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VARIABILITY OF *HALOXYLON AMMODENDRON* (C.A. MEY) BUNGE POPULATIONS FROM DIFFERENT HABITATS

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Abstract

Haloxylon ammodendron (C.A. Mey) *Bunge* occupies a wide range of different habitats in north-west China. The aim of this study was to quantify variation in population growth characteristics of *H. ammodendron* from different sites and to relate this variation to different environmental conditions. To this end, 6 populations with visible differences were chosen and a range of morphological as well as seed-related characteristics like density, height, crown, basal diameter, seed mass, 1000 seed weight, seed number, seed diameter and germination rate were measured. The variations in the averages of overall traits were explained. The differences between-populations were 33%, whereas those within population were 67%. The largest variation was detected in morphological-related traits between-populations (38%). In particular, the density, height, 1000 seed weight and germination rate differed strongly between populations. The population growth characteristics were closely related to the soil property at the sites of origin. The soil property can explain most of the variations in the morphological-related traits. They were concluded that the diversity of population growth characteristics in different habitats provides the potential of population reproduction and the protection of original habitats is extremely important.

Key words: Density, Habitat, *Haloxylon ammodendron*, Morphology, Seed, Variance components.

Introduction

*Haloxylonammodendron*C.A. MeyBunge is a perennial, xerophytic, stem –succulent desert shrub. In Xinjiang Uygur Autonomous Region, northwest of China, it is mainly distributed along the edge of Gurbantünggüt Desert which is situated in the center of the Junggar Basin. Its leaves are very small and the green branches are used for photosynthesis. No endosperm is in its seeds and only a fully differentiated spiral seedling is coated by pericarp. The germination process of this type of seed seems to consist simply of water absorption by the dry spiral seedling and its subsequent stretching (Wallace *et al*., 1968; Sharma & Sen, 1989). Under the natural selection through a couple of generations *H. ammodendron* has great capabilities of drought resistance and salinity tolerance. This has resulted the wide distribution of this taxon in various habitats. It occupies areas between fixed and semi-fixed sand dunes, also occurs in the lower part of fixed or semi-fixed sand dunes, clay desert, gravel desert and saline land in Junggar Basin.

H. ammodendron is the dominant species of desert vegetation in Junggar Basin and always taller than other species. The desert vegetation dominated by *H. ammodendron* is knownas '*H. ammodendron* forest' in this region (Lv *et al*., 2012, 2014). In dry parts of China it has served as livestock feed and firewood and had been widely used in recent decades. This had resulted it in the list of "Threatened species" in the Red Data Book of China Plants (Fu &Jin, 1992). With the development of local economy and the increasing of population, the *H. ammodendron* desert had suffered rapid degradation and the quality of the extant forests was going down, which had resulted in the expansion of desertification due to worsened ecological environment (Huang, 2002).

The desert ecosystem has a simple physiognomic structure (Phillips & Mac Mahon, 1981) and under high environmental stress, their ecosystem services and function play an important role in sustainable development of this region (Shinwari & Qaiser, 2011). The diversity of the population growth and reproduction characteristics based on habitat diversity implies the diversity of this species and the plant adaptation to the natural environment (MacArthur, 1955; Bradshaw, 1965; McNaughton *et al*., 1974; Zavala & Oria, 1995). Also the diversity is closely related to the stable growth of this key species and the stability of this fragile ecosystem. At the same time the predomination of the *H. ammodendron* forest necessitates its management. Sound management practices are needed to optimize the production and stop the degradation of these forests, also protecting the diversity of desert ecosystem. However, the silviculture and forest management lack theoretical grounds on which to base actuation and quantify their effects.

This study compares the 6 populations of *H. ammodendron*from different habitats, with the objective;

(i) to examine the diversity of the population growth and reproduction characteristics;
(ii) to explain the relationship between population characteristics and habitat conditions;
(iii) to recommend conservation and management practices for this species.

