Regeneration characteristics of Haloxylon ammodendron seedlings in the Mosuowan region of the Gurbantünggüt Desert, China

Verjüngungsentwicklung von Haloxylon ammodendron in der Mosuowan Region der Gurbantünggüt Wüste, China

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Key words:	*H. ammodendron*; Seedling regeneration; Age structure; Reforestation;
Stichworte:	*H. ammodendron*; Verjüngung; Altersstruktur; Wiederbewaldung; Aufforstung;

Abstract

Although *Haloxylon ammodendron* (C.A. Mey.) Bunge (Chenopodiaceae) is the dominant species in the Gurbantünggüt desert; few studies have examined the natural regeneration of seedlings and microhabitat effects on regeneration. The age classes of regenerated seedlings were investigated and the differences between the different microhabitats in the Mosuowan region of Gurbantünggüt desert, China, were examined. The highest age class was found to be 3-year old seedlings, at an average of 116.7 stems per hectare. The correlations between 5-year-old and 6-year-old seedlings ($R^2 = 0.69$, $p < 0.01$), mature trees and 5-year-old seedlings ($R^2 = 0.54$, $p < 0.05$), and mature trees and 6-year-old-seedlings ($R^2 = 0.55$, $p < 0.05$) were significant. The fertile land under *H. ammodendron* adult trees was not conducive to seedling regeneration in the sampling areas. The withered herbaceous cover layer ranged from 1.70% to 14.50%, with an average of $5.92\% \pm 1.47$ SE. *H. ammodendron* seedlings regenerated best under the withered herbaceous layer, with a regeneration rate of 180.56 ± 33.54 stems per hectare.

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We concluded that: (1) natural *H. ammodendron* regeneration can benefit from withered herbaceous plants; (2) during the ecological restoration of *H. ammodendron* populations, an enclosure policy against grazing should be applied in order to protect the herbs and (3) where there is bare ground or mobile dunes without vegetation, checkerboards should be constructed and fixed to the sand surface in order to promote *H. ammodendron* seed settlement. A conceptual model of *H. ammodendron* seedling regeneration is also presented in this paper.

Kurzfassung

Obwohl *Haloxylon ammodendron* (C.A. Mey.) Bunge (Chenopodiaceae) die Hauptbaumart in der Gurbantünggütwüste, China, ist, gibt es nur wenige Studien, die das Naturverjüngungspotential dieser Art untersucht haben. Ziel dieser Studie ist es, die Entwicklung unterschiedlich alter Verjüngung, wie sich diese aus den kleinstandörtlichen Gegebenheiten der Mosuowan Region in der Gurbantünggütwüste ableiten lassen, zu analysieren. Die Ergebnisse lassen sich wie folgt zusammenfassen: Die ältesten Sämlinge waren 3 Jahre alt und hatte eine durchschnittlich Stammzahl von 116.7 Individuen je Hektar. Die Korrelation von 5-jährigen Individuen und erwachsenen Bäumen sowie 6-jährigen und den erwachsenen Bäumen war signifikant. ($R^2 = 0.69$, $p < 0.01$ bzw. $R^2 = 0.55$, $p < 0.05$). Im Untersuchungsgebiet konnten keine Unterschiede im Ankommen der Verjüngung in Abhängigkeit von der Bodenfruchtbarkeit festgestellt werden. Die Konkurrenzvegetation ergab eine Überschirmung zwischen 1.70% bis 14.50%, mit einem Durchschnittswert von 5.92% ± 1.47 SE. *H. ammodendron* Keimlinge verjüngten sich am besten in Kombination mit der häufig vorkommenden Grasvegetation mit Verjüngungsraten von 180.56 ± 33.54 Individuen je Hektar. Daraus lässt sich schließen, dass (1) Naturverjüngung von H. ammodendron von einer vorkommenden Grasvegetation profitiert, (2) für die Wiederbewaldung von *H. ammodendron* Populationen unbedingt die Beweidung der Gebiete vermieden werden soll, damit die Gräser geschont werden und (3) dass dort, wo keine schützende Grasvegetation vorhanden ist, technische Hilfsmittel konstruiert werden sollten um die Wanderung der Dünen zu verhindern. Mit diesen Maßnahmen sollte die ankommende Verjüngung von *H. ammodendron* geschützt werden können.

