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Species richness and vegetation pattern in interdune lowlands of an active dune field in Inner Mongolia, China

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ABSTRACT

Vegetation pattern in lowlands between active sand dunes has rarely been studied, but it may play an important role in maintaining the biodiversity. This paper aims to quantify relationships between lowland area and species richness, composition and vegetation distribution and to provide suggestions on biodiversity conservation in the active dune field. Considering each interdune lowland as a self-contained unit, we investigated species composition and vegetation pattern in 25 interdune lowlands (ranging from 0.06 ha to 9.5 ha) of an active sand dune field. Our results showed that species richness increased with lowland area following a power function. The richness of psammophytes relative to the overall species richness decreased with lowland area logarithmically, but increase in lowland area did not lead to significant decrease in psammophyte's richness. With decrease of lowland area, frequency of psammophytes logarithmically increased, but that of nonpsammophytes logarithmically decreased. When the lowland area was about 2 ha, frequency of the psammophytes was equal to that of the nonpsammophytes (limnocryptophyte-meadow species and steppe species). Furthermore, a consistent pattern of vegetation differentiation along the direction of dune advancement occurred for lowlands larger than 1 ha: a psammophyte zone near the foot of leeward slope, a limnocryptophyte-meadow species zone in the central part of interdune lowland, and then followed by a psammophyte zone towards the foot of the windward slope. We concluded that lowland size is an important determinant of species diversity and vegetation pattern, and thus has implications for biodiversity conservation in sand dune fields.

1. Introduction

Biodiversity conservation in fragmented habitats has been a major research focus in recent years (van der Merwe and Kellner, 1999; Grootjans et al., 2002; Ayyad, 2003; Barrows et al., 2006). Active dunes, located in the dry inland regions of continents and in the sea shores or river banks in the humid regions (Zhu et al., 1998), are unfavorable for survival of most plants due to substrate instability, but favorable for psammophytes (Li, 1980; Crawford, 1989; Kent et al., 2005). The topographic depressions between active dunes, i.e., interdune lowlands or dune slacks, serve as "vegetation islands", composed of psammophytes and nonpsammophytes (Yan et al., 2005), among which some are endemic or rare species (Groom et al., 2007). Interdune lowlands may function to provide diaspores for revegetation of bare active dunes (Yan et al., 2005). Although interdune lowlands contribute significantly to the dynamic equilibrium of partly vegetated dune fields, important to biodiversity conservation (Avis and Lubke, 1996; Grootjans et al., 2002), and have been intensively studied in recent years (Mclachlan et al., 1996; Lammerts et al., 2001; Acosta et al., 2003; Adema et al., 2003; Sykora

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et al., 2004; van Bodegom et al., 2004), quantified relationships between lowland area and variables such as species richness, composition and vegetation distribution are still scarce.

In rehabilitating desertified grassland in Inner Mongolia, northeastern China, in recent years, little attention has been paid to plant diversity conservation in the active dune field. Rehabilitation actions, on one hand, enhance the plant diversity of bare dunes, but on the other hand, lower the plant diversity of interdune lowlands, which are frequently reclaimed as afforestation lands, artificial grasslands, or farmlands, making limnocryptophyte-meadow species lose their habitats. Furthermore, planting trees on the active sand dune, or establishing dense vegetation mainly composed of shrubs, has also stabilized shifting sand and deteriorated the moisture condition of the interdune lowland, making the habitats unfavorable for psammophytes and limnocryptophyte-meadow species (Jiang et al., 2002).

Species richness can be described by a species–area curve (He and Legendre, 1996; Losos and Schluter, 2000; Collins et al., 2002; Keeley, 2003), which may differ due to structural differences of plant assemblages (Keeley, 2003), and between islands and continents (Losos and Schluter, 2000). Interdune lowlands are “islands” affected by dune encroachment, aeolian activity and hydrological factors. In this study, we analyzed the relationships between interdune lowland size and species richness and composition, and vegetation distribution in an active dune field in northeastern Inner Mongolia, China, and discussed the implications of our results for biodiversity conservation in the study area.

Species composition is associated with spatial heterogeneity and dynamics (Allen, 1988; Nash et al., 1999), which may be determined by erosion, sand accumulation and dune encroachment in active dune fields (Avis and Lubke, 1996; van Bodegom et al., 2004). Furthermore, species in the interdune lowland may belong to different functional groups responding to habitat differentiation (e.g., Munoz-Reinoso and Novo, 2005). Since comparisons of species–area relationships among functional groups can help understand differences in their spatial dynamics as well as responses to spatial heterogeneity (Holt et al., 1999), we analyzed how different plant functional groups, i.e., psammophytes, limnocryptophyte-meadow species and steppe species, are associated with interdune lowland areas. Here, we hypothesize that high species richness and functional diversity only occur in large lowlands.

Psammophytes, including some endemic or rare species (Groom et al., 2007) and having unique functions (Danin, 1991; Hesp, 1991), have attracted attention of ecologists in biodiversity conservation practice in recent years (Riksen et al., 2006). It is observed that psammophytes are a component of vegetation in the interdune lowland of an active dune field (Cao et al., 2000). However, we suspect that there might be differences in abundance (density and frequency) of the psammophyte between different interdune lowland sizes. Therefore, we test the hypothesis that psammophyte’s abundance is constrained by lowland size, and in the larger lowland psammophyte’s abundance is lower but that of non-psammophytes is higher.