Material and Methods

Study area: Based on extensive survey, 6 *H.ammodendron* populations occurring in typical habitats along the edge of the Gurbantünggüt Desert were chosen (Fig. 1, Tables 1 & 2).

1. Population 01 and 02 (P-01, 02) are located in the northwestern margin of Junggar Basin.

P-01 it is distributed on the hilly slope of gravel desert. This region is denudated by the northwest wind perennially and the hills and deserts are interlaced. Natural vegetation is rare and the water table is extremely deep here.

P-02 is sited in Lacustrine sedimentary area ofthe Manas lake which was drying up in recent decades. This area is belonged to the Urho basin and has a high water table. Before 1970s, the water was found about 1m under the ground. But now it is 2 m (Anon, 1999).

2. Population 03, 04 and 05 (P-03, 04, 05) are seated in the Ganjiahu national reserve in the southwestern margin of Junggar Basin. It has the largest area and well protected vegetation of *H. ammodendron* in the world which is under almost original conditions. *H. ammodendron* originates in various habitats here and the growing status is significantly different.

P-03 the soil is sticky and compact with a weak possibility of water and gas permeation. So it is adverse for plant growth. The *H. ammodendron* vegetation is small and dense here.

P-04 there is a crunchy salt crust on the surface soil and the underneath is soft sandy loam. As the salt crust has high salt content (Table 2), *H. ammodendron* regenerates badly. And the *H. ammodendron* vegetation is tall and sparse here.

P-05 the terrain is flat here. The soil is thick and has a fine texture. The water condition is fine and the *H. ammodendron* vegetation is tall (Anon., 2000).

3. Population 06 is situated in the southeastern margin of Junggar Basin. The water table is about 3m and it is slightlychanged with seasonal variation. The soil is aeolian sandy soil. The *H. ammodendron* vegetation ishere (Liu *et al*., 2010).

