Long-Term Ecosystem Effects of Sand-Binding Vegetation in the Tengger Desert, Northern China

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Abstract

The planting of sand-binding vegetation in the Shapotou region at the southeastern edge of the Tengger Desert began in 1956. Over the past 46 years, it has not only insured the smooth operation of the Baotou–Lanzhou railway in the sand dune section but has also played an important role in the restoration of the local eco-environment; therefore, it is viewed as a successful model for desertification control and ecological restoration along the transport line in the arid desert region of China. Long-term monitoring and focused research show that within 4–5 years of establishment of sand-binding vegetation, the physical surface structure of the sand dunes stabilized, and inorganic soil crusts formed by atmospheric dust gradually turned into microbiotic crusts. Among the organisms comprising these crusts are cryptogams such as desert algae and mosses. In the 46 years since establishing sand-binding vegetation, some 24 algal species occurred in the crusts. However, only five moss species were identified, which was fewer than the species number in the crust of naturally fixed sand dunes. Other results of the planting were that near-surface wind velocity in the 46-year-old vegetation area was reduced by 54.2% compared with that in the moving sand area; soil organic matter increased from 0.06% in moving sand dunes to 1.34% in the 46-year-old vegetation area; the main nutrients N, P, K, etc., in the desert ecosystem increased; soil physicochemical properties improved; and soil-forming processes occurred in the dune surface layer. Overall, establishment of sand-binding vegetation significantly impacted soil water cycles, creating favorable conditions for colonization by many herbaceous species. These herbaceous species, in turn, facilitated the colonization and persistence of birds, insects, soil animals, and desert animals. Forty-six years later, some 28 bird species and 50 insect species were identified in the vegetated dune field. Thus, establishment of a relatively simple community of sand-binding species led to the transformation of the relatively barren dune environment into a desert ecosystem with complex structure, composition, and function. This restoration effort shows the potential for short-term manipulation of environmental variables (i.e., plant cover via artificial vegetation establishment) to begin the long-term process of ecological restoration, particularly in arid climates, and demonstrates several techniques that can be used to scientifically monitor progress in large-scale restoration projects.

Key words: biodiversity, China, ecological restoration, long-term effects, sand-binding vegetation, Tengger Desert.

Introduction

Restoration of species-rich communities is an important way to counteract global losses in biodiversity (Naveh 1994; Young 2000). Establishment of sand-binding vegetation is one of the main techniques for ecological restoration in arid zones; this method has been widely used in arid desert regions of the world and is one of the most effective ways to combat desertification (Le Houérou 2000, 2002). Numerous reports deal with ecological restoration through the establishment of planted vegetation and indicate that biodiversity restoration is an important condition for regional ecological health (Odum 1989), sustainable development, and positively impacting food production (Bullock et al. 2001). Biodiversity is not only closely related to biomass production (Tilman et al. 1996; Bullock et al. 2001; Oba et al. 2001), but is also related to ecosystem stability (Grime 1998; Peterson et al. 1998; Tilman 1999). Change in species composition is also one of the most active forces driving the evolution of an ecosystem. Much of the research deals with the restoration of mining areas (Skousen et al. 1990; Urbanska et al. 1997; Miao & Marrs 2000), wastelands (Mitsch et al. 1989; Gardiner 1993), wetlands (Vivian & Handel 1996; Brown & Bedford 1997), rangeland (Van Der Merwe & Keller 1999), and tropical and subtropical forest systems (Yu 1994). Studies on the restoration of desert environments are relatively rare, particularly in the case of long-term monitoring and systematics, although coastal sand dunes have received more attention (Pickart et al. 1998; Roze & Lemauviel 2004). Nevertheless, long-term study is the most basic method for the understanding of ecological restoration.

Since the 1950s, China has paid great attention to ecological construction in arid and semiarid desertified regions

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and initiated a series of ecological engineering projects. Approximately 1.21 million ha of windbreak and sand-binding forests have been established in arid desert regions and aerial seeding of the vegetated area has reached 362,000 ha (Zhou 1998). This has played a large role in the control of soil erosion, land degradation, and desertification, as well as in grassland construction. However, without systematic monitoring and long-term study, little information is available on long-term feedback influences of vegetation on the environment, making it impossible to scientifically evaluate and understand the role of vegetation construction on the restoration of biodiversity. Based on over 40 years of monitoring and study at the Shapotou Desert Research and Experiment Station, Chinese Academy of Sciences, this paper analyzes the influences of planted vegetation on species changes over time to provide a strategy for the conservation and restoration of biodiversity, and further expand our knowledge of ecological restoration in arid zones.

Methods

Research Site Description

Shapotou is located at 37°33′ N, 105°02′ E in Ningxia Hui Autonomous Region at the southeastern edge of the Tengger Desert in northern China, elevation 1,339 m. It is classified as a steppified desert zone, and is a transitional zone between desert and oasis. Natural vegetation is dominated by *Hedysarum scoparium* (slenderbranch sweetvetch) and *Agriophyllum squarrosum* (squarrose Agriophyllum), with a cover of approximately 1% (Li et al. 2000). The area is characterized by high, dense, and continuous reticulate barchan dunes. The soil substrate is loose and impoverished moving sand, with a moisture content varying between 2 and 4%. During 46 years of observations (1956–2001), the mean annual air temperature in the area was 9.6°C, with extreme minimum and maximum temperatures of −25.1 and 38.1°C, respectively. Mean annual sunshine hours were 3,264.7 hr, mean annual precipitation was 186.6 mm, mean annual wind velocity was 2.9 m/s, and mean annual number of dust storm days was 59 days. To insure smooth operation of the Baotou–Lanzhou Railway in the sand dune area, a vegetation protective system was established along the railway line in 1956 by the Chinese Academy of Sciences and related departments (Zhao 1988; Fullen & Mitchell 1994).

The first stage was the installation of a "sand barrier" made of woven willow branches or bamboo to act as a windbreak. Behind the sand barrier, straw checkerboards (1×1 m) were established (Fig. 1). The straw was inserted to a depth of 15–20 cm, so that it protruded approximately 10–15 cm above the dune surface. This remained intact for 4–5 years, and allowed time for xerophytic plants to establish. A number of native shrubs were planted inside the checkerboards, such as *Caragana korshinskii* (Korshinsk peashrub), *Artemisia ordosica* (Ordos wormwood), and *H. scoparium* (Fig. 2). On the north side of the railway line a 500-m wide protective belt was set up and on the south side a 200-m wide protective belt was established; the total length of the protective system was 16 km (Fig. 3). Over the 40 years since vegetation establishment, the environment in the area improved, and the stabilized sand surface created a condition for the colonization of many species. Mass propagation of psammophytes transformed the original moving sand into a complex man-made and natural desert vegetation landscape (Li et al. 2000).

Sampling Method and Data Collection

Data used in this paper were collected from the database for desert ecosystem monitoring of the Chinese Ecological

Figure 1. Straw checkerboards are used to fix moving sand dunes along the railway of Baotou–Lanzhou in Shapotou, Tengger Desert.

Figure 2. Xerophytic shrubs were planted in checkerboards.

