Chapter

Evaluation of Soil Seed Banks in Different Aged Caragana microphylla Plantation in Desert Steppe Ecosystems

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Abstract

Soil seed bank (SSB) represents potential plant communities, which is essential in the restoration of degraded ecosystems. Consequently, SSB is crucial in the reconstruction and recovery of aboveground plants because they largely determine the process and direction of vegetation restoration. SSB is also important indicators that can be used to evaluate the effects of management on degraded desert steppe. Here, field sampling and soil seed germination experiments were used to investigate the role of SSB in the recovery of degraded desert steppe. Results indicated that (1) the species composition of SSB and ground vegetation significantly differed in different aged *Caragana microphylla* plantation and control in the Yanchi County. (2) The abundance of SSB was significantly promoted by *C. microphylla* plantation. The average seed density in *Caragana* plantation SSB was 11248.75 m^{-2}, which was 17 times than that of SSB in areas without *C. microphylla* plantation. (3) The ages of *C. microphylla* plantation were closely related to the composition and density of SSB.

Keywords: desert steppe, soil seed bank (SSB), species composition, vertical distribution pattern, species diversity

1. Introduction

The soil seed bank (SSB) comprises seeds that have survived at the soil surface and in the soil [1]. The SSB represents potential plant communities and is essential for rehabilitating degraded ecosystems via revegetation and restoration. Moreover, the SSB determines the progress and direction of the future vegetative composition of communities [2–4]. Consequently, understanding species composition, density, and diversity of SSB can provide a basis for understanding mechanisms of vegetation succession, and is a particularly important indicator for evaluating the effects from treating degraded desert steppe ecosystems [5]. Human disturbance always generate significant negative effects on the SSB in desertified regions in a semi-arid climate [6]. The research on seed banks in a degraded desert shrubland showed there were consistently positive relationships between ground cover of litter and viable seed density [7]. In degraded drylands, the re-establishment of post-disturbance native plant community was almost exclusively conducted using seeds [8]. The average seed density decreased from stabilized sand dune to interdune lowland of stabilized sand dune, to interdune lowland of active sand dune, and to active sand dune [9]. The latest researches indicated that vegetation cover and seed bank size were notably lower in the degraded grassland. And there were significant differences in understory vegetation and soil seed stocks among different vegetation types on the Loess Plateau [10]. The restoration effect of planted forest was obviously better than that of abandoned farmland [11]. Tree seed density and diversity increased with regeneration time and vegetation structure [12]. Spatially, the distribution of the seed density and species diversity of the SBB in the marginal zones were higher than those of seed banks in the hinterland of the desert [13, 14]. Although considerable research has investigated various aspects of SSB characteristics for different vegetation types, little research has been conducted to systematically evaluate SSB of planted shrubs, and how those treatments can affect dessert steppe ecosystems.

Beginning in the 1970s, plantation of *C. microphylla* in addition to fencing has been used in Yanchi County to restore degraded desert steppe. Currently, there are 600,000 hectares *C. microphylla* plantation. In this study, the SSB was investigated in semi-fixed dune, and *C. microphylla* plantation with different ages within fencing in a degraded desert steppe, while using a neighboring natural steppe without desertification as a control. Several important indicators of SSB were evaluated, including species composition, the number of germinations, and species diversity. The changes of plant species and seed density in SBB of *C. microphylla* plantation with different ages can provide scientific basis for the selection of plant species and the determination of seeding amount for aerial seeding [15].

2. Material and methods

2.1 Study site and plot layout

The study area was based in the Ningxia Hui Autonomous Region of Eastern China (37°04′ ~ 38°10’N, 106°30′ ~ 107°41′E) and features an elevation of 1,295 ~ 1,951 m. Yanchi County is connected to the Mu Us Sandland in the north and to the Loess Plateau in the south, which is considered to be a typical geographic transition zone. Desertification areas are expanding in Yanchi County due to overuse of ecosystem resources. Sand land has become one of the main landform types in the Ordos slope hills of the area. The total area of Yanchi County is 8,661.3 km^2. It has a typical temperate continental climate with hot summer, cold winter, extensive drought, significant wind, and strong evaporation. The average annual temperature was 8.1°C.The average annual rainfall was 250–350 mm, wherein greater than 80% of the rainfall occurred from May to September. The primary winds in the area were west and northwest winds. The main soil of Yanchi County is sierozem, followed by black loam and eolian soil [16]. The primary vegetation in Yanchi County is classified as a transition zone between the central Asian sub-regions of Eurasian steppe zone and the central steppe region. Vegetation types in the area include shrubs, steppe, meadows, swamps, and deserts. Vegetation exhibits transitional characteristics with gradual succession that is staggered extending from the south to the north. Yanchi County contains only plantation forests that mainly consist of *Salix psammophila* shrubland and *C. microphylla* shrubland [17]. The survey included semi-fixed dunes without *C. microphylla* plantation (plot ID: NO.1), and soil substrates were sierozem [18]. The dominant species in Plot 1 are *Agriophyllum squarrosum* and *Setaria viridis*. *C. microphylla* plantation with 7, 16, 25, and 37 years were included in the study and are identified as plots NO.2–5, respectively. Lastly, a neighboring natural steppe that did not exhibit desertification was used as a control (NO.6) (**Figure 1**). The dominant species in Plot 6 are *Artemisia scoparia* and *Sophora alopecuroides*.

