Arid Land Research and Management 18: 283–293, 2004

ISSN: 1532-4982 print/1532-4990 online
DOI: 10.1080/15324980490451410

Floristic Composition of Vegetation and the Soil Seed Bank in Different Types of Dunes of Kerqin Steppe

YULIN LI
JIANYUAN CUI
XUEYONG ZHAO
HALIN ZHAO

Cold and Arid Regions Environmental and
Engineering Research Institute
Chinese Academy of Sciences
Lanzhou, P.R. China

The floristic composition of the vegetation and the soil seed bank in different types of dunes of Kerqin steppe were compared. The aim of this study was to examine the influence of desertification on the floristic composition of the vegetation and soil seed bank. An indirect germination method was used to study the seed bank. Thirty species of the vegetation and 25 of the seed bank were identified, 23 species being common to both. Differences between four types of dunes (mobile sand dune, MSD; semifixed sand dune, SSD; fixed sand dune, FSD; interdunal lowland, ILD) in floristic composition of the vegetation and the soil seed bank were examined using nonparametric methods. In the four types of dune, species composition varied significantly except between site MSD and site SSD as well as between site FSD and site ILD in aboveground vegetation. As for soil seed bank, the number of species and seeds differed significantly only between site FSD and site ILD. Species diversity revealed that species numbers increased in the sequence of MSD, SSD, FSD and ILD. The dominant species of aboveground vegetation in site MSD and site SSD were Agriophyllum squarrosum and Setaria viridis, respectively. While in both site FSD and site ILD, the dominant was Eragrostis pilosa. Of total germinated seed, the most abundant species in site MSD were Agriophyllum squarrosum, but the dominant species was Eragrostis pilosa in the other three sites. In each site, more than half of the species recorded in aboveground vegetation were found in the seed bank, even more in the seed bank of site FSD and site ILD. In site FSD and site ILD, high correspondence was observed between the species composition of the aboveground vegetation and of the associated soil seed bank. Spearman's rank correlation coefficients were 0.295, 0.046, 0.704, and 0.612 for site MSD, site SSD, site FSD and site ILD, respectively. These results indicated that desertification development decreased correlation between the seed bank and vegetation in Kerqin Steppe.

Keywords China, desertification, germination, Shannon-Weaver diversity, species density

Received 12 May 2003; accepted 1 October 2003.

This research was supported by the National 973 Project "The Desertification Process and its Prevention in North China" (G2000048704). Authors appreciated the anonymous referees' constructive suggestions.

Address correspondence to Yulin Li,Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, 260 Donggang West Road, Lanzhou 730000, P.R. China. E-mail: liyleml@263.net

Kerqin Steppe is one of the most important and largest rangelands in China, where soil surface was well covered with vegetation and where stock raising was the main industry before the end of 1950 s in China (Liu et al., 1996). In recent decades, the land was severely desertified due to inappropriate anthropogenic activities such as prolonged overgrazing, poor farmland management and overlumbering (Zhu & Wang, 1992). Zhu et al. (1989) estimated that the area of different types of desertified land had increased 33.8% from the end of 1950's to the end of 1970's and would expand in a progressive way subsequently. Such desertified lands were mainly concentrated where large areas of rangelands were overgrazed or cultivated. Presently, the urgent task is to combat desertification and restore vegetation in this region. To manage and restore vegetation, we need improved information on the regeneration ability of the dominant species on different sand dunes. Factors affecting regeneration, specifically the availability of seeds, may differ from different types of dunes. Soil seed bank studies are a common means of estimating the availability of seeds within a community (Leck et al., 1989).

The soil seed bank plays an important role in the composition of different plant communities and, thus, for their conservation (Grubb, 1977; Leck et al., 1989; Mcdonald, 1996; Thompson, 1986; Wisheu & Keddy, 1991). Many studies have proven that seed banks are especially important in desert ecosystems, where annual plants account for a large part of the flora and their seeds may remain viable in the soil for many years (Chambers et al., 1991; Henderson et al., 1988). The composition of the seed bank depends on the production and composition of present and previous plant communities, as well as on the longevity of the seeds of each species at local conditions. If there is a disturbance to the plant community, such as desertification, the seed bank may intervene in reestablishing the original community. Thus, knowledge of the seed bank and an understanding of the population dynamics of buried viable seeds are of practical importance in vegetation regeneration.