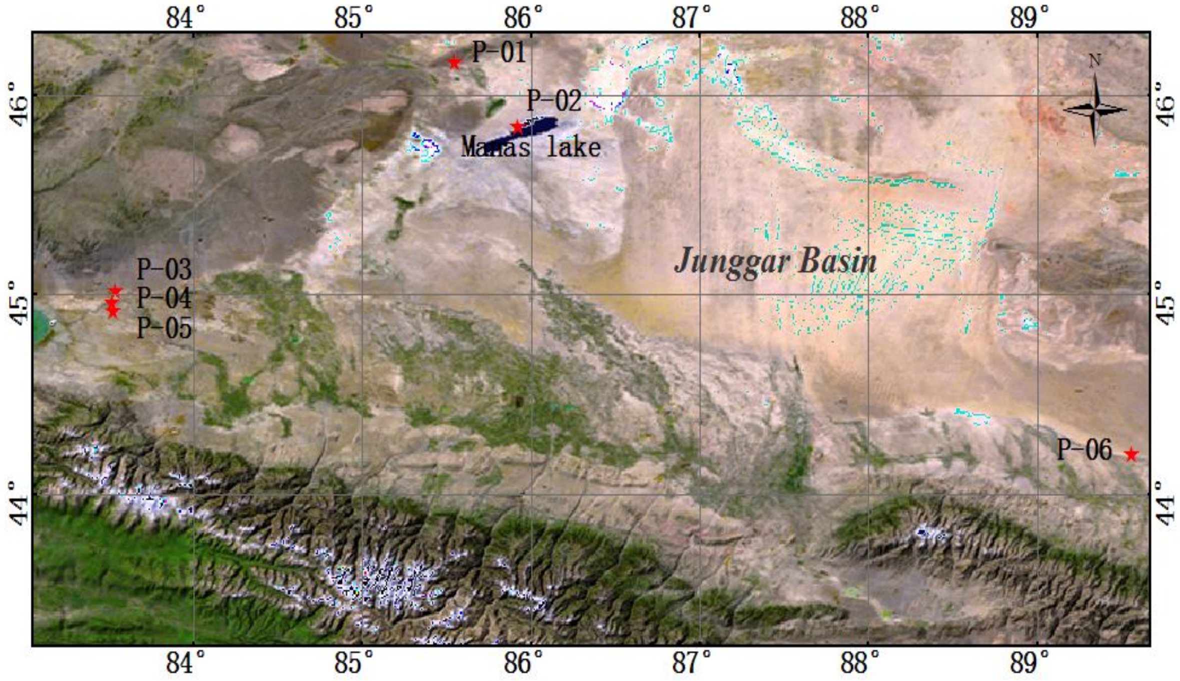

Fig. 1. The location of the studied *H. ammodendron* populations

Table 1. Location of *H. ammodendron*populations in Junggar Basin.

Plot	Longitude(E)	Latitude(N)	Altitude (m)	Mean temperature( )				Mean annual rainfall(mm)			Mean annual evaporation (mm)
				Mean In Jan	Mean In Jul	Min In Jan	Max in Jul	Mean	Min	max	
P-01	85°33.087′	46°10.012′	419	-15.8	27.8	-40.2	43.8	96.4	56.0	117.8	3016.4
P-02	85°55.593′	45°50.460′	252								
P-03	83°32.268′	44°56.588′	231	-19.2	26.2	-42.1	43.7	150.0	97.2	180.0	2000.0
P-04	83°32.368′	44°56.737′	219								
P-05	83°32.553′	44°56.224′	208								
P-06	89°33.632′	44°11.803′	648	—	—	-42.6	43.0	176.0	—	—	2141.0

Climatic data based on Anonymous (1999); Xu & Han (1996); Liu *et al*. (2010).

Table 2. Habitat characteristics of *H. ammodendron* populations in Junggar Basin.

Population	Soil properties				
	Soil layers (cm)	**pH value**	**Conductance (ms/cm)**	**Organics (g/kg)**	**Total salt (g/kg)**
P-01	0-10	8.90	0.095	4.294	0.755
	10-20	9.03	0.077	2.910	0.700
	20-30	9.04	0.083	2.341	0.750
	□30	8.95	0.108	2.836	0.800
P-02	0-10	9.37	7.940	6.699	25.350
	10-20	8.98	6.820	3.855	23.330
	20-44	8.66	2.480	3.064	9.550
	44-68	8.68	3.240	4.324	13.150
	□68	8.57	1.590	2.543	5.850
P-03	0-17	8.67	1.430	11.266	4.525
	17-27	8.06	2.900	6.818	10.050
	27-57	7.73	5.680	10.120	20.950
	57-90	8.57	0.634	2.196	2.350
	90-97	8.24	0.891	2.026	3.250
	□97	8.22	0.923	2.017	3.175
P-04	0-10	7.16	15.150	46.236	42.050
	10-20	7.35	9.100	11.832	37.500
	20-34	7.45	8.040	9.477	31.550
	34-69	7.69	4.350	3.591	17.975
	69-72	7.77	3.780	3.779	13.850
	72-86	7.85	3.160	3.076	11.600
	□86	7.85	3.560	2.693	13.250
P-05	0-10	9.57	2.090	10.672	9.150
	10-20	8.12	1.770	10.511	6.875
	20-37	7.9	1.258	13.545	4.975
	37-40	7.68	1.254	60.597	4.825
	□40	8.03	0.930	9.815	3.775
P-06	0-30	8.53	0.123	1.510	0.060
	30-60	7.81	0.705	4.500	0.310
	□60	8.63	1.340	7.890	0.500

Sampling and measurements

Morphological-related traits: For every population, 6 plots (25x25m^2) were selected randomly to examine the population growth characteristics. The basal diameter, height, crown and the location of all individuals of *H. ammodendron* were recorded for further examination in April 2009.