2.2 Ground vegetation survey

Typical sampling methods were used in mid-August of 2015 to survey aboveground plant species composition, densities, heights, coverage, and frequencies in the various *C. microphylla* plantations. The specific location of plants in the plots, micro-topography, and other characteristics were simultaneously recorded in addition to sub-cover via grid needling methods. Each of the six plots consisted of ten 1 m × 1 m quadrats for a total of 60 quadrats.

2.3 Soil seed bank analyses

Transect line sampling was conducted, as previously described [19, 20]. Specifically, random arrangement of two 10 m long sample lines were placed in each sample plot in April 2013 using a customized soil seed bank sampler with equidistant 1 m sections that were then sampled at 0–2 cm, 2–5 cm, and 5–10 cm depths. Soil samples (n = 360) were placed in bags and transported back to the laboratory where they were then used for soil seed bank germination experiments. Indoor soil seed germination experiments were conducted as described previously [21]. The sampling area of each sample plot was 0.8 m^2, and the total sampling area of the six sample plots was 4.8 m^2. Briefly, direct germination measurements were used to estimate the portion of the seed bank capable of producing germinating seeds and the species composition of the SSB. Seedling germination can usually detect more than 90% of the species within the SSB of grassland ecosystems [22]. Soils were sun-

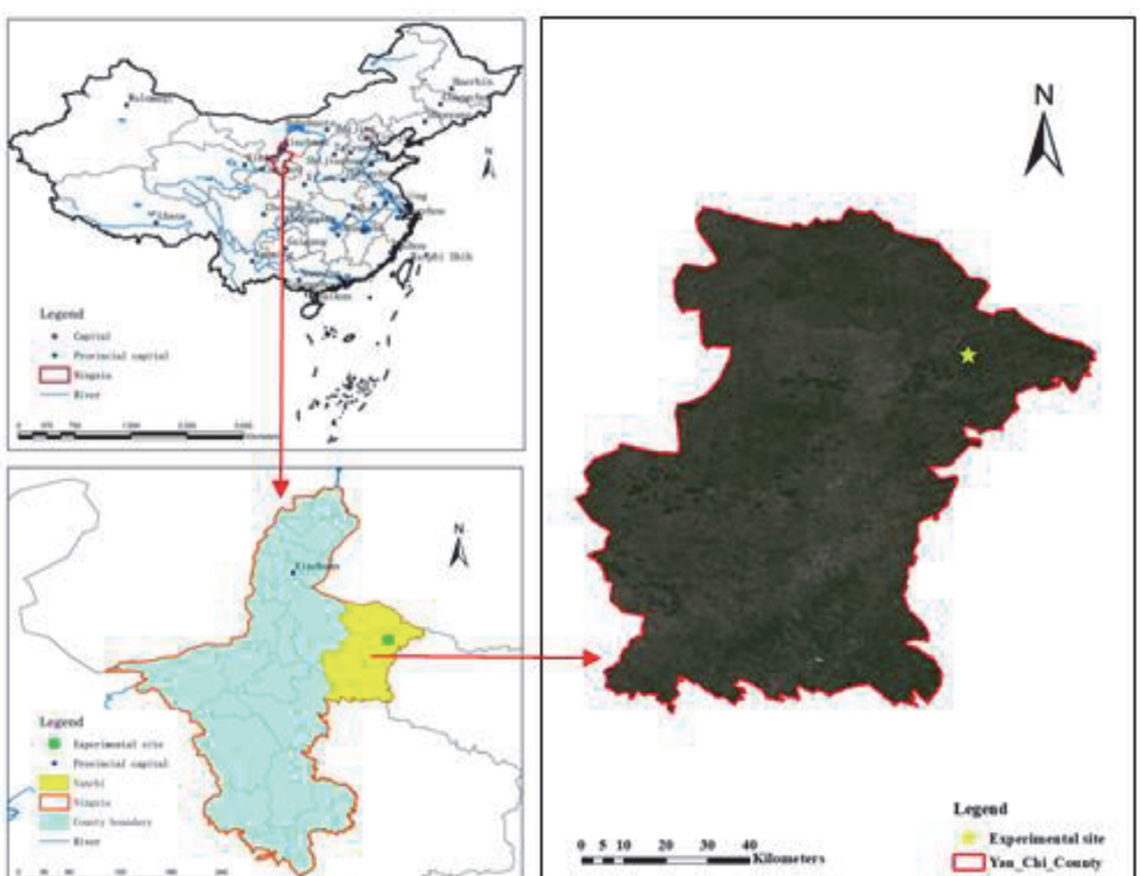

Figure 1.
The locations of the sampling sites.