Introduction

During the process of forest community succession and ecological restoration, it is critical to maintain the natural regeneration stages of woody

plant seedlings. The natural regeneration of forests could lead to high levels of biodiversity and ecological quality, depending on the natural development of the understory vegetation (Moktan et al. 2009). The transition from seedling to later life stages and the success of each stage depends on the site factors, which can be considered as all the physical and biotic factors that define the habitat (Matney and Hodges 1991), including their interactions and disturbances that may alter that habitat. They include climatic, physiographic and soil factors, as well as biotic factors, which involve interactions with associated plants, animals and microorganisms above and below ground (Barnes et al. 1998). A number of studies have suggested that surrounding plants limited seedling regeneration due to competition for nutrients, water, space and other resources (Fenner 1987; Akashi, 1997; Kajimoto et al. 1998). However, recent studies have shown that plants may improve water relations and reduce herbivory and temperature buffering in order to improve seedling growth and survival (Flores and Jurado 2003; Callaway 2007). This is particularly well demonstrated in stressful environments, such as deserts (Tirado and Pugnaire 2003).

A certain pattern of seedling distribution has occurred naturally, which is representative of the Gurbantünggüt desert's recent regeneration. Environmental heterogeneity is often associated with regeneration patterns and is the key to understanding the habitat requirements for seedling survival (Itoh et al. 1997; Nicotra et al. 1999; Baraloto and Goldberg 2004). In the Gurbantünggüt desert, stable or semi-stable dunes account for 96% of the total area of the desert. Psammophyte and drought-resistant plants are the main plants in the desert, but *H. ammodendron* was the dominant species in the original halophytes/xerophytic vegetation. Studies have indicated that the fertile island created under *H. ammodendron* adult crowns has a significantly lower pH and electrical conductivity, a higher soil organic carbon content and higher total nitrogen and available phosphorus in the layers adhering to the taproot. The high nutrient and low alkalinity/salinity island created around the taproot favor the growth of established plants (Li et al. 2011). However, it is unclear whether "fertile islands" will help *H. ammodendron* seedling regeneration.

In the Gurbantünggüt desert, ephemeral and ephemeroid plants have proliferated (Qian et al. 2004). The ephemeral plants mean vegetation cover in mid-may was 40.2% and the plant height was 20 cm. The ephemeral plants sprouted in early April and completed their life-cycle within about two months. This coincides with an increase in aeolian sand activity between April and June in the desert regions of northern Xinjiang. Therefore, ephemeral plants have acted as a major contributor to dune surface stabilization in the Gurbantünggüt desert (Wang et al. 2003). Ephemeral

plants complete their life cycle quickly by using a suspended wet layer of aeolian soil (Rooyen et al. 1992), leaving only withered aboveground parts after June. As an integral part of the ecosystem, withered aboveground parts could effectively reduce the ground surface wind speed and prevent *H. ammodendron* seeds from blowing away. Furthermore, dead ephemeral plants no longer consume soil water, which should facilitate *H. ammodendron* seedling regeneration.

H. ammodendron is a typical desert plant, which was primarily distributed on shifting or half-shifting sand dunes of narrow sub-desert areas in middle and west Asia. This species is of great ecological and economic importance because it can survive harsh environmental conditions and stop wind erosion of the sand. *H. ammodendron* has many xeromorphic characteristics (Fahn and Cutler 1992; Huang et al. 2003), such as adaptions to drought, salinity, poor nutrition, strong wind, sand movement and high light intensity. Recent studies have mainly been concerned with reproductive allocation patterns (Song et al. 2011), genetic variation in seed and seedling traits (Liu et al. 2011), seedling physiology under water or salt stress (Liu et al. 2003; Han et al. 2010), growth and biomass allocation (Shan et al. 2008) and root distribution (Shan et al. 2009). Studies investigating the natural regeneration of *H. ammodendron* seedlings in the Gurbantünggüt desert have been rare.