Seed-related traits: As the individual of *H. ammodendron* in fruiting stage can be tall or small in nature condition, 8-12 plants were selected using the methods of uniform distribution in the size range of plant individuals. 12, 8, 12, 11, 12, 12 plants were marked separately in P-01, 02, 03, 04, 05, 06.

It is hard to study the seed yield precisely. Before the seeds begin to mature all the sampling trees were covered entirely with nylon net of 1mm mesh in October 2008. It is necessary to strengthen the junction between the stem and nylon net to avoid the loss of seeds. After all the seeds matured and dropped out (March, 2009) they were collected individually. As the seed weight is similar with the weight of dry branches, it is hard to separate them. The Winnowing and dustpan screening were done first. And handpicking was used finally in order to obtain pure seeds. Then the pure seeds of each sampling tree were weighed.

Mixed seed simples were collected form more than 200 individuals randomly in each population soon after maturation in November 2008. They were dried and stored at room temperature until the starting of germination experiment. The seed diameter (200 replicates respectively) was measured using the vernier caliper. The 1000-seed weight (100 replicates respectively) was weighed with a Sartorius R160P (Gottingen, Germany) balance. For the germination rate, 50 seeds were sown on two layers of filter paper in 90-mm plastic Petri dishes in January 2009. Petri dishes were kept in an incubator at 10 , as 10 is the optimum temperature for seed germination of *H. ammodendron* (Huang *et al*., 2003). Filter papers were moistened daily using distilled water and observations were taken on seed germination every day after first germination. Seeds were considered germinated according to the emergence of cotyledon. The seed germination of each population replicated 6 times.

Soil characteristics: In each population a soil profile was set. Different layers were classed according to the characteristics of soil genesis. Soil moisture content was determined through oven-dried method (Bao, 2000). Soil samples were air-dried and sieved through a 2-mm soil sieve for laboratory analysis.

Measurements of soil physics properties: Soil pH was determined using a pH meter (PH-2C pH meter, Shanghai Lida Apparatus Manufactory, China) with 1:5 soil/water ratio. Soil electric conductivity (EC) was measured with a conductance instrument (EC 215 conductance instrument, Hanna Co., Italy) using a 1:5 soil/water ratio. Total salt was measured using the distillation residue method.

Measurements of soil chemical properties: Soil organic matter (SOM) was determined by the Walkley–Black dichromate wet digestion method (Nelson & Sommers, 1996); Total nitrogen and available nitrogen were detected by Kjeldahl method with H_2SO_4+H_2O_2 digestion using nitrogen instrument (Kjeltec 1026, Foss Tecator, Sweden). Total phosphorus was measured by using the HCl-HF digestion molybdenum antimony impedance colorimetry and available phosphorus by bicarbonate extraction (Olsen & Sommers, 1982) with a spectrophotometer (UV-120-02 Spectrophotometer, Shimadzu, Kyoto, Japan). Total potassium was measured by atomic absorption spectrophotometry and available potassium by using the ammonium acetate extract method.

Soil Na^+ and K^+ were extracted using a 1:5 soil/water ratio and analyzed with a flame photometer (Model 2655-00 Digital Flame Analyzer, Cole-Parmer Instrument Company, Chicago, IL). CO_3^{2-}, HCO_3^-, Cl^-, $SO4^{2-}$, Ca^+ and Mg^{2+} were extracted using a 1:5 soil/water ratio and measured by using the conventional titration method (Bao, 2000).

Data analysis: All the Data were analyzed with SPSS for Windows (release 13.0; SPSS Inc., Chicago, IL, USA). Analyses of Variance (ANOVAs) was used to determine whether there were significant differences in the measured traits between populations and within populations. Variance components were calculated from the mean sum of squares, derived from a nested ANOVA (Sokal & Rohlf, 1981). Relations between the various population traits and the environmental conditions were detected by linear multiple regression analyses using the step selection procedure.