dried inside of a greenhouse then sieved to remove litter, roots, rocks, and other debris. Soil samples were evenly spread and then placed in pots (42 cm × 28 cm × 15 cm) with a soil thickness of 1.5 cm with seed-less sand used as matrix at the bottom of the pots at a height of 10 cm.

2.4 Statistical analyses

Seed density was measured as the number of germinated plants in the soil seed bank of each plot, which was then converted to a seed bank number (in 1 m^2 units). Species diversity of the SSB was calculated based on seed densities and species composition via the Shannon-Wiener diversity index (H), the Simpson diversity index (D), and the Pielou evenness index (E) [23–25], as follows

$$\text{Richness index} : \mathrm{R} = (\mathrm{S} - 1)/\mathrm{lnN} \tag{1}$$

$$\text{Shannon} - \text{Wiener diversity index (H)} : H = -\sum_{i-1}^{s} (P_i 1\text{n} P_i) \tag{2}$$

$$\text{Simpson diversity index} : D = 1 - \sum_{i=1}^{S} P_i^2 \tag{3}$$

$$\text{Pielou evenness index (E)} : E = H/1\text{n}S \tag{4}$$

Where N is the total number of seeds in the SSB for each plot type, S is the total number of species in the SSB of each plot, and Pi is the number of the i-th species' seeds divided by the total number of seeds in a given plot.

The SPSS19.0 software package was used for single-factor analysis of variance (one-way ANOVA) tests of SSB differences, while the least significant difference method (LSD) was used to evaluate the statistical significance of differences. Microsoft Excel 2003 was used for graphical representations and other statistical analyses.

3. Results

3.1 Community characteristics of different age *C. microphylla* plantation

Ground vegetation communities within different aged *C. microphylla* plantation belonged to 10 families and 31 genera (**Table 1**), in which the Asteraceae (seven species), and Leguminosae (seven species) comprised the majority of plants, followed

Plot	Species	Coverage	Dominant species	Companion species
NO.1	5	< 1%	*Agriophyllum squarrosum*, *Setaria viridis*	*Agropyron desertorum*
NO.2	18	39.80%	*Artemisia scoparia*, *Corispermum mongolicum*	*Cynanchum komarouii*, *Salsola beticolor Setaria viridis*
NO.3	31	61.90%	*A. scoparia*	*A. desertorum*, *Lespedeza potaninii*
NO.4	17	71.70%	*A. scoparia*	*C. microphylla*, *Pennisetum centrasiaticum*
NO.5	16	49.80%	*A. scoparia*	*Setaria viridis*, *Sophora alopecuroides*
NO.6	12	69.50%	*A. scoparia*, *Sophora alopecuroides*	*Lespedeza potaninii*, *Euphorbia esula*

Table 1.
Community characteristics among 6 plots of C. microphylla *plantation and control.*

by the Gramineae (six species), the Chenopodiaceae (four species), and Convolvulacese (three species) in addition to Euphorbiaceae, Asclepiadaceae, and Zygophyllaceae that each comprised two species, and the Liliaceae and Polygalaceae that each constituted only one species. The species were divided into three kinds of life forms, including 3 shrubs or semi-shrubs (*Sophora alopecuroides*, *Caragana microphylla*, and *Lespedeza potaninii*), 11 annual plants, and 21 perennial herbaceous plants.

3.2 Species composition and seed density of SSB in different aged *C. microphylla* plantation

There were 33 species of plants in the soil seed bank and 35 species of above-ground vegetation in all sample plots in the study area, among which 18 species of plants were found in both SBB and above-ground vegetation. Among the plots, 15 species only appeared in SSBs, while 17 species only appeared in the aboveground vegetation communities. A total of 33 plant species were identified in the study area that belonged to 13 families and 27 genera. The highest number of species were present in Gramineae (10) followed by Chenopodiaceae (7), and then Leguminosae (3) in addition to two species each for Asteraceae, Euphorbiaceae and Asclepiadaceae, and then one species each for Plantaginaceae, Zygophyllaceae, Rosaceae, Caryophyllaceae, Amaranthaceae, Convolvulacese, and Polygalaceae. In terms of plant life form, two species of semi-shrubs were identified (*Sophora alopecuroides* and *Lespedeza potaninii*), in addition to 11 perennial herbs and 20 species of one or two years herbaceous plants (**Table 2**).

