HOW DO PLANTS RESPOND TO PATCH AREA AND ITS DISTRIBUTION PATTERN IN HORQIN SAND LAND, CHINA

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(Received 30th Sep 2018; accepted 29th Nov 2018)

Abstract. To elucidate the plant response to habitat fragmentation, 18 interdune lowlands with different sizes in active sand dunes of Horqin Sand Land were selected, and the interdune lowland was considered as fragmented habitat patch. In our study, the effect of patch size on plant distribution pattern was explored and different protocols of species diversity conservation were proposed. Our results showed different plant sensitivities to habitat fragmentation: type I, species are restricted by patch area and distributed regularly in fragments; type II, species are not restricted by patch area, and their distribution is irregular in fragments; type III, species mainly distributed in large fragments; type IV, species mainly distributed in small fragments; type V, species mainly distributed in middle-sized fragments. Exploring the effects of fragmentation habitat size on plant species diversity and its distribution pattern will provide theoretical basis for plant diversity conservation in semi-arid sand dunes.
Keywords: *biodiversity, habitat loss, habitat isolation, patch, landscape*

Introduction

Habitat fragmentation has been considered as one of the major threats to biodiversity (Brunet et al., 2011; Wu et al., 2013; Murphy and Romanuk 2014; Matthews et al., 2014; Ducatez and Shine, 2017). Fragmentation processes often result in "patchy" habitat segments, called patchy habitat. As the degree of fragmentation increases, the original patch is isolated from the highly altered retrogressive landscape and gradually recedes and eventually develops into a biogeographic "habitat islands", producing a range of ecological or biological effects at different levels of population, community, ecosystem and even landscape.

The size, environmental heterogeneity and marginal effects of habitat patches have important effects on species richness and abundance in patches (Benedick et al., 2006; Santos et al., 2008; Leal et al., 2012; Fahrig et al., 2015). Different species have different sensitivity, adaptability and tolerance to landscape fragmentation (Haila, 2002; Hill et al., 2003; Swihart et al., 2003; Kolb et al., 2005; Hudson et al., 2017). The influence of habitat patches such as Qiandao Lake and Three Gorges Reservoir on plant diversity has been reported in China (Ding, 2005). Many studies have focused on the real islands in geography (Halley et al., 2014; Phillips et al., 2018), but less attention has been paid to the ecological effects of habitat patches in the broad sense of biogeography and ecology. As a relatively independent vegetation unit in sand dune ecosystem, the interdune lowlands have unique patch properties in sand dune landscape, which can be regarded as "fragmented habitat islands" in sand dune ecosystem, and play an important role in determining plant diversity and distribution pattern of sand dune ecosystem.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_12231234

However, the impact of fragmented patch area in the sand dune ecosystems of semi-arid regions (i.e., interdune lowlands) on plant diversity and island accumulation has not been reported.

Therefore, we investigated the plant diversity of interdune lowlands in the active dune ecosystem of the Horqin Sandy land, and conducted regression analysis on the relationship between the relative frequency and abundance of typical species and fragmented island area. This study is aiming to explore the plant diversity protection scheme applicable to different ecological groups and reveal the processes and mechanisms of the impacts of the habitat island on the plant diversity. This study can provide a theoretical basis for biodiversity protection and guides the practice of biodiversity protection in semi-arid areas.

Material and Methods

Study site

The study site is located at Wulanaodu region (42°47′- 43°25′ N, 118°38′-120°43′ E, 480 m a.s.l.), eastern Inner Mongolia, China (*Figure 1*). The region has a semi-arid climate. The annual average temperature is 6.3°C. The annual average 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.