Results

Variation of population growth characteristics: The mean, minimum and maximum values, as well as the coefficients of variation of each measured trait related to *H. ammodendron* population are given in Table 3. The percentage variation explained by differences between and within populations for each trait separately as well as the significance of the variance components were also listed in Table 3. The variables are subdivided into two groups by morphological and seed related traits. The division is somewhat arbitrary, but is made to facilitate comparison of sets of traits.

The coefficient of variation shows the variability of all the traits. For all morphological-related traits, the coefficient of variation is >60%. Circa 78% of the variation in density is explained by the differences between populations, whereas only 22% of the variation is explained by the differences within populations. By contrast, 37%, 20% and 16% of the variation in morphological-related traits such as height, crown and basal diameter, is explained by the differences between populations. For seed-related traits, separately 48% and 46% of the variation in germination rate and 1000-seed weight is explained by the differences between populations, however the variation in other seed-related traits is <20%. It concluded that most traits, except the density, were found to have more variation within populations than between populations (Table 3).

In summary, most of the variations in measured traits were associated with differences within populations rather than with differences between populations (Fig. 2a). This is particularly true for the seed-related traits, where only 29% of the variation (Fig. 2b) is explained by differences between populations. The highest proportion of variance explained by differences between populations was observed for morphological-related traits (Fig. 2b).

Table 3. Morphological-related and seed-related traits as well as the percentage of variation per trait explained by differences between and within populations for *H. ammodendron* populations.

						Variance components	
Traits	**Mean**	**Min**	**Max**	**Units**	**Coefficient Of Variation (%)**	**Between populations (%)**	**Within populations (%)**
Morphological-related							
Basal diameter	5.1	0.1	48.4	mm	60	16	84
Height	143.7	7.0	515.0	cm	93	37	63
Crown	1.7752	0.0024	53.9600	m^2	193	20	80
Density	1885	125	6464	stems ha^{-1}	88	78	22
Seed-related							
Seed diameter	1.91	1.36	2.38	mm	12	17	83
1000-seed weight	2.06	0.17	4.03	g	28	46	54
seed mass	48.61	0.02	155.63	g	405	16	84
Seed number	24641	7	782825	Seeds $plant^{-1}$	406	19	81
Germination rate	89.17	78.00	100.00	%	8	48	52

Percentages printed in bold indicate that the between population variation was significant in ANOVA (p□0.05)