Vegetation pattern frequently corresponds to differentiation of natural conditions (Avis and Lubke, 1996; Mclachlan et al., 1996; Beyer et al., 1998; Munoz-Reinoso and Novo, 2005), and vegetation zonation can be found in some individual interdune lowlands (Kidron, 1999; Acosta et al., 2003; Sykora et al., 2004). Since vegetation pattern is very likely to be associated with the scale level (Wu, 2000; Bossuyt and Hermy, 2004), we expected that vegetation zonation in an interdune lowland is related to its area. Here, we hypothesize that only the lowlands large enough show distinct vegetation zonation.

Considering each interdune lowland as a self-contained unit, we investigated species composition and vegetation pattern in 25 interdune lowlands of an active sand dune field.

2. Methods

2.1. Study site

The study site is located at Wulanaodu region (119°39′–120°02′E, 42°29′–43°06′N, 480 m a.s.l.), northeast Inner Mongolia, China. The region has a semi-arid climate. The annual average temperature is 6.3 °C. The average annual rainfall is ca. 340 mm, most of which is received during June to September. The windy season is from March to May. The growing season starts in late April and ends in late September. The area has been intensively grazed since 1950. Over-grazing is the major force leading to desertification (Li et al., 2000). At present, 90% of the total land has been desertified and 70% of the meadows have become saline and sodic, and active sand dunes are distributed over some areas of this region.

The vegetation before the start of intense grazing is wooded steppe with perennial grasses, e.g., *Leymus chinensis* (Trin.) Tzvel., and *Cleistogenes squarrosa* (Trin.) Keng, and scattered trees, mainly *Ulmus pumila* Linn. Psammophile-dominated vegetation with *Artemisia halodendron* Turcz. Ex Bess., *Artemisia wudanica* Liou et W., *Caragana microphylla* Lam., *Salix gordejevii* Y.L. Chang et Skv., and *Agriophyllum squarrosum* (Linn.) Moq. was well developed.

2.2. Field sampling

Sampling was performed in June, 2004. Active sand dunes in the sampling area were 15–25 m in height, advancing with a speed of ca. 6–7 m year^{-1}. Twenty five interdune lowlands of different sizes, the smallest one 0.06 ha, largest one 9.5 ha (Table 1), surrounded by active sand dunes (with a vegetation coverage less than 5%), were selected in a fenced dune field. Lowland area was measured with GPS. The whole sampling was completed in a week.

In field investigation, we took each interdune lowland as a self-contained unit (Mclachlan et al., 1996). In each lowland two transects were selected, one was running along the extending direction of the crescent dune (denoted as transect 1, Fig. 1) and the other was running along the direction of dune advancement, i.e., the direction of the prevailing wind (denoted as transect 2, Fig. 1). Therefore, the lengths of transect 1 and 2 were the length and width of each lowland, respectively. 1 m × 1 m quadrats, 3 m spaced, were selected along each transect. Eight quadrats in total were investigated for the smallest lowland, and 174 quadrats for the largest one. 2052 quadrats in total were investigated in 25 interdune low-

Table 1 – General description of the interdune lowlands investigated

Lowland	Location		Area (ha)	Quadrats along the dune advancement direction	Quadrats along the dune extending direction
	N	E			
1	43°00.156′	119°37.650′	0.06	3	5
2	43°00.101′	119°37.667′	0.06	3	10
3	43°00.038′	119°37.695′	0.42	14	24
4	43°59.811′	119°37.620′	6.24	40	61
5	42°59.643′	119°36.794′	1.01	21	45
6	42°59.707′	119°36.851′	0.06	8	12
7	42°59.132′	119°36.328′	2.06	22	44
8	42°59.294′	119°36.676′	3.49	30	110
9	42°58.959′	119°36.776′	2.38	27	69
10	42°59.165′	119°37.018′	3.57	45	59
11	42°59.437′	119°37.256′	0.94	17	55
12	42°59.494′	119°36.909′	4.47	43	118
13	42°59.794′	119°36.533′	0.10	7	16
14	42°59.737′	119°36.540′	4.30	32	122
15	42°59.620′	119°36.271′	0.46	24	23
16	42°59.877′	119°36.331′	2.88	36	53
17	42°59.928′	119°35.961′	9.50	41	133
18	42°59.462′	119°35.926′	5.08	105	35
19	42°59.891′	119°35.658′	2.62	57	14
20	42°59.788′	119°35.684′	6.50	69	28
21	42°59.791′	119°37.952′	2.50	23	98
22	43°00.173′	119°37.864′	1.07	23	23
23	43°00.078′	119°38.107′	1.31	27	30
24	43°00.035′	119°38.060′	0.90	22	43
25	43°00.212′	119°38.023′	1.89	45	26

lands. Species composition and abundance were recorded in each quadrat. For bunchgrasses (e.g., *C. squarrosa*), we counted the number of clusters to get the density. For clonal species (e.g., *S. gordejevii* and *Phragmites communis*), we counted the number of ramets to get the density. For species with discrete individuals (e.g., *A. squarrosum*), the number of individuals is counted as the density. Frequency of each species was determined within each interdune lowland.

2.3. Data analysis

Curve-fitting was done in Excel software package, and exponential equation, power function and logarithmic function were tried to analyze the relationship between species richness and frequency and interdune lowland area (He and Legendre, 1996; Keeley, 2003). Significance tests were done with SPSS software package.