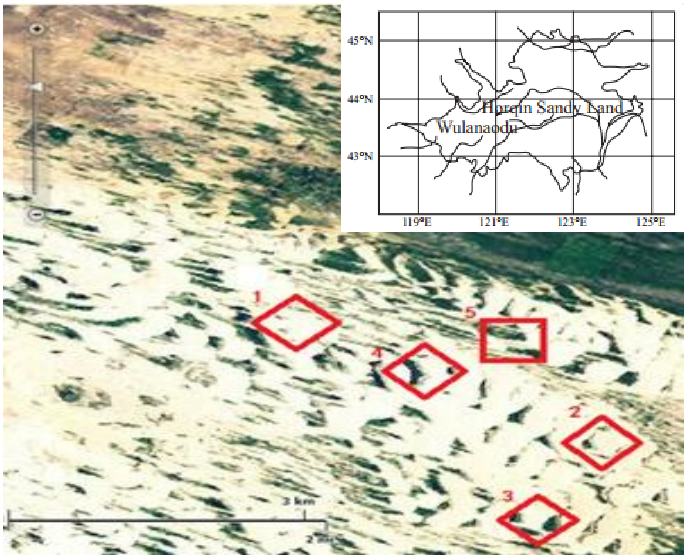

Figure 1. *Location map and five sampling sites in Horqin sandy land*

The active sand dune areas, 15–35 m in height, are advancing at a speed of ca. 6–7 m year-1, and, following the aforementioned fencing since the 1980s, are permanently closed off from the natural grassland (>600 ha). The natural grassland and the active sand dunes experience the same climatic conditions, i.e. similar rainfall, temperature, humidity etc. The vegetation before the intense grazing period was dominated by perennial grasses, such as *Phragmites communis* and *Calamagrostis epigeios*, whereas after the onset of grazing pasammophilous species, such as *Artemisia wudanica* and *Agriophyllum squarrosum*, became more established.

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

We selected 18 interdune lowlands ranging in size from 0.10 to 5.64 hm^2 in 2012 (*Table 1*) (Liu et al., 2003). We used grid sampling at a resolution of 10 × 10 m. We established transects divided into 10-m intervals in each plot, all running in the vertical direction of the prevailing wind, and then selected 1 × 1 m quadrats, 10-m-spaced, along each transect (Wu et al., 2016). The species richness and abundance in the sample were recorded. For bunchgrasses (e.g. *C. squarrosa*), we counted the number of clusters to obtain the abundance, whereas for clonal species (e.g. *S. gordejevii* and *P. communis*) we counted the number of ramets, and for discrete species (e.g. *A. squarrosum*) the number of individuals were counted. The frequency of each species was determined within each plot.

Table 1. *Basic information of 18 selected interdune lowlands*

Plot number	Geographical coordinates of the center of the interdune lowland	Size (hm^2)	Dam Height (m)
1	42°59.900 N, 119°38.009 E	0.05	25
2	42°59.367 N, 119°38.789 E	0.27	28.5
3	42°58.089 N, 119°38.169 E	0.30	25.5
4	42°58.170 N, 119°37.886 E	0.32	25
5	43°00.964 N, 119°38.887 E	0.60	24
6	42°59.789 N, 119°37.236 E	0.66	25
7	42°59.767 N, 119°37.709 E	0.67	22.5
8	42°59.640 N, 119°37.886 E	1.00	25
9	42°59.805 N, 119°37.964 E	1.35	24.5
10	43°00.001 N, 119°37.870 E	2.27	23
11	42°59.862 N, 119°37.974 E	2.94	19
12	42°59.958 N, 119°37.844 E	3.22	23
13	42°59.442 N, 119°38.749 E	4.35	26.5
14	43°00.336 N, 119°37.609 E	5.01	25
15	42°00.498 N, 119°37.154 E	5.25	24.5
16	42°00.598 N, 119°38.504 E	6.19	26
17	42°00.156 N, 119°38.454 E	6.84	22
18	42°00.453 N, 119°37.231 E	11.3	24.5

Species diversity measure

- Species abundance: number of species within a community.
- Frequency of a species (%) =occurrence of the certain species/number of total samples.
- Abundance of a species (%) = total plants of certain species/ total plants of total species.