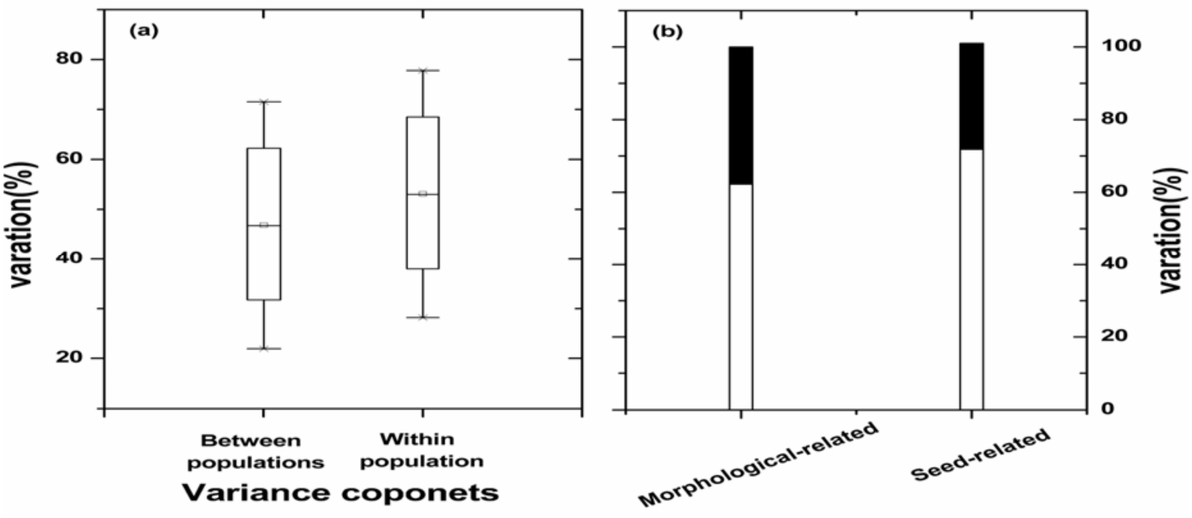

Fig. 2. (a) Average percentage of variation explained by the variance components, for all 9 traits. The box shows 50 % (median), the range of the 25% and 75% quartiles. The error bars show the 10% and 90% borders. (b) Percentage of total variation explained by the variance components (average values). Variations: closed bar between populations; open bars, within populations.

Multiple regressions between population characteristics and habitat soil properties: Significant correlations were detected between most of the investigated traits and parts of the soil characteristics (Table 4). Population density was only positively correlated with available K, whereas negatively with the content of $SO4^{2-}$ and $K^{+}+Na^{+}$. A positive relationship was noted between height and soil moisture, total N, available N, available P, CO_3^{2-}, $SO4^{2-}$ and $K^{+}+Na^{+}$. The 1000-seed weight was negatively correlated with soil moisture, conductance, organics, total N, available N, total salt and CO_3^{2-}. Seed mass had a positive relationship with pH, conductance, total salt, $SO4^{2-}$ and $K^{+}+Na^{+}$. Approximately more than 80% of the variation in morphological- related traits was explained by the measured soil characteristics. And soil characteristics could explain 44% of the variation in seed mass and 63% of the variation in 1000-seed weight (Table 4).

Discussion

Variation of population growth characteristics: Approximately 70% of all traits showed high coefficient of variation (>60%). For morphological- related traits, the high between-population variation was found in the density and height, by contrast the basal diameter and crown had a large within-population variation. Even the variation coefficient of the crown is >1 because of the big differences of individuals within populations. It implies that the morphological trait had to adjust to diverse environments. The density and height are quite sensitive to the environmental diversity and the growths of individual plant change with its habitat conditions. Li *et al*. (1995) had found obvious difference in morphology of *H.ammodendron* between different habitats. Their study supported our results and they also believed that the diversity of morphology was well adjustment to the environment in population evolution.

However, lower between-population variations were noticed in seed-related traits, compared to within-population variations. The seed quality including the 1000-seed weight and the germination rate had a relatively high variation between populations. It implies that the seed quality was affected more by the difference of the soil properties, like the soil nutrient in different habitats (Harper, 1977; Zbigniew *et al*., 2015).The low between-population variations were found in seed mass and seed number. Particularly the variation coefficient of the seed mass and seed number is >1, since the number of samples is limited due to sampling suffering. It was believed that the seed quantity and quality reflects the reproduction potential of population and are mainly decided by the biological characteristics of species (Heydecker, 1972; Solbrig, 1981; Wilson, 1985; Esma *et al*., 2013). And they were also affected by plant nutrition, life history strategy and the condition in the community succession (Harper, 1977). Additionally they were found to be different in some microhabitats (Harper, 1967; Heydecker, 1972; Abrahamson, 1979).

Multiple regressions between population characteristics and habitat soil properties: According to multiple regression analyses (Table 4), soil property variables explained a large part of the morphological-related variation in the density (78%), height (93%), basal diameter (78%), and the crown (89%). This might imply that the morphological-related differences between populations are the results of plant adaptation to the environmental factors. Webelieved that the morphological-related traits were sensitive to environment changes and it seemed to be a viable way for the population to adjust to the diversity of habitats (Schlichting, 1986; Sultan, 1995, 1997, 2000). Toshihiko (1991) and Sun & Qian (1999) also got similar conclusions.

Table 4. Summary of multiple regression analyses between traits and soil characteristics of 6 *H.ammodendron* populations.

