut Desert. – Sci. China Ser. D-Earth Sci. 48: 778-785.

[25] Wang, X. Q., Zhang, Y. M., Jiang, J., Chen, J. J., Song, C. W. (2006): Variation pattern of soil water content in longitudinal dune in the southern part of Gurbantünggüt Desert: how snow melt and frozen soil change affect the soil moisture. – Journal of Glaciology and Geocryology 28: 262-268 (in Chinese).

[26] West, N. E. (1983): Temperate deserts and semi-deserts. – Elsevier Scientific Publishing Company, Amsterdam.

[27] Wu, Z. Y. (1995): Vegetation of China. – Science Press, Beijing (in Chinese).

[28] Wu, Z. (1997): Preliminary study on the aeolian sand landforms in Junggar Basin. – In: Wu Z, ed. Study on the Desert and Coast in China. Science Press, Beijing (in Chinese).

[29] Yarranton, M., Yarranton, G. A. (1975): Demography of a jack pine stand. – Can. J. Bot. 53: 310-314.

[30] Zhou, Z. B., Xu, X. W. (2002): Absorption characteristics of ions in three species of shrubs of the artificially-planted greenbelts in the hinterland of Taklamakan Desert. – Arid Zone Res. 19: 49–52(in Chinese).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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