Species abundance was analyzed as density (numbers of each species per m^2 in all quadrats), and frequency (percentage occurrence of a species in quadrats within each lowland). Variations of species frequency corresponding to area, width and length of the lowlands were analyzed with Canonical Correspondence Analysis (CCA) using CANOCO 4, and ordination plots were produced with CanoDraw (ter Braak and Šmilauer, 1998). Dividing the lowland areas into 4 classes, i.e., <0.5 , 0.5–2, 2–5 and <5 ha, we analyzed the relationships between lowland area and both density and the frequency of the main psammophilic species, *S. gordejevii* and *A. squarrosum*, and. between lowland area and both density (numbers of the psammophyte per m^2 in all quadrats) and frequency (percent-

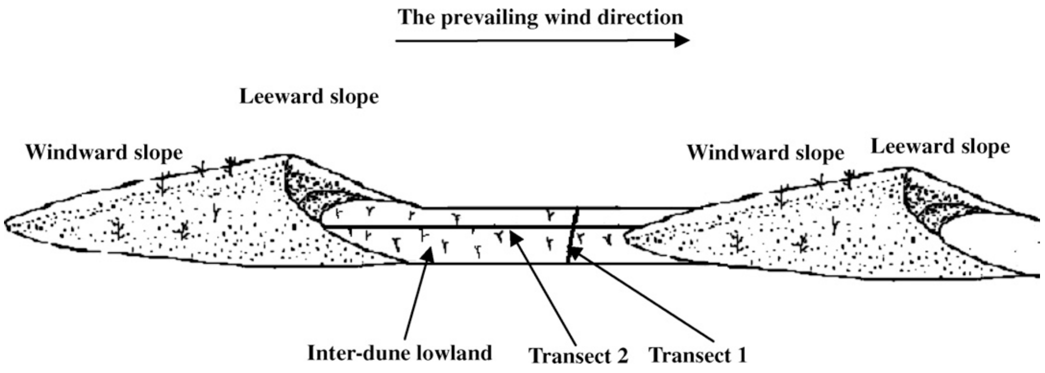

Fig. 1 – Transects (transect 1 = distance along the extending direction of the crescent dune = the length of the interdune lowland, and transect 2 = distance along the direction of the dune advancement or the prevailing wind direction = the width of the interdune lowland) used to investigate vegetation distribution and species composition in the interdune lowland of an active sand dune field.

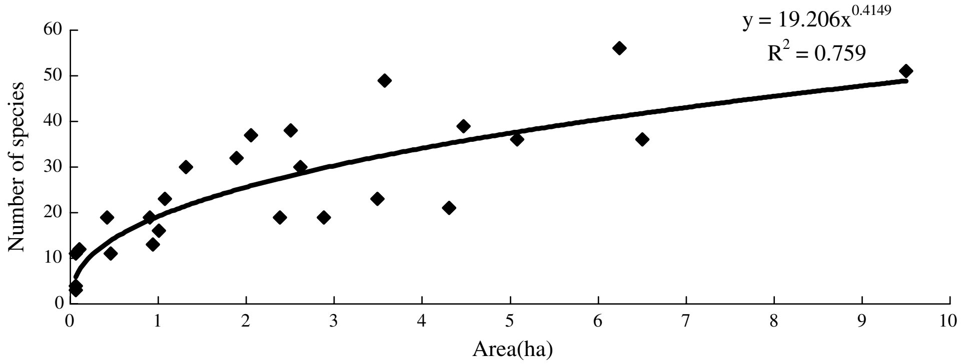

Fig. 2 – Relationship between species richness and area of interdune lowlands. The relationship can be described by a power function ($p < 0.05$).

age occurrence of the psammophyte in quadrats within each lowland) of the psammophyte. After one-way ANOVA analysis was done, LSD's test was applied *post hoc* (SPSS software) to distinguish between density and frequency at different lowland sizes. Differences obtained at a level of $p < 0.05$ were considered significant.

Species functional groups were determined following TCSIMNAR (1985), and psammophytes, limnocryptophyte-meadow species and steppe species were classified. Psammophytes are defined as the pioneering dune plant species. Limnocryptophyte-meadow species are defined as the species colonizing the habitats with good soil moisture or with surface water (pool). Steppe species are the species colonizing desiccated habitats.

3. Results

3.1. Species richness and composition in lowlands

Species richness increased with the enlargement of interdune lowland, which could be well described by a power function (Fig. 2). With increase in lowland area, psammophytes' richness relative to the overall species richness decreased logarithmically (Fig. 3). However, increase in lowland area did not necessarily lead to decrease in number of the psammophytes. For both limnocryptophyte-meadow and steppe species, richness increased, but not statistically significantly.

3.2. Relationship between psammophyte's abundance and lowland area

The resulting CCA ordination diagram (Fig. 4) expressed the relationships between the species frequency and three variables: interdune lowland area, length (distance along the extending direction of the crescent dune, Fig. 1) and width (distance along the direction of the dune advancement or the prevailing wind direction, Fig. 1). The first axis explained 19.3% of variation, and was most strongly correlated with area and also with width. The second axis explained 5.3% of variation and was partially correlated with the width of the lowlands (Table 2). With the decrease of both lowland area and width, frequency of the psammophytes increased. With the increase of lowland area and the decrease of lowland width, frequency of limnocryptophyte-meadow species increased (Fig. 4).

