Determining the Width of Buffer Zone for Open-Forest Nature Reserve in Hunshandak Sandland*

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Abstract: Many nature reserves have been established for conserving forests throughout the world. Creating a buffer zone around a core area is often suggested, but determining the width of the buffer zone is a challenge. The soil seed bank is an important indicator for the restoration capacity of a degraded vegetation ecosystem. This could be useful for designing nature reserves. According to the restoration potential and similarity index of seed banks of some sites with different distances from the core zone, the minimum width of a buffer zone can be determined. Different samples, outside of the core zone, with a different distance from the boundary of the core zone were chosen. Analysis of variance was used to analyze species, seedling and seed banks among different samples, the Sorensen's similarity index was calculated. Based on a field survey, the buffer zone of the open-forest nature reserve in Hunshandak Sandland, China has been designed. The minimum width of buffer zone should be 300 m in lowland, 600 m in shifting sandy dunes, and 1 000 ~ 1 200 m in fixed and semi-fixed sandy dunes. Seed bank approaches will be useful for determining the buffer zone width of the forest nature reserve and can be applied and extended to the other nature reserves which aim at preserving endangered species/ecosystems and their habitats.

Key words: nature reserve; buffer zone; open-elm-forest; soil seed bank; similarity index; Hunshandak Sandland

浑善达克榆树疏林自然保护区缓冲区宽度研究

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摘 要：世界上建设有很多森林自然保护区以保护各种类型的森林，自然保护区的核心区外围常常要求建设缓冲区，但是如何设计缓冲区宽度的研究很少。土壤种子库是衡量退化森林生态系统生态恢复潜力的重要指标，利用种子库进行缓冲区的设计。采用植物群落学调查及种子库分析的方法，在核心区内外选择一系列样方，调

* **收稿日期**：2012 - 02 - 22
基金项目：中央民族大学 985 工程资助项目（MUC98504 - 14；MUC9850 7 - 08）；高等学校学科创新引智计划资助项目（2008 - B08044）
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查样方种子库及其地面的植物种类组成，计算样方与核心区种子库、植物群落的相似性指数，根据核心区外不同距离的样方的相似性指数，确定了缓冲区的宽度。研究结果发现，缓冲区最低宽度在低地为 300 m，在流动沙地为 600 m，在固定沙地和半固定沙地为 1 000 ~ 1 200 m。对于沙漠化地区的自然保护区缓冲区的设计有一定的借鉴价值。

关键词：自然保护区；缓冲区；榆树疏林；土壤种子库；相似性指数；浑善达克沙地

中图分类号：Q948　　**文献标志码**：A　　**文章编号**：0529 - 6579（2012）05 - 0078 - 08

The world's forests are lost at an estimated annual rate of 14. 6 million ha[1]. Between 1990 and 2000, about 2. 3 million ha of forests in Southeast Asia were cleared every year and changed to other forms of land use [2]. Nature reserve is an effective approach to conserve forests throughout the world. The nature reserve, created by UNESCO's Man and the Biosphere Program (MAB), includes delineation of core zone surrounded by a buffer zone and then a transition zone. The core area excludes all human disturbances except for scientific research. Activities such as research, education, training and tourism, which do not conflict with the protection of the core zone, are allowed within the buffer zone, while development activities are permitted in the transition area [3]. Establishing a buffer zone can protect the core zone more effectively, and at the same time compensate the local inhabitants for their loss of access to biological resources within the reserve [4]. Buffer zones, even as narrow as 200 m wide, can effectively protect reserves and reduce negative edge effects [5]. Although designing a buffer zone outside of the core zone is often suggested, there are few studies about how to determine its width. Some buffer zones were only determined by descriptive methods, not quantitative ones [6]. For endangered species, some researchers used suitable habitats as the factor to zone the nature reserve [7-8]. However, these studies focused on animal or bird species. For plant species, Wan et al. [9] suggested to design the buffer zone by vegetation successional stage. However, in sandland or desert areas, aboveground vegetation is rare and discontinuous. Here we used seed bank data as a method to determine the width of a buffer zone for a forest nature reserve in sandland.

