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Effects of Re-vegetation on Herbaceous Species Composition and Biological Soil Crusts Development in a Coal Mine Dumping Site

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Abstract Despite the critical roles of plant species' diversity and biological soil crusts (BSCs) in arid and semi-arid ecosystems, the restoration of the diversity of herbaceous species and BSCs are rarely discussed during the process of vegetation restoration of anthropogenically damaged areas in these regions. In this study, the herbaceous plant species composition, along with the BSCs coverage and thicknesses, was investigated at six different re-vegetation type sites, and the natural vegetation site of the Heidaigou open pit coal mine in China's Inner Mongolia Autonomous Region was used as a reference. The highest total species richness (16), as well as the species richness (4.4), occurred in the Tree and Herbaceous vegetation type site. The species composition similarities between the restored sites and the reference site were shown to be very low, and ranged from 0.09 to 0.42. Also, among the restored sites, the similarities of the species were fairly high and similar, and ranged from 0.45 to 0.93. The density and height of the re-vegetated woody plants were significantly correlated with the indexes of the diversity of the species. The Shrub vegetation type site showed the greatest total coverage (80 %) of BSCs and algae crust coverage (48 %). The Shrub and Herbaceous type had the greatest thicknesses of BSCs, with as much as 3.06 mm observed, which was followed by 2.64 mm for the Shrub type. There was a significant correlation observed between the coverage of the total BSCs, and the total vegetation and herbaceous vegetation coverage, as well as between the algae crust coverage and the herbaceous vegetation coverage. It has been suggested that the re-vegetated dwarf woody plant species (such as shrubs and semi-shrubs) should be chosen for the optimal methods of the restoration of herbaceous species diversity at dumping sites, and these should be planted with low density. Furthermore, the effects of vegetation coverage on the colonization and development the BSCs should be considered in order to reconstruct the vegetation in disturbed environments, such as mine dumpsites in arid areas.

Keywords Arid and semi-arid regions · Open pit coal mine · Re-vegetation types · Vegetation coverage · Species diversity

Introduction

The destruction of ecosystems through mining for minerals, in order to meet the needs of industry, has acted as an intrinsic component of modern development. The further demand for mineral resources will accelerate the degradation of natural habitats and environments (Singh et al. 2002). Surface coal mining, which represents one of the most severe disturbances to the forest/grasslands of China, has resulted in biotic and abiotic components of the ecosystem undergoing complete disruption, in particular, plant diversity and biotic soil surface properties, such as biological soil crusts (BSCs) (Bowker 2007; Brom et al. 2012). As natural resources continue to be utilized, and opportunities to recover or reconstruct the ecosystems

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which have been damaged by human activities (for example, surface mining) become more and more common, recovery and reconstruction increasingly play vital roles in the environment and the enhancement of species' diversity protection, as well as the improvement of human livelihood (He and Yin 2010; Bullock et al. 2011).

Plant species diversity is usually considered to be a beneficial, and even essential, property of healthy ecosystems. The human exploitation and conversion of the world's ecosystems are causing lowered widespread biodiversity, as well as declines in ecosystem conditions, which thereby have led to reduced provision of ecosystem services (Butchart et al. 2010). Furthermore, the BSCs constitute one of the most important dryland landscapes and play irreplaceable roles in the interconnection between surface biotic and abiotic components in arid and semi-arid regions (Belnap and Lange 2003; Bowker 2007; Li 2012). Many previous studies have documented that the loss or degradation of BSCs have altered the redistribution of water (Eldridge et al. 2002; Li et al. 2010); decreased fertility (Belnap and Lange 2003); increased invasibility by exotics (Serpe et al. 2006); and most importantly, increased soil erosion (Belnap and Gillette 1998; Li 2012). Therefore, the restoration of plant species' diversity, as well as the coverage of BSCs, is necessary to these ecosystems.

Plantation is an effective technology for the restoration of ecosystems which have been damaged by human activity (Filcheva et al. 2000), due to the fact that plantation can play a critical role in improving ecosystem stability and enhancing service functions in degraded areas (Schaller 1993). One of the main focuses in achieving the satisfactory restoration of a surface mined landscape is to establish a permanent vegetation cover (Parrotta et al. 1997). The number of restored surface mining areas in northern China has increased during the last 20 years. Using the Hedaigou opencast coal mine for an example, the many vegetation arrangements, such as Tree, Tree and Shrub, and Tree, Shrub, and Herbaceous combinations, have been used to rehabilitate the vegetation cover and habitat, and to decrease the soil erosion in the dumping sites. On one hand, although the restoration of vegetation cover and habitat have been targets for managers during the last several decades, few attempts have been made to evaluate the effects of woody plant restoration by means of studying the different types and arrangements of herbaceous plant species richness, abundance, and composition. On the other hand, the vegetation landscape pattern in water-driven desert environments is characterized by the mosaic distributions of vascular vegetation and BSCs patches (Belnap and Lange 2003). Nevertheless, it is difficult to identify the effects of vegetation on the BSCs in desert systems, and the results of the recently conducted studies regarding these effects are still debatable (Bowker 2007; Ochoa-Hueso et al. 2011; Li 2012). Moreover, few studies have been devoted to the link between artificial vegetation and BSCs at dumping sites in surface mining areas, particularly in arid and semi-arid regions.