Increase in frequency of the psammophytes or decrease in frequency of the nonpsammophytes (limnocryptophyte-meadow species and steppe species) with the enlargement of interdune lowland could be described by logarithmic functions. When the lowland area was about 2 ha, frequency of

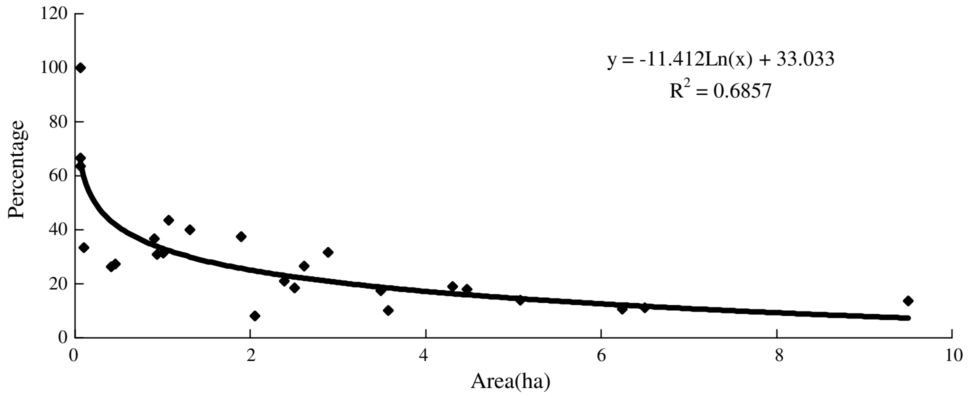

Fig. 3 – Relationship between the richness of psammophytes relative to the overall species richness and area of interdune lowlands. The relationship can be described by a power function ($p < 0.05$).

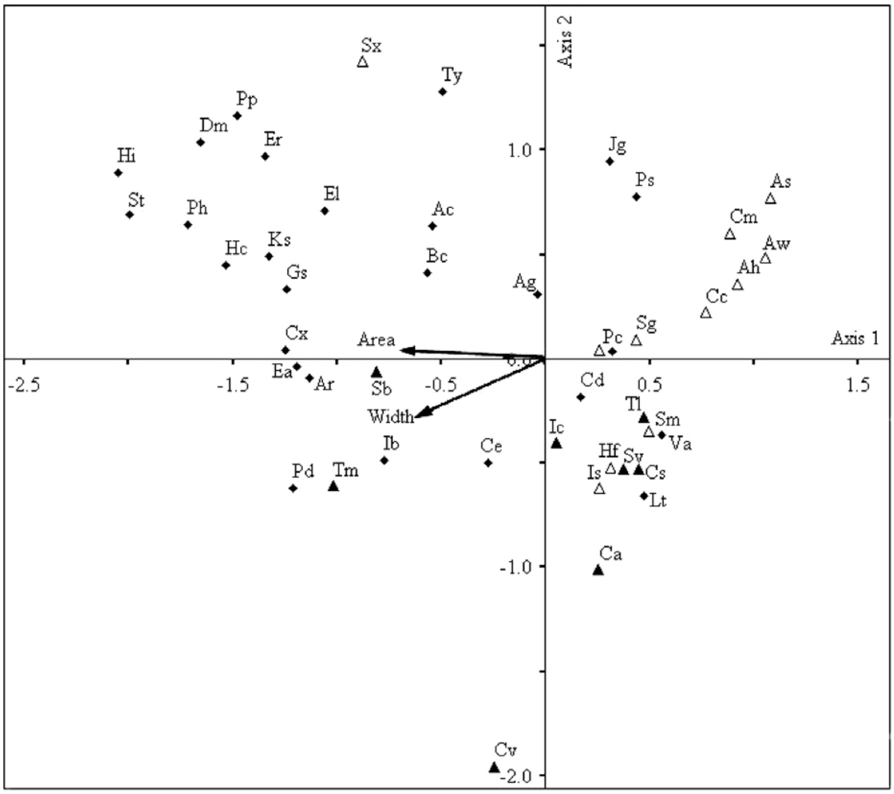

Fig. 4 – CCA ordination diagram showing the response of species frequency to lowland area, width and length for the 25 investigated interdune lowland. Only species with scores >0.20 (44 in total) are shown for clarity. The first and second axes explain 19.3% and 5.3% of variation, respectively. The species functional groups are shown with different symbols: limnocryptophyte-meadow species by solid rhombuses, psammophytes by hollow triangles, steppe species by solid triangles. Species names are abbreviated, see Appendix for full names.

the psammophytes was equal to that of the nonpsammophytes (Fig. 5).

When the lowland area was smaller than 0.5 ha, frequency of the psammophytes was 91.4%; When the lowland area was larger than 5 ha, frequency of the psammophytes was 34.5% (Table 3). Although density of the psammophytes also decreased with increase in the lowland size, but in most cases the differences were not statistically significant (Table 3). For the two main psammophilic species, *S. gordejevii* and *A. squarrosum*, both frequency and density decreased with increase in lowland size, showing a similar trend as those of the psammophytes (Table 4). For both *S. gordejevii* and *A. squarrosum*, changes in density were very evident when lowland area decreased from 0.5 ha to 5 ha. Compared to the change in frequency of *S. gordejevii*, the change in frequency of *A. squarrosum* was much quicker when lowland area decreased from 0.5 ha to 5 ha (Table 4).

3.3. *Relationship between vegetation distribution and lowland area*

A distinctive vegetation zonation was generally found in lowlands larger than 1 ha. The vegetation pattern consisted of a psammophyte belt near the leeward slope, a limnocryptophyte-meadow species belt in the central interdune lowland, and a psammophyte belt near the windward slope, or, a limnocryptophyte-meadow species belt near the leeward slope, and a psammophyte belt near the windward slope. In lowlands smaller than 1 ha, the vegetation consisted mainly of psammophytes.