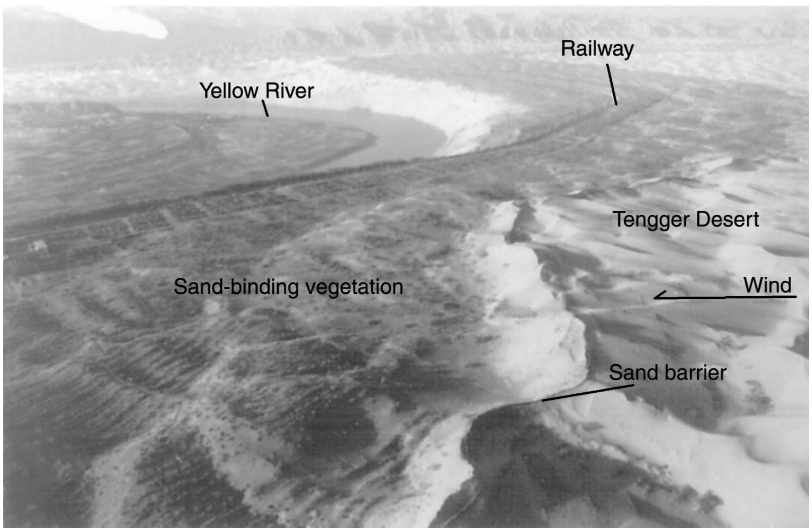

Figure 3. Sand-binding vegetation along the Baotou–Lanzhou railway (photograph, 2002).

Research Network (CERN) at Shapotou Desert Experiment and Research Station, Chinese Academy of Sciences. Six study sites were used: five were different-aged sites planted with sand binders (1956, 1964, 1973, 1982, and 1992) and one was a control site of moving sand dune.

For plant species, 10 quadrats were established in each of the five planted sites in the 16-km long and 500-m wide planted vegetation area to the north of the railway, with a total of 50 quadrats. The survey area of shrubs was 10×10 m, whereas that of herbs was 1×1 m. The plant species numbers, height, and coverage for each species in the sand stabilization areas of different years were recorded or measured. In addition, the thickness of microbiotic crusts, topsoil, and litter fall in different sites was also recorded.

In this study, Simpson index D (Simpson 1949), Shannon–Wiener index H' (Peet 1974), and Pielou evenness index J (Pielou 1975) were used to measure diversity of plants, $D = 1 - \sum p_i^2$; $H' = -\sum p_i \ln p_i$; $J = (-\sum p_i \ln p_i)/\ln S$, where p_i is the relative importance value (IV) of species i (relative height + relative coverage), and S is the total number of species i in the quadrat, that is, an abundance index.

Beta (β)-diversity refers to species replacement with environmental gradient changes. Some scholars refer to this as species turnover rate, species replacement rate, or rate of biotic change. It can be described by binary attribute data or quantitative data. In this study, the well-defined binary attribute data Sorenson index (C_J) and two widely used quantitative variables C_N and C_{MH} were used for the calculations (Whittaker 1972; Ma et al. 1995): the Sorenson index, $C_J = j/(a + b)$, where j is the number of species in common of two communities, and a and b are the species number of community A and community B, respectively, and the Bray–Curtis index (Bray & Curtis 1957), $C_N = 2jN/(aN + bN)$, where aN is the species number of sample plot A; bN is the species number of sample plot B; and jN is the sum of fewer individual number of species in common in sample plots A (jaN) and B (jbN). In the calculation, the IV of species was used to replace individual numbers according to the Morisita–Horn index (Li 2001), $C_{MH} = 2\Sigma(an_i \cdot bn_i)/[(da + db)aN \cdot bN]$, where aN and bN are the same as in the above formula; an_i and bn_i are the individual number of species in sample plots A and B, respectively (replaced by IV); and $da = \sum an_i^2/aN^2; db = \sum bn_i^2/bN^2$.

Cryptogam samples were collected and incubated in the laboratory for analysis and identification (Li et al. 2002) (Appendices 1 & 2). To measure algal and cyanobacteria species, 10 0.25-m^2 plots were located in each site of the five different-aged vegetated areas in a hollow between stabilized sand dunes. A total of 50 plots were sampled and compared with the control plot (moving dunes). For mosses, we chose an adjacent naturally fixed sand dune as a control plot. Cryptogamic cover was measured using a 10-pin, point sampling frame (Kleiner & Harper 1977) (Tables 1 & 2).

Since the long-term study began with the establishment of straw checkerboard sand barriers in 1956, 1964, 1973, and 1982, soil water content was monitored and soil water variation was determined. Soil samples were taken using a core sampler, dried at 105° C for 24 hr, and weighed to determine water content (Namjing Institute of Soil Research, Chinese Academy of Sciences 1980). Soil samples were taken at 16 different depths: 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, and 300 cm with three replicates at each depth. There were 10 such plots in the five different-aged vegetated sites and the control site, for a total 60 plots.

For determining other soil parameters, samples were taken from the five different-aged vegetation areas and the moving dunes (Table 3). Soil bulk density was measured by the method of cutting ring (Namjing Institute of Soil Research, Chinese Academy of Sciences 1980); soil particle size was determined by the pipet method (Liu 1996); pH was determined by preparation of a suspension consisting of a soil–water mixture in a ratio of 1 : 5 and measured with a calibrated pH meter (PHS-4, Jiangsu Manufactory of Electrical Analysis Instruments, Jiangying, Jiangsu Province, China); soil organic matter was determined by the $K_2Cr_2O_7$ method as described by the Agricultural Chemistry Specialty Council, Soil Science Society of China (1983). Soluble salts were determined by the methods introduced by the Namjing Institute of Soil Research, Chinese Academy of Sciences (1980). Total N was measured with the Kjeldahl system using a 1026 Distilling Unit (Tecator AB, Höganäs, Sweden). Phosphorus and potassium were measured using standard methods for observation and analysis developed by the CERN (Liu 1996). Wind was measured at 20 cm above the surface using an anemometer in spring (10 days between March and April in 2001).

To study insect species diversity, daytime net trap, manual catch, and night lamp catch methods were used (Sun 1989). Five replications (5 times of investigation) were conducted in moving dune plots before the establishment of sand-binding vegetation in the summer of 1956, and in the vegetated areas in the summer of 1982 and 2001, respectively. Sweep net sampling was conducted between 0900 and 1700 hours. A linen net with 38-m diameter, 65-cm depth, and handgrip of 1-m length was used. A total of 20 sampling units was designed in each different-aged vegetation area. One unit contained 20 repetitions along a linear distance of 10 m; the range of every sweep

Table 1. Changes in algal and cyanobacteria species composition and cover after revegetation on moving dunes sampled in 10 0.25-m^2 plots on each different-aged site.