Numerous studies have examined the soil seed bank composition in agricultural habitats or natural communities in grasslands (Fenner, 1985; Kinucan & Smeins, 1992; Thompson, 1986; Willms & Quinton, 1995). Soil seed bank in desert habitat has also been detected (Assaeed & Al-Doss, 2002; Chambers et al., 1991; Henderson et al., 1988). To our knowledge, a lesser number of studies are available on seed reserves in dunes, especially in Kerqin steppe. We conducted this study to determine the floristic composition of the vegetation and the soil seed bank in different types of dunes of Kerqin steppe. The aim of the study was (1) to evaluate the influence of desertification on the floristic composition, both of the vegetation and of the soil seed bank on the different types of sand dunes and interdunal lowland, (2) to determine which species groups are most represented in each of the above cases, and (3) to understand the relationship between the floristic composition of vegetation and the soil seed bank on the different types of sand dunes and interdunal lowland.

Materials and Methods

Study Area

The study was carried out at Naiman Desertification Research Station (lat. 42° 58′ N, long. 120° 43′ E, at an elevation of 345 m of Chinese Ecosystem Research Network (CERN), eastern Inner Mongolia, China, located at the southwestern end of Kerqin steppe, in a zone of continental semiarid monsoon climate. In this region, the geomorphologic landscape is characterized by sand dunes alternating with gently undulating interdunal lowlands where farmlands and grasslands are separately distributed. The native vegetation in this zone is characterized by ruderals and some grasses. The major species are *Artemisia halodendron*, *Salsola collona*, *Eragrostis pilosa*, *Caragana microphylla*, *Artemisia scoparia*, and *Setaria viridis* with lesser numbers of *Agriophyllum squarrosum*, *Lespedeza davurica*, *Hedysarum fruticosum* var. *ligosum*, and *Salix gordejevii*. The main meteorological conditions are summarized as follows by Liu et al. (1996): the mean annual air temperature is about 6.4°C, and the coldest and warmest monthly mean temperatures are 13.1°C of January and 23.7°C of July. The mean annual accumulated air temperature above 10°C ranges from 3000 to 3400°C. The frost-free period is 137–150 days per year. The mean annual precipitation is 362 mm nearly 70% of which falls from June through August. The mean annual pan evaporation is 2000 mm. Prevailing wind directions are northwest in winter and spring, and southwest to south in summer and autumn. The mean annual wind speed ranges from 3.4 to 4.1 $m \cdot s^{-1}$.

Dunes in this region could be classified into mobile sand dunes (MSD), semifixed sand dunes (SSD) and fixed sand dunes (FSD) according to Zhu's criteria (Zhu et al., 1989). If vegetation coverage was about to 30–50% and area of shifting sand accounted for about 5–20% of the total land surface of sand dune, then the dune was regarded as fixed sand dune. If vegetation coverage was reduced to 10–30% and area of shifting sand accounted for about 20–50% the total area of sand dune, then the dune was regarded as semifixed sand dune. If vegetation coverage was reduced to less than 10% and area of shifting sand accounts for more than 50% the total area of the sand dune, then the dune was regarded as mobile sand dune.

Selection of Sampling Plots

Four types of dunes were selected: fixed sand dunes (FSD), semifixed sand dunes (SSD), mobile sand dunes (MSD) and interdunal lowland (ILD). Three plots which were similar in size (about 60 × 50 m) and topography were selected in each type. In total, 12 plots were selected as study areas in the four types. The studied plots were randomly distributed on some sand dunes and interdune lowlands around the Naiman Station of Desertification Research, Chinese Ecosystem Research Network (CERN). All the plots which were slightly grazed were selected in August 2000 when the plants reached maximum biomass and coverage.

Sampling Method

Since seeds of most plants in a temperate zone need a period of low temperature treatment before germination, soil seed bank was sampled in spring (5 April, 2001), before the vegetation turns green. In each of the 12 plots described above, two 50-m parallel transects with 3-m intervals were established. The directions of the two transects were from northwest to southeast. Along each transect, five soil samples were taken at 10 m intervals, giving a total of 10 samples in each plot. Soil samples were from 0–5 cm (with litter) with the area of 20 × 20 cm. In August 2001, at the time of maximum plant diversity, a quantitative vegetation survey was conducted in each of these plots and species composition data were collected using a 1 m^2 quadrat along the two transects. The sample points were at 10 m intervals along each transect, giving a total of 10 sample points in each plot.