In the semi-fixed sand dunes, there were 661.25 / m^2 germinated seeds of the SSB consisting of 13 plant species that were dominated by *Setaria viridis* and *Digitaria ischaemum*, which accounting for 70.13% and 13.42% of plant community composition, respectively. In the 7 years *C. microphylla* plantation, there were 12,290.00·m^{-2} seeds comprising 21 plant species that were dominated by *Artemisia scoparia*. The SSB seed number decreased to 10,553.75·m^{-2} in the 16 years *C. microphylla* plantation, but there were 29 species that were mostly represented by nine species of Gramineae that accounted for 12.59% of the total plant composition. The SSB density of the 25 years *C. microphylla* plantation was 15,891.25·m^{-2}, which was highest among the SSB of *C. microphylla* plantation, although low species evenness was observed, with *Artemisia scoparia* accounting for 93.81% of the plants in these plots. The SSB density in the 37 years *C. microphylla* plantation was 6,260.00·m^{-2}, which was significantly lower than in other *C. microphylla* plantation. This decreased density in the oldest forest may be related to the types of species present in these plots and significantly reduced ground vegetation coverage (**Table 2**).

The average density of germinated seeds from SSBs in *C. microphylla* plantation was 11,248.75, with a total range from 6,262.00 - 15,891.25·m^{-2}. SSB seed numbers increased with forest age rapidly, followed by slight decreases with age after that. The mid-aged forests thus had the highest seed densities, while the density of the SSB in semi-fixed sand dunes was 661.25·m^{-2}. The difference equates to a 17-fold increase in seed density in planted area SSBs compared to non-planted areas (**Table 2**).

The densities of the SSB in *C. microphylla* plantation were lower than that of the natural grassland (19,788.75·m^{-2}). However, there were less species in the SSB of the natural grassland (22), relative to the 16 and 37 years *C. microphylla* plantation (**Table 2**).

3.3 Vertical distributions of species numbers of SSB in different aged *C. microphylla* plantation

The vertical distribution of seeds within the SSB is an essential component for SSBs within degraded desert steppe ecosystems. With increasing age of

Species	Plot1		Plot 2		Plot 3		Plot 4		Plot 5		CK	
	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}
Plantago asiatica	—	—	—	—	—	—	0.01	1.25	—	—	—	—
Euphorbia humifusa	0.19	1.25	0.19	23.75	0.06	6.25	0.03	5.00	0.06	3.75	0.04	8.75
Euphorbia esula	—	—	0.02	2.50	0.01	1.25	—	—	—	—	0.01	1.25
Sophora alopecuroides	—	—	0.02	2.50	0.04	3.75	0.02	3.75	—	—	0.01	1.25
Gueldenstaedtia stenophylla	—	—	—	—	0.18	18.75	0.04	6.25	0.02	1.25	—	—
Lespedeza potaninii	—	—	0.06	7.50	2.55	268.75	0.06	8.75	0.12	7.50	0.02	3.75
Tragus racemosus	—	—	—	—	0.75	78.75	0.96	152.50	2.94	183.75	—	—
Setaria viridis	70.13	463.75	1.13	138.75	2.27	240.00	0.96	152.50	1.00	62.50	0.25	50.00
Enneapogon borealis	—	—	—	—	1.40	147.50	—	—	0.08	5.00	—	—
Chloris virgata	0.19	1.25	0.01	1.25	0.01	1.25	—	—	0.06	3.75	0.01	1.25
Eragrostis poaeoides	0.76	5.00	3.25	400.00	4.18	441.25	1.09	173.75	5.03	315.00	0.20	38.75
Setaria glauca	—	—	0.70	86.25	1.07	112.50	0.08	12.50	1.14	71.25	—	—
Eleusine indica	4.35	28.75	0.27	33.75	0.01	1.25	0.03	5.00	0.06	3.75	0.11	22.50
Stipa glareosa	—	—	—	—	0.28	30.00	0.03	5.00	0.02	1.25	0.01	1.25
Digitaria ischaemum	13.42	88.75	1.45	178.75	2.62	276.25	0.57	90.00	2.40	150.00	0.86	170.00
Tribulus terrestris	—	—	0.05	6.25	0.08	8.75	0.02	2.50	—	—	0.03	5.00
var. *graminifolia*	—	—	0.07	8.75	—	—	0.01	1.25	0.08	5.00	0.01	1.25
Artemisia scoparia	3.40	22.50	90.78	11156.25	82.27	8682.50	93.81	14907.50	83.23	5210.00	97.85	19362.50
Salsola ruthenica	0.57	3.75	0.05	6.25	0.02	2.50	0.03	5.00	0.08	5.00	0.01	1.25