In this study, the richness, abundance, and composition of the herbaceous plant species are described, as well as the coverage and thicknesses of the BSCs at the restored sites and the reference dumping site in the open pit coal mine of Heidaigou, in order to address the following questions: (1) How do the richness, abundance, and composition of herbaceous plant species, as well as the coverage of BSCs, and the thicknesses of the different re-vegetation types vary among the restored sites and the reference site? and (2) Do vegetation types and their distribution patterns strongly influence the composition of herbaceous plant species, as well as the development of BSCs?

Methods

Study Site

The dumpsite study area was situated in the northern region of the Heidaigou opencast coal mine (39°43′–39°49′N; 111°13′–111°20′E). The total area was 197 km^2, and the site was located in the eastern area of Junggar Banner in Inner Mongolia Autonomous Region of China (Fig. 1). The soil type was loessial soil. The natural vegetation site was located 2 km from the dumping site, with an average elevation of 1163 m. The annual average temperature, annual rainfall, and relative humidity were 7.2 °C, 426.3 mm, and 58 %, respectively. Strip mining had not only directly damaged large portions of the land but also waste rocks and tailings occupied a large land area. The soil structure had been changed, and the vegetation had been completely destroyed after being mined. Re-vegetation activities were initiated in the northern dumpsite in 1995. The dumpsite contained the following vegetation for rehabilitation: *Populus alba* var. *pyramidalis* Bunge; *Pinus tabulaeformis* Carr; *Hippophae rhamnoides* Linn; *Astragalus adsurgens* Pall; and *Medicago sativa* L. (Wang et al. 2013).

Experimental Design and Field Measurements

In 1995, a total of six restoration sites (artificial vegetation areas) and a reference site (natural vegetation areas) were selected for the field survey. The sites were as follows: Tree (Tr, re-vegetated plant species were *Populus alba* var. *pyramidalis* Bunge, and *Pinus tabulaeformis* Carr.); Shrub (Sh, re-vegetated plant species was *Prunus sibirica* L.); Tree and Shrub (TS, re-vegetated plant species were *P. alba* var. *pyramidalis* Bunge, *P. tabulaeformis* Carr., and *P.*

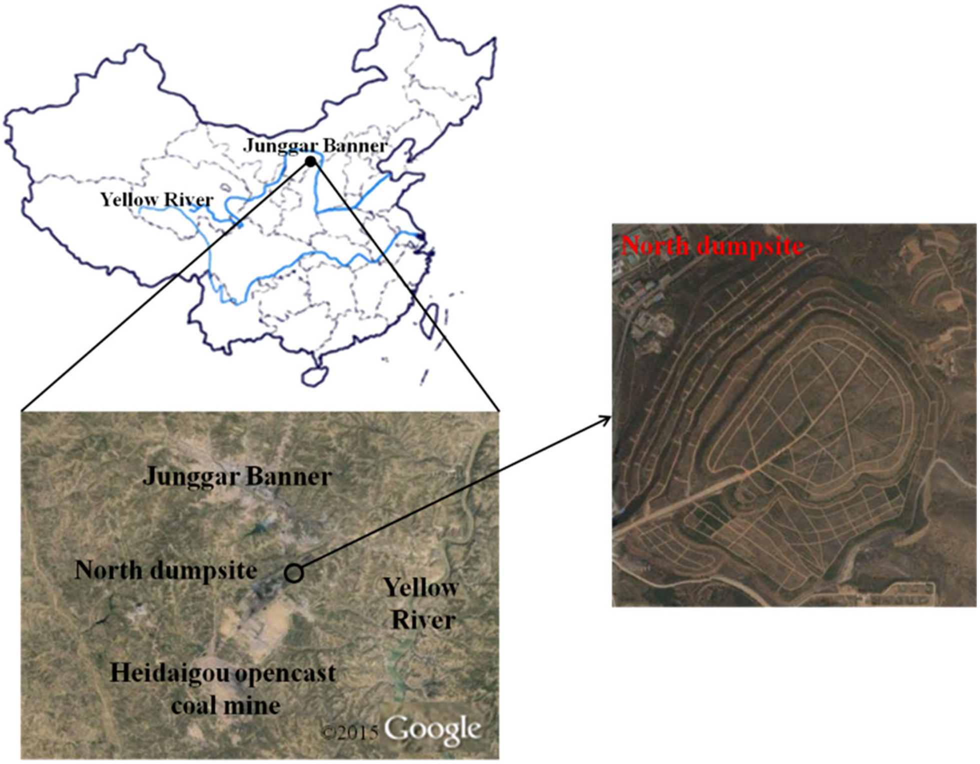

Fig. 1 Diagram showing the dumping sites at the Heidaigou opencast coal mine of Junggar Banner in Inner Mongolia Autonomous Region, China