Classification of typical plant responses to habitat fragmentation

Based on the differences of typical plant responses to the habitat area, plants were divided into the five categories (*Table 2*).

Data analysis

All the statistic analysis was conducted in SPSS software. Model selection was based on maximum R^2, and residual analysis showed that the model fit was adequate.

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Statistical significance was determined at P = 0.05. We analyzed the relationships between patch area and frequency and relative abundance for 6 type's species.

Table 2. *Classification of typical plant responses to habitat fragmentation*

Type	Relationship	Distribution
I	Significant	Regular
II	No significant	Irregular
III	Significant	Mainly distributed in large fragments
IV	No significant	Mainly distributed in small fragments
V	No significant	Mainly distributed in middle-sized fragments

Results

Species composition

According to the data of 18 interdune lowlands, there are 114 species belonging to 36 families in the patch habitat of horqin Sandy land. Among them, 25 species belong to *Compositae*, 13 species belong to *Graminae*, 11 species belong to *Leguminosae*, 6 species belong to *Cyperaceae*, 7 species belong to *Chenopodiaceae*, and the remaining 57 species belong to 31 families. Among them, 10 species is Psammophytes, 76 species are meadows plants and 22 species are steppes (*Table 3*).

Table 3. *Species list in the 18 selected patchy habitats*

Number	species	General	Ecological group	Life form	Frequency
1	*Artemisia halodendron*	**Compositae**	P	SS	0.99
2	*Artemisia wudanica*		P	SS	1.36
3	*Artemisia frigida*		P	SS	1.24
4	*Inula salsoloides*		P	PH	10.7
5	*Artemisia gmelinii*		LMS	SS	0.33
6	*Artemisia lavandulaefolia*		LMS	PH	23.5
7	*Erigeron acer*		LMS	BH	0.06
8	*Eupatorium lindleyanum*		LMS	PH	0.07
9	*Hypochoeris grandiflora*		LMS	PH	0.03
10	*Inula britannica*		LMS	PH	8.78
11	*Lactuca indica*		LMS	BH	1.06
12	*Lactuca tatarica*		LMS	PH	5.70
13	*Leibnitzia anandria*		LMS	PH	6.89
14	*Taraxacum mongolicum*		LMS	PH	16.7
15	*Taraxacum borealisinense*		LMS	PH	3.45
16	*Carduus nutans*		LMS	BH	0.02
17	*Cirsium segetum*		LMS	PH	0.46
18	*Ixeris chinensis*		LMS	PH	34.1
19	*Scorzonera capito*		LMS	PH	0.05
20	*Senecio jacobacea*		LMS	PH	0.42
21	*Sonchus brachyotus*		LMS	PH	10.4
22	*Serratula cardunculus*		LMS	PH	0.04
23	*Xanthium sibiricum*		LMS	AH	0.07