Species	Plot1		Plot 2		Plot 3		Plot 4		Plot 5		CK	
	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}	Composition/ %	Density/ Seeds·m^{-2}
Chenopodium glaucum	5.67	37.50	0.39	47.50	0.32	33.75	0.37	58.75	0.98	61.25	0.35	70.00
Corispermum tylocarpum	0.19	1.25	—	—	—	—	—	—	—	—	—	—
Corispermum mongolicum	0.38	2.50	0.07	8.75	—	—	—	—	0.02	1.25	0.01	2.50
Agriophyllum squarrosum	—	—	0.58	71.25	0.04	3.75	—	—	—	—	0.05	10.00
Bassia dasyphylla	—	—	—	—	—	—	—	—	—	—	0.03	5.00
Salsola beticolor	0.38	2.50	0.72	88.75	1.02	107.50	1.86	295.00	1.32	82.50	0.08	15.00
Cynanchum chinense	—	—	—	—	—	—	—	—	—	—	0.01	1.25
Cynanchum komarouii	—	—	0.02	2.50	—	—	—	—	0.02	1.25	—	—
Potentilla chinensis	—	—	—	—	0.07	7.50	—	—	0.02	1.25	—	—
Stellaria media	—	—	—	—	0.33	35.00	—	—	—	—	—	—
Amaranthus retroflexus	—	—	0.05	6.25	0.02	2.50	0.01	1.25	0.04	2.50	0.08	15.00
Cuscuta chinensis	0.38	2.50	0.09	11.25	0.25	26.25	0.02	3.75	1.22	76.25	0.01	1.25
Polygala tenuifolia	—	—	—	—	0.15	16.25	—	—	—	—	—	—
Unknown	—	—	—	—	—	—	—	—	0.08	5.00	—	—
Total	100.00	661.25	100.00	12290.00	100.00	10553.75	100.00	15891.25	100.00	6260.00	100.00	19788.75

Table 2.
Average species compositions and seed densities in the SSB of different aged C. microphylla *plantation and control.*

C. microphylla plantation, the overall richness of species in the SSB increased dramatically, then decreased slightly (**Figure 2**). Within 0–2 cm soils along the age gradient of semi-fixed dunes to older *C. microphylla* plantation, the species richness was 10, 18, 21, 20 and 20, respectively. Species richness trended similarly along the age gradients for soils within the 2–5 cm, 5–10 cm, and 0–10 cm. The level of species richness was higher in the *C. microphylla* plantation compared to the natural steppe for all soil depths, with the exception of those of the 25 years *C. microphylla* plantation. The number of species in the 2–10 cm soil layer was 3, 3, 4, 0, 3, and 4, respectively.

3.4 Vertical distribution of seed densities of SSB in the different aged *C. microphylla* plantation

The total level of germinated seeds in the SSB of different aged *C. microphylla* plantation followed the progression of: 25 years >7 years >16 years >37 years. The number of germinated seeds significantly differed among all plots, except for between the 7 and 16 years. As was observed for SSB species richness, the number of SSB germinating plants first increased in younger plantation, then declined. Seed densities were primarily concentrated in the 0–2 cm soils, followed by the 2–5 cm depth soils and then the 5–10 cm depth soils. The number of seeds in the 0–2 cm SSB of the semi-fixed dune was 227.50 seeds·m^{-2}, which accounted for 34.40% of the 0–10 cm seed abundance, and was significantly lower ($P < 0.05$) than in other plots. Thus, these analyses focused on the seeds below 2 cm in the semi-fixed dune plots, since there were considerably lower seed numbers in the 0–2 cm depth interval. The density of seeds in the 0–2 cm depths of the 7, 16, 25, and 37 years *C. microphylla* plantation were 9,665.00 seeds·m^{-2}, 8,216.25 seeds·m^{-2}, 12,981.25 seeds·m^{-2} and 4,986.25 seeds·m^{-2}, respectively, which accounted for 78.64%, 77.85%, 81.69%, and 79.65% of the total 0–10 cm SSB. Significant differences were observed for the seed densities within the 0–2 cm soils of each forest plot. These results thus indicate that planting *Caragana* had a positive enrichment effect on the seed density in the 0–2 cm surface layer of SSBs, and that the strength of this effect varied with *C. microphylla* plantation age wherein: seed density in the 25 years >16 years >7 years >37 years. Compared to the natural grassland plots, both the germination total seeds and densities in each vertical soil interval were significantly lower in the planted forest plots, and the degree of difference varied among plots (**Table 3**).