Soil seed bank is a major theme in current ecological research[10]. Soil seed bank is comprised of all viable seeds present above or in the soil or associated leaf litter [12]. Soil seed bank is regarded as a stage in the life cycle of a plant community [13]. It is not only the base for forest establishment, but also reveals the dynamic process of forest community succession [10, 11]. Soil seed distribution plays a major role in, and is positively related to, the distribution of mature plants [14]. As for the forest in sandland, the seed bank is particularly important. Forests in sandland ecosystems are often sparsely distributed, usually with open bare patches among tree groups [15]. Some seeds can colonize the bare soil[16]. In some cases, bare soil areas are more favorable for seedling establishment regarding to survival probability than sites near individual plants [17]. From this point of view, it is reasonable to assume that soil seed bank is an important indicator in determining a degraded forest's potential for restoration.

Because the core zone in a nature reserve is the most important area to be protected, if a site outside the core zone is similar in terms of its seed bank to that of the core zone, this site should have some conservation value. With increasing distance from the core zone, the similarity between seed banks of the area and the core zone should decrease and, the conservation value will also decrease. Once we determine the endpoint with least similarity to the core zone, both in species composition and in species number, the minimum width of the buffer zone can be determined.

1　Methods

1. 1　Study area

The investigation was conducted in and outside of the core zone in the potential Hunshandak Nature Reserve (located in Zhenglan Banner, 43°56′47" N, 116°08′15" E) in Hunshandak Sandland, Inner Mongolia, China. The Hunshandak Nature Reserve, a proposed project with area of 6 212 km^2, aims to protect open-forest in Hunshandak Sandland in Inner Mongolia, China. The open-forest is a natural vegetation type in Hunshandak Sandland, with a landscape quite similar with that of Savanna in South Africa. Elm trees (*Ulmus pumila* L.) are sparsely and randomly distributed in the sandland, usually clustered together with 3 ~ 5 plants, with crown coverage ranging from only 20% to 30 % of the land surface. *Ulmus pumila* is a unique species that only occurs in sandland in northern China. *Ulmus pumila* has been identified as a key species in the ecosystem of open-forest. For the conservation of this landscape, *Ulmus pumila* should be given conservation priority.

The habitats of open-forest could be classified into four types: fixed sand dune, semi-fixed sand dune, shifting sand dune (the main body of sandland, accounting for 43% of total area), and lowland. The proposed nature reserve aims to 1) restore degraded open-forest, and 2) preserve this unique landscape. In recent years, this area has been degraded sharply. Many fixed sandy dunes have transformed into shifting dunes, and the ratio of area in shifting sandland to total land increased from 14% in 1950 to 43% in 2002, and is still increasing. This directly endangers open-forests. Degradation of the open-forest is also due to overgrazing and human disturbance [8,18]. With the establishment of a nature reserve, the grazing in potential core zone and buffer zone would be prohibited, and open-forest should be restored.

The prevailing climate in the study area is the temperate arid and semi-arid type. The average annual temperature is about 1.7 ℃ (16.6 ℃ in July and -24. ℃ in January). Annual precipitation is about 250 ~ 350 mm, with uneven distribution throughout the year. The strong wind, with an average speed of 7 ~ 8 $m \cdot s^{-1}$, and the strongest of 30 $m \cdot s^{-1}$, greatly intensifies the degradation of forests. The annual transpiration is 2 000 ~ 2 700 mm. The zonal soil is brown calcium soil in lowland. *Artemisia frigida*, *Polygonum divaricatum* and *Agropyron desertorum* are dominant in the semi-shifting sand dune and fixed sand dune, while *Iris lactea* var. *chinensis*, *Chenopodium glaucum* and *Potentilla sericea* are most common in the lowland. *Agriophyllum squarrosum* is most common in shifting sand dunes.

1.2 Soil seed sampling

Seed bank sampling and analysis were carried out according to the method of Ter-Heerdt et al. [19]. Soil seed samples were taken in spring (from 3 February to 25 March) of 2005 before seed germination. Four different plots, outside of the core zone, with a distance of 300, 600, 900 and 1 200 m from the boundary of the core zone were chosen. In each plot, four different microhabitats were selected as subplots: shifting sandy dune, semi-fixed sandy dune, fixed sandy dune and lowland. In each subplot, 10 quadrats, each measuring 25 cm (25 cm, were chosen and the distance between adjacent quadrats was about 1 m. All quadrats were marked by inserting a colored steel tube. The upper 5 cm of soil in each quadrat was collected. The soil was sieved passing a 0.15 mm mesh. The seeds remaining in the sieve were put in seed trays and then placed in a greenhouse to germinate. Seedlings were identified and counted. In the third month, a full seed bank estimation was obtained (seedlings from seeds + ungerminated seeds) for each subplot.