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Number	species	General	Ecological group	Life form	Frequency
24	*Heteropappusaltaicus*		STS	PH	0.18
25	*Agriophyllum squarrosum*	**Chenopodiaceae**	P	AH	0.34
26	*Corispermum candelabrum*		P	AH	5.77
27	*Salix gordejevii*	**Salicaceae**	P	S	34.5
28	*Caragana microphylla*	**Leguminosae**	P	S	1.56
29	*Hedysarum fruticosum*		P	SS	3.76
30	*Agrostis clavata*	**Gramineae**	LMS	PH	16.8
31	*Arthraxon hispidus*		LMS	AH	9.87
32	*Calamagrostis epigeios*		LMS	PH	46.6
33	*Pennisetum alopecuroides*		LMS	PH	1.31
34	*Phragmites communis*		LMS	PH	60.4
35	*Miscanthussacchariflorus*		LMS	PH	15.6
36	*Echinochloa frumentacea*		LMS	PH	0.31
37	*Septoria mougeotii*		LMS	PH	0.02
38	*Chloris virgata*		LMS	AH	10.8
39	*Eragrostis pilosa*		LMS	AH	30.2
40	*Setaria viridis*		LMS	AH	0.98
41	*Pennisetum centrasiaticum*		LMS	PH	1.67
42	*Astragalus adsurgens*	**Leguminosae**	LMS	PH	0.45
43	*Glycine soja*		LMS	AH	3.06
44	*Kummerowia striata*		LMS	PH	2.64
45	*Melilotus suaveolens*		LMS	ABH	0.67
46	*Trigonella korshinskyi*		LMS	AH	0.01
47	*Vicia amoena*		LMS	PH	0.34
48	*Swainsonia salsula*		LMS	SS	1.78
49	*Thermopsis lanceolata*		LMS	PH	1.83
50	*Radix Glycyrrhizae*		STS	PH	0.65
51	*Bolboschoenus compacts*	**Cyperaceae**	LMS	PH	5.91
52	*Bolboschoenus planiculmis*		LMS	PH	0.37
53	*Carex caespitosa*		LMS	PH	10.6
54	*Carex duriuscula*		LMS	PH	12.3
55	*Heleochalis intersita*		LMS	PH	0.26
56	*Scirpus tabernaemontani*		LMS	PH	0.02
57	*Populus spp.*	**Salicaceae**	LMS	S	5.76
58	*Salix microstachya*		LMS	S	31.5
59	*Salix mongolica*		LMS	S	0.87
60	*Alisma orientale*	**Alismataceae**	LMS	PH	0.04
61	*Sagittaria trifolia*		LMS	PH	0.05
62	*Chenopodium acuminatum*	**Chenopodiaceae**	LMS	AH	0.04
63	*Chenopodium glaucum*		LMS	AH	3.67
64	*Bassia dasyphylla*		STS	AH	0.34
65	*Chenopodium aristatum*		STS	AH	0.22
66	*Salsola ruthenica*		STS	AH	0.12
67	*Polygonum hydropiper*	**Polyonaceae**	LMS	PH	0.02
68	*Polygonum lapathifolium*		LMS	AH	0.01
69	*Polygonum thunbergii*		LMS	AH	0.01

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Number	species	General	Ecological group	Life form	Frequency
70	*Polygonum laxmanni*		P	PH	0.01
71	*Equisetum ramosissimum*	**Equisetaceae**	LMS	PH	0.02
72	*Eguisetum sylvalicum*		LMS	PH	0.02
73	*Euphorbia humifusa*	**Euphorbiaceae**	LMS	AH	0.02
74	*Gentiana squarrosa*	**Gentianaceae**	LMS	PH	0.02
75	*Plantago depressa*	**Plantaginaceae**	LMS	PH	3.09
76	*Glaux maritima*	**Primulaceae**	LMS	PH	0.05
77	*Halerpestes cymbalaria*	**Ranumculaceae**	LMS	PH	5.93
78	*Potentilla discolor*	**Rosaceae**	LMS	PH	1.32
79	*Potentillae Chinensis*		LMS	PH	1.02
80	*Potentilla supina*		LMS	PH	0.67
81	*Potentilla anserina*		LMS	PH	0.66
82	*Typha minima*	**Typhaceae**	LMS	PH	1.33
83	*Artemisia laciniata*	**Compositae**	STS	PH	1.78
84	*Artemisia scoparia*		STS	ABH	3.65
85	*Artemisia sieversiana*		STS	ABH	1.34
86	*Heteropappus altaicus*		STS	PH	0.34
87	*Lespedeza davurica*	**Leguminosae**	STS	SS	10.9
88	*Oxytropis ramosissima*		STS	PH	0.02
89	*Sophora flavescens*		STS	PH	1.98
90	*Cynanchum sibiricum*	**Asclepiadaceae**	STS	PH	0.31
91	*C. chinense*		STS	PH	0.01
92	*Cleistogenes squarrosa*	**Gramineae**	STS	PH	6.81
93	*Galium verum*	**Rubiaceae**	STS	PH	0.28
94	*Rubiaschumahhiaha*		P	PH	0.01
95	*Ulmus pumila*	**Ulmaceae**	STS	S	0.05
96	*Linaria vulgaris*	**Scrophulariaceae**	LMS	PH	0.01
97	*Portulaca oleracea*	**Portulacaceae**	STS	AH	0.05
98	*Spiked Loosestrlfe*	**Lythraceae**	LMS	PH	0.01
99	*Lythrum virgatum*		LMS	PH	0.01
100	*Erodium stephanianum*	**Geraniaceae**	LMS	PH	0.01
101	*Allium odorum*	**Liliaceae**	LMS	PH	0.01
102	*Asparagus brachyphyllus*		LMS	PH	0.01
103	*Asparagua dahuricus*		LMS	PH	0.01
104	*Viola philippica*	**Violaceae**	LMS	PH	0.01
105	*Viola prionantha*		LMS	PH	0.01
106	*Tragus bertesonianus*	**Rutaceae**	STS	PH	0.01
107	*Lappula echinata*	**Boraginaceae**	STS	ABH	0.01
108	*Radix Arnebiae*		STS	PH	0.01
109	*Scutellaria baicalensis*	**Labiatae**	STS	PH	0.01
110	*Tirbulus terrestris*	**Zygophyllaceae**	LMS	AH	0.01
111	*Saposhnikovia divaricata*	**Umbelliferae**	STS	PH	0.01
112	*Silene jenisseensis*	**Caryophyllaceae**	STS	PH	0.02
113	*Cuscuta chinensis*	**Convolvulaceae**	STS	AH	0.01
114	*Betula platyphylla*	**Betula**	LMS	S	0.01