Year Since Stabilization (Year Observed)	*4 (1960)*	*20 (1976)*	*29 (1983)*	*38 (1992)*	*46 (2001)*	*Control (Moving Sand Dunes, Observed in 2001)*
Total species number, all plots	5	14	17	23	24	1*
Mean species number per plot	3.0 ± 1.05^a	10.7 ± 2.21^b	13.9 ± 1.85^c	18.4 ± 2.55^d	19.0 ± 2.71^d	–
Mean percentage cover	1.1 ± 0.59^a	20.0 ± 3.43^b	42.0 ± 4.64^c	50.2 ± 6.44^d	55.0 ± 8.56^e	–

Different letters indicate significant differences at $p \leq 0.01$ level using Tukey's post hoc test.
*One species (*Naviaila minima* var atomoides) appeared in one plot.

Table 2. Changes in species composition and cover of mosses after revegetation, sampled in 10 0.25-m^2 plots in each different-aged site.

Year Since Stabilization (Year Observed)	*4 (1960)*	*38 (1992)*	*46 (2001)*	*Control (Natural Fixed Sand Dunes, Observed in 2001)*
Total species number, all plots	1	3	5	13
Mean species number per plot	0.80 ± 0.42^a	2.50 ± 0.71^b	4.30 ± 0.71^c	9.30 ± 2.16^d
Mean percentage cover	25 ± 2.38^a	75 ± 3.19^b	80 ± 2.94^c	86 ± 2.91^d

Different letters indicate significant differences at $p \leq 0.01$.

Table 3. Changes in texture, nutrient, physicochemical properties of topsoil (depth 0–20 cm), and its habitat over time after the establishment of sand-binding vegetation in Shapotou, Tengger Desert (one-way ANOVA analysis, Tukey's post hoc tests).

Sites/Year Vegetated	*Particle Size (%)*			*Bulk Density (number/km²)*	*Nutrient Contents (g/kg)*			*Organic Matter (%)*	*pH*	*Total Soluble Salt (%)*	*CaCO₃*	*Thickness of Crusts and Topsoil (cm)*	*Wind Velocity at 20 cm above Surface (m/s)*	*Litter Fall (g/m²)*
	Sand	*Silt*	*Clay*		*N*	*P*	*K*							
Control	99.7 ± 0.26^{a}	0.1 ± 0.07^{a}	0.2 ± 0.56^{a}	1.53 ± 0.02^{a}	0.17 ± 0.02^{a}	0.11 ± 0.05^{a}	0.91 ± 0.14^{a}	0.06 ± 0.02^{a}	7.44 ± 0.26^{a}	0.04 ± 0.01^{a}	0.03 ± 0.00^{a}	0^{a}	5.9 ± 0.18^{a}	0^{a}
10 (1992)	79.9 + 1.51^{b}	15.6 ± 1.35^{b}	4.4 ± 2.20^{b}	1.52 ± 0.02^{a}	0.39 ± 0.11^{b}	1.21 ± 0.16^{b}	1.01 ± 0.10^{a}	0.12 ± 0.03^{a}	7.81 ± 0.05^{b}	0.06 ± 0.01^{b}	1.23 ± 0.08^{b}	0.72 ± 0.02^{b}	3.6 ± 0.05^{b}	7.24 ± 0.25^{b}
20 (1982)	71.5 ± 1.18^{b}	23.6 ± 1.92^{c}	4.9 ± 0.97^{b}	1.50 ± 0.02^{a}	0.54 ± 0.08^{c}	1.41 ± 0.11^{c}	1.64 ± 0.07^{b}	0.77 ± 0.09^{b}	7.90 ± 0.13^{b}	0.08 ± 0.01^{b}	1.92 ± 0.05^{c}	1.40 ± 0.04^{c}	3.3 ± 0.04^{c}	10.11 ± 0.16^{c}
29 (1973)	70.5 ± 1.20^{b}	24.2 ± 1.82^{c}	5.3 ± 0.87^{b}	1.50 ± 0.02^{a}	0.66 ± 0.09^{d}	1.48 ± 0.12^{c}	1.66 ± 0.05^{b}	0.96 ± 0.07^{c}	7.91 ± 0.09^{b}	0.08 ± 0.01^{b}	1.99 ± 0.02^{c}	70 ± 0.02^{d}	3.3 ± 0.10^{c}	10.21 ± 0.10^{c}
38 (1964)	68.3 ± 1.71^{d}	24.8 ± 1.58^{c}	6.9 ± 1.12^{c}	1.47 ± 0.02^{b}	0.74 ± 0.10^{d}	1.50 ± 0.10^{c}	1.72 ± 0.05^{b}	1.32 ± 0.05^{d}	7.95 ± 0.05^{b}	0.11 ± 0.01^{c}	2.30 ± 0.12^{d}	2.20 ± 0.12^{e}	2.7 ± 0.03^{d}	14.21 ± 0.75^{d}
46 (1956)	66.4 ± 1.77^{d}	22.6 ± 2.02^{c}	11.0 ± 0.83^{d}	1.44 ± 0.02^{c}	1.02 ± 0.21^{e}	1.59 ± 0.06^{d}	1.76 ± 0.05^{b}	1.34 ± 0.04^{d}	7.99 ± 0.07^{b}	0.11 ± 0.01^{c}	2.39 ± 0.02^{e}	2.50 ± 0.03^{f}	2.7 ± 0.02^{d}	14.22 ± 0.45^{d}

Control site = moving dunes, data were collected in 2001; mean ± standard error, values with different letters are significantly different at $p \leq 0.01$ ($n = 10$).

was 180°. The net was shaken and insects were emptied into a plastic bag for identification and counting after each sampling unit was finished. Meanwhile, a manual trap was used to catch insects crawling on the soil surface. Night lamp observations were conducted between 1900 and 0600 hours the next day. There was one set of observation instruments at each site. The instrument consisted of a funnel, a vertical metal cylinder, and an ultraviolet light. The funnel was placed on the cylinder, and the light was suspended above the funnel. Insects that flew to the tube light fell down the funnel and were trapped in the jar. An insecticide, such as a piece of vapona strip, was placed in the collection jar. The insect data are reported as the sum of the three methods.

The line transect method was used to survey bird diversity, and density was calculated by the route statistical method. Investigation was carried out at a walking rate of 1.5 km/hr at 0630–1130 hours and 1500–1800 hours between May and July. Bird numbers were recorded in a 200-m width along the line transect. Each 10-km long route in vegetated areas was surveyed three times and the mean value was taken. Density was expressed in individuals/km^2 (Zhang et al. 2002). In addition, the adjacent steppe desert was surveyed in 2001.

Statistical analyses (ANOVA with LSD and Tukey's post hoc tests) were carried out by using SPSS 10.0 for Windows software at $p < 0.01$ significance level.

Results

Effect of Sand-Binding Vegetation on Habitat

Compared with moving dunes, most soil parameters measured in vegetated areas had very significant differences (Table 3), indicating that revegetation has remarkable effects on soil texture, nutrient state, and other features. Forty-six years after planted vegetation was established on sand dunes, the proportion of sand-sized particles in the topsoil (0–20 cm depth) was reduced from 99.7% in moving dunes to 66.4% in vegetated areas; the proportion of silt and clay increased from 0.12 and 0.21 to 22.6 and 11.0%, respectively. With the exception of vegetated areas between 1973 and 1982 ($p < 0.01$) and 1956 and 1964 ($p < 0.01$), there were significant differences in sand content among different ages of vegetated areas and the control plot ($p < 0.01$). There were no significant differences in silt content after 20 years of revegetation (22.6 and 23.6%); however, significant differences were found in clay content after 38 years of revegetation (Table 3). In addition, a significant difference was observed between vegetation plots of 1956 and vegetation plots of 1964 ($p < 0.01$).