We surveyed *H. ammodendron* seedling regeneration in the Mosuowan region of the Gurbantünggüt desert and examined the relationships between seedlings, mature trees of *H. ammodendron* and the surrounding vegetation and soil cover conditions. The objectives of this study were to (1) explore *H. ammodendron* seedling age structure and (2) investigate which was the most suitable microhabitat for *H. ammodendron* regeneration.

Methodology

Description of the study sites

The Gurbantünggüt desert is the second largest desert in China, with an area of 48,800 km². It has an arid climate with an average annual temperature of 5–5.7°C, evaporation of 2,000–2,800 mm, strong winds for 25–77 days of the year, a wind velocity of 2–3.6 m/s, precipitation of 80–190 mm and 2,700–3,050 h of sunlight. Unlike most other arid zones, this area has an average annual snow cover period of about 95–110 days, beginning in late November and ending in mid-March of the following year. The predo-

minant soil is stable or semi-stable aeolian sand followed by saline–alkaline and gravel soils. Stable or semi-stable dunes account for 96% of the total area of the desert. *H. ammodendron* was the dominant species in this desert. The seeds of this plant mature at the end of October to early November and germinate at the beginning of April the following year. Nine 20 × 20 m plots were established in the Mosuowan region of the Gurbantünggüt desert (N 44°59' E 86°17').

Field sampling

Nine plots were randomly selected at 100 m intervals. For each plot, we recorded species, surveyed the basal diameters and heights using a caliper and a ruler and measured the crown area of each shrub and tree using the "cross" method [coverage was calculated using the formula for elliptical areas, $C = \pi XY/4$, where X and Y refer to the major and minor axis lengths of each respective crown (Phillips and MacMahon 1981)]. We selected three 1 × 1 m subplots within each plot along the diagonal and identified the species present and visually estimated herbaceous coverage (Causton 1988). In addition, we estimated the age of the *H. ammodendron* seedlings by counting the number of bifurcated branches, assuming one year of growth per branch bifurcation. This study defined seedling emergence in the spring of 2012 as 1-year-old seedlings and the emergence of seedlings in the spring of 2007 as 6-year-old seedling.
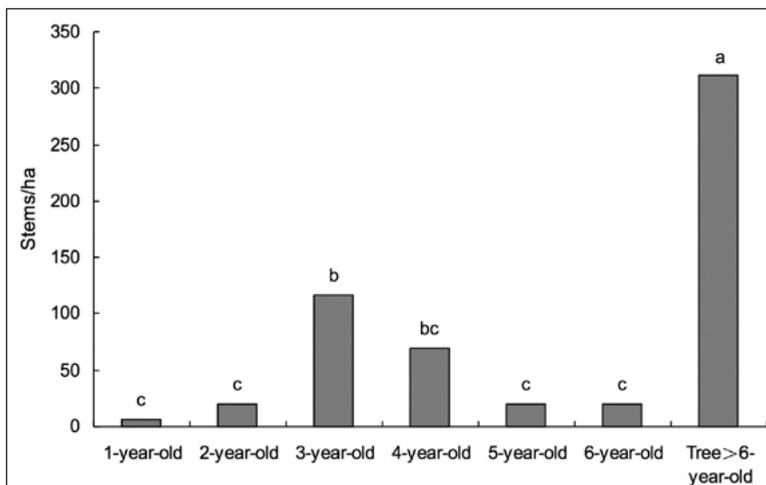