sibirica L.); Tree and Herbaceous (TH, re-vegetated plant species were *P. alba* var. *pyramidalis* Bunge, *P. tabulaeformis* Carr., and *Medicago sativa* Linn); Shrub and Herbaceous (SH, re-vegetated plant species were *P. tabulaeformis* Carr., and *M. sativa* Linn); Tree, Shrub, and Herbaceous (TSH, re-vegetated plant species were *P. alba* var. *pyramidalis* Bunge, *P. sibirica* L., *Caragana Korshinskii Kom.*, and *M. sativa* Linn); and the Reference site (Ref, woody vegetation was *Lespedeza davurica* Laxm. Schindl.). The descriptions of each of the re-vegetation types and soil physicochemical properties are presented in Tables 1 and 2. The field work was conducted during August and September of 2013. At each of the restoration sites and the reference site, three plots (10 m × 10 m) were randomly chosen and covered, and the density and height of the woody and large type herbaceous species (if the crown diameter of a single plant was more than 0.5 m × 0.5 m, these were defined as large type herbaceous species, for example, *Astragalus adsurgens* and *Medicago sativa*) were measured. Three additional plots

Table 1 Descriptions of re-vegetation types of at the dumping sites

Types	Years[a]	Density of woody plant (100 m^2)	Height of woody plant (cm)	Coverage (%)		
				Total vegetation	Woody vegetation	Herbaceous vegetation
Tr	1995	26.33 ± 0.88	264.07 ± 2.63	67.99 ± 8.05	17.45 ± 1.33	52.50 ± 8.68
Sh	1995	29.67 ± 2.40	146.25 ± 14.84	74.04 ± 5.77	30.40 ± 1.86	44.50 ± 4.97
TS	1995	17.33 ± 8.35	245.62 ± 28.53	52.69 ± 5.39	24.83 ± 4.48	27.86 ± 6.14
TH	1995	9.67 ± 2.33	571.92 ± 34.21	44.51 ± 5.51	29.61 ± 3.63	14.90 ± 3.73
SH	1995	46.67 ± 9.25	148.04 ± 12.06	39.43 ± 8.44	7.93 ± 2.02	31.50 ± 7.80
TSH	1995	8.67 ± 1.76	293.30 ± 20.47	87.95 ± 4.13	60.71 ± 1.49	31.70 ± 5.51
Ref		6.33 ± 0.33	79.20 ± 3.49	70.08 ± 4.79	5.98 ± 1.74	64.10 ± 4.89

Re-vegetation types: *Tr* Tree, *Sh* Shrub, *TS* Tree + Shrub, *TH* Tree + Herbaceous, *SH* Shrub + Herbaceous, *TSH* Tree + Shrub + Herbaceous, *Ref* Reference site

[a] Year of re-vegetation

Table 2 Descriptions of soil physicochemical properties at different re-vegetation types at the dumping sites

Sites	TN (g/kg)	TP (g/kg)	SOM (g/kg)	SMC (%)	SBD (g/cm^3)
Tr	0.17 ± 0.01d	4.96 ± 0.27a,b	4.08 ± 0.27c,d	12.43 ± 0.62a	1.27 ± 0.05b
Sh	0.30 ± 0.02c	3.45 ± 0.94c	3.12 ± 0.94c,d	9.60 ± 0.62b	1.27 ± 0.05b
TS	0.39 ± 0.08b	5.64 ± 0.80a	5.28 ± 0.80b	8.00 ± 1.14c	1.28 ± 0.02b
TH	0.21 ± 0.01c,d	3.47 ± 0.06c	3.78 ± 0.06c,d	11.56 ± 0.94a	1.27 ± 0.05b
SH	0.21 ± 0.02c,d	3.20 ± 0.59c	2.97 ± 0.59d	5.74 ± 0.69d	1.44 ± 0.06a
TSH	0.25 ± 0.05c,d	2.81 ± 0.92c	4.18 ± 0.92c	7.42 ± 1.08c	1.33 ± 0.02b
Ref	0.46 ± 0.04a	4.63 ± 0.41b	9.18 ± 0.41a	7.35 ± 1.17c	1.13 ± 0.02c