Table 3 indicates that soil bulk density was reduced from 1.53 in moving dunes to 1.44 in the 46-year-old vegetation area. Although this change was small, a significant difference did occur between the 1956 vegetation plot and vegetation plots of other ages. Interestingly, there was a general tendency for soil bulk density to reduce over time after revegetation.

Forty-six years after the establishment of sand-binding vegetation, soil organic matter content increased from 0.06% in moving sand to 1.34% in the vegetated land. With the exception of vegetation plots of 1956 and 1964, organic matter content was significantly different among the vegetation plots of different ages. Similarly N, P, and K content in the topsoil layer (0–20 cm) increased from 0.17, 0.11, and 0.91 to 1.02, 1.59, and 1.76%, respectively, over the 46 years. Although soil pH had a tendency to increase over time, there were no significant differences among the vegetation plots of different ages ($p < 0.01$). Total soluble salt content increased from 0.04 to 0.11% after 46 years since revegetation; in other words, the accumulation of soluble salts in topsoil was relatively small. By contrast, carbonate accumulations reached a relatively high level in response to the development and succession of planted vegetation. Significant differences in the thickness of microbiotic soil crusts and topsoil occurred in the vegetation plots of different ages ($p < 0.01$). After 46 years since establishment of the sand-binding vegetation, the thickness of crusts and topsoil reached 2.50 cm. Likewise, the amount of litter fall in vegetated areas was positively correlated with the ages of vegetation (Table 3). Conversely, wind velocity at 20 cm above the soil surface was negatively correlated with the age since revegetation. Mean wind velocity at the 20-cm height was reduced from 5.9 m/s in moving dune fields to 2.7 m/s in the 1956 revegetated area.

Long-term observations indicated that soil water content in moving dunes (control) increased from the shallow layer (1.5–2.5%) to the deep layer (3–3.5%), whereas in older vegetation areas soil water content decreased with depth (Fig. 4). Vertical distribution of soil water content in

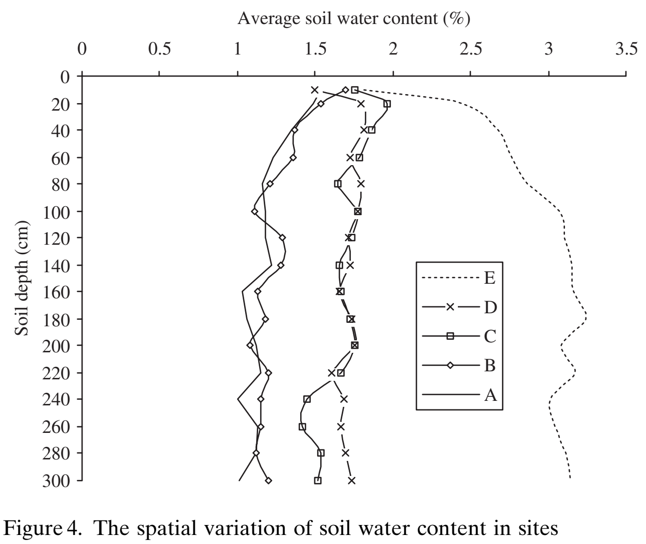

Figure 4. The spatial variation of soil water content in sites revegetated in different years. A, site revegetated in 1956; B, site revegetated in 1964; C, site revegetated in 1973; D, site revegetated in 1982; E, control site (moving dunes).

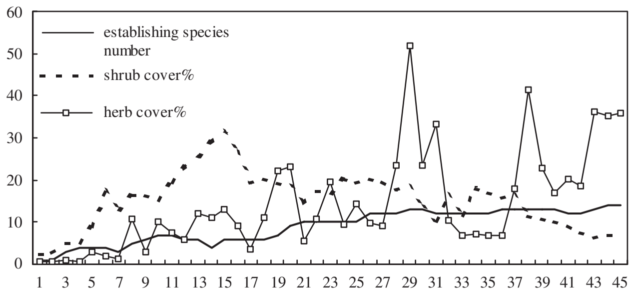

Figure 5. Vegetation changes over time since it was established in moving dune field of Tengger Desert.

older vegetation areas (1956 and 1964) was much lower than that in relatively younger vegetation areas (1973 and 1982).

Succession of Planted Vegetation in Relation to Plant Species Diversity

β-Diversity Changes in the Successional Processes of Planted Vegetation. It can be seen from the curve in Figure 5 that 40 years after revegetation, the probability of new plant species gradually diminished and species composition gradually tended toward a relatively balanced state (species number varied between 12 and 14). Among those that reestablished were *Artemisia ordosica*, and annuals such as *Eragrostis poaeoides* (little lovegrass), *Bassia dasyphylla* (divaricate bassia), *Corispermum* sp. (tickseed), *Salsola rutherica* (Russian thistle), and *Aristida adscensions* (6 weeks three-awn-grass). Measurement of β-diversity of the different-aged vegetation showed that after 46 years of succession (planted in 1956), the diversity of plant species reached a relatively high level ($D = 0.706$–0.822, $H' = 1.393$–1.893), whereas the vegetation planted 10 years ago had a lower diversity ($H' = 0.501$–0.702, $D = 0.819$–1.074) (Table 4). Viewed from the diversity indices, the planted vegetation in Shapotou still has a lower diversity index, suggesting that the planted vegetation structure is relatively simple, and that community stability is weak and susceptible to disturbance.

β-Diversity Changes. Table 4 also lists the Sorenson, Bray–Curtis, and Morisita–Horn indices used to measure the β-diversity of vegetation planted in the five different periods. Although the first one is the calculation formula of binary data and the latter two are the calculation of quantitative data, the comparative results are the same.

The results show that the difference in species composition between 1992 and 1982 was largest ($C_{MH} = 0.935$, $C_N = 0.332$, $C_J = 0.819$), that is, species turnover rate was largest, followed by the β-diversity indices of 1964 and 1956 vegetation. Therefore, during the 40 years of vegetation succession, two time intervals, namely 10–20 and 30–40 years, show the largest turnover rate of species, in other words, community structure such as species composition

Table 4. The comparison of plant diversity and the measurement of β-diversity in the sand areas stabilized in different years.

Year Stabilized	*1956*	*1964*	*1973*	*1982*	*1992*
Simpson index (D)	0.706–0.822	0.595–0.856	0.627–0.777	0.631–0.788	0.501–0.702
Mean	0.767	0.752	0.696	0.711	0.539
Shannon–Wiener index (H')	1.393–1.893	1.232–1.814	1.247–1.633	1.171–1.690	0.819–1.074
Mean	1.642	1.515	1.385	1.390	0.859
Pielou evenness (J)	0.638–0.961	0.661–0.862	0.554–0.743	0.658–0.877	0.524–0.712
Mean	0.701	0.775	0.646	0.745	0.534
Sorenson index (C_J)		0.801	0.657	0.538	0.819
Bray–Curtis index (C_N)		0.216	0.189	0.034	0.332
Morisita–Horn index (C_{MH})		0.845	0.307	0.242	0.935

The measurement of β-diversity was made by comparing two adjacent dates, so the β-diversity values of the first planting years since stabilization are absent.

and layer of structure in these stages indicate the largest change.