In order to compare these with the seed bank of the core zone in the proposed nature reserve, the same sampling strategy was used in the core zone. The representative habitats in the core zone were selected as reference and ten 25 cm (25 cm quadrats were chosen. These were placed about 1m apart from each other. The sampling method and analysis were similar as the above.

1.3 Vegetation analysis

In July of 2005, during the peak of the local plant growth season, the vegetation was sampled in adjacent areas to the seed bank sample subplots in all plots in the core zone. In each subplot, 4 quadrats with a size of 1 m × 1 m each, were randomly selected. In each quadrat, species composition and percent coverage were identified and counted.

1.4 Data analysis

Analysis of variance (ANOVA) was used to analyze species, seedling and seed banks among subplots. For each subplot (habitat), the Sorensen's similarity index (SI) was calculated [20]. This measures the similarity in species composition for two sites, A and B, by the equation

$$SI = \frac{2ab}{a+b} \times 100\%,$$

where a is the number of species found in site A; b is the number of species in site B and ab is the number of species shared by the two sites. Similarity index values range from 0 (when no species are shared between any two communities) to 1 (when all species are shared).

For SI between seed bank and its aboveground vegetation (SI_{sv}), a is the number of species found in the seed bank in one site, b is the number of species in aboveground vegetation in this site and ab is the number of species shared by the seed bank and its aboveground vegetation in the site.

For SI between the sites out of the core zone and in the core zone, a is the number of species found in one site outside of core zone, b is the number of species found in sites in the core zone and ab is the number of species shared by both sites.

SI_{vv} was calculated for species in vegetation between two sites, and SI_{ss} was calculated for seed bank between two sites. SI_{sv}, SI_{vv} and SI_{ss} were calculated in each quadrat, with a distance of 300, 600, 900 and 1 200 m from the core zone, respectively.

The total similarity between one site outside of the core zone and the site within the core zone was calculated as the equation

$$SI_t = \frac{1}{2}(SI_{vv} + SI_{ss}).$$

Table 1　The seed bank density, species, functional types and their composition of vegetation in the core zone of planed nature reserve in Hunshandak Sandland, China

Species	Percentage in vegetation /%	Seed bank density/m^{-2}	Functional types[1)]
Agriophyllum squarrosum	0	20 (7	A, D
Aristida adscensionis	59.3	96 (72	P, D
Artemisia lavandulaefolia	19.5	9 (6	P, D
Artemisia ordosica	19.5	64 (43	A, D
Artemisia scoparia	97.3	2 295 (590	A, D
Bassia dasyphylla	52.6	9 (4	A, D
Calamagrostis epigejos	13.1	0	P, D
Chenopodium glaucum	72.4	145 (90	A, D
Chloris virgata	13.1	2 (2	A, M
Cleistogenes squarrosa	13.1	67 (40	P, D
Corispermunm sp	52.6	61 (27	A, D
Cynanchum thesoioides	13.1	0	A, M
Eragrostis poaeoides	0	16 (9	A, M
Erodium stephanianum	33	7 (2	A, D
Euohorbia humifusa	72.4	116 (35	A, D
Euphorbia esula	13.1	2 (1	A, M
Gueldenstaedtia stenophylla	19.5	0	P, L
Inula salsoloides	13.1	0	A, D
Ixeris denticulate	33	4 (3	P, M
Kummerowia striata	13.1	0	A, M
Lespedeza sp	59.3	60 (30	P, L
Leymus secalinus	59.3	8 (2	P, M
Melissitus ruthenicus	52.6	20 (10	P, L
Penisetum centrasiaticum	52.6	5 (3	A, M
Portulaca oleracea	0	4 (1	A, D
Potentilla bifurca	0	7 (1	P, D
Psammochloa villosa	52.6	4 (2	P, M
Salsola collina	52.6	60 (29	A, D
Setaria viridis	72.4	268 (114	A, M
Tribulus terrestris	0	2 (2	A, D
Ulmus pumila	7.8	1 158 (282	P, F

