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Assessment of the Ecosystem Service Function of Sandy Lands at Different Times Following Aerial Seeding of an Endemic Species

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Abstract: Desertification is a global and pressing environmental problem in the course of environmental changes, and considerable efforts have been made to restore these degraded ecosystems. Aerial seeding has been widely used to accelerate ecological restoration around the world. However, few efforts have been made to assess the ecosystem service function after aerial seeding has occurred. In this study, we analyzed variations in the ecosystem service function after varying periods of elapsed time after aerial seeding of *Hedysarum laeve* Maxim. (14a, 30a and 38a) in the Mu Us Sandy Land, China. We also assessed the carbon sequestration ability, biodiversity, soil properties, wind-break and sand-fixation ability on a typical windward slope. We found that the overall assessment value of ecosystem services had generally increased with the elapsed time after aerial seeding. Additionally, the assessment values increased as the slope position moved downwards. Moreover, we observed a gradual replacement of *H. laeve* by *Artemisia ordosica* Krasch and grass species with the increase in elapsed years after aerial seeding, indicating a positive succession towards locally native vegetation. Compared with the local natural vegetation, our results suggest that the practice of aerial seeding stimulated vegetation restoration without the need for follow-up field interventions, and the practice of aerial seeding might fit more ecosystems with similar vegetation degradation problems.

Keywords: ecosystem services; restoration; analytic hierarchy process (AHP); aerial seeding; biodiversity; positive succession; *Hedysarum laeve* Maxim.

1. Introduction

Desertification is a global environmental problem, and the expansion of desertified land has threatened the sustainable development of human society [1]. It is generally agreed that restoration of the degraded vegetation can efficiently curb desertification. Restoration of the degraded vegetation will improve the ecosystem services [2–4]. Natural vegetation recovery can form a more rational and stable structure [5] and is a simple way of restoring vegetation [6]. However, in harsh environments with very few seeds, such as sandy areas, natural regeneration and subsequent forest succession may take much longer time [7,8]. To overcome this issue, aerial seeding is commonly applied to promote vegetation recovery and thus, shorten the time required for ecosystem restoration. Aerial seeding uses the plane as platform, broadcasts the tree (grass) seed on the proper ground to make the seeds germinate, with the help of natural rainfall and optimum temperature, due to the characteristics of forest's natural renewal ability, and with such methods the forest resources could sequentially expand and the forest vegetation increase. Aerial seeding has been widely used around the world [9–13]. Nevertheless, aerial seeding as a means of vegetation recovery, and its effectiveness on the restoration of ecosystem service function, has been rarely examined [9].

Some recovery plans illustrate the benefits of implementing biodiversity and providing ecosystem services in practice [14], while other examples indicate that restoration will not automatically enhance both biodiversity and services [15,16]. Both positive and negative outcomes of the practice of vegetation restoration by aerial seeding were also reported. For instance, Greipsson et al. [10] found aerial seeding of *Festuca rubra* L. in Iceland did not create a lasting coverage and facilitate rapid succession, *F. rubra* disappeared in 10 years after aerial seeding. At the same time, he also found that, with the increasing years after aerial seeding, mosses, plant litter and native forbs started to increase. These studies demonstrate that vegetation restoration is a complicated process resulting from the behavior of component populations and species [17]. Therefore, a systematic assessment of the ecosystem services after the seeding is highly necessary. Studying the spatiotemporal changes of ecosystem service function of a particular vegetation type will help guide the relative authorizes to make their restoration effort in a more efficient way at landscape to regional scale.

Here, we synthesized a unique dataset composed of census data of plant communities and soil samples from landscapes after varying periods of elapsed time after aerial seeding (14a, 30a and 38a), control and the local natural vegetation in the Mu Us Sandy Land. Mu Us Sandy Land, one of the four main sandy lands in China, is among the areas undergoing current desertification [18]. To effectively curb desertification and improve the local ecological and living conditions, aerial seeding has become the primary means of vegetation restoration used to combat desertification and is prominently used in this region. In this region, the seeding species is *Hedysarum leave* Maxim., which is an endemic shrub species, accounting for approximately one-quarter of the total area of artificial shrubbery in this region [19]. Till now, there is a nearly 40 year history of aerial seeding in this region (since 1978a), which is an ideal research area. We assessed the spatio-temporal changes of ecosystem service function of all sample plots by using the analytic hierarchy process (AHP), including carbon sequestration ability, biodiversity, soil properties, wind-break and sand-fixation ability on the typical windward slope. We wanted to test the hypotheses that aerial seeding of *H. laeve* would stimulate the succession of degraded ecosystem towards local natural vegetation and the ecosystem service will be restored. Given that the ecosystem services are supplied at various spatial scales, which are also critical in ecosystem management [20]. We further analyzed the ecosystem services by slope positions to test the hypothesis that the restoration performance would be varying between slope positions due to the microhabitat differences.