Fig. 1: Mean number of stems per hectare for H. ammodendron age classes. Means with the same letter are not significantly different at P ≤ 0.05 using LSD test
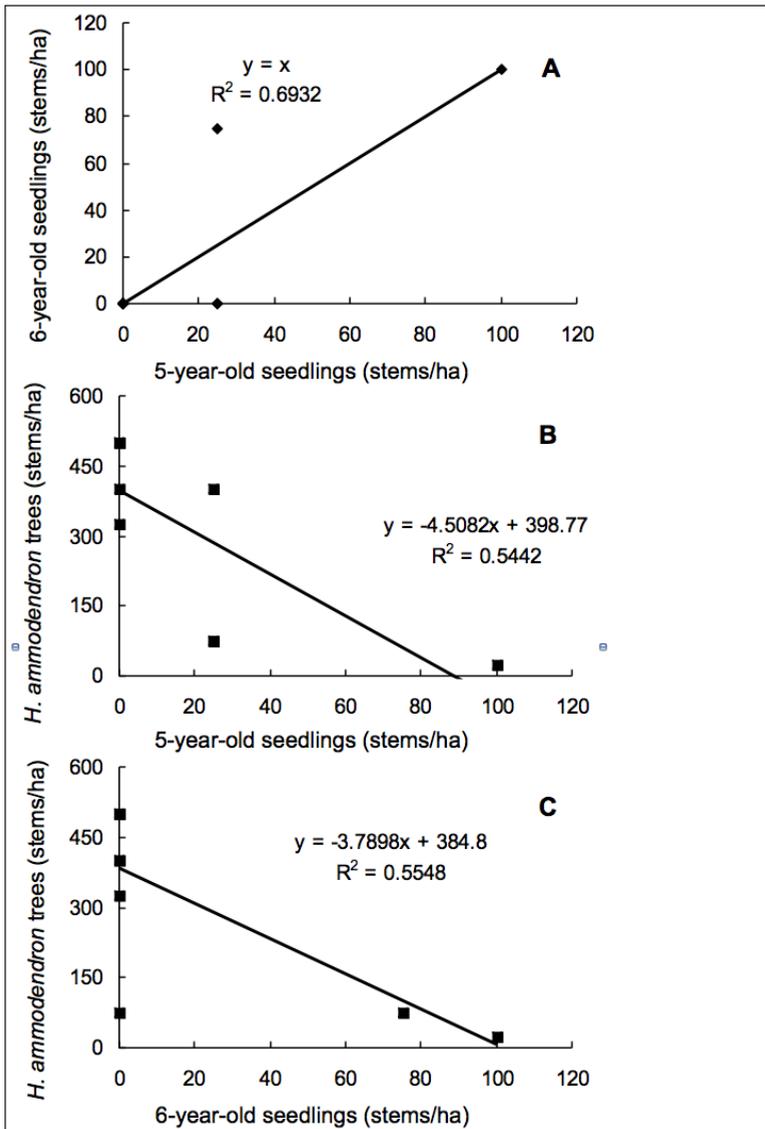
Fig. 2: The relationship between different age class density. **A** *5-year-old and 6-year-old seedlings,* **B** *5-year-old-seedlings and H. ammodendron trees (> 6-year-old),* **C** *> 6-year-old seedlings and H. ammodendron trees (>6-years-old)*

Table 1: H. ammodendron tree size range at different plant ages (n = 9)

Age	Height (cm)		Basal diameter (cm)	
	Mean±SE	Minimum–Maximum	Mean±SE	Minimum–Maximum
1-year-old	/	3.5-7	/	0.26-0.43
2-year-old	23.29±4.54	6-40	0.70±0.12	0.22-1.2
3-year-old	34.98±2.66	11-83	0.71±0.08	0.32-2.72
4-year-old	44.60±3.53	25-88	0.87±0.09	0.25-2.05
5-year-old	58.71±9.12	28-97	1.28±0.15	0.56-1.89
6-year-old	89.75±12.39	69-120	1.71±0.26	1.25-2.45
Tree (>6 year old)	243.75±9.48	60-530	/	