Values (mean ± SE) with different letters are significantly different at $P < 0.05$

Re-vegetation types: *Tr* Tree, *Sh* Shrub, *TS* Tree + Shrub, *TH* Tree + Herbaceous, *SH* Shrub + Herbaceous, *TSH* Tree + Shrub + Herbaceous, *Ref* Reference site. Soil physicochemical properties: *TN* total nitrogen, *TP* total phosphorus, *SOM* soil organic matter, *SMC* soil moisture content, *SBD* soil bulk density

(1 m × 1 m) were randomly set up within each 10 m × 10 m plot for the purpose of measuring the species, cover, density, and height of the herbaceous plants. Also, another 3 plots (0.2 m × 0.2 m) were randomly established within each 1 m × 1 m plot, in order to measure the coverage and thicknesses of the BSCs (see Fig. A1 (online) for the field sampling design sketch). In total, 273 sample plots (21 sample plots for woody plant species, 63 for herbaceous plants, and 189 for BSCs) were placed at the dumping site in the Heidaigou opencast coal mine. The unknown plants were photographed and collected, and then taken to the laboratory for further identification. Then, the Latin names of the plants and syntaxonomical classification were given, as described by *The Flora of China* (1998). The BSCs' coverage was measured by utilizing a "Point Sampling Frame" (Li 2005; Li et al. 2010), and the thicknesses of the BSCs were measured by a Vernier caliper.

Data Analyses

The abundance, richness, and Jaccard index were calculated as follows:

1) Abundance = D,
2) Richness = S,
3) Jaccard index = $c/(a + b - c)$,

where D was the species density within the plot and S was the species number within the plot. In addition, a and b were the numbers of all the species in sites a and b, respectively, and c was the number of species that occurred in both sites.

The degree of species similarity was then compared among the restored sites and the reference site. The relationships between the abundance, richness, and total number of herbaceous plant species, as well as the re-vegetated plant coverage, plant density, and plant height, were examined using a Pearson correlation analysis. There were three sampling plot sizes (100, 1.00, and 0.04 m^2) used in this study. Therefore, the data of each of the plots were first transformed to the unit area (in this study, 1 m^2 as unit area was used), and then the relationship amounts with the different factors were analyzed. A regression analysis was used to examine the relationship between the vegetation coverage and the coverage and thicknesses of the BSCs. These procedures were performed using Windows-based SPSS 16th edition software (Chicago, USA) (Table 3).

Results

Herbaceous Plant Species Richness, Abundance, and Composition at Different Re-vegetation Type Sites

The reference site was found to have the highest total species richness (20), and the species richness (5.94) of herbaceous plants was significantly higher than that in the restored sites ($P < 0.05$). Within the restored sites, the TH site had the highest total species richness (16), followed by the TS (14) and TSH (13) sites, which were found to be significantly higher than the other restored sites ($P < 0.05$). The TH (4.4) sites were found to have the highest species richness, followed by the TS (3.5), and TSH (3.2) sites (Fig. 2a). The species abundance was observed to be the highest at the SH (179.44/m^2) site, followed by the reference site (119.67/m^2), and were significantly higher than the other restored sites (Fig. 2b). The correlation analysis results showed that the site types, re-vegetated plant coverage, plant density, and plant height had different effects on the different diversity measures, as shown in Table 4. The site types were found to be significantly associated with all of the diversity measures, total species richness ($r = 0.66$, $P < 0.01$), species richness ($r = 0.69$,

Table 3 Herbaceous plant species only found at each re-vegetation types at the dumping sites

Species only found in references site	Species only found in restored sites
Artemisia frigida Willd.	*Astragalus scaberrimus* Bunge
Cleistogenes songorica (Roshev.) Ohwi	*Cynanchum chinense* R. Br.
Erodium stephanianum Willd.	*Oxytropis chiliophylla* Royle
Glycyrrhiza uralensis Fisch.	*Calamagrostis pseudophragmites* (Hall. F.) Koel.
Hypericum attenuatum Choisy	*Pennisetum alopecuroides* (L.) Spreng.
Iris tenuifolia Pall.	*Deyeuxia conferta* Keng
Messerschmidia sibirica L.	*Bidens parviflora* Willd.
Peganum harmala L.	
Phalaris arundinacea Linn.(A)	
Potentilla bifurca L.	
Stipa capillata Linn.	
Vicia sepium Linn	