Table 2 – Correlations between CCA ordination axes and factors

Factor	Axis 1		Axis 2		Axis 3	
	Correlation	*p*	Correlation	*p*	Correlation	*p*
Area	−0.847	0.000	0.067	0.314	0.225	0.441
Length	−0.346	0.117	−0.079	0.251	0.637	0.002
Width	−0.744	0.000	−0.404	0.003	−0.170	0.381

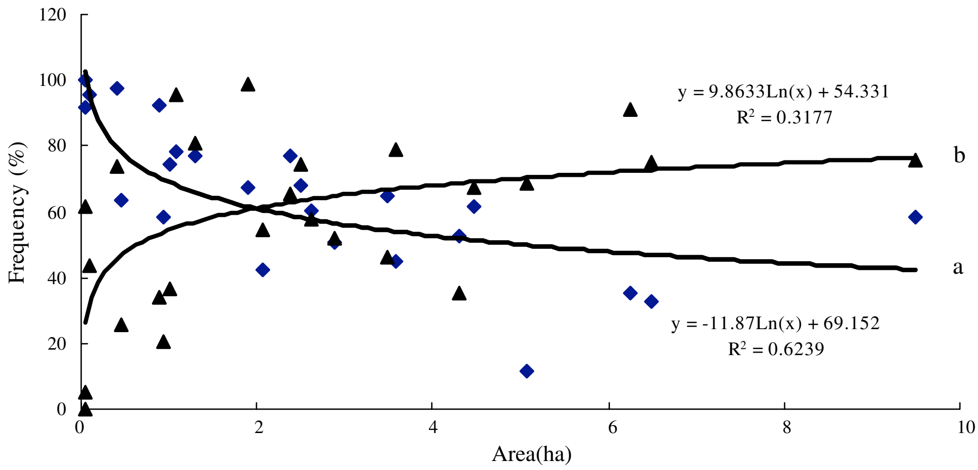

Fig. 5 – Relationships between area of interdune lowlands and frequency of the psammophytes (a), and frequency of the nonpsammophytes (b). Both relationships can be described by logarithmic functions ($p < 0.05$).

Table 3 – Density (numbers of the psammophytes per m^2 in all quadrats) and frequency (percentage occurrence of the psammophytes in quadrats within each lowland) of the psammophytes in interdune lowlands with different area levels

Lowland area (ha)	Density (Mean ± SE)	Frequency (Mean ± SE)
<0.5	67.6 ± 16.7^{a}	91.4 ± 5.7^{a}
0.5–2	26.3 ± 4.8^{b}	74.7 ± 4.7^{b}
2–5	11.6 ± 2.5^{b}	58.1 ± 3.8^{c}
>5	10.4 ± 7.6^{b}	34.5 ± 9.6^{d}

Values within a column sharing the same letter do not differ significantly ($p < 0.05$).

In interdune lowlands, species richness along the dune advancement direction could be: (1) without marked fluctuations (in the smallest areas) (Fig. 6a); (2) gradually decreased with marked fluctuation in the intermediate and large lowlands (Fig. 6b); and (3) increased at first and then decreased, i.e., low near the leeward slope, high in the central lowland, and low near the windward slope, in the intermediate and large lowlands (Fig. 6c).

4. Discussion

4.1. *Species richness, species composition, and vegetation distribution*

Our study showed that species richness increased with increasing area of the interdune lowland following the power function, consistent with the general species–area trend of island biogeography (Collins et al., 2002).

With the increase in the interdune lowland area, richness of psammophytes relative to the overall species richness decreased (Fig. 3), but that of limnocryptophyte-meadow and steppe species increased. In addition, in the larger lowland psammophytes' abundance was lower but that of nonpsammophytes was higher (Figs. 4 and 5; Table 3). These results indicated that area constraints should be considered in analyzing vegetation processes of an active sand dune field.

A distinctive vegetation differentiation is likely to occur in large lowlands rather than in small lowlands, indicating that vegetation distribution is scale-dependent. However, sand dune encroachment and wind–sand activity (sand burial and erosion) also contribute to the existing vegetation pattern.

Table 4 – Density and frequency of two main psammophlic species, Salix gordejevii and Agriophyllum squarrosum, in interdune lowlands with different area levels

Lowland area (ha)	Density (Mean ± SE)		Frequency (Mean ± SE)	
	Salix gordejevii	*Agriophyllum squarrosum*	*Salix gordejevii*	*Agriophyllum squarrosum*
<0.5	50.9 ± 20.3^{a}	14.7 ± 10.4^{a}	61.0 ± 14.3^{a}	41.8 ± 13.6^{a}
0.5–2	15.0 ± 6.3^{b}	3.4 ± 1.2^{ab}	40.8 ± 3.6^{ab}	31.2 ± 8.1^{a}
2–5	10.6 ± 2.5^{b}	0.4 ± 0.2^{b}	51.1 ± 3.3^{ab}	9.1 ± 2.3^{b}
>5	9.7 ± 7.8^{b}	0.2 ± 0.2^{ab}	33.7 ± 9.5^{b}	2.1 ± 1.1^{b}

Values within a column sharing the same letter do not differ significantly ($p < 0.05$).