Data analysis

All analyses were performed using SPSS 11.5 software. Descriptive statistics were used to calculate averages and the standard error for the data from each set of duplicates. We averaged *H. ammodendron* regeneration density over all plots by each age class in order to determine the shape of the age distribution curve. One-way ANOVA, followed by a LSD Test (Least significant difference), were used to compare differences in the measured means of each variable. We examined the relationship between soil cover conditions and seedling and tree density, which were averaged over data from each of the nine 20 × 20 m plots. The parameters measured were: mature (> 6-year-old) *H. ammodendron* tree density, *H. ammodendron* seedlings from 1 to 6-year-old, withered herbaceous layer cover, the crown area of the shrubs and trees and the area of exposed land without vegetation.

Table 2: Mean and range (minimum and maximum) for H. ammodendron seedling regeneration in each microhabitat (n = 9, stems/ha)

Microhabitat	Mean±SE	Minimum–Maximum
Under the crown of *H. ammodendron* tree	25.0±11.79 b	0-100
Under the crowns of other shrubs (excluding *H. ammodendron*)	2.78±2.78 b	0-25
Under the withered herbaceous layer	180.56±33.54 a	75-325
Under fallen coarse woody debris	38.89±13.25 b	0-100
Exposed land without vegetation	47.22±14.69 b	0-125

Different letters within a row denote significantly different means as determined by an LSD Test (P < 0.01)

Table 3: Mean density (stems/ha) of seedlings under and outside the withered herbaceous layer

	under the withered herbaceous layer	outside the withered herbaceous layer
1-year-old	5	0
2-year-old	20	0
3-year-old	75	42.5
4-year-old	55	15
5-year-old	10	7.5
6-year-old	17.5	2.5

Results

An overall significant difference in stem density among the age classes ($F = 14.96$, $P < 0.01$) was observed in our experiment, but this was driven by differences ($P < 0.01$) between the trees (> 6-year-old) and seedlings between 1- and 6-year-old (Fig. 1). The density of trees was far more than the seedling densities for any age class. Seedling densities were not significantly different between age classes except for 3-year-old seedlings. There was an equal density of 5-year-old seedlings compared to 6-year-old seedlings (Fig. 1).

The relationship between the age class variables was explored in this study. The only highly positive correlation was observed between the 5-year-old and 6-year-old seedlings ($P < 0.01$, $R^2 = 0.69$, Fig. 2A), and there was a nega-
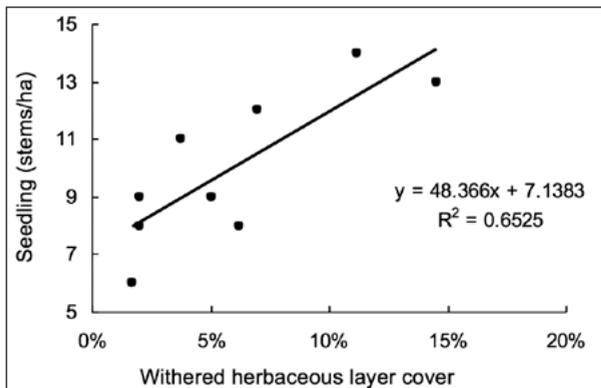