Greenhouse Method

In the laboratory, the soil samples were spread thinly ($\leq$2 cm) in separate plastic flats with 5 cm depths of fine sand. The flats were placed in a greenhouse and watered regularly to maintain soil moisture. Air temperature and humidity inside the greenhouse varied averagely from 12°C and 60% (night) to 30°C and 80% (day). Control flats filled with fine sand were interspersed among the seed bank sample flats on the greenhouse bench at a ratio of one control flat for every 10 sample flats. This provided a means for detecting potential contaminant seeds introduced to sample flats within the greenhouse. Identification and counting of seedlings was done weekly after the first seedling emerged from the soil. The identified seedlings were removed during counting. Those species which could not be identified at the seedling stage were transplanted to another flat for adult identification. Seedling identification and species nomenclature follow Liu & Yang (1991). The germination monitoring was ended at the end of August.

Data Analysis

The species making up the vegetation and the soil seed bank were classified into Poaceae, Fabaceae and other forbs. Seed densities detected in seed bank analysis were expressed as seeds m^{-2} to a depth of 5 cm In general, seed bank as well as vegetation data are far from fitting normal distribution, so this kind of quantification is performed by nonparametric tests. In this study, the seed and plant densities of species detected in seed banks and aboveground vegetation survey were compared in pairs by a nonparametric Mann-Whitney U test after a H-test by Kruskal-Wallis had revealed overall significant difference ($P < 0.05$). To compare similarities among sites, both in terms of species composition and abundance in the vegetation and in the seed bank, correspondence analysis (CA) was applied according the procedure of Sun (2001). The similarities between the seed banks and their associate vegetation were also examined using Spearman's rank correlation coefficient. Diversity indices of aboveground vegetation and soil seed bank were calculated separately for each site for Poaceae, Fabaceae, other forbs, and all species combined. Shannon-Weaver diversity (H) and equality (J) were calculated in the following way as described by Begon et al. (1986):

$$H = -\sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N}, J = \frac{H}{\ln S}, \tag{1}$$

where S is the number of species observed, N is the total number of individuals, and n_i is the number of individuals of species i.

Results

Aboveground Vegetation

In the four types of experimental sites, a total of 30 species (Table 1) were identified, of which eight were Poaceae, five were Fabaceae, and 17 were classified in other forbs. Among the 30 species, only 10 (33.3% of the total) were found in site MSD, 14 (47.3% of the total) in site SSD, and 25 (83.3% of the total) in both site FSD and site ILD. The dominant species in site MSD and site SSD vegetation were *Agriophyllum squarrosum* and *Setaria viridis*, respectively. In both site FSD and site ILD vegetation, the dominant species was *Eragrostis pilosa*. Although 30 species were encountered in the plant density quadrats, many species were represened by less than 1 individual m^{-2} in the four types of experimental sites (e.g., *Melissetus ruthenicus*, *Bassia dasyphylla,* and *Cynanchum thesioides* in site MSD; *Euphorbia esula*, *Chenopodium glaucum*, and *Ixeris denticulate* in site SSD; *Chloris virigata*, *Caragana microphylla*, *Melissetus ruthenicus*, *Cuscuta chinensis*, *Cynanchum thesioides*, and *Erodium stephanium* in site FSD; *Euphorbia esula, Cuscuta chinensis*, and *Gueldenstaedia verna* in site ILD).

The Kruskal-Wallis H-test showed that plant density varied highly significantly among the four sites (Chi-square = 19.466, df = 3, $P < 0.001$). Mann-Whitney U test revealed that most pairs of the experimental sites showed significant differences in plant density (e.g., MSD and FSD, $P < 0.001$; MSD and ILD, $P < 0.001$; SSD and FSD, $P < 0.05$; SSD and ILD, $P < 0.05$), except two pairs (MSD and SSD; FSD and ILD). Diversity statistics for aboveground vegetation revealed that overall, there were a greater number of species with Shannon-Weaver diversity in site FSD and site ILD

TABLE 1 Plant Density (Plant Number Per m^2) for Four Types of Experimental Sites Measured at Three Locations in Naiman, Inner Mongolia (Means ± SD, n = 30)[a]