Sand deposition is severe in small interdune lowlands of the active sand dune field (Li, 1980; Crawford, 1989; Zhu et al., 1998), thus unfavorable for the formation of depressions with emergent groundwater and accordingly to the establishment of limnocryptophyte-meadow species (Owen et al., 2004; Kent et al., 2005). Therefore, only psammophytes adapting to wind–sand activity become established (Liu et al., 2006; Yan et al., 2007). When the whole lowland is merely covered by psammophytes, no distinctive vegetation differentiation can be detected.

On the other hand, in large lowlands, communities belonging to different succession phases appear in the same lowland areas, but occupy different locations characterized by different physical conditions (Avis and Lubke, 1996; Mclachlan et al., 1996; Beyer et al., 1998; Kidron, 1999; Acosta et al., 2003; Sykora et al., 2004; Munoz-Reinoso and Novo, 2005). Severity of wind–sand activity is not evenly distributed in the large lowland, severe at locations close to leeward and windward slopes. Psammophytes occupy locations where

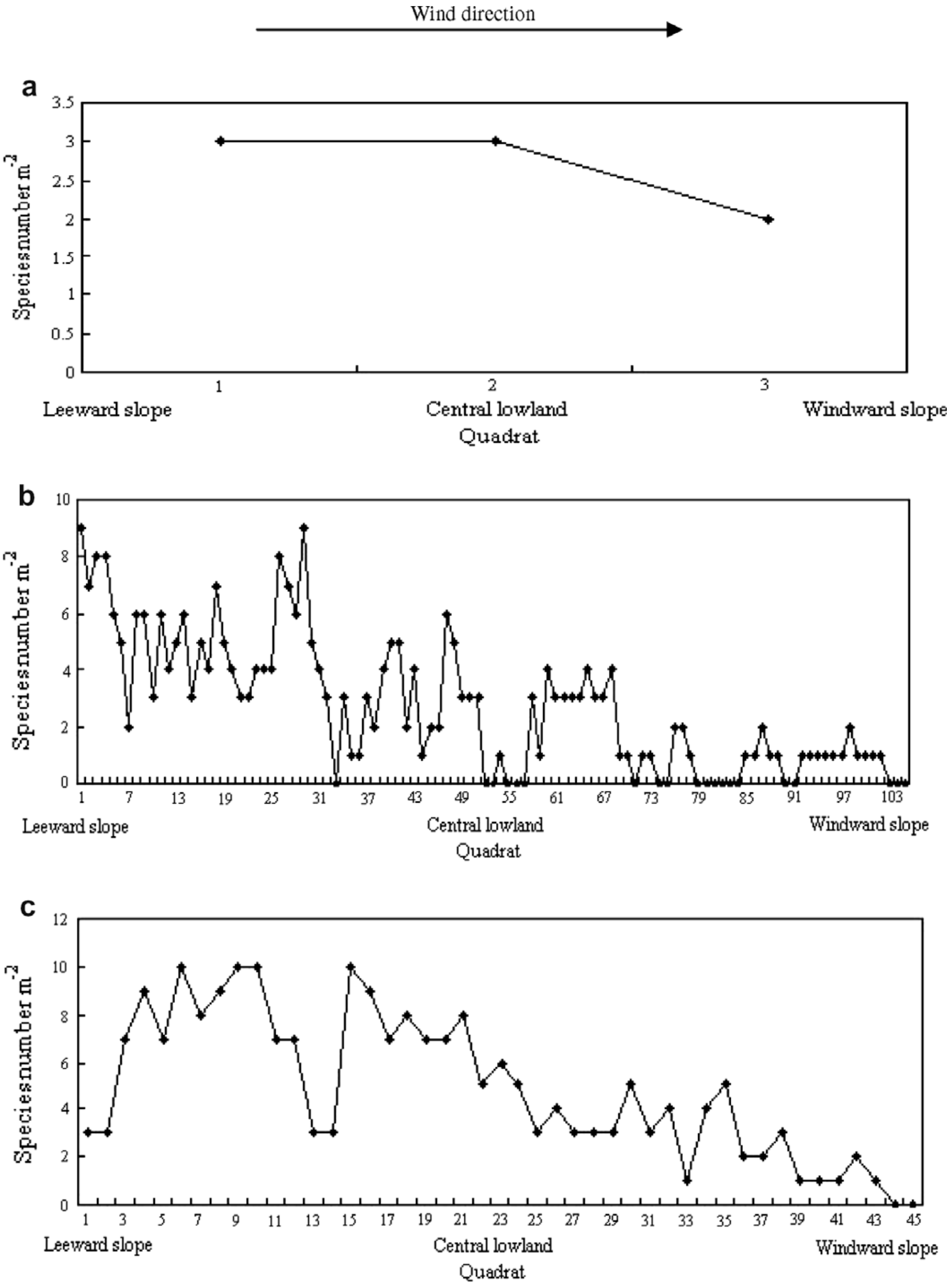

Fig. 6 – Species richness patterns along the transect from the foot of leeward slope to the foot of windward slope: (a) without marked fluctuations in the smallest areas; (b) gradually decreased with marked fluctuation in the intermediate and large lowlands; and (c) increased at first and then decreased, i.e., low near the leeward slope, high in the central lowland, and low near the windward slope, in the intermediate and large lowlands.

wind–sand activity is severe and nonpsammophytes occupy locations where wind–sand activity is gentle. Sand dune encroachment results in destruction (mainly through burial) of the original vegetation near the leeward slope and development of new vegetation (mainly through erosion) on the newly-formed naked land near the foot of the windward slope. Thus, from the leeward slope to the windward slope (i.e., the prevailing wind direction), the history of vegetation is becoming shorter, and a successional series is presented. Psammophytes and limnocryptophyte-meadow species were restricted to the beginning and the central portion of the chronosequence, respectively (Avis and Lubke, 1996). In the Alexandria coastal dune field, the succession across 30–40 m lowland floor amounts to a 5-year temporal scale (Mclachlan et al., 1996). For the large lowlands investigated here, the succession across a lowland floor more than 100 m, amounted to a temporal scale of ca. 20 years. The typical interdune lowlands larger than 1 ha studied here had three distinctive vegetation belts, similar to the case in the eastern Cape studied by Mclachlan et al. (1996).