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The responses of typical plants to fragmented patch area

Type I (species is restricted by patch area and distributed regularly in fragments)

The frequency and relative abundance of *Artemisia wudanica, Phragmites communis* decreased logarithmically. The frequency and relative abundance of *Lespedeza davurica* showed a change of binomial function with the increase of the area of the fragmented habitat, when the area of plaque is around 2 hm^2, its frequency is lowest, and its relative abundance tends to increase with patch area (*Figure 2*).

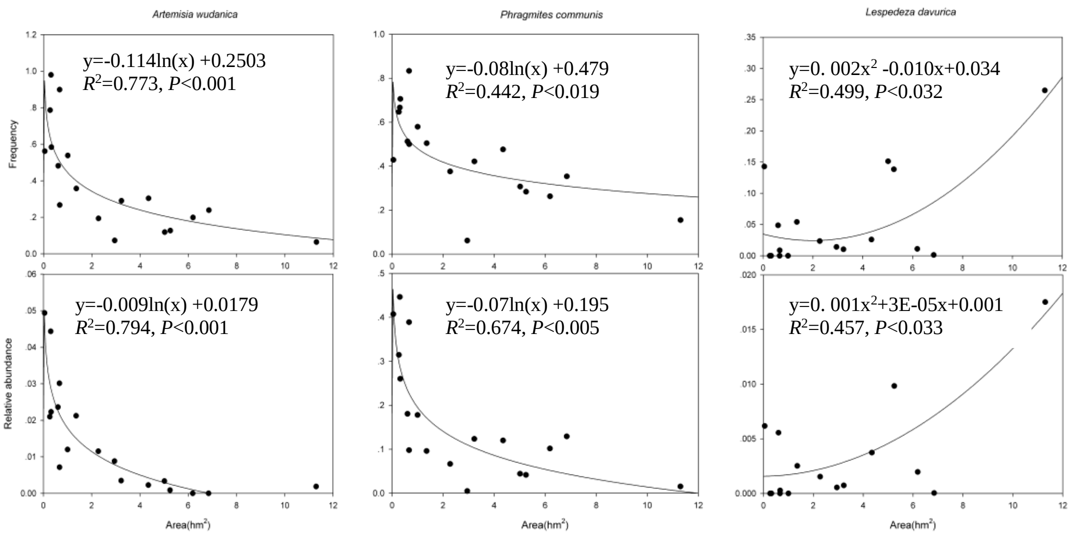

Figure 2. *Changes in the frequency and abundance of Artemisia wudanica, Phragmites communis, Lespedeza davurica with increasing interdune lowland size*