Species	MSD	SSD	FSD	ILD
Poaceae				
Aristida adscensionis L.	0 ± 0	0 ± 0	13.6 ± 0.6	28.7 ± 1.4
Chloris virigata Swartz	0 ± 0	0 ± 0	0.3 ± 0.5	54.0 ± 12.7
Cleistogenes squarrosa (Trin.) Keng	0 ± 0	0 ± 0	14.6 ± 7.6	11.5 ± 4.7
Digitaria cillaris (Rotz.) Koeler	0 ± 0	0 ± 0	2.7 ± 0.7	2.2 ± 0.4
Eragrostis pilosa (L.) Beauv.	0 ± 0	0 ± 0	145.6 ± 46.8	273.8 ± 62.1
Pennisetum centrasiatum Tzvel.	0 ± 0	4.6 ± 1.5	2.1 ± 0.7	4.2 ± 0.8
Phragmites australis (Cav.) Trin. ex Steudel	1.9 ± 0.4	0 ± 0	0 ± 0	2.2 ± 0.8
Setaria viridis (L.) Beauv.	21.8 ± 4.6	138.7 ± 68.2	52.7 ± 33.6	17.0 ± 5.5
Fabaceae				
Caragana microphylla Lam.	0 ± 0	13.1 ± 4.5	1.2 ± 0.6	2.3 ± 0.6
Gueldenstaedia verna (Georgi) Boriss	0 ± 0	0 ± 0	0 ± 0	0.2 ± 0.4
Kummeowia stipulacea (Maxim.) Makino	0 ± 0	0 ± 0	0 ± 0	1.5 ± 0.9
Lespedeza davurica (Laxm.) Schindl.	0 ± 0	2.1 ± 0.8	48.1 ± 9.5	65.0 ± 12.3
Melissetus ruthenicus (L.) C. W. Chang	0.2 ± 0.4	2.1 ± 0.5	0.5 ± 0.5	0 ± 0
Other forbs				
Agriophyllum squarrosum (L.) Moq.	25.0 ± 6.9	0 ± 0	0 ± 0	0 ± 0
Allium bidentatum Fisch. ex Prokh	0 ± 0	0 ± 0	1.5 ± 0.8	1.0 ± 0.6
Artemisia halodendron Turcz. ex Bess.	3.2 ± 1.3	8.1 ± 3.1	2.3 ± 1.5	1.2 ± 0.8
Artemisia scorparia Waldst. et Kit	0 ± 0	0 ± 0	7.3 ± 4.7	16.2 ± 4.1
Bassia dasyphylla (Fisch.et Mey.) Kuntze	0.5 ± 0.5	17.3 ± 5.4	16.7 ± 7.5	6.2 ± 3.3
Carex duriuscula C. A. Mey.	0 ± 0	0 ± 0	2.3 ± 1.6	0 ± 0
Chenopodium glaucum L.	0 ± 0	0.1 ± 0.3	1.9 ± 0.8	5.8 ± 3.6
Corisperum dilutum (Kitag.) Tsien et C. G. Ma	7.5 ± 4.7	88.9 ± 23.6	2.7 ± 2.0	1.0 ± 0.6
Cuscuta chinensis Lam.	0 ± 0	0 ± 0	0.5 ± 0.5	0.3 ± 0.9
Cynanchum thesioides (Freyn) K.Schum.	0.1 ± 0.3	9.6 ± 2.4	0.7 ± 0.5	0 ± 0
Erodium stephanianum Willd.	0 ± 0	0 ± 0	0 ± 0	1.5 ± 0.6
Euphorbia esula L.	0 ± 0	0.3 ± 0.5	0.1 ± 0.3	0.2 ± 0.4
Euphorbia humifusa Willd	0 ± 0	0 ± 0	7.9 ± 3.2	5.5 ± 1.2
Ixeris denticulate (Houtt.) Stebb.	2.9 ± 0.4	0.7 ± 0.5	1.4 ± 1.2	0 ± 0
Salix gordejevii Chang et Skv	1.2 ± 0.4	1.3 ± 0.3	2.4 ± 1.0	1.2 ± 0.8
Salsola collona Pall.	0 ± 0	10.2 ± 3.6	15.3 ± 5.7	19.2 ± 6.9
Tribulus terrestris L.	0 ± 0	1.3 ± 0.8	1.9 ± 0.9	2.2 ± 1.2

[a]MSD = mobile sand dune, SSD = semifixed sand dune, FSD = fixed sand dune, ILD = interdunal lowland.