A annuals; all other species are perennials

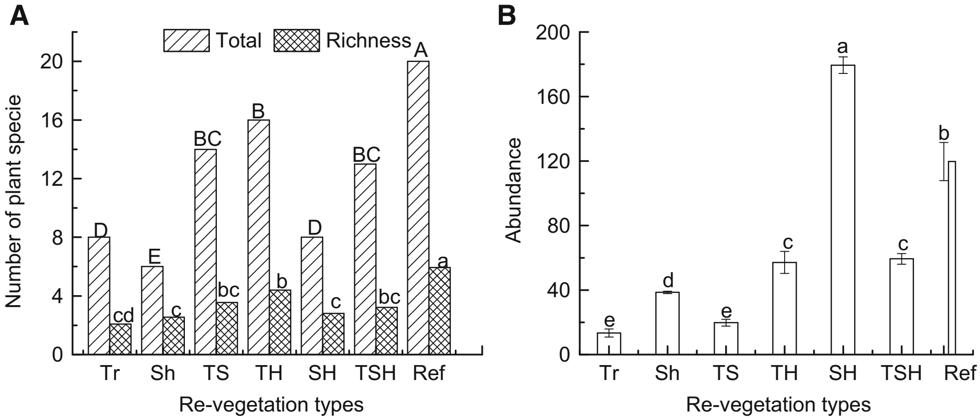

Fig. 2 Total number, richness (**a**), and abundance (**b**) of herbaceous plant species at each re-vegetation types of Tree (Tr), Shrub (Sh), Tree + Shrub (TS), Tree + Herbaceous (TH), Shrub + Herbaceous (SH), Tree + Shrub + Herbaceous (TSH), and Reference site (Ref) at the dumping sites

Table 4 Coefficients of correlation among wild herbaceous plant species abundance (HA), wild herbaceous plant species richness (HR), total number of wild herbaceous plant species (THM) and re-vegetated plant coverage (RC), re-vegetated plant density (RD), and re-vegetated plant height (RH)

	RC	RD	RH	HA	HR	THM
RC	1.000					
RD	0.255	1.000				
RH	0.073	−0.315	1.000			
HA	0.238	0.393*	−0.422*	1.000		
HR	−0.222	−0.444*	0.296	0.115	1.000	
THM	−0.075	−0.469**	0.284	0.111	0.828**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

$P < 0.01$), and species abundance ($r = 0.37$, $P < 0.05$). The density of the re-vegetated woody plants was found to be significantly negatively associated with all of the diversity measures, total species richness ($r = -0.47$, $P < 0.01$), species richness ($r = -0.44$, $P < 0.05$), and species abundance ($r = -0.39$, $P < 0.05$). The heights of the re-vegetated woody plants were found to be significantly negatively associated with the species abundance ($r = -0.42$, $P < 0.05$).

The community in the reference site had more species than the restored sites. It was found that *Leymus chinensis* (Trin.) Tzvel was a dominant species not only at the restored sites but also at the reference site, as shown in Table 3. When examining the species composition similarities in each site, the correlation in the species composition among the restored sites and reference site was very low and ranged from 0.09 to 0.42. Also, the species' composition was fairly high and similar among the restored sites and ranged from 0.45 to 0.93 as shown in Table 5.

Coverage and Thickness of the BSCs at the Different Re-vegetation Type Sites

There were significant differences in the total BSCs, algae crust, and moss crust coverages, as well as the thicknesses of the BSCs among the re-vegetation types ($P < 0.05$). The

Table 5 Similarity in plant species composition between re-vegetation types at the dumping sites

	Ref	Tr	TS	Sh	SH	TH	TSH
Ref	1.000						
Tr	0.174	1.000					
TS	0.138	0.484	1.000				
Sh	0.091	**0.800**	0.483	1.000			
SH	0.273	0.462	0.500	0.531	1.000		
TH	0.429	**0.632**	**0.696**	0.461	**0.625**	1.000	
TSH	0.308	0.471	**0.700**	0.453	0.588	**0.932**	1.000

Correlations above 0.60 are in bold

Re-vegetation types: *Tr* Tree, *Sh* Shrub, *TS* Tree + Shrub, *TH* Tree + Herbaceous, *SH* Shrub + Herbaceous, *TSH* Tree + Shrub + Herbaceous, *Ref* Reference site

Sh (Shrub) type had the highest coverage of total BSCs (up to 80 %), which was significantly higher than those of the other re-vegetation types. The algae crust coverage in the Sh type site was 48.01 %, which was also significantly higher than the SH (Shrub and Herbaceous), TSH (Tree, Shrub, and Herbaceous), and Ref (Reference) sites. The SH site showed the highest (43.25 %) moss crust coverage, which was significantly higher than that of the Tr, TS, TH, and Ref sites (Fig. 3a–c). With the exception of the Tr, TSH, and Ref sites, the relative total BSCs' coverage in the re-vegetated areas was more than 50 %. The Ref showed the thickest BSCs (3.40 mm), which was significantly higher than that of the other re-vegetation types. The BSC thickness in the SH was 3.06 mm and 2.64 mm in the Sh type site (Fig. 3d, e).