1) A = annual grasses; P = perennial species; D = Dicotyledons; M = monocotyledons

2 Results

2.1 Seed bank density

The seed bank density, and representation in standing vegetation of different species in the core zone are listed in Table 1. Comparable data of increases distances from the core zone are shown in Table 2. With increase of the distance from boundary of core zone, seed density of *Ulmus pumila* in four habitats decreased with different degree (Table 2). This decrease was most obviously in shifting sandy dune, followed by semi-fixed sandy dune, fixed sandy dune and lowland. No seeds of *Ulmus pumila* were found beyond 1 200 m, regardless of the habitat. For shifting sandy dune, no seed could be found when the distance beyond 900 m.

Table 2 The seed density of *Ulmus pumila* in the distances with 300m, 600m, 900m and 1200m from the core zone of planed Hunshandak Nature Reserve in Hunshandak Sandland, China seed /m²

Site types	300 m	600 m	900 m	1200 m
Shifting sandy dune	92.2 ±21.3	12.2 ±5.3	0	0
Semi-fixed sandy dune	164.7 ±24.8	24.5 ±6.7	1.2 ±0.7	0
Fixed sandy dune	181.4 ±35.5	27.2 ±11.2	4.8 ±3.6	0
Lowland	117.3 ±27.6	13.6 ±7.4	5.9 ±2.8	0

2.2 Relationship between seed bank and vegetation

A close relationship of species composition was found between seed bank and established vegetation in all samples (Fig. 1). SI_{sv} varied from 21.2% to 82.3%. Similarity indices of fixed sandy dune were larger (65.8 ~82.3%) at all distances, while those of semi-fixed sandy dune were also large, but decreased sharply (from 64.6% to 34.7%) with increasing distances from 300 m to 1 200 m. However, with increasing of distance, the similarity indices of lowland increased. For shifting sandy dune, the index remained almost constant (Fig. 1).

2.3 Similarity between sites outside and inside of the core zone

Among four habitats, SI_t of fixed sandy dune was the largest (54.8% ~ 95.2%), followed by semi-fixed sandy dune, shifting sandy dune and lowland (Fig. 2). SI_t decreased with the distance increased from 300 m to 1 200 m, that of fixed sandy dune and semi-fixed sandy dune decreased sharply, whereas that of shifting sandy dune and lowland decreased more slowly.

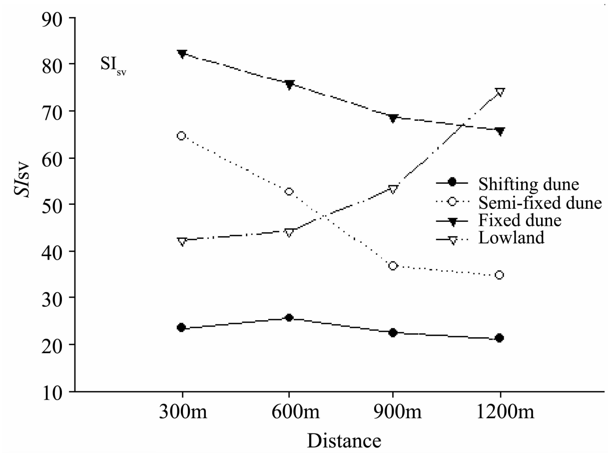

Fig. 1 Similarity indexes between seed bank and its aboveground vegetation of four habitats with a distance of 300, 600, 900 and 1 200 m from the core zone, respectively, in planed biosphere reserve in Hunshandak Sandland, China

In order to analyze the difference between similarity indices of vegetation (SI_{VV}) and that of seed bank (SI_{SS}), the values of each of these indexes were also calculated (Fig. 2). Averagely SI_{SS} was larger than SI_{VV}, regardless distances or habitats. Both SI_{SS} and SI_{VV} exhibit the same trend as that of SI_t.