TABLE 2 Species Diversity Statistics for Above-Ground Vegetation in Four Experimental Sites[a]

	MSD	SSD	FSD	ILD
Poaceae (8)				
Number of species	2	2	7	8
Shannon-Weaver *H*	0.179	0.342	1.072	1.161
Shannon-Weaver *J*	0.258	0.493	0.551	0.559
Fabaceae (5)				
Number of species	1	3	3	4
Shannon-Weaver *H*	0	0.723	0.669	0.669
Shannon-Weaver *J*	0	0.658	0.608	0.483
Other forbs (17)				
Number of species	7	9	15	13
Shannon-Weaver *H*	0.623	0.661	2.156	2.226
Shannon-Weaver *J*	0.317	0.288	0.796	0.867
All species (30)				
Number of species	10	14	25	25
Shannon-Weaver *H*	0.617	0.648	1.684	1.792
Shannon-Weaver *J*	0.291	0.246	0.623	0.556

[a]MSD = mobile sand dune, SSD = semifixed sand dune, FSD = fixed sand dune, ILD = interdunal lowland.

than in site MSD and site SSD (Table 2). Diversity and equability statistics for other forbs were highest across four sites, but all the groups showed the increase trends in the sequence of MSD, SSD, FSD and ILD except for Fabaceae group.

Soil Seed Bank

A total of 3731 seeds germinated in the soil samples. Fifty eight died before they could be identified, and 3673 seedlings were identified into 25 species. Of these seven were Poaceae, five were Fabaceae, and thirteen were from other forbs. Among the 25 species, only nine (36% of the total) were found in site MSD, 16 (64% of the total) were found in site SSD, 20 were (80% of the total) were found in site FSD, and 21 (84% of the total) found in site ILD. The most abundant species in site MSD soil samples were *Agriophyllum squarrosum*. In SSD, FSD and ILD soil samples, the most abundant species were *Eragrostis pilosa*. The second most abundant species in all plots was the grass *Setaria viridis*, which was more abundant in soil from site FSD and site ILD (Table 3).

The Kruskal-Wallis H-test showed that number of germinable seeds in the seed bank differed significantly among the four sites (Chi-Square = 23.317, df = 3, $P < 0.001$). The number of seeds was highest in ILD soil samples, while FSD site had intermediate and SSD and MSD sites had lowest number of seeds. Seed density in a 5 cm layer ranged from 2302 m^{-2} (ILD site) to 57 m^{-2} (MSD site). Mann-Whitney U test revealed that most pairs of experimental sites showed significant differences in seed density (e.g., MSD and SSD, $P < 0.05$; MSD and FSD, $P < 0.001$; MSD and ILD, $P < 0.001$; SSD and FSD, $P < 0.05$; SSD and ILD, $P < 0.005$), except one pair (FSD and ILD). Diversity statistics for soil seed banks gave similar results with those for aboveground vegetation. Shannon-Weaver diversity revealed that there were a greater number of species in FSD and ILD soil samples and the species numbers of other forbs were highest across four sites. For all groups, the values of Shannon-Weaver diversity increased in the sequence of MSD, SSD, FSD and ILD (Table 4).

TABLE 3 Total Germinable Seed Density (Seed Number per m^2) in the Top 5 cm of Soil for Four Types of Experimental Sites Measured at Three Locations in Naiman, Inner Mongolia (Means ± SD, n = 30)[a]