The correlation analysis results showed that the woody vegetation and herbaceous vegetation coverages had different effects on the coverage and thicknesses of the BSCs. The woody vegetation coverage was significantly associated with the coverage of the total BSCs ($r = 0.388$, $P < 0.01$), algae crust coverage ($r = 0.250$, $P < 0.05$), and thicknesses of the BSCs ($r = -0.299$, $P < 0.01$). The coverage of the herbaceous vegetation was significantly associated with the coverage of the total BSCs ($r = -0.260$, $P < 0.01$), as shown in Table 6. The regression analyses between the total vegetation coverage, woody vegetation coverage, and herbaceous vegetation, and the coverage and thicknesses of the BSCs are shown in Fig. A1 (online).

Discussion

Effects of Re-vegetation on Herbaceous Plant Species Diversity

The land-use history in a long-term perspective, as well as the landscape connectivity, may play key roles in creating and maintaining plant species diversity patterns. Moreover, the proper conditions for species establishment are important in order to achieve the former species richness and composition (Lindborg and Eriksson 2004). Herbaceous vegetation was dominant in the undisturbed vegetation near the study areas. Meanwhile, herbaceous vegetation can adjust to local climatic conditions, with a high survival rate. The low survival rate of trees was a problem under the rainfed conditions for re-vegetation in the study area (Jiang et al. 2013). Therefore, it was concluded that the planting of herbaceous vegetation should be considered for dumpsite re-vegetation in arid and semi-arid regions.

The results of this study showed that re-vegetation types, woody plant density, and plant heights had different effects on the different diversity measures. As illustrated in Table 2, the establishment of different type sites created different habitat conditions, such as the soil physico-chemical properties (soil water content, nitrogen content, phosphorus content, organic matter, and soil bulk density), and the microclimate (air temperature, soil temperature, relative air humidity) as shown in the study by Zhao et al. (2015). Typically, the plant species' diversity is driven by the spatial heterogeneity (spatial and temporal variability in soil resources and microclimate conditions) (Bartels and Chen 2010). The factors described above caused significant differences in the plant species across the area sites. Therefore, the spatial heterogeneity created by the different vegetation types, as well as the arrangements, had significant impacts on the herbaceous plants' total species richness, species richness, and abundance.

In arid and semi-arid regions, seedling establishment, species composition, and species distribution are mainly limited by the soil's water and nutrient availability, which becomes a major bottleneck for plant recruitment in water- and nutrient-limited environments (Soliveres et al. 2012). The fact that woody and herbaceous species compete for the availability of soil water and nutrients may help explain this study's findings. This intense competition is particularly true for plants growing in water- and nutrient-limited environments where there are contrasting results for growth rates under benign conditions (Castro et al. 2004; Maestre et al. 2005). The competition for limiting the amount of suitable space for colonization may also help explain the relationships observed in this study. There is no doubt that the availability of light influences the establishment of plants and the community succession (Bartels and Chen 2010). The reduced radiation due to the shade provided by the woody plants may have limited the distribution of the herbaceous species and their growth under these trees. The photosynthetic active radiation under the canopies of the large trees was reduced by up to 50 % of the values in the open grassland areas (Ludwig et al. 2004). The canopy