Microheterogeneity in landscape may regulate the pattern of erosion or burial at a given spot (Wilson et al., 1999; van Bodegom et al., 2004), consequently, resulting in vegetation heterogeneity on a fine scale. Our investigations showed that: on the fine scale, psammophyte patches were in many cases, intertwined in the limnocryptophyte-meadow species belts; similarly limnocryptophyte-meadow species patches in many cases were intertwined in psammophyte belts.

At community level, burial by sand reduces both species abundance and richness, but the intensities vary (Owen et al., 2004). In our case (as shown in Fig. 6c), near the foot of leeward slope, where sand burial takes place frequently, species richness might be high or low.

4.2. *Impacts of the hydrological condition on vegetation distribution and species composition*

Vegetation pattern is mediated by water availability (Lammerts et al., 2001; Munoz-Reinoso and Novo, 2005). In the interdune lowland, groundwater table is high, and there may be pools in the rainy season and/or in surface depressions of lowlands (Jansen et al., 2001), favorable for establishment of the limnocryptophyte-meadow species (Avis and Lubke, 1996; Lammerts et al., 2001; van Bodegom et al., 2004) and for emergence of *S. gordejevii* seedlings is provided (Yan et al., 2007).

Soil condition, micro-landform and vegetation development strongly affect the hydrological condition in interdune lowlands (Yan et al., 2007). Obviously, vegetation development may deteriorate the hydrological condition, dropping down the groundwater table and desiccating the soil (Liu, 1992; Zhu et al., 1998; van Bodegom et al., 2004). In large interdune lowlands, hydrological condition is an important factor responsible for the existing vegetation distribution and species composition (Munoz-Reinoso and Novo, 2005).

4.3. *Plant strategies and vegetation distribution*

Vegetation distribution and species composition respond to plant strategies (Adema and Grootjans, 2003; Adema et al., 2004, 2005; Bossuyt and Hermy, 2004; Kent et al., 2005; Saunders et al., 2006). Changes in frequency between *S. gordejevii* and *A. squarrosum* were different when lowland area decreased from 0.5 ha to 5 ha (Table 4). In the large lowlands, different psammophytes had different optimal habitats. Firstly, *A. wudanica* was dominant only in the psammophyte belt near the windward slope. Secondly, when psammophytes *S. gordejevii*, and *P. communis* or *A. squarrosum* coexisted near the windward slope, *S. gordejevii* was generally distributed at the side close to the lowland whereas *P. communis* or *A. squarrosum* were at the side close to the dune. Thirdly, for *S. gordejevii*, adults and juveniles occupied different sites: the former distributed at the places where sand accumulation took place but the latter at the places where wind erosion was intensive.

S. gordejevii is a shrub distributed over various parts of an active sand dune field. Quick growth and active vegetative regeneration are responsible for its occupation of the foot of leeward slopes (Ren et al., 2001). Regeneration from seeds gives it ability to cluster at the foot of windward slopes (Yan et al., 2007). In the large interdune lowland, *P. communis* occurs as either limnocryptophyte or psammophyte. As psammophyte, it colonizes the location close to the windward slope, just outside of the *S. gordejevii* belt. It extends towards active sand dunes by means of rhizomes, therefore, a *P. communis* belt is formed along the foot of windward slopes.

4.4. *Biodiversity conservation in the active sand dune field*

Species–area relationships are associated with plant diversity conservation (Collins et al., 2002). Our results indicated that: (1) conservation strategies should incorporate species richness as well as species composition in the active sand dune field; (2) large lowlands in the active sand dune field are important determinants of plant species diversity and small lowlands are more favorable for psammophytes; (3) some threshold values could be referred to draw up biodiversity conservation plans. Therefore, we conclude that: (1) if our objective is to maintain and enhance plant diversity in an active sand dune field we should focus on large interdune lowlands; (2) if our objective is to conserve endemic psammophytes in an active sand dune field, we should focus on small interdune lowlands; (3) since with decrease of lowland area, frequency of psammophytes logarithmically increased but that of nonpsammophytes logarithmically decreased, and frequency of the psammophytes was equal to that of the nonpsammophytes when the lowland area was about 2 ha, we could conserve lowlands smaller than 2 ha for maintaining high abundance of psammophytes, or conserve lowlands larger than 2 ha for maintaining high abundance of nonpsammophytes.

For the sake of plant diversity conservation, on one hand, it is not wise to reclaim interdune lowlands of an active dune field as afforestation land, or as artificial grassland, or as farmland. On the other hand, it is necessary to conserve some small lowlands to allow the establishment of psammophytes. In a well-stabilized dune field, management practices like grazing at a low stocking rate may be needed to mitigate the negative effects of stabilization of mobile sand and deterioration of soil moisture on plant species diversity.