3 Discussion and conclusion

Seed banks frequently offer the seed source for vegetation restoration [21-22]. The number and species composition in a seed bank is determined by the seed bank's age, distance to mother plant, soil properties and more importantly, disturbance. For example, a 70 years old forest, in its early stage, has a rich soil seed bank, however, the soil seed density in the site with a distance of 150 m to the forest, was only one third of the forest site [23]. With the increase of distance, the soil seed density could change from 6 065 ind · m^{-2} to 944 ind · m^{-2} [24]. This indicated that with the increase of distance from the core zone, the contribution of seed bank to potential restoration decreased.

Seed banks are also influenced by grazing and human disturbance. Grazing can also decrease the species

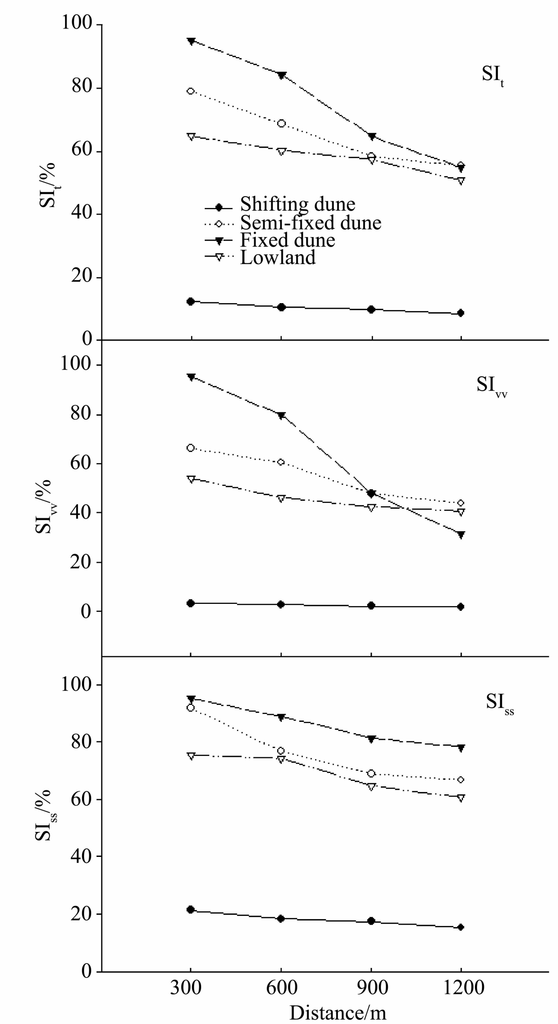

Fig. 2　Similarity indexes in seed bank (SI_{ss}), vegetation (SI_{vv}) and its mean value (SI_t) in four habitats with a distance of 300, 600, 900 and 1 200 m from the core zone, respectively, in planed biosphere reserve in Hunshandak Sandland, China

diversity in the seed bank [25]. Still, although grazing can decrease the soil seed number of a majority of plant species, some species can be increased [26]. Smith et al. (2002) reported that in a degraded meadow in its 10 yr restoration [27], the number of plant species both in vegetation and in the seed bank continued to increase with the increase of its restored time. Thus, it should consider influences of disturbance when determining the width of buffer zone.

Seed disperse method is another factor should be consideration when determining buffer zone. Seeds of *Ulmus pumila* are dispersed by wind, the direction of wind and prevailing climate need take into account [28]. Our research showed that even with a long distance (900 m), the seed density of *Ulmus pumila* still was rich. This is perhaps because *Ulmus pumila* disperse its seeds by wind, and we sampled in the foot of dunes downwind from maturity *Ulmus pumila*. However, considering that all samples were measured following the same method and located in same wind direction, the differences in seed bank among different sampling sites induced by wind direction can be ignored.

The species composition between seed bank and adjacent vegetation in our research was not the same. The main reason may be due to the effects of heavy livestock grazing. In the proposed Hunshandak Nature Reserve, livestock grazing was the main disturbance and reason for the degradation of the open-forest. Obviously, grazing has less effect on seed bank than on vegetation, which was proved by our results (SI_{sv} , SI_{VV}). Compared with that of vegetation in the same site, the species composition of the seed bank was more similar with that of core zone. This implies that some areas around the core zone could be restored, once it is protected as a buffer zone, because they have sufficient seed bank underground.