Changes in Cryptogam Diversity

Table 1 indicates the changes in algal species composition in crusts with the duration of sand stabilization. Four years after revegetation two diatoms, *Pinularia microstaucon* and *Hantzchia amphioxys* var. capitata and three cyanobacteria, *Lyngbya martensiana*, *Hydrocoleus violacens*, and *Phormidium amblgum* occurred in the surface layer of fixed dunes (Appendix 1). Twenty years later 14 algae were identified, and 46 years later a total of 24 algal species were found in the vegetation-fixed area. As can be seen in Table 1, with the development of sand-binding vegetation, algal diversity in microbiotic crust significantly increased, but 38 years after the establishment of sand-binding vegetation, the increase in algae slowed and its diversity gradually became saturated. In addition, algal cover reached up to 50–55%. With the exception of differences between the 38-year-old and 46-year-old vegetation plots, significant differences in mean species numbers occurred in the different-aged vegetation plots and the control plot ($p < 0.01$). Likewise, the calculation of mean algal cover had significant differences among the five sites and the control plot ($p < 0.01$).

Table 2 summarizes the diversity changes of another important cryptogam, mosses, in the composition of microbiotic crusts. Like the algae, replanted vegetation promoted the colonization of mosses in the area. Compared with algae, moss species showed little change. Four years after revegetation, *Byum argenteum* occurred in crusts in places such as interdune depressions (Appendix 2). After 46 years of succession, only five moss species occurred in crusts; this was less than one-half of the moss species in naturally occurring sand areas. Mean species number and cover of mosses had significant differences among the three sites with different-aged vegetation and the naturally occurring sand dunes (control plot) ($p < 0.01$). From the perspective of diversity of moss species, the development of crusts was in an unstable stage (Li et al. 2002).

Changes in Insect Species Diversity

Table 5 and Appendix 3 summarize the results of insect diversity in the sand-binding vegetation areas in different periods (observed in 1956, 1982, and 2001). Only 10 common insect species were found in the control site, including the most drought-resistant, heat-resistant, and hunger-resistant species, *Sternoplax* sp. and *Anatolica potauivi*, owing to the sparse vegetation in the moving sand area of Shapotou in the Tengger Desert. Table 5 also summarizes that with succession of the sand-binding vegetation, insect species numbers significantly increased ($p < 0.01$). Thirty-four insect species were found in the 20-year-old vegetation area and 50 insect species were found in the 46-year-old vegetation area. Compared with moving dunes, there were significant differences in species richness in different-aged vegetation areas. In addition, there was a significant difference between 20-year-old and 46-year-old vegetation based on Tukey's post hoc test ($p < 0.01$).

Table 5. Changes in insect species composition after revegetation on moving dunes (observed in summer).

	Control (Moving Dunes, Observed in 1956)	*Year Since Revegetation (Year Observed)*	
		20 (1982)	*46 (2001)*
Total number of species	10	34	50
Mean species richness per sample (± SE, $n = 5$)	8.00 ± 1.58	29.60 ± 3.58^{a}	$42.60 \pm 5.27^{a,b}$

[a]The mean difference is significantly different from control at $p < 0.01$.
[b]The mean difference between 20-year-old and 46-year-old vegetation is significant at $p < 0.01$ level.

Table 6. Changes in bird species composition after revegetation on moving dunes (observed in summer).

Year Since Stabilization (Year Observed)	*30 (1986)*	*42 (1998)*	*46 (2001)*	*Control (Steppe Desert, Observed in 2001)*
Total species number	11	33	28	21
Mean species number per sample (± SE, $n = 3$)	8 ± 1.8^a	27 ± 3.3^b	25 ± 2.6^b	17 ± 3.0^c
Mean density (number/km^2 ± SE, $n = 3$)	21.6 ± 2.8^a	18.6 ± 1.6^b	18.9 ± 1.5^b	18.2 ± 2.2^b

Different letters indicate significant differences at $p < 0.01$.

Changes in Bird Species Diversity

Eleven bird species (Table 6) were found in the 30-year-old vegetation-fixed dune areas in summer, with a density of 21.64 birds/km^2, only one of which was granivorous, namely *Streptopelia o. orientalis* (Rufous Turtle Dove). Dominant species were *Lanius cristatus speculigerus* (red-tailed shrike) and *Passer ammodendri stoliczkae* (saxaul sparrow) (Appendix 4). In the 42-year-old vegetation area, there were 33 bird species, with a density of 18.6 birds/km^2, three of which were granivorous, namely *Streptopelia o. orientalis*, *Columba rupertris rupestris* (blue hill pigeon), and *Streptopelia decaocto decaocto* (collared turtle dove). Dominant species were *Passer ammodendri stoliczkae* and *L. cristatus speculigerus*. In the 46-year-old sand-binding vegetation area, there were 28 bird species, with a density of 18.9 birds/km^2. Five were granivorous, including the three above-mentioned species, *Carduelis s. sinica* (greenfinch), and *Syrrhaptes paradoxus* (pallas' sand grouse), accounting for 17.8% of the region's total bird species. Nongranivorous species occupied 82.2%, with the dominant species being *L. cristatus speculigerus*. There were significant differences in mean species number between 30-year-old vegetation and other vegetation and control plots ($p < 0.01$). The highest species number occurred in the areas fixed by sand binders for 42 years. Afterward, the species numbers and density tended to decrease; however, we failed to find significant differences between 1998 and 2001 ($p < 0.01$). Interestingly, significant differences in species number occurred between planted vegetation areas and the control plot, but no significant differences in density were found between cultivated and natural vegetation plots.

Discussion

Habitat

Before establishing the sand-binding vegetation system, the main feature of the desert environment was its unstable sand surface. Establishment of planted vegetation in the moving sand environment contributed to changes in soil texture, such as the decrease in sand grain proportion and the increase in silt and clay proportion, due to straw checkerboard barriers enhancing surface roughness (the roughness of the moving sand surface varied between

Table 7. The dominant plant species (% cover) in sand areas stabilized in different periods (observed in September 2001).