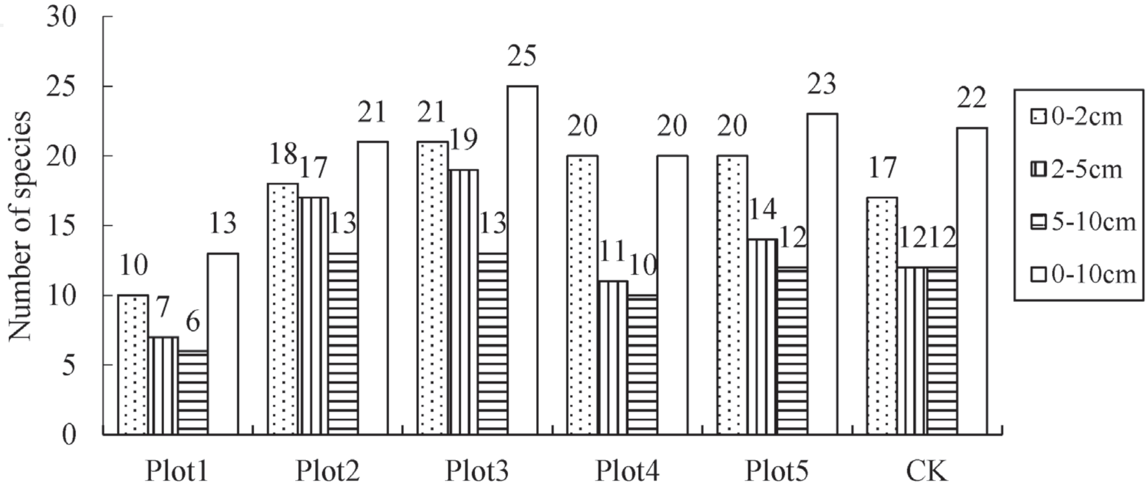

Figure 2.
Vertical distribution of species in the SSB of different aged C. microphylla *plantation and control.*

Sample Number	Germinated seeds of SSB(seeds·m^{-2})			Total seeds of SSB (seeds·m^{-2})
	0-2 cm	2-5 cm	5-10 cm	
NO.1	227.50 ± 84.85 d	246.25 ± 15.91 d	187.50 ± 127.28 b	661.25 ± 196.22 e
NO.2	9665.00 ± 1834.94 b	1651.25 ± 302.29 b	973.75 ± 47.73 ab	12290.00 ± 2184.96 c
NO.3	8216.25 ± 1568.01 b	1395.00 ± 144.96 bc	942.50 ± 102.53 ab	10553.75 ± 1815.50 c
NO.4	12981.25 ± 97.23 a	1556.25 ± 362.39 b	1353.75 ± 680.59 ab	15891.25 ± 220.97 b
NO.5	4986.25 ± 15.91 c	931.25 ± 199.76 c	342.50 ± 148.49 b	6260.00 ± 332.34 d
NO.6	15203.75 ± 924.54 a	2407.50 ± 91.92 a	2177.50 ± 1074.80 a	19788.75 ± 242.18 a
Note: The different letters indicates significant difference among plot at 0.05 level.				

Table 3.
Soil seed bank vertical distribution in different aged C. microphylla *plantation and control.*

3.5 Species diversity of SSB in different aged *C. microphylla* plantation

The species richness of SSBs in *C. microphylla* plantation first increased with age, but then decreased (**Figure 3**). The number of species was highest in the 16 years *C. microphylla* plantation (22), and species richness was significantly different between each older plantation and the semi-fixed sand dunes. However, there was no significant difference between older plantation and the natural steppe ($P > 0.05$).

The Shannon-Wiener and Simpson indices trended similarly, with each value increasing as plantation age increased, but with different degrees of difference among each plantation age. The Pielou evenness index varied as plantation age increased. The number of species in the natural grassland (16.500 ± 3.536) was lower than the number of species in each of *C. microphylla* plantation. Meanwhile,