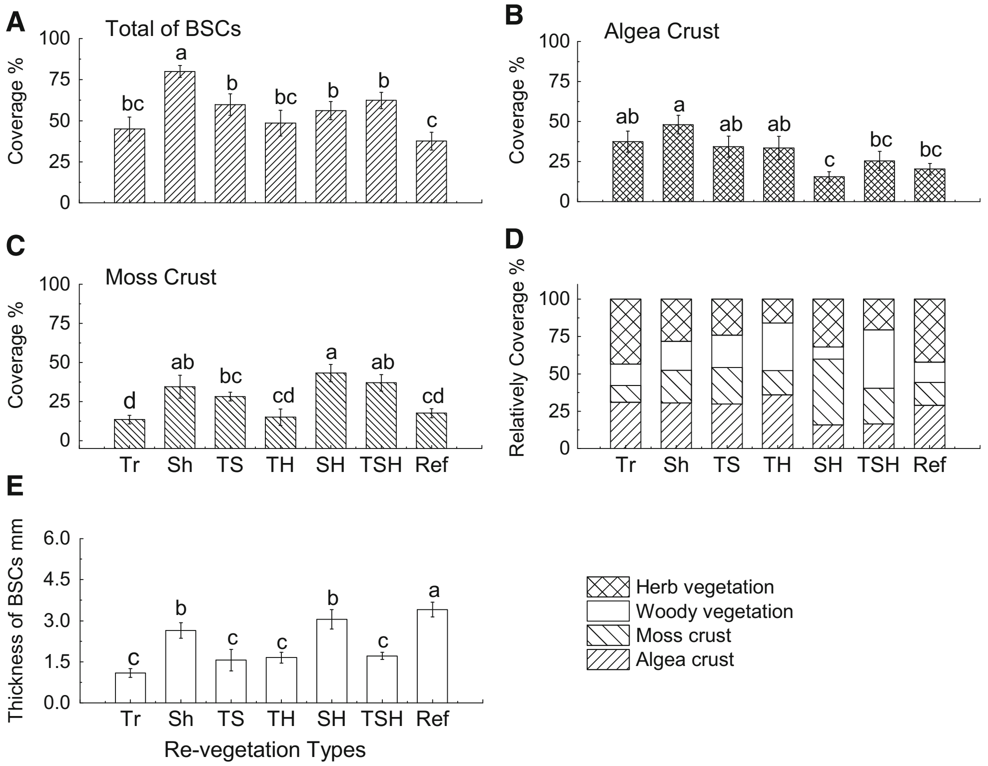

Fig. 3 Coverage of total BSCs (**a**), algae crust (**b**), moss crust (**c**), relatively coverage of algae crust, moss crust, woody vegetation and berb vegetation (**d**), and thickness of BSCs (**e**) in the re-vegetation types of Tree (Tr), Shrub (Sh), Tree + Shrub (TS),Tree + Herbaceous (TH), Shrub + Herbaceous (SH), Tree + Shrub + Herbaceous (TSH), and Reference site (Ref) at the dumping sites

Table 6 Coefficients of correlation among coverage of total BSCs (CTB), coverage of algae crust (CAC), coverage of moss crust (CMC), thickness of BSCs (THB), coverage of total vegetation (CTV), coverage of woody vegetation (CWV), and coverage of Herbaceous vegetation(CHV)

	CTB	CAC	CMC	THB	CTV	CWV	CHV
CTB	1.000						
CAC	0.549**	1.000					
CMC	0.611**	−0.303**	1.000				
THB	0.178	−0.259*	0.479**	1.000			
CTV	0.010	0.007	−0.006	−0.023	1.000		
CWV	0.388**	0.250*	0.177	−0.299**	0.336**	1.000	
CHV	−0.260*	−0.180	−0.115	0.198	0.720**	−0.398**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

opening controlled the level of light reaching the herbaceous layer, and impacts the photosynthesis of the herbaceous species. In the light-textured soil-moisture recharge of the surface layers, as influenced by the canopy openings, a main control over the herbaceous species abundance was exerted (Abdallah and Chaieb 2012).

Despite the fact that the restored sites over time recovered in terms of species richness, a large portion of the rare species had not returned to the restored sites when this examination was performed following 19 years of restoration. Difficulties in re-colonization may have occurred, due to scattered and isolated populations (Lindborg and Eriksson 2004). Therefore, this study suggested using the species abundance of the fairly common herbaceous plant species which occurred in the reference site for re-vegetation in the dumping sites. Based on these results, it is suggested that *Leymus chinensis* (Trin.) Tzvel, *Stipa capillata* Linn, *Cleistogenes songorica* (Roshev.) Ohwi, and *Melilotus officinalis* (Linn.) Pall should first be considered for the re-vegetation process. This study's results clearly indicated that the abundance of a plant species in the species pools and the similarity in plant species composition between the reference site and the restored sites are important factors in predicting colonization success. For example, the species with a higher abundance and similarity nearby and/or in the surrounding areas are more likely to colonize the restored sections. This signifies that either there is a dispersal limitation among the restored sites or that the species have very specific habitat requirements and thereby fail to colonize (which is rarely found in re-vegetation sites), or a combination of the two. The species' ability to re-colonize is affected by the dispersal from the source populations or by its longevity in a seed bank (Eriksson and Ehrlén 2001). Due to the absence of seed bank relicts, as well as the fragmentation and isolation of the restored sites, without artificial seed sowing or transplantation, it will likely be difficult for many of the herbaceous species to re-colonize. However, species introductions should be seen as a last resort, after first attempting to improve the conditions for regeneration from an available seed bank (Bekker et al. 1997; Lindborg and Eriksson 2004) or after trying to enhance the natural dispersal (Strykstra et al. 1998). Therefore, if introduction is considered, this should be achieved by propagules from neighboring populations.