2. Materials and Methods

2.1. Study Area

The study was conducted in the hinterland of the Mu Us Sandy Land (37°27′30′′ N–39°22′30′′ N, 107°20′ E–111°30′ E), in Wushen County and Yinjinhuoluo County, Inner Mongolia, China. The altitude ranges from 1200 m to 1600 m in the study area. The annual average temperature is 6.0–8.5 °C, annual rainfall is 250–440 mm, and most of it falls in August. The zonal vegetation in the region is a part of the Eurasian steppe; because of the sand matrix and special climate conditions, semi-fixed and fixed sand dunes are widely distributed. Common shrub species in the research region include *Artemisia ordosica* Krasch, *Salix cheilophila* Schneid., *H. laeve*, *Caragana intermedia* Kuang et H. C. Fu and *Sabina vulgaris* Ant. [21].

2.2. Sample Plot Setup and Data Collection

The samples investigated included aerial seeding in 2002, 1986 and 1978, control and local natural vegetation, and all data on community characteristics and soil samples were collected in August and September 2015, that is to say, aerial seeding in 2002, 1986 and 1978 represented 14a, 30a and 38a after aerial seeding, respectively. Because the windward slope has a shallower slope and well-preserved vegetation, the survey was carried out on the windward slope. The sample plots are shown in Table 1, and the geographic location and photos of the sample plots are shown in Figure 1.

Table 1. Basic conditions of sample plots in Mu Us Sandy Land, China.

Sample Plot	Geographical Position (Latitude and Longitude)	Altitude (m)	Aerial Seeding Species	Site Types before Aerial Seeding	Seeding Density (kg/hm^2)	Area (hm^2)
Elapsed time after aerial seeding (a)						
14 (in 2002)	N:38°51′ E:109°15′	1309	*H. laeve*	Moving and semi-moving sandy land	8–9	667
30 (in 1986)	N:39°23′ E:109°50′	1329	*H. laeve*	Moving and semi-moving sandy land	8–9	333
38 (in 1978)	N:39°08′ E:109°31′	1350	*H. laeve*	Moving and semi-moving sandy land	8–9	667
Others						
Control	N:39°07′ E:109°27′	1391	Not Implemented	Moving and semi-moving sandy land in 1978	/	/
Local natural vegetation	N:38°52′ E:109°13′	1306	Not Implemented	Always been *A. ordosica* community	/	/

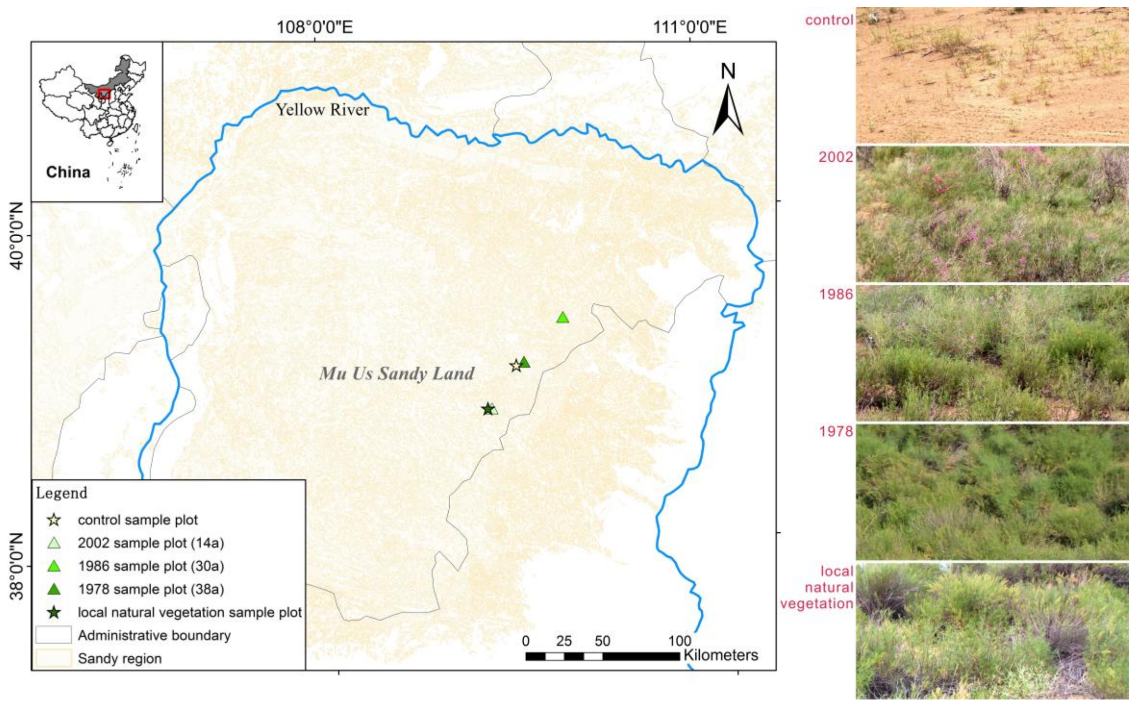

Figure 1. The geographic location and photos of the sample plots.