Species	MSD	SSD	FSD	ILD
Poaceae				
Aristida adscensionis L.	0 ± 0	0 ± 0	117.0 ± 16.2	79.7 ± 5.7
Chloris virigata Swartz	0 ± 0	0 ± 0	0 ± 0	20.8 ± 1.6
Cleistogenes squarrosa (Trin.) Keng	0 ± 0	0 ± 0	12.5 ± 0.9	13.3 ± 0.8
Digitaria cillaris (Rotz.) Koeler	1.7 ± 0.4	14.9 ± 0.9	32.8 ± 2.4	11.6 ± 0.7
Eragrostis pilosa (L.) Beauv.	4.2 ± 0.5	22.4 ± 1.2	843.3 ± 37.4	1367.8 ± 69.2
Phragmites australis (Cav.) Trin. ex Steudel	0 ± 0	4.2 ± 0.5	1.7 ± 0.4	0.8 ± 0.2
Setaria viridis (L.) Beauv.	13.3 ± 0.8	79.7 ± 6.9	292.2 ± 15.2	361.9 ± 23.7
Fabaceae				
Caragana microphylla Lam.	0 ± 0	5.8 ± 0.5	12.5 ± 3.3	10.8 ± 2.7
Gueldenstaedia verna (Georgi) Boriss	0 ± 0	0 ± 0	0 ± 0	5.8 ± 0.5
Kummeowia stipulacea (Maxim.) Makino	0 ± 0	0 ± 0	0 ± 0	13.3 ± 1.6
Lespedeza davurica (Laxm.) Schindl.	0 ± 0	11.6 ± 0.7	77.2 ± 4.5	111.2 ± 7.7
Melissetus ruthenicus (L.) C. W. Chang	4.2 ± 0.5	9.1 ± 0.6	5.8 ± 0.5	5.8 ± 0.5
Other forbs				
Agriophyllum squarrosum (L.) Moq.	13.3 ± 0.6	1.7 ± 0.4	0 ± 0	0 ± 0
Amaranthus retroflexus L.	1.7 ± 0.4	0 ± 0	5.8 ± 0.5	0 ± 0
Artemisia halodendron Turcz. ex Bess.	10.8 ± 0.7	14.9 ± 1.1	7.5 ± 0.4	4.2 ± 0.4
Artemisia scorparia Waldst. et Kit	0 ± 0	1.7 ± 0.4	69.7 ± 2.3	166 ± 9.3
Bassia dasyphylla (Fisch. et Mey.) O. Kuntze	0 ± 0	0 ± 0	5.8 ± 0.5	22.4 ± 0.9
Chenopodium glaucum L.	0 ± 0	0 ± 0	49.0 ± 2.4	24.9 ± 1.5
Corisperum dilutum (Kitag.) Tsien et C. G. Ma	0 ± 0	9.1 ± 0.6	14.9 ± 1.1	14.9 ± 0.9
Cynanchum thesioides (Freyn) K. Schum.	0 ± 0	0 ± 0	5.8 ± 0.5	11.6 ± 0.7
Euphorbia humifusa Willd	0 ± 0	1.7 ± 0.4	45.7 ± 3.3	45.7 ± 4.2
Ixeris denticulate (Houtt.) Stebb.	4.2 ± 0.4	11.6 ± 0.7	4.2 ± 0.5	5.8 ± 0.5
Portulaca oleracea L.	4.2 ± 0.5	5.8 ± 0.5	0 ± 0	0 ± 0
Salsola collona Pall.	0 ± 0	4.2 ± 0.4	102.1 ± 6.6	0 ± 0
Tribulus terrestris L.	0 ± 0	1.7 ± 0.3	0.8 ± 0.2	4.2 ± 0.5

[a]MSD = mobile sand dune, SSD = semifixed sand dune, FSD = fixed sand dune, ILD = interdunal lowland.

TABLE 4 Species Diversity Statistics for Soil Bank in Four Experimental Sites[a]

	MSD	SSD	FSD	ILD
Poaceae (7)				
Number of species	3	4	6	7
Shannon-Weaver *H*	0.401	0.561	0.979	1.016
Shannon-Weaver *J*	0.365	0.405	0.546	0.522
Fabaceae (5)				
Number of species	1	3	3	5
Shannon-Weaver *H*	0	0.461	0.608	0.675
Shannon-Weaver *J*	0	0.420	0.553	0.419
Other forbs (13)				
Number of species	5	9	11	9
Shannon-Weaver *H*	0.995	1.186	1.804	1.785
Shannon-Weaver *J*	0.618	0.540	0.752	0.812
All species (25)				
Number of species	9	16	19	21
Shannon-Weaver *H*	0.762	0.939	1.688	1.508
Shannon-Weaver *J*	0.347	0.339	0.573	0.495

[a]MSD = mobile sand dune, SSD = semifixed sand dune, FSD = fixed sand dune, ILD = interdunal lowland.