Fig. 3: The relationship between the number of H. ammodendron seedlings regenerated and the withered herbaceous layer cover
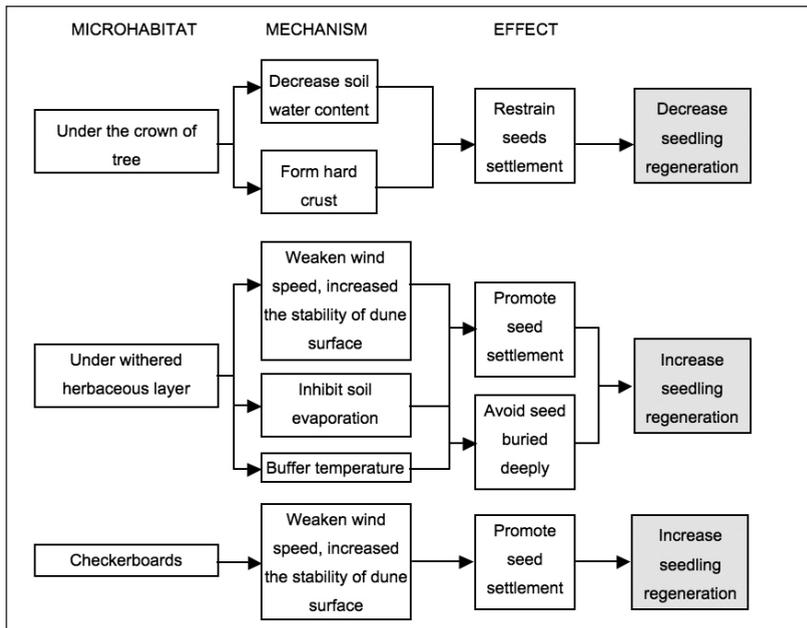
Fig. 4: Conceptual diagram illustrating how microhabitats increase or decrease Haloxyon ammodendron seedling regeneration

tive correlation between the mature trees (> 6-year-old) and 5-year-old and 6-year-old seedlings ($P < 0.05$, $R^2 = 0.54$, $R^2 = 0.55$, respectively, Fig. 2B, C).

H. ammodendron seedling regeneration was significantly different between microhabitats (F = 14.76, $P < 0.01$). Seedling regeneration under the withered herbaceous layer was significantly higher than in the other microhabitats ($P < 0.01$, Table 2).

Across all age classes, there were higher densities of *H. ammodendron* seedlings under the withered herbaceous layer compared to the other microhabitats (Table 3). The total number of *H. ammodendron* seedlings in the nine 20 m × 20 m plots under the withered herbaceous layer were 182.5 stems, but only 67.5 stems were observed in all the other microhabitats (Table 3).

The withered herbaceous layer cover on the nine 20 m × 20 m plots ranged from 1.70% to 14.50%, with an average of 5.92% ± 1.47 SE. The number of regenerated seedlings was positively related ($P < 0.01$, $R^2 = 0.65$, Fig. 3) to the withered herbaceous layer cover in the plot. In this study, 73% of the regenerated seedlings appeared to occur under the withered herbaceous layer.

Discussion and Conclusions

Generally, desert areas are sparsely populated and inaccessible. The survival of *H. ammodendron* populations mainly depends on natural regeneration. Research on natural update patterns have led to a greater understanding of the formation and maintenance mechanisms involved in the population structure. It is difficult to recruit seedlings of desert perennial plants and only a few studies have confirmed that some desert species can regenerate under natural conditions (Sheps 1973; Friedman and Orshan 1975; Meyer and Pendleton 2005). Our research showed that the study area was well protected from disturbance and every plot contained seedlings of *H. ammodendron*. The age structure of *H. ammodendron* seedlings did not change significantly over time (Fig. 1) and was not a typical Deevey III type (Silvertown 1982). The results were similar those found for eastern white pine (*Pinus strobus* L.) regeneration in Virginia, USA, which showed that the regeneration size classes of this species did not indicate uniform recruitment, but rather a higher abundance of individuals in the small and large sapling size classes (Fredericksen and Agramont 2013). As far as desert plants are concerned, favorable weather sequences may be necessary for seedlings recruitment and such sequences may occur infrequently in deserts (Bowers 1997). A higher number of 3-year-old *H. ammodendron* seedlings were detected in this study (Fig. 1), which indicated that the overall environmental conditions in 2010 were favorable for seedling germination and survival. We deduced that these favorable factors may have been that the adult tree produced adequate seeds in the previous year and that there was a good suspended wet sand layer formed by melting snow and precipitation during spring coupled with limited summer air speeds and soil drought. However, further studies are needed in order to reveal the details.