Year Stabilized	*Dominant Species* — *Shrub and Subshrub Species*	*Dominant Species* — *Herbaceous Species*
1956	*Caragana korshinskii* (1) *Artemisia ordosica* (8)	*Bassia dasyphylla* (15) *Eragrostis poaeoides* (12) *Salsola ruthenica* (3) *Aristida adscensions* (4) *Corispermum* sp. (2) *Setaria viridis* (3)
1964	*C. korshinskii* (5) *A. ordosica* (9)	*E. poaeoides* (10) *B. dasyphylla* (12) *S. ruthenica* (2)
1973	*Caragana korshinskii* (8) *Artemisia ordosica* (10)	*E. poaeoide* (12) *S. ruthenica* (11) *B. dasyphylla* (18)
1982	*Caragana intermedia* (8) *A. ordosica* (12)	*E. poaeoides* (5) *B. dasyphylla* (5) *S. ruthenica* (2)
1992	*Hedysarum scoparium* (8) *C. intermedia* (2) *C. korshinskii* (8) *A. ordosica* (6)	*Agriophyllum squarrosum* (0.5) *E. poaeoides* (1)

0.007 and 0.093 cm; after the establishment of 1×1–m straw grids, the roughness varied between 1.517 and 2.398 cm). With the increase in near-surface (below 1 m) roughness, wind velocity significantly weakened (Lin 1991). This further increased atmospheric dust deposition ($d < 0.063$ mm) on the stable sand surface, and the proportion of silt and clay in the soil was positively correlated with the accumulation of dust deposits (Xiao et al. 1996; Fearnehough et al. 1998). Studies on the temporal and spatial patterns of dust deposition in the artificially fixed dune area in Shapotou (Fearnehough et al. 1998; Xiao 2002) showed that the annual dust deposition rate in the region was about 372 g/m^2, and that its spatial pattern depended on the prevailing wind direction, topographic factors, horizontal distribution, and vertical structure of shrubs. On average, a 1.6 mm-thick layer of blowing dust deposits on the surface of fixed dunes each year and atmospheric dust deposits at a rate of 0.144 mm/year. Dust deposition on the fixed dune surface promoted the formation of sand surface crusts (Li et al. 2002) and development of soils. The establishment of planted vegetation also contributed to dune surface receiving much more dustfall (Chen 1991). As vegetation cover reached 10%, wind velocity reduced by 10–20%; when vegetation cover reached 10–20%, wind velocity reduced by 20–40%. As wind velocity at 20-cm height in the vegetation-fixed dune area reached 2.9 m/s, wind velocity at the same height in the moving dune area reached 5.9 m/s, or two times higher than that in the vegetated area (Annual Report of Shapotou Desert Research and Experiment Station, Chinese Academy of Sciences 1993). The stable physical environment created a prerequisite for the formation of sand surface crust and the development of soils (Duan & Liu 1996).

The changes in other soil physicochemical properties were related to the formation and development of microbiotic soil crusts on fixed sand surface in vegetated areas (Li et al. 2003). Numerous observers have noted that microbiotic crusts enhanced soil nutrient status (West 1990), soil structure, and aggregate stability (Greene et al. 1990). Table 3 indicates that the thickness of microbiotic crust and surface soil layer increased with time; soil texture, physicochemical properties, and nutrient condition also improved. In addition, the increase in surface litter fall also played an important role in the improvement of soil fertility and topsoil structure (Xiao et al. 1996). Therefore, according to the above analysis, it is clear that the improvement of habitat is the prerequisite for colonization by new species.

Plant Species Diversity

With the succession of planted vegetation, plant community structure gradually changed from single shrub and subshrub composition into complex structure dominated by herbaceous species, due to the decrease in soil moisture content in the deep soil layer, and deep-rooted shrubs gradually were eliminated from the community. Hence, shrub cover tended to lessen but species numbers in plant composition and herb cover increased (Table 7).

The measurement of β-diversity demonstrated that there were two important species turnover stages in the successional processes of planted vegetation during the 46 years, that is, the stage between 10 and 20 years, and the stage between 30 and 40 years after the establishment of sand-binding vegetation. This result can be explained as follows: during the first stage, some annual species such as *Agriophyllum squarrosum* and *Eragrostis poaeoides* invaded and plant communities changed from a single shrub layer into a multilayer structure; during the second stage, more shrub species were eliminated from the vegetation composition, the planted subshrubs *Caragana korshinskii*, *Hedysarum scoparium*, and *Artemisia ordosica* gradually declined, successful reproduction of numerous seeds made community structure more complex, and ground surface included three obvious layers, namely subshrub, herb, and algae–moss. Herbs became dominant (its coverage was greater than shrub or algae–moss). Hence, temporally dynamic changes in plant diversity can reflect the succession features of vegetation to a certain degree. This finding may provide basic knowledge for management of planted vegetation in arid regions.

Cryptogam Species Diversity

Straw checkerboard barriers and planted vegetation on dune surfaces created favorable conditions for the establishment and colonization of cryptogams. This is mainly manifested in the reduction of wind velocity, atmospheric dust accumulation, and litter accumulation, and increase of soil microorganism populations in the vegetation-fixed dune area (Li et al. 2003). In addition, rainfall in the Shapotou region also promoted the formation of soil crusts. The impact of raindrops makes soil particles on sand surfaces pack densely, and the deposition of fine particles, including atmospheric dust on fixed sand surfaces, provides a material basis for the formation of crusts (Fearnehough et al. 1998; Li et al. 2000). The development of crusts experienced three stages: the stage of gray-white dustfall and fine-grained aeolian sediment crust formed through raindrop impact, the stage of black-brown microbiotic crust formed mainly by algae, and the stage of cryptogam crust formed by moss-dominated microphytes (Li et al. 2002). Lichen was not found in the composition of cryptogam. Our observations indicate that five algae and one moss species occurred in the 4-year-old vegetation plots; this means that microbiotic soil crusts began to play a significant role in the stabilization of sand dunes 4 years after vegetation was established. The highest species richness of algae and moss was found in the oldest vegetation plot (1956), and the lowest species richness was found in the youngest vegetation plot (1998); this can be explained by the relationship between cryptogam and soil properties. Algal and moss cover and their species richness were found to be positively correlated with soil pH, silt and clay content, soil organic matter, and N content (Li et al. 2003). Compared with naturally fixed sand, moss has lower species richness and cover, indicating that the richness of cryptogams had not reached saturation. Even so, the colonization of cryptogams significantly altered the environmental conditions of fixed dune surfaces, including improvement of the sand nutrient condition.

Insect Species Diversity

The composition of insect species is closely related to sand-binding vegetation and adjacent natural vegetation composition. The establishment of planted vegetation created a suitable habitat for the reproduction of many insect species and also provided them with a food source (Ren & Wang 1991). Twenty years after vegetation establishment some major insect populations, such as *Tenebrionide*, *Curculionidue*, *Scarabaeidae*, and *Harpalus*, occurred in the dune field. Some insect species, such as *Chrysolina aeuginosa*, *Diglossotrox mannerheimi*, *Brachynema germarii Kolenati*, *Anatolica* sp., and *Orayia ericae*, were harmful to sand-binding plants. Among the dominant underground destructive insect species were *Tenebrionide*, *Serica orientalis Motschusky*, *Moladera verticalis*, and *Curculionidue*.