SI_{SS} index shows the degree of similarity in seed banks between sampled sites and core zone, the higher the SI_{SS} value, the higher the conservation value. Furthermore, since we also know that the seed bank has the potential to regenerate vegetation, a site with high SI_{SS} has a high potential to restore vegetation after establishment of a buffer zone. SI_{VV} showed that under the grazing disturbance, the similar degree in vegetation between sampling sites and core zone. Thus, it could be regarded as the second indicator to determine the width of buffer zone. Seed density of *Ulmus pumila*, a key species in open-forest ecosystem, could also be regarded an important indicator for the establishment of forests,.

Around the core zone, there are four habitats. According to our results, using three kinds of indicators, the width of buffer zone in shifting sandy dune, should be at least 600 m. And vegetation in shifting sandy dune should be restored into elm forest. For fixed sandy dune, the width of buffer zone should be moderate, because similar vegetation already existed. If the width of buffer zone is too narrow, the possibility of disturbance will be increased. Also, if the width of buffer zone is too broad, the land use for industry or intensive agriculture would be limited. Lowland was the main grazing place for livestock of local residents, and, lowland also has less importance to the conservation of core zone for its low seed density of *Ulmus pumila*, SI_t, SI_{ss} and SI_{VV}. The width of lowland, therefore could be reduced to 300m. But in this case, the boundary should be strictly protected. As for semi-fixed sandy dune, the width should range from 600 ~ 1 200 m, according that of fixed and shifting sandy dune.

The determination of the width of the buffer zone, should also take into account land use, such as tourism, environmental education and training[8]. Thus, the width of the buffer zone should be as large as possible. The maximum width of the buffer zone, which was approved by the local government, was 5 km. However, in some areas of potential buffer zone, for example where there is industrial land use, the width was ordered to be limited to less than 200 m. Still, the local government was concerned that a 200 m width in some industrial area was not sufficient to conserve open-forest. Also, many local inhabitants lived in the proposed buffer zone, and we suggest that the proposed buffer zone width be determined in cooperation with them where possible.

Although seed bank can be regarded as an indicator to determine the width of buffer zone, it would be limited in many cases. For multiple goals, for example, grassland, wetland or rain forest, there exist many kinds of vegetation. Still, considering that soil seed bank distributes more complicated in mountain areas, therefore, using the soil seed bank to determine the width of the buffer zone was limited to nature reserve in plain areas. Determining the buffer zone must also consider the policies of local government and requirements of the local inhabitants. In the all, soil seed bank could be used as indicator for determine duffer zone aiming at preserving endangered plant species, forest, grassland, or shrub with simple composition in plain region.

In conclusion, using seed bank as an indicator to determine the width of the buffer zone in the proposed open-forest nature reserve, the minimum width should be 300 m in lowland, 600 m in shifting sandy dunes, and 1 000 ~ 1 200 m in fixed and semi-fixed sandy dunes. If approved by local government and local residents, the width should be extended even further. Soil seed bank approaches can be useful for determining the buffer width of endangered plant species, or simple vegetation and their habitats in plain areas.

Acknowledgements: The authors would like to express thanks to Professor Charles M. Peters, from New York Botanical Garden, for his suggestions and English improvement.

References:

[1] INNES J L, ER K H. Global forest regulation in the ten years after Rio Conference [J]. Trends in Ecology and Evaluation, 2002, 17: 445.

[2] PHATA N K, KNORRA W, KIM S. Appropriate measures for conservation of terrestrial carbon stocks—analysis of trends of forest management in Southeast Asia [J]. Forest Ecology Management, 2004, 191:283 – 299.

[3] WRI, IUCN, UNEP. Global biodiversity strategy [M]. 2002.

[4] BRIDGEWATER P B. Nature reserves: special places for people and nature [J]. Environmental Science & Policy, 2002, 5:9 – 12.

[5] GÖTMARK F, SUNDERLAND H, THORELL M. Buffer zones for forest reserves: opinions of landowners and conservation value of their forest around nature reserves in southern Sweden [J]. Biodiversity and Conservation, 2000, 9:1377 – 1390.

[6] CORRELL D L. Principles of planning and establishment of buffer zones [J]. Ecological Engineering, 2005, 24: 433 – 439.

[7] LI W J, WANG Z J, MA Z J. Designing the core zone in a biosphere reserve based on suitable habitats: Yancheng Biosphere Reserve and the red crowned crane (*Grus japonensis*) [J]. Biological Conservation, 1999, 90:167 – 173.