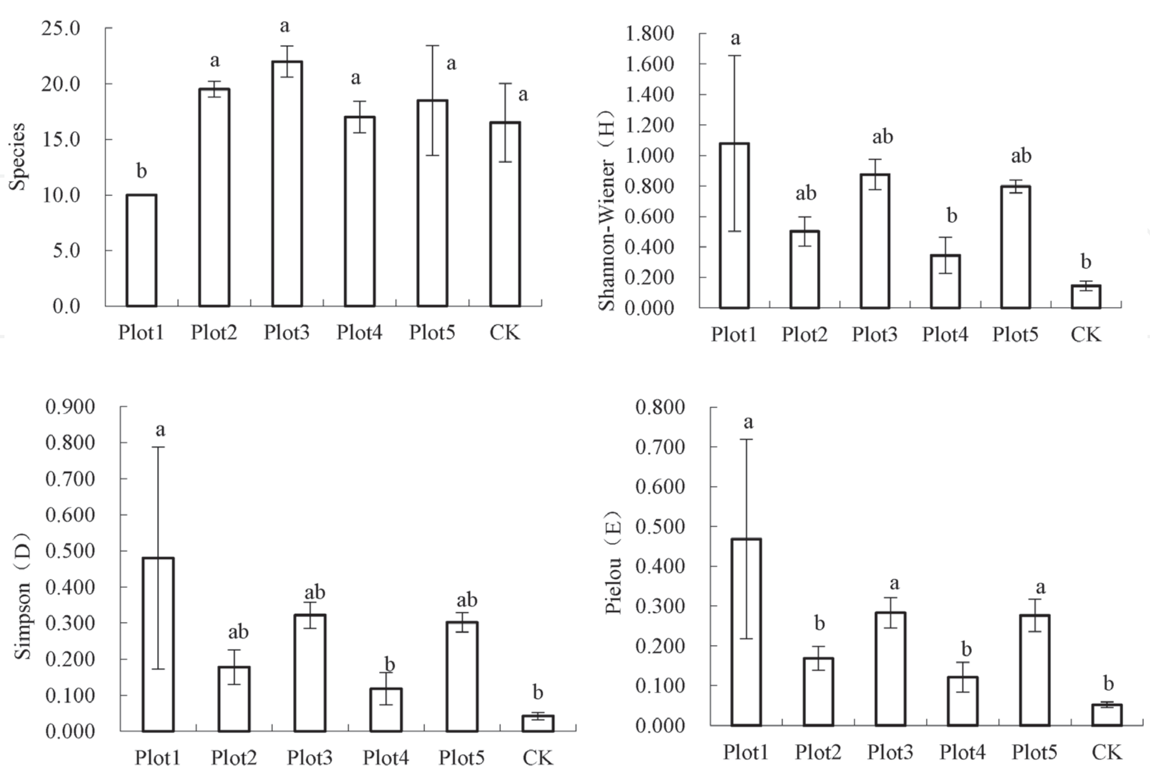

Figure 3.
Diversity of SSBs in different aged C. microphylla *plantation and control. Note: Different letters indicate statistically significant differences among plots.*

the Shannon-Wiener, Simpson, and Pielou evenness indices were also lowest in the natural grassland, (0.146 ± 0.032, 0.042 ± 0.010, 0.052 ± 0.007 respectively).

4. Discussion

One of the primary goals in restoring degraded areas is to improve species diversity and environmental stability. Consequently, much attention has been paid towards understanding the process of restoration succession and mechanisms of ecological recovery. Numerous studies have thus focused on developing effective means to rehabilitate and reconstruct ecosystems by conducting species diversity surveys in context of community recovery based on SSBs [26, 27]. In particular, the species diversity of SSB is an important component to understand restoration of degraded desert steppe environments [28]. SSB species richness and seed density are important metrics that underpin the recovery of degraded desert steppe [18]. Seed density within the topsoil (0–5 cm) was five times higher in passive restored plots than that in control treatment [29]. In this study, a total of 33 species were identified in the SSB from six plots spanning an age gradient of *C. microphylla* plantation. The increases in Gramineae grass abundances suggests improvement of grass quality that coincides with an increased species diversity in the SSB and consequently, a potentially positive effect on the recovery of ground vegetation due to the planting and maturation of *C. microphylla* plantation. Among these, annual and biennial herb species comprised 20 of the species and accounted for 58.8% of the total richness. This may be due to annual and biennial plants primarily propagated by seeds with a short life cycle, contrary to perennial plants with a longer life cycle [30]. Perennial plants commonly use asexual reproduction during drought conditions, and although they form seeds, there are far fewer than during sexual reproduction. Consequently, perennial herbs will generally occupy a smaller proportion of the SSB compared to annual and biennial herbaceous plants. A total of 35 species were identified in the aboveground vegetation, whereas 18 species were identified in the SSB and in the aboveground vegetation that included *Euphorbia humifusa*, *Setaria viridis*, *Tribulus terrestris*, *Sophora alopecuroides*, *Cynanchum komarouii*, *Corispermum mongolicum*, *Gueldenstaedtia stenophylla*, *Lespedeza potaninii*, *Euphorbia esula*, *Agriophyllum squarrosum*, *Stipa glareosa*, var. *graminifolia*, *Cuscuta chinensis*, *Bassia dasyphylla*, *Eragrostis poaeoides*, *Polygala tenuifolia*, *Artemisia scoparia* and *Salsola beticolor.* Thus, these results indicate that *C. microphylla* plantation had a significantly positive effect on the enrichment of seeds in the SSBs of the steppe. A total of 15 species only occurred in the SSB, while 17 species only occurred in the above ground vegetation, and 53% of the species were mutual to the ground vegetation and SSB. These results indicated that species composition differed between the ground vegetation and SSB communities in the Yanchi County.