	Soil moisture （Mar）	pH	Conductance	Soil nutrient							Soil salinity								R^2
				Organics	Total N	Total P	Total K	Available N	Available P	Available K	Total salt	CO_3^{2-}	HCO_3^-	Cl^-	$SO4^{2-}$	Ca^+	Mg^{2+}	K^++Na^+	
Basal diameter	0	0	++	+	+	-	0	+	0	0	++	++	0	+	++	0	0	++	0.78
Height	++	0	0	++	++	-	+	++	++	0	0	++	0	0	++	0	0	+	0.93
Crown	0	0	++	0	0	--	0	0	0	0	++	++	0	++	++	0	0	++	0.89
Density	0	0	0	0	0	0	0	0	0	++	0	-	0	-	--	0	0	--	0.78
Seed diameter	0	-	-	0	0	0	++	0	0	++	-	0	0	0	--	0	0	--	0.72
1000-seed weight	--	0	--	--	--	0	0	--	-	0	--	--	0	-	-	-	0	0	0.63
seed mass	0	++	++	0	0	-	--	0	-	-	++	0	0	+	++	0	0	++	0.44
Seed number	0	++	++	0	0	-	--	0	0	0	++	0	0	+	++	0	0	++	0.48
Germination rate	-	0	0	0	0	0	-	0	-	--	0	0	0	0	0	0	0	0	0.54

+, $P<0.05$, positive correlation; ++, $P<0.01$, positive correlation; -, $P<0.05$, negative correlation; --, $P<0.01$, negative correlation; 0, no significant correlation.

In contrast, soil property variables only explained a part of the seed-related variation in the seed mass (44%), seed number (48%), 1000-seed weight (63%), germination rate (54%), and the seed diameter (72%). We concluded that the seed-related traits were mainly decided by the biological characteristics of species (Heydecker, 1972; Solbrig, 1981; Wilson, 1985) and the influence of environment was limited here. Martin & Lee (1993) found that plant grew on richer soils may have more resources available to invest to reproduction. And we didn't notice significant relationship between seed mass and the soil nutrition in this study. The potential reason can be that soil nutrient was not the key factor of this ecosystem in the north-west of China. In this arid area, the available water is the key factor limiting ecosystem processes and functional responses (Sala *et al*., 1997; Ehleringer *et al*., 1999; Dube & Pickup 2001; Cheng *et al*., 2006) and the soil salinity is also very important here. Since the snowmelt is the major water resource in Junggar Basin and March is the best period of favorable soil water condition. Significantly negative relationships were detected between the 1000-seed weight, germination rate and soil water content. It indicated that the soil water condition had negative influence on the seed quality. Additionally seed mass had significantly positive relationship with the soil salinity. It meant that the seed mass was influenced more by the soil salinity. Oostermeijer *et al*. (1998) studied the perennial *Gentianapneumonanthe* L. and found that the number of ovules per fruit (a component of reproductive effort) was positively associated with calcium, potassium, SO_4^{2-}, NH_4^-, and electric conductivity. Their findings were coincide with this study.

Conservation and management: An analysis of the population characteristics of *H. ammodendron* can give valuable insights into population processes, in combination with an analysis of the environmental conditions. It can indicate suitable management measures to preserve this population. The morphological traits, population structures, and the seed traits were different between the populations of different habitats. The diversity is valuable and important for the conservation of this species. It provides the potential of the population reconstruction. However, the lacking of seedlings is risky and it may restrict the sustainability of this species.

With the rapid economic development and population growth, many habitats of *H. ammodendron* have been developed as farmland and this leaded serious habitat fragmentation. Simultaneously the utilization of the species as livestock feed and firewood is more and more intensive and the quality of the extant forests is falling rapidly. Therefore, intensive management practices are needed to protect the extant population and stop the degradation of the species. For in-situ conservation of the species, regular monitoring of the habitats and complete protection of the habitats are suggested. Strict implementation of rules and regulations in the protected areas are also required. Additionally, the process of seedling recruitment plays an important role in the natural reproduction of the species. We suggested that more effect on identifying and classifying limitations, also on management needs.

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