Of the 25 species present in the seed bank, 23 species were detected in the aboveground vegetation. Only two seed bank species were not present in the vegetation. The relationship between aboveground vegetation and soil seed bank was analyzed by a correspondence analysis (Figure 1). In the ordination diagram,

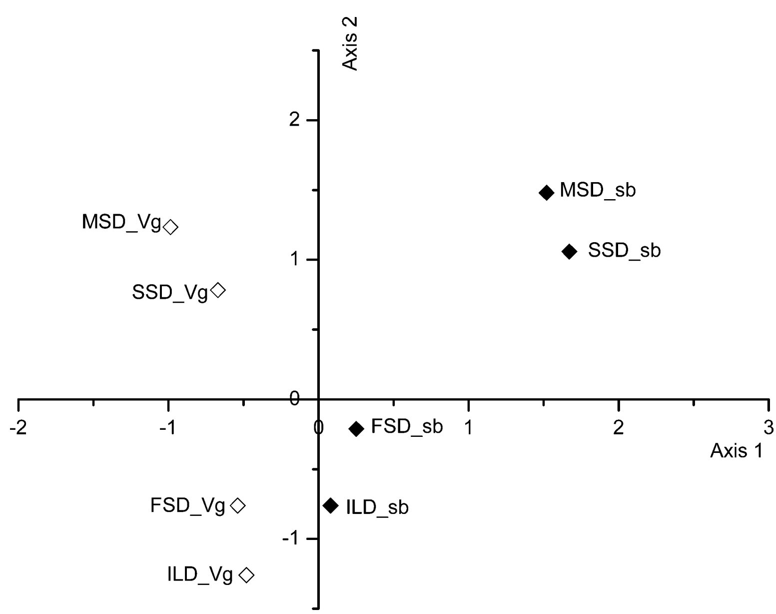

FIGURE 1 Scatter diagram of CA ordination (Aboveground vegetation and soil seed bank) on frequency data of sampling site. (Vg-aboveground vegetation; sb-soil seed bank; MSD-mobile sand dune; SSD-semifixed sand dune; FSD-fixed sand dune; ILD-interdunal lowland).

TABLE 5 Spearman Correlation Indices and Significance Level Between Floristic Composition and Soil Bank Frequency

Types of Desertified Land	N	Spearman's *rho*
Mobile sand dune	14	0.295
Semi fixed sand dune	22	0.046
Fixed sand dune	28	0.704*
Interdunal lowland	29	0.612*

N: species number in each type of desertified land.
*: Correlation is significant at $P = 0.01$.

aboveground vegetation and soil seed bank of the four sites were separated along the second axis. The four sites arranged in the same order along the second axis. This shows that the composition of the seed bank is related to its associate vegetation. The distances between aboveground vegetation and soil seed bank are greater in sites MSD and SSD, which indicate a decrease in correlation between vegetation and seed bank when desertification occurred. Spearman's rank correlation coefficients also confirmed this result (Table 5). In sites FSD and ILD seed bank composition was significantly correlated with aboveground vegetation ($P<0.01$). In sites MSD and SSD, the correlations between vegetation and seed bank were not significant.

Discussion

The comparison of vegetation on the four sites revealed that interdunal lowland (site ILD) as well as fixed sand dune (site FSD) are characterized by species richness and a higher species diversity than semifixed sand dune and mobile sand dune (site SSD and site MSD) as also described by other authors (e.g., Cao et al., 2000; Liu et al., 1996). Furthermore, most of the abundant species on site MSD and site SSD are ruderals (e.g., *Setaria viridis*, *Agriophyllum squarrosum*, and *Corisperum dilutum*) which are mainly typical of severely degraded grasslands (Zhao et al., 1993). Percentage of floristic groups based on plant density differed among the four sites (Figure 2). Plant density of Poaceae group increased in the sequence of MSD, SSD, FSD, and ILD, and that of the other forbs group decreased in such sequence. Such trends were also observed in seed bank investigation (Figure 2). These differences can be ascribed mainly to different desertification processes, and also can be regarded as different processes of vegetation restoration (Liu et al., 1996).