Type II (species is not restricted by patch area, and their distribution is irregular in fragments)

There was no significant change in the frequency and relative abundance of *Salix gordejevii* with the increase of plaque habitat area. *Salix gordejevii* appeared in different interdune lowlands, and the relative abundance of *Salix gordejevii* decreased with the increase of patch area (*Figure 3*).

Type III (species mainly distributed in large fragments)

The frequency and relative abundance of *Eragrostis pilosai* increased significantly with the increase of patch area, that is, the population size and distribution of *Eragrostis pilosai* declined sharply (*Figure 4*).

Type IV (species mainly distributed in small fragments)

The frequency and relative abundance of *Vicia amoena* showed no significant change with the increase of patch area. *Vicia amoena* is more frequent in small and medium-sized interdune lowlands; the population size of *Vicia amoena* varies little with increased habitat fragmentation (*Figure 5*).

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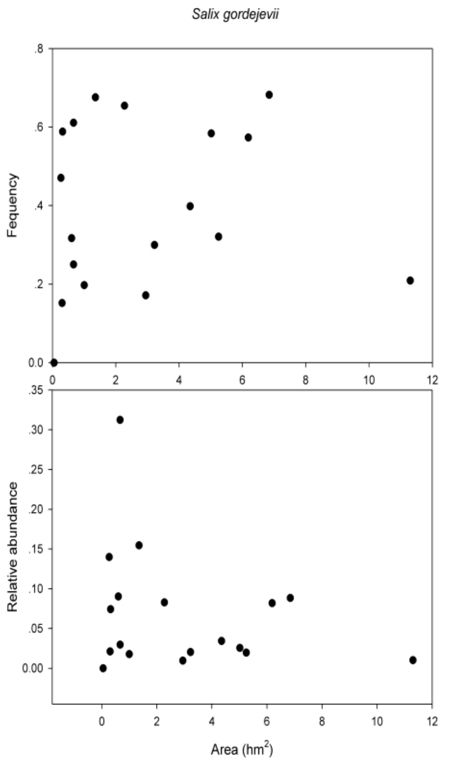

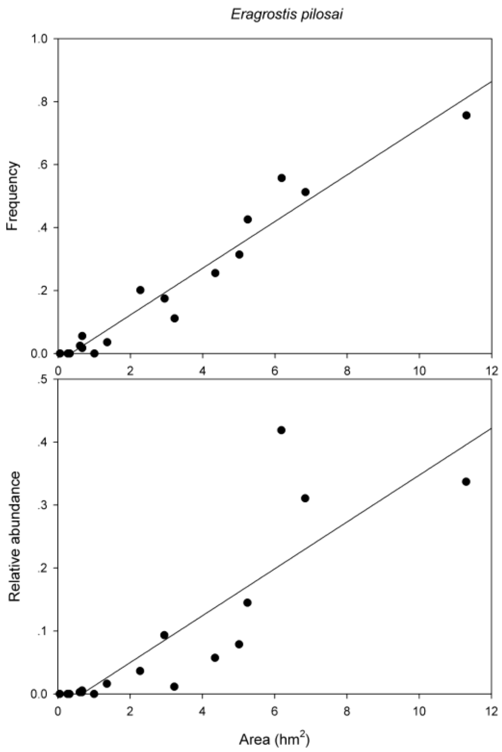

Figure 3. *Changes in the frequency and relative abundance of Salix gordejevii population with interdune lowland area*

Figure 4. *Changes in the frequency and relative abundance of Eragrostis pilosai population with interdune lowland area*