[8] 秦新生，张荣京，陈红锋，等. 海南岛石灰岩地区珍稀濒危植物及其保护 [J]. 中山大学学报:自然科学版，2005，44: 291 – 298.

[9] WAN S W, QIN P, LI Y, et al. Wetland creation for rare waterfowl conservation: A project designed according to the principles of ecological succession [J]. Ecological Engineering, 2001, 18:115 – 120.

[10] KIRKHAM F W, KENT M. Soil seed composition in relation to the aboveground vegetation in fertilized and unfertilized hay meadows on a Somerset peat moor [J]. Journal of Applied Ecology, 1997, 34:889 – 902.

[11] AKINOLA M O, THOMPSON K, HILLIER S. H Development of soil seed banks beneath synthesized meadow communities after seven years of climate manipulations [J]. Seed Science Research, 1998, 8:493 – 500.

[12] SHUMWAY S W. Facilitative effects of a sand dune shrub on species growing beneath the shrub canopy [J]. Oecologia, 2003, 124: 138 – 148.

[13] HARPER J L. Population biology of plants [M]. London, UK: Academic Press, 1997.

[14] SCHENKEVELD A J, VERKAAR H J. The ecology of short-lived forbs in chalk grasslands: distribution of germinative seeds and its significance for seedlings emergence [J]. Journal of Biogeography, 1984, 11:251 – 260.

[15] CHARLEY J L, WEST N E. Plant induced soil chemical patterns in some shrub-dominated semi-desert ecosystemts in Utah [J]. Journal of Ecology, 1975, 63: 945 – 963.

[16] CHAMBER J E, MACMAHON J A, HAEFNER J H. Seed entrapment in alpine ecosystems: effects of soil particle size and diaspore morphology [J]. Ecology, 1991, 72:668 – 1677.

[17] AGUIAR M R, SALA O E. Competition, facilitation, seed distribution and the origin of patches in a Patagonian steppe [J]. Oikos, 1994, 70:26 – 34.

[18] 张佳华, 姚凤梅, 郑凌云. 中国藏北高寒生态遥感植被变化及成因分析[J]. 中山大学学报:自然科学版, 2009,48: 143 – 147.

[19] TER-HEERDT G N J, VERWEIJ G L, BEKKER R M, et al. An improved method of seed bank analysis: seedling emergence after removing the soil by sieving [J]. Functional Ecology, 1996, 10:144 – 151.

[20] MAGURRAN A E. Measuring biological diversity [M]. London:Blackwell Science Ltd, 2003.

[21] AKINOLA M O, THOMPSON D, BUCKLAND S. Soil seed bank of an upland calcareous grassland after 6 years climate and management manipulations [J]. Journal of Applied Ecology, 1998, 35:544 – 552.

[22] PYWELL R F, PUTWAIN P D, WEBB N R. The decline of heathland seed populations following the conversion to agriculture [J]. Journal of Applied Ecology, 1997, 34: 949 – 960.

[23] YOUNG K R, EWEL J J, BROWN B J. Seed dynamics during forest succession in Costa Rica [J]. Vegetatio, 1987, 71:157 – 17.

[24] KALAMEES R, ZOBEL M. Soil seed bank composition in different successional stages of a species rich wooded meadow in Laelatu, western Estonia [J]. Acta Oecologica, 1998, 19:175 – 180.

[25] MEISSNER R A, FACELL J M. Effects of sheep exclusion on the soil seed bank and annual vegetation in chenopod shrublands of South Australia [J]. Journal of Arid Environments, 1999, 42:117 – 128.

[26] JUTILA B E, HELI M. Seed bank of grazed and ungrazed Baltic seashore meadows [J]. Journal of Vegetation Science, 1998, 9:395 – 408.

[27] SMITH R S, SHIEL R S, WARD D M, et al. Soil seed banks and the effects of meadow management on vegetation change in a 10 – year meadow field trial [J]. Journal of Applied Ecology, 2002, 39:79 – 293.

[28] MEDJIBE V, HALL J S. Seed dispersal and its implications for silviculture of African mahogany (*Entandrophragma* spp.) in undisturbed forest in the Central African Republic [J]. Forest Ecology Management, 2002, 170:249 – 257.