The 5-year-old and 6-year-old seedlings showed a significant negative correlation with adult trees. We did not find any notable positive relationships between the number of adult trees and the number of seedlings (Fig. 2B, C), which indicated that although the adult trees may produce a large number of seeds, there may not necessarily be proportional increase in the number of seedlings. In a desert environment, adequate seed production is just one of the prerequisites for seedling regeneration. Seedling regeneration also depends on whether there is a suitable habitat to allow the seeds to colonize and germinate. Therefore, we have proposed a conceptual model that can analyze *H. ammodendron* seedling regeneration in various microhabitats (Fig. 4).

A number of studies have shown that nurse effects exist in deserts (Flores and Jurado 2003; Tewksbury and Lloyd 2001). Fertile islands form under tree

crowns, because they change the soil moisture, nutrient contents, shade and temperature regulation in the surrounding microhabitats (Tielbörger and Kadmon 2000; Valiente-Banuet and Ezcurra 1991; Turner et al. 1966; McAuliffe 1986; Nobel 1980) and promote seedling regeneration. In these ecosystems, plants tended to cluster together as they profit from the presence of the other, often larger, plants (called nurse plants) (Smit et al. 2007). However, in this paper *H. ammodendron* crowns did not show any nurse effects. In all nine plots, only occasionally did we find the seedling establishment under *H. ammodendron* crowns. The average was 25.0 ± 11.79 trees per ha, significantly lower than the number of seedlings found under the withered herbaceous layer (Table 2). Our results indicated that the fertile islands in the site area were unsuitable for *H. ammodendron* seedling regeneration. We hypothesized that herbaceous plants were rarely distributed beneath the crowns of *H. ammodendron* which prevented seed distribution, or allelopathy of the plant (Fisher 1980) and/or competition to resources (Akashi, 1997; Kajimoto et al. 1998) inhibited seedling survival, resulting in poor seedling regeneration under *H. ammodendron* crowns, although the fertile islands did improve soil properties (Fig. 4) (Li et al. 2011).

The results of this study confirmed the previous hypotheses: that the mean number of seedlings regenerating under the withered herbaceous layer was 1.7 times higher than under other microhabitats (Table 3) and that seedling regeneration was positively correlated with the withered herbaceous layer cover (Fig. 3). The *H. ammodendron* seed develops fruit wings and depends on wind dispersal. The seedlings that successfully regenerated were able to do so because the microhabitats were suitable for seed colonization and germination. Seeds of this species usually mature at the end of October to early November after most ephemeral plants have completed their brief lifecycle, leaving only withered aboveground parts. The withered aboveground parts of the ephemeral plants played the same role as checkerboards in that they decreased wind speed and increased the stability of the dune surface, which prevented the seeds from blowing away. The stabilization of the dune surface meant that the seeds were not buried too deeply (Qian et al. 2002; Wang et al. 2003) and the increased shade from the withered ephemeral plants helped reduce evaporation and high soil temperatures (Maun 1994), which created a relatively good conditions for seedling regeneration. Thus, it was clear that the microhabitat under the withered herbaceous layer was better than other microhabitats for *H. ammodendron* seedlings regeneration (Fig. 4). This finding was consistent with the results of previous studies (Germino et al. 2002), which found that seedling survivals of *Picea engelmannii* and *Abies lasiocarpa* were greater in microsites with a grass cover compared without ground cover.

Therefore, if *H. ammodendron* vegetation in bare land and mobile sand surface areas in Gurbantünggüt desert is to be restored, seed dispersal characteristics and suitable habitats for germination need to be considered. An enclosure policy against grazing should be continued in order to protect the seedlings. Checkerboards also need to be constructed to stabilize the dune surface (Qian et al. 2002), promote *H. ammodendron* seed settlement and eventually to complete ecological reestablishment.

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