The seed bank in the four sites at Kerqin steppe were relatively small both in size and species number, which is a common feature of grasslands in temperate regions in general (Parker et a1., 1989). In each site, more than half of the seeds recorded belonged to only several species (e.g., *Agriophyllum squarrosum*, S*etaria viridis*, and *Artemisia halodendron* in site MSD; *Setaria viridis*, *Eragrostis pilosa*, and Artemisia *halodendron* in site SSD; *Eragrostis pilosa* and *Setaria viridis* in site FSD and site ILD). This means that seed banks of most species are transient in desertified grasslands. The number of species and seeds in the seed bank declined significantly in the processes of desertification development. In site SSD and site MSD, the number of species and seeds in the seed bank was rather low. The possible reason was a low seed production. The plant density and species numbers of aboveground vegetation in these two sites were significantly low. Therefore, the capacity of seed production in these two sites is relatively weak.

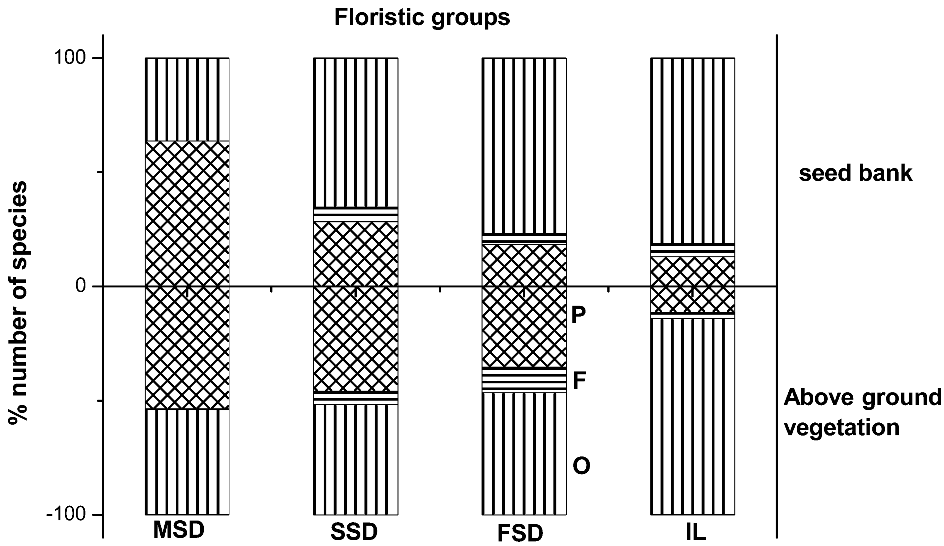

FIGURE 2 Percentage number of species in vegetation and soil seed bank (0–5 cm) for different types of desertified land classified according to floristic group (P-Poaceae; F-Fabaceae; O-Other forbs; MSD-mobile sand dune; SSD-semifixed sand dune; FSD-fixed sand dune; ILD-interdunal lowland).

Although the correlations between vegetation and seed bank were not significant in site MSD and site SSD, more than half of the species recorded in aboveground vegetation were found in the seed bank, even more in the seed bank of site FSD and site ILD. In site FSD and site ILD, a high correspondence was observed between the species composition of the aboveground vegetation and of the associated soil seed bank. Most species with high seed densities in the soil were also frequent in the aboveground vegetation. These findings were different from most of the results obtained in seed bank studies of grasslands (Rice, 1989; Thompson, 1986). Most species recorded both in seed bank and vegetation investigations were annual species and the most abundant species were also annual species, which indicated that large plant density of annual species had high capacity of producing persistent seed bank. Willems (1983) also suggested that the richness of the species should be related to that of the seed bank, although the abundance of some species varies as a function of their reproductive strategies.

Conclusions

Desertification development in a sandy grassland will result in vegetation degradation, and degraded vegetation gradually loses its ability to produce persistent seed bank which is important in vegetation restoration. In the four sites, severely desertified land (site MSD and site SSD) contained relatively power species than slightly desertified land (site FSD and ILD) in both aboveground vegetation and soil seed bank investigations. Species diversity and density (including plant density and seed density) increased in the sequence of MSD, SSD, FSD and ILD. These variations may characterize different desertification processes. These results also suggest that seed input may be an effective way to accelerate vegetation restoration in severely desertified land. Correlation analyses and Spearman's rank correlation coefficients revealed that aboveground vegetation correlated to soil seed bank, especially in site FSD and ILD, and correlations between aboveground vegetation and soil seed bank changed with desertification development.

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