However, over-grazing is not recommended because it may destroy large interdune lowlands. Also we do not encourage the destruction of grassland to create active dunes to provide habitats for the psammophyte, because in that situation, steppe species will lose their habitats.

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Appendix

A list of the entire species involved in the study. AH = annual herb, ABH = annual-biennial herb, BH = biennial herb, PH = perennial herb, S = shrub, SS = semi-shrub. P = psammophyte, LMS = limnocryptophyte-meadow species, STS = steppe species (TCSIMNAR, 1985).

Species	Family	Life form	Species functional group	Uniqueness
Artemisia gmelinii (Ag)	Compositae	SS	LMS	
Artemisia halodendron (Ah)		SS	P	Rare
Artemisia laciniata (Ai)		PH	STS	Rare
Artemisia lavandulaefolia (An)		PH	STS	
Artemisia scoparia (Ap)		ABH	STS	
Artemisia sieversiana (Av)		ABH	STS	
Artemisia wudanica (Aw)		SS	P	Endemic
Carduus nutans (Cn)		BH	STS	
Cirsium segetum (Ci)		PH	STS	
Erigeron acer (Ea)		BH	LMS	
Eupatorium lindleyanum (El)		PH	LMS	
Heteropappus altaicus (Ha)		PH	STS	
Hypochoeris grandiflora (Hg)		PH	LMS	Rare
Inula britannica (Ib)		PH	LMS	
Inula salsoloides (Is)		PH	P	
Ixeris chinensis (Ic)		PH	STS	
Lactuca indica (Li)		BH	LMS	
Lactuca tatarica (Lt)		PH	LMS	
Leibnitzia anandria (La)		PH	LMS	Rare
Sonchus brachyotus (Sb)		PH	STS	
Taraxacum mongolicum (Tm)		PH	STS	
Xanthium sibiricum (Xs)		AH	STS	
Agrostis clavata (Ac)	Gramineae	PH	LMS	
Arthraxon hispidus (Ar)		AH	LMS	Rare
Calamagrostis epigeios (Ce)		PH	LMS	
Chloris virgata (Cv)		AH	STS	
Cleistogenes squarrosa (Cl)		PH	STS	
Eragrostis pilosa (Ep)		AH	STS	
Pennisetum alopecuroides (Pa)		PH	LMS	
Phragmites communis (Pc)		PH	P, LMS	
Setaria viridis (Sv)		AH	STS	
Agriophyllum squarrosum (As)	Chenopodiaceae	AH	P	
Chenopodium acuminatum (Ca)		AH	STS	
Chenopodium glaucum (Cg)		AH	STS	
Corispermum candelabrum (Cc)		AH	P	
Populus spp. (Ps)	Salicaceae	S	LMS	
Salix gordejevii (Sg)		S	P	Rare
Salix microstachya (Sm)		S	P	Rare
Salix mongolica (Sx)		S	P	Rare

(*continued on next page*)

Appendix – *continued*

Species	Family	Life form	Species functional group	Uniqueness
Bolboschoenus compacts (Bc)	Cyperaceae	PH	LMS	Rare
Bolboschoenus planiculmis (Bp)		PH	LMS	Rare
Carex caespitosa (Cx)		PH	LMS	
Carex duriuscula (Cd)		PH	LMS	
Heleochalis intersita (Hi)		PH	LMS	Rare
Scirpus tabernaemontani (St)		PH	LMS	
Astragalus adsurgens (Aa)	Leguminosae	PH	LMS	
Caragana microphylla (Cm)		S	P	Rare
Glycine soja (Gs)		AH	LMS	
Hedysarum fruticosum (Hf)		SS	P	Rare
Kummerowia striata (Ks)		PH	LMS	
Lespedeza davurica (Ld)		SS	STS	
Melilotus suaveolens (Ms)		ABH	LMS	
Oxytropis ramosissima (Or)		PH	STS	
Sophora flavescens (Sf)		PH	STS	Rare
Swainsonia salsula (Ss)		SS	STS	
Thermopsis lanceolata (Tl)		PH	STS	
Trigonella korshinskyi (Tk)		AH	LMS	Rare
Vicia amoena (Va)		PH	LMS	
Halerpestes cymbalaria (Hc)	Ranumculaceae	PH	LMS	
Typha minima (Ty)	Typhaceae	PH	LMS	
Cynanchum chinense (Cy)	Asclepiadaceae	PH	STS	
Cynanchum sibiricum (Cs)		PH	STS	
Plantago depressa (Pd)	Plantaginaceae	PH	LMS	
Ulmus pumila (Up)	Ulmaceae	S	STS	
Parnassia palustris (Pp)	Saxifragaceae	PH	LMS	Rare
Galium verum (Gv)	Rubiaceae	PH	LMS	
Euphorbia humifusa (Eh)	Euphorbiaceae	AH	LMS	
Equisetum ramosissimum (Er)	Equisetaceae	PH	LMS	
Potentilla discolor (Po)	Rosaceae	PH	STS	
Alisma orientale (Ao)	Alismataceae	PH	LMS	
Sagittaria trifolia (Sa)		PH	LMS	
Glaux maritima (Gm)	Primulaceae	PH	LMS	
Polygonum hydropiper (Ph)	Polyonaceae	PH	LMS	
Polygonum lapathifolium (Pl)		AH	LMS	
Gentiana squarrosa (Ge)	Gentianaceae	PH	LMS	Rare
Juncus gracillimus (Jg)	Juncaceae	PH	LMS	
Dragocephalum moldavica (Dm)	Labiatae	PH	LMS	

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