Planted *C. microphylla* was correlated to a significant enrichment of seeds in the SSB. For example, the average density of seeds was 11,248.75 seeds·m^{-2} in the *C. microphylla* plantation, while the seed bank density was 661.25·m^{-2} in the semi-fixed sand dunes, representing a 17-fold decrease compared to the *C. microphylla* plantation soils. *Artemisia scoparia* seeds accounted for 82.27% - 93.81% of all seed density among plots in the different aged *C. microphylla* plantation SSB. Abundant rain lead to high levels of *Artemisia scoparia* germination in the early ground vegetation community, while late rainfall lead to the production of large amounts of seeds. These results further indicated that the SSB composition and density were related to the temporal and quantitative distribution of rainfall. The change in water spatial gradients was one of the primary factors that affected the composition, quantity, and spatial distribution of SSB, the correlation between seed banks and surface vegetation, and the seed yield of plant [31].

Seeds were significantly enriched in the 0–2 cm depth interval of the SSB of *C. microphylla* plantation, which is consistent with other studies [27, 32]. In contrast, there was a greater density of seeds below 2 cm in the semi-fixed sand dune SSB that could be due to increased porosity in the surface of the semi-fixed sand dune relative to the *C. microphylla* plantation, thereby allowing deeper movement of seeds into soils [33]. The number of seeds in the 0–2 cm SSB first increased, and then decreased with forest age, wherein seed densities followed the pattern: 25 years >16 years >7 years >37 years. This may be associated with the initial growth of *C. microphylla* plantation gradually flourishing that would help lower surface wind speed and promote the accumulation of soil nutrients, in which increased the richness of ground plant species and the seed amount in the SBB. After the growth of *C. microphylla* plantation for 20 years, the large absorption and consumption of soil water and nutrients caused the decline of the communities of other above-ground species, leading to the decrease of the number of seeds in the SBB. At present, there are few researches in this topic and the coupling analysis among SBB, aboveground vegetation and soil physical and chemical components should be strengthened in the future.

Many studies focused on analyzing SSB species diversity in order to explain the community succession and recovery mechanism, in which could be useful to guide the rehabilitation [34, 35]. Understanding the characteristics of species diversity in SSBs was an important pathway to restoration of the degraded desert steppe [36]. This study suggested that SSB diversity and evenness changed with age in *C. microphylla* plantation, which was inconsistent with the results of Bao [37]. The species density and diversity of SSB in typical steppe in Inner Mongolia of China were conducted under four season nomadic grazing (FSNG), two season rotation grazing (TSRG), settlement grazing (SG). The results of similarity between SSB and vegetation revealed that similarity coefficients under FSNG, TSRG,,FSRG and SG were 0.323, 0.351, 0.511 and 0.500 and that similarity coefficient between SSB and vegetation was higher when vegetation was more degraded [37].

The persistent seed bank only comprised three species among the plots analyzed here, indicating a lower species diversity in the persistent seed bank of desert steppe ecosystems. However, SSB species diversity was lower in the natural steppe ecosystem than in each plots of the *C. microphylla* plantation, which indicated a positive effect on SSB diversity. In order to explain the responses of SSB and vegetation to the increasing intensity of human disturbance in a semi-arid region of Northern China, four land use types were selected (native grassland, abandoned artificial grassland, artificial grassland and farmland). The results showed that native grassland had a significantly higher soil seed density and species richness than the other land use types. Moreover, the common species both in the SSB and vegetation between the native grassland and other land use types gradually decreased as disturbance intensity increased [6]. *Caragana korshinskii* of different ages was planted in degraded steppe of Mu Us Sandy Land in Ningxia. The results showed that planting *C. korshinskii* forest had a positive effect on vegetation restoration of degraded grassland. The diversity of plant community increased with the increase of the age of *C. korshinskii* [38]. Our results were similar to those of the two previous studies.

5. Conclusions

Our findings suggested that (1) the species composition of the SSB and the aboveground vegetation communities differed among *C. microphylla* plantation with different ages in Yanchi County. A total of 33 species were observed in the SSB and 35 species in the aboveground vegetation communities, moreover, 18 mutual species. Among the plots, 15 species only appeared in SSB, while 17 only appeared in the aboveground vegetation communities. (2) The *C. microphylla* plantation had a significantly positive effect on the enrichment of seeds in the SSBs. The average seed density in the SSB of *C. microphylla* plantation was 17 times than that in the semi-fixed sand dunes The SSB were primarily concentrated in the 0–2 cm soil depth interval, which accounted for 80% of the seeds in the 0–10 cm range. (3) Different aged *C. microphylla* plantation exhibited different SSB enrichments, i.e., the highest number was in 25 years plantation, then the 7 years plantation, thirdly the 16 years plantation, finally the 37 years plantation. (4) Overall, *C. microphylla* plantation resulted in positive ecological effects on the SSB species diversity in degraded desert steppe.

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