Occurrence and reproduction of some insect species were closely related to their hosts, especially those that were harmful to psammophytes. For example, *C. aeuginosa* mainly occurred in the initial development stage of sand-binding plants; this was mainly related to the damage of *Artemisia sphaerocephala*. Once *A. sphaerocephala* was eliminated from the community, *C. aeuginosa* numbers decreased and was not found in the 46-year-old vegetation area. Similarly, the number of the destructive insect *Deilephia hippopoes* Esper decreased as *E. angustifolia* was eliminated from the sand-binding vegetation. However, in the relatively stable dominant species *A. ordosica*-distributed area, *B. germarii* always had a high occurrence. With the succession of planted vegetation, annual herbs became dominant (Li et al. 2000), and the insect species number of *Pyralidae*, which is harmful to weeds, increased in the 46-year-old sand-binding vegetation area. These species include *Loxostege sticticalis*, *Staudingera steppicola*, *Calguia defiguralis*, *Salebria ellenlla*, *Ancylosis lencocephala*, *Ancylosis citrinella*, *Pristophorodes florella*, *Sitochroa verticalis*, and *Togostoma uniforma*.

Although little work has been done on the role of insects in the desert ecosystem in China, study of the evolution processes of insect species from moving sand to a steppified desert ecosystem has an important theoretical significance in reversing processes of desertification (Sun 1989). Changes in insect species diversity are also important considerations in maintaining and promoting the development of ecosystems (Kim 1993).

Bird Species Diversity

Like other desert organisms, birds are important components of the desert ecosystem (Zhang & Wang 1992). However, birds were seldom found in the moving sand area of the Tengger Desert owing to harsh habitat and lack of food (Annual Report of Shapotou Desert Research and Experiment Station, Chinese Academy of Sciences 1993). The establishment of planted vegetation and variations of its composition, structure, and function provided suitable habitats and reproduction conditions for many birds.

Our study indicates that with stabilization of moving sand by planted vegetation and further vegetation succession, bird diversity significantly increased. After 42 years, bird diversity essentially reached a balanced state and maintained about 30 species or so, but bird density showed little change, with *Lanius cristatus speculigerus* as the dominant species. Comparing bird composition in the adjacent steppified desert area, bird species number was higher in the 40-year-old sand-binding vegetation area than in the natural vegetation area, but bird density was virtually unchanged. The dominant species *Galerida cristata magna* (crested lark) in the natural vegetation area can also be found in the sand-binding vegetation area; to a certain degree this reflects the succession tendency of planted vegetation toward natural vegetation. In addition, the occurrence and increase of granivorous birds in the bird community (*Streptopelia o. orientalis*, *Columba rupertris rupestris*, *Streptopelia decaocto decaoct*, and *Cardulis s. sinica*) may explain the association with the colonization of numerous annual plants in the vegetation community.

Although little information on the function of bird diversity in the desert ecosystem has been reported (Zhang et al. 2002), its role has been widely understood. Each *Falco tinnunculus interstinctus* (Kestrel) on average eats three rats/day and *Buteo hemilasius* (upland buzzard) is the natural enemy of field rats and wild rabbits. *Cuculus canorus* (cuckoo) mainly feeds on larva of *Lepidopptera*; *Phylloscopus inornatus* (yellow-browed willow warbler) feeds on spiders, *Diptera*, mosquitos, flies, and *Coleoptera*; and *Phylloscopus b. borealis* (arctic willow warbler), an insectivorous bird, feeds primarily on destructive insects. *L. cristatus speculigerus* and *Sturnus cineraceus* (ashy starling) mainly kill locusts and mole crickets in sand-binding forest areas. *Upupa epops* (Hoopoe) can dig and kill destructive insects such as chafers, snap beetles, and *Lepidopptera larva*. *Hirundo rustica gutturalis* (house swallow) and *Anthus hodgsoni* (oriental tree pipit) kill a number of destructive insects such as locusts, mole crickets, flies, mosquitoes, *Lepidopptera* larva, woodlice, and aphids. Birds can reduce insect damage to sand-binding vegetation and maintain the balance of the sand-binding vegetation system.

Conclusion

The establishment of planted sand-binding vegetation in the Shapotou region promoted the improvement and restoration of regional habitats and provided suitable conditions for the multiplication of biodiversity in the desert ecosystem. Habitat restoration in turn drives the succession of the sand-binding vegetation system. The increase and changes in cryptogam, insect, and bird species diversity depended to a certain degree on the changes of sand-binding vegetation, especially changes in the composition of plant species. The occurrence of steppified desert representative insect and bird species (*Galerida cristata magna*) indicates that the desert ecosystem has been transformed into a steppified desert ecosystem.

The present study and long-term monitoring demonstrate the contribution of vegetation establishment to the restoration of biodiversity, suggesting a positive correlation between revegetation and increase of biodiversity in arid zones. It provided a theoretical basis for the conservation of biodiversity in vast arid regions, especially regions with precipitation below 200 mm. Further study and long-term continuous monitoring are needed to increase our understanding of the mechanisms to reverse desertification and reconstruct the environment in arid regions.

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Appendix 1. Variations of algal and cyanobacteria (*) species diversity after revegetation on moving dunes in Tengger Desert (+++ indicates dominant species, ++ subdominant species, + rare species).

Species	Control (Moving Dunes, Observed in 2001)	Years Since Stabilization (Year Observed)				
		4 (1960)	20 (1976)	29 (1983)	38 (1992)	46 (2001)
Anabaena azotica Ley	—	—	++	++	++	++
Chlamydomonas sp.	—	—	++	—	+	++
Chlorella vulgaris Beij Gom	—	—	—	—	+	++
Chlorococcum humicola (Naeg.)Rab.	—	—	—	—	+	++
Chrococcus epiphyticu Jao	—	—	++	—	+	++
Euglena sp.1	—	—	++	++	++	++
Euglena sp.2	—	—	+	+	—	+
Gloeocapsa sp.	—	—	—	++	++	++
Hantzschia amphioxys var capitata Grum	—	+++	++	++	+++	+++
Hydrocoleus violacens Gom. (*)	—	++	—	—	—	—
Lyngbya crytoraginatus Schk. (*)	—	—	+	—	+	++
Lyngbya martensiana Meneneghini (*)	—	++	—	—	—	—
Microcolous vaginatus Gom.	—	—	++	++	++	++
Navicula minima var. atomoides Grum.	+	—	+	+++	++	++
Nostoc flagelliforme Borm.	—	—	—	—	—	+
Nostoc sp.	—	—	+	—	+	+
Oscillatoria obscura Gom.	—	—	—	++	++	++
Oscillatoria pseudogeminate G. Schm.	—	—	—	++	++	++
Oscillatoria subbreis Schmidle.	—	—	—	+	+	+
Phormidium amblgum Gom. (*)	—	++	—	—	—	—
Phormidium autumnale (Ag.) Gom. (*)	—	—	—	+	+	+
Phormidium foveolarum (Mont.) Gom. (*)	—	—	—	—	—	+
Phormidium luridum (KÜtz) Gom. (*)	—	—	—	++	++	++
Phormidium tenue Gom. (*)	—	—	+	+	+	+
Pinnularia borealis Her.	—	—	+	+	+	+
Pinnularia microstauron Cleve	—	++	—	—	—	—
Protococcus viridis Ag.	—	—	+	—	+	+
Schizothrix rupicola Gom.	—	—	—	—	+++	—
Scytonema javanicum(KÜtz)Bornet Flash	—	—	+	+	++	+
Scytonema millei Bron.	—	—	—	+	+	—
Synechocystis aqutillis Sauv.	—	—	—	+	—	—

Appendix 2. Variations of moss species diversity after revegetation on moving dunes in Tengger Desert (+++ indicates dominant species, ++ subdominant species, + rare species).