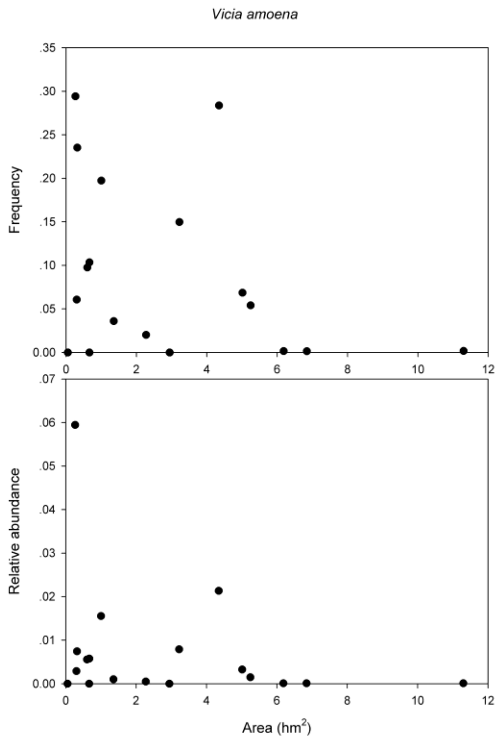

Figure 5. *Changes in the frequency and relative abundance of Vicia amoena population with interdune lowland area*

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Type V (species mainly distributed in middle-sized fragments)

The frequency and relative abundance of *Chenopodium aristatum* showed no significant change with the increase of patch area, the frequency of *Chenopodium aristatum* was higher in medium size patch and lower in small and large size patch. The population size of *Chenopodium aristatum* had no significant change with the increase of habitat fragmentation. There was no significant change in the frequency and relative abundance of *Sophora miltiorrhiza* with the increase of patch area, and the size of population was not significant change with the increase of habitat fragmentation (*Figure 6*).

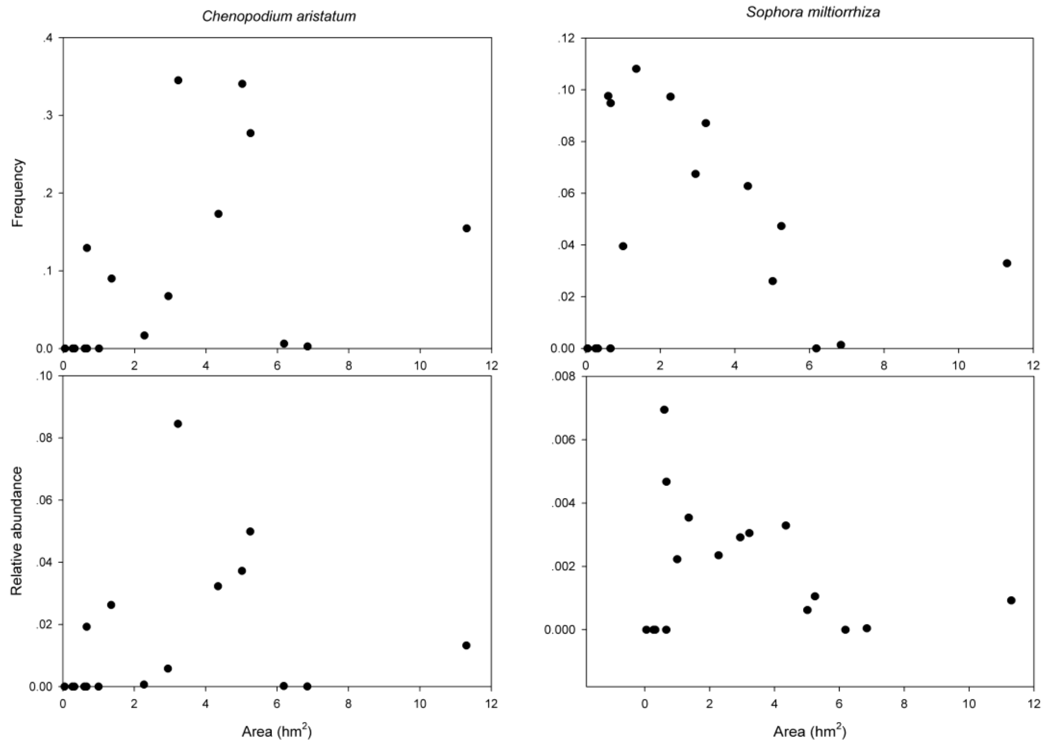

Figure 6. *Change in the frequency and relative abundance of Chenopodium aristatum and Sophora miltiorrhiza with interdune lowland area*