Effects of Re-vegetation on BSCs Colonization and Development

In this study, the re-vegetation of the Sh (Shrub) type had the highest coverage of total BSCs, which was significantly higher than that of the other re-vegetation types. When compared with tree type, the shrub had dense and limp branches, and vigorous growth. Also, it showed a strong ability to reduce wind speed, and to capture vegetation litter and fine soil particles (Zhao et al. 2007; Guo et al. 2008). The results of this study confirmed the finding of the previous study (Zhao et al. 2010) and demonstrated that the BSCs' development was more prominent in the shrub vegetation than in the semi-shrub or tree vegetation types. It was therefore obvious that the re-vegetation types and their distribution pattern significantly affected the colonization and development of the BSCs.

The coverage of the BSCs can be enlarged with the increase of vegetative coverage in the early growth stage of re-vegetation. However, the developed BSCs will be destroyed and disappear with further increases of vegetative coverage in late growth stage of re-vegetation (Li 2012). Vegetation coverage, particularly woody plant coverage, can slow down the land near-surface wind speed and subsequently stabilize the soil surface'ss environment. It can also directly screen solar radiation, reduce daytime air and soil temperature, and increase relative air humidity (McPherson 2007; Brom et al. 2012). The vegetation of the land's surface increased in roughness at the near-surface (below 1 m) and increased the dust from atmosphere ($d < 0.063$ mm) on the stable soil surface (Li et al. 2010). The process eventually facilitated the colonization and growth of the organisms of the BSCs in the soil. The diurnal carbon fixation of the BSCs determined the BSCs growth rate, which was largely regulated by the availability of water and daytime wetness (Li et al. 2012). The woody vegetation coverage increased the rates of transpiration through leaf cover and subsequently increased the relative air humidity. Also, the relative air humidity increased with the increase in vegetation coverage (Belnap and Lange 2003; Li 2012). Increases in the relative air humidity can increase the availability of water content, and decreases in the air and soil temperature can reduce the water evaporation from the BSCs, and thereby prolong daytime wetness.

Light is another vital factor which influences the colonization and growth of BSCs. As the crusts contain photoautotrophic organisms, strong light inhibits their photosynthesis, and therefore, reduced light intensity can be beneficial to the growth of BSCs. Woody vegetation cover can screen direct solar radiation reaching the soil surface, and the BSCs can grow well under those conditions (Guo et al. 2008; Zhao et al. 2010). However, complete shading by woody vegetation can decrease the coverage and growth rates of the BSCs (Schlensog et al. 2013; Zaady et al. 2013). In the present study, the total coverage of the BSCs and algae crust coverage were decreased when the total vegetation and woody vegetation coverages reached more than 45 and 40 %, respectively. For the most part, light intensity is decreased with the increase of woody vegetation coverage, and if the woody vegetation coverage is high enough to inhibit the photosynthetic activity of the BSCs, then the colonization and growth the BSCs may be inhibited. These results were confirmed in this study, where negative correlations were demonstrated between the coverage of the total BSCs and the coverage of total vegetation, as well as between the algae crust coverage and the coverage of woody vegetation, during the late growth stage of re-vegetation.

Herbaceous vegetation may inhibit the colonization and development of the BSCs through competition for such resources as water, nutrients, light, and space (Bowker 2007). The coverage of the BSCs had a negative relationship with herbaceous vegetation, due to the increased competition for light and moisture (Ponzetti et al. 2007). Also, due to the crust propagules being dispersed by wind, the crust can be colonized on the open spaces formerly occupied by perennial plants, and in this way, its coverage can be increased (Zaady et al. 2013). However, the study conducted in the Columbia Basin found that the coverage of the bunchgrasses, blue bunch wheatgrass, and Sandberg's bluegrass was positively related to the BSCs' coverage. Due to the fact that these bunchgrasses typically maintain interspaces with few other vascular plants, they provide an open soil surface for the BSCs' species to establish and survive (Ponzetti et al. 2007). Therefore, herbaceous vegetation management should be considered during the restoration of BSCs in the re-vegetation areas of dumping sites.

Conclusions

The highest total plant species richness, as well as the species richness, was found to occur in the Tree and Herbaceous vegetation type site. The Shrub and Shrub and Herbaceous vegetation type sites showed the greatest coverage and thicknesses of the BSCs. The vegetation types and their distribution patterns strongly influenced the composition of the herbaceous plant species, as well as the development of the BSCs. This study's results indicated that for the re-vegetation at dumping sites, dwarf tree or shrub species should be chosen, and these should be planted with a low level density. From the results of this study, it was also concluded that the coverage of woody and herbaceous vegetation should be controlled within the threshold level, in order to ensure the sustainable colonization and development of the BSCs during the process of vegetation restoration in arid and semi-arid regions.

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