Species	Years Since Stabilization (Year Observed)			Control (Naturally Fixed Sand Dunes, Observed in 2001)
	4 (1960)	38 (1992)	46 (2001)	
Aloina breviristris (Hook & Grev.)	—	—	—	+
A. cornifolia Delgadillo	—	—	—	+
A. rigida (Hedw.) Limpr.	—	—	—	+
Byum argenteum Hedw.	+++	+++	++	+++
Didymodon constrictus (Mitt.) Saito.	—	—	+	+++
D. nigrescens (Mitt.) Saito.	—	+	+	++
D. nigrescens var. ditrichoides Zand.	—	—	—	++
D. perobtusus Broth.	—	—	—	++
D. reedii Robins.	—	—	—	+
D. tectorum (C. Muell) Saito.	—	—	—	+
Pterygoneurum subsessile Jur.	—	—	—	+
Tortula bidentata Bai Xue Liang	—	+++	+++	++
T. desertorum Broth.	—	—	++	++

Appendix 3. Variations of insect species diversity after revegetation on moving dunes in Tengger Desert (+++ indicates dominant species, ++ subdominant species, + rare species).

Species	Control (Moving Dunes, Observed in 1956)	Years Since Revegetation (Year Observed) 20 (1982)	46 (2001)
Acronycta incretata Hps.	—	—	+
Adalia bipumctata (Linnaeus)	—	+	+
Adosomus sp.	++	++	++
Agrilus sp.	++	—	—
Agrotis ypsilon (Rottemberg)	—	+	+
Aleucanitis flexuosa Menetres	—	+	++
Anatolica potauivi Rett.	+++	+	++
Anatolica sp.	—	+++	++
Anax goliathas Fraser	—	++	++
Ancylosis lencocephala (Staudinger)	—	—	+++
Ancylosis citrinella Roesler	—	—	+++
Apis cerana Fabricius	—	+	—
Brachynema germarii Kolenati	—	+++	+++
Calguia defiguralis Walker	—	—	+++
Calliptamus barbarus (Casta)	—	++	++
Chrysolina aeuginosa Faldermann	—	+++	—
Chrysopa phyllochroma Wesmael	—	++	++
Cicindela elisae Msts	—	++	++
Coccinella septempumtata L.	—	+	++
Coccygomimus disparis Viereck	—	+	—
Cryllotalpa africana palisot de Beauvois	—	++	+
Cucullia duplicata Stauclinger	—	+	++
Deilephia hippoploes Esper	—	+++	—
Derdroleon pantherium Fab.	—	—	+
Dicromia sagitta Fab.	—	+	+
Diglossotrox mannerheimi Popoff	—	+	+
Diglossotrox sp.	—	+++	++
Eupithecia sp.	—	—	++
Gonocaphalum reticulatum Motsch	++	+	+
Holcocerus artemisiae Chou et Hua	—	—	+
Lasiopticus pyrastri Linnaeus	—	—	+
Leis axyridis (Pallas)	++	—	—
Leucania pudorina Sch	—	++	++
Lixus sp.	++	—	—
Leptopternis gracilis (EV.)	—	—	+
Loxostege sticticalis (L)	—	—	+++
Lygus pratensis (L)	—	++	++
Machimus scuellaris Cog.	—	—	+
Melanophila decastigma Fatr.	—	+	+
Moladera verticalis Fairmaire	—	+++	++
Netelia ocellaris (Thomson)	—	—	+
Oliarus apicalis Uhler	—	—	+
Orgyia ercae Germar	—	+++	+
Pristophorodes florella Mann.	++	—	+++
Salebria ellenella Roesler	—	—	+++
Scotogramma trifolii Rott.	—	++	++
Serica orientalis Motschusky	—	—	+++
Sitochroa verticalis (Linnaeus)	—	++	+++
Sogatella furcifera (Horvath)	—	—	+
Sphaerophoria scripta (Linnaeus)	—	—	+
Sphingomotus ningsianus Zheng et Gow	—	++	++
Staudingera steppicola (Caradja)	++	++	+++
Sternoplax sp.	+++	—	—
Stigmatophora micana Bremer	—	+	+
Sympetrum ferquens Selys	—	++	++
Togostoma uniforma Amsel	—	—	+++
Torymus sp.	++	+	++
Zichya tenggerensis Zheng	—	—	+

Appendix 4. Variations of bird species after revegetation on moving dunes in Tengger Desert (in summer) (+++ indicates dominant species, ++ subdominant species, + rare species).

Species	Years Since Stabilization (Year Observation) 30 (1986)	42 (1998)	46 (2001)	Control (Steppe Desert, Observed in 2001)
Anthus hodgsoni	—	+	+	—
Apus apus pekinensis	—	+	—	—
Ardeola bacchus	—	+	++	—
Athene noctua plumipes	++	++	+	+
Buteo hemilasius	—	+	+	—
Carduelis s. sinica	—	—	—	+
Calandrella rufescens beicki	—	—	—	+
Columba rupestri rupestris	—	+	++	—
Corvus frugilegus pastinator	—	—	—	++
Corvus monedula dauuricus	—	—	+	++
Cuculus canorus linne	++	+	+	—
Dicrurus macrocercus	++	++	—	—
Dicrurus macrocercus cathoecus	+	—	—	++
Falco tinnunculus interstinctus	++	—	+	++
Ficedula parva	—	+	++	+++
Galerida cristata magna	—	+	++	++
Hirundo rustica gutturalis	—	+	—	++
Lanius cristatus lucionensis	—	—	+++	++
Lanius cristatus speculigerus	+++	+++	+	++
Lanius isaballinus	+	+	++	—
Lanius sphenocercus sphenocercus	—	+	—	—
Milvus korschun	++	+	—	—
Motacilla cinerea	—	+	++	+
Motacilla citreola	—	++	++	—
Muscicapa latirostris	—	++	—	—
Oenanthe hispanica pleschanka	—	+	++	—
Oenopopelia tranquebarica	—	+	+++	++
Passer ammodendri stoliczkae	+++	+++	++	—
Parus major	—	++	+	—
Passer montanus Stejneger	—	—	++	—
Phylloscopus b. borealis	—	++	++	+
Phylloscopus fuscatus	—	+	+	—
Phylloscopus inornatus	—	+	—	++
Pyrrhocorax pyrrhocorax	—	—	+	—
Pica pica serricea	—	+	—	++
Riparia riparia ijimae	—	—	+	—
Streptopelia d. decaocto	++	++	—	—
Streptopelia o. orientalis	+	—	+	—
Sturnus cineraceus	—	+	+	—
Syrrhaptes paradoxus	—	—	+	+
Sylvia curruca blythi	—	+	—	—
Tringa stagnatilis	—	+	+	+
Upupa epops saturata	—	+	—	—