Discussion

Contrary to the existing view that species frequency show a negative trend with decreasing fragment area (Hill and Curran, 2003; Echeverría et al., 2007; Kornera and Jeltschb, 2008), our results showed that some species responded positively to habitat fragmentation and the species tolerance to habitat fragmentation was different. The plant-environmental feedback process in the dune system has a significant effect on plant growth and reproduction (Hambäck et al., 2007; Giladi et al., 2014; Winfree et al., 2015). The feedback process of *Artemisia wudanica* to wind erosion is as follows: After *Artemisia wudanica* is blown by the wind, the plant will fall down at a certain wind erosion depth, and the sand blocking area will increase accordingly. The microenvironment of the buried parts of the plants has changed. For example, 1) the soil volume has increased and the soil water content has increased; 2) mycorrhizal fungus activity capacity increased; 3) in the effective use of resources increased in the soil.

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These changes have created favorable conditions for the adventitious roots on the sandy branches. In the case of a large number of adventitious roots, the growth of the plant increases, and the ability to block sand increases.

Reeds can appear in meadow grasslands and in the interdune lowlands. On the one hand, they belong to meadows, and on the other hand, they have the ability to adapt to wind sand. Previous studies have concluded that reeds can quickly invade and settle in habitats with intense sand activity due to its strong cloning and reproduction ability, (Liu et al., 2006; Liu et al., 2008). Therefore, in the broken patches of mobile dunes, especially in small areas with intense sand activity (Ma et al., 2010; Zobel et al., 2010; Wu et al., 2013), reeds show the ability to adapt to sandstorm interference (Liu et al., 2007). Reeds can be rapidly expanded from lowland to windward slopes through Rhizome extension and asexual strains. As pioneers, they create suitable habitat conditions for other species to invade, drive new vegetation succession in transition zones, and reduce wind and sand fluidity.

Lespedeza davurica has a persistent soil seed bank and can also ensure its population development under strong interference, while playing an important role in maintaining community diversity and system stability (Li et al., 2006). *Lespedeza davurica* population can expand the adjacent space by increasing the number of branches. The high-density population of *Lespedeza davurica* expands the plant elevation space in the form of lateral branches, that is, transverse space. The low-density population of *Lespedeza davurica* occupied the longitudinal space by increasing its branches, gradually occupied the horizontal space (Li, 2005).

Conclusions

In the practice of species diversity conservation, programmers should be tailored to the sensitivity of the species to habitat fragmentation. For example, with the increase in the area of patches, the frequency and relative diversity of *Artemisia wudanica*, *Phragmites communis*, and *Vicia amoena* are all reduced. Therefore, when protecting *Artemisia wudanica*, *Phragmites communis*, and *Vicia amoena*, the focus should be on protecting small islands. The frequency and relative abundance of *Lespedeza davurica* increase with the increase of patch area. Therefore, when protecting *Lespedeza davurica*, we should focus on a large area of islands; the frequency and relative abundance of *Chenopodium aristatum* and *Sophora flavescens* are higher in the middle area islands, therefore, when protecting *Chenopodium aristatum* and *Sophora flavescens*, the middle area islands should be protected.

Acknowledgments. We thank Jianqiang Qian and Yongming Luo for field assistance. The study was financially supported by the National Natural Science Youth Foundation of China (31600443) and the Liaoning Natural Science Foundation (201800170) .

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