2.2.1. Plant Community Investigation

The data were collected along the slope, from the bottom to the middle slope to the top, with four replicates for each slope position. Specifically, a quadrat of 5 m × 5 m was used for shrub plots. Within each quadrat, we recorded the species name, the crown width and height of each individual, the numbers of dead and living branches, the ground diameter of each individual and the aboveground biomass of each individual (i.e., the weight of the plant after being dried at 75 °C). A herb quadrat of 1 m × 1 m was used for each herb quadrat. The species name, the coverage height and the number of each species were recorded, and the aboveground biomass of each species was determined after being dried at 65 °C. The habitat characteristics, such as latitude and longitude, altitude, and soil type, were also recorded.

2.2.2. Soil Sampling and Laboratory Analyses

The soil was sampled in every shrub quadrat at depths of 0–20 cm and 20–40 cm. In the laboratory, soil samples were air-dried. After drying, coarse gravel, rubble, and biotic residuals were carefully picked out and discarded. Soil organic matter (SOM) was analyzed using the potassium permanganate volume method, total nitrogen (TN) was analyzed with the Kjeldahl procedure, soil available phosphorus (SAP) was measured by the 0.5 M $NaHCO_3$ method, and soil available potassium (SAK) was tested by flame photometry (ISSCAS 1978) [22].

2.2.3. Long-Term Monitoring of Soil Moisture

A time-domain reflectometry (TDR) measurement tube (2 m) was buried in every shrub quadrat in May 2015. Then, we measured soil moistures at depth layers of 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm, 100–120 cm, 120–140 cm, 140–160 cm and 160–180 cm separately, using the TRIME-PICO-BT (It's a soil moisture collection module.) portable soil water quick-test device, in August and November 2015, and April, June, September and November 2016. Soil water data were measured using the PICO-BT portable soil water quick-test device at each soil depth with three replicates.

2.2.4. Long-Term Monitoring of Wind Erosion

The wind erosion spile was buried in May 2015 in every shrub quadrat. We measured wind erosion spile height in November 2015 and November 2016 and calculated the differences to represent the wind erosion conditions.

2.3. Assessment Method

In this study, considering that the basic goal of sand vegetation restoration is the improvement of its ecosystem service function, so we used analytic hierarchy process (AHP) to build ecosystem service function assessment system referring to "Specifications for assessment of forest ecosystem services in China" [23], which included a total target layer (A layer), five criteria layers (B layer), and 10 index layers (C layer) (Table 2).

Table 2. Ecosystem service function assessment system.

Total Target Layer	Criteria Layer	Weight	Index Layer	Weight	Combined Weight	Index Attribute
A Ecosystem service function assessment	B_1 Carbon sequestration ability	0.08	C_1 Aboveground biomass per unit area of shrub (*ABS*) + Aboveground biomass per unit area of herb (*ABH*) (*ABSH*)	1.00	0.0833	positive
	B_2 Biodiversity	0.25	C_2 Richness index (*R*)	0.33	0.0833	positive
			C_3 Simpson index (*D*)	0.33	0.0833	positive
			C_4 Shannon–Wiener index (*H*)	0.33	0.0833	positive
	B_3 Soil fertility	0.08	C_5 Soil organic matter (*SOM*)	0.50	0.0417	positive
			C_6 Total nitrogen (*TN*)	0.25	0.0208	positive
			C_7 Soil available phosphorus (*SAP*)	0.13	0.0104	positive
			C_8 Soil available potassium (*SAK*)	0.13	0.0104	positive
	B_4 Water conservation functions	0.17	C_9 Soil moisture (*SM*)	1.00	0.1667	positive
	B_5 Wind-break and sand-fixation	0.42	C_{10} Wind erosion spile height change (*WEC*)	1.00	0.4167	negative

"Positive" means that the bigger the better, and "negative" means that the bigger the worse. The values of weight and combined weight are the result of the expert survey.

We used the bar graph to analyze the difference of each index, and we also determined the combined weight of each index for the overall assessment [24,25]. Firstly, we conducted the consultation from relevant experts (In this study, 30 questionnaires were issued. The research area of consulting experts included soil erosion and desertification control, ecology, forest cultivation and management, and their professional title included professor, associate professor and assistant researcher, and so on. Specific questionnaire items included the importance of the five criteria layers, and the importance of the 10 index layers in their respective criteria layer, "1" represented the most important, "2" represented secondarily important, and so on.), used 1~9 scaling method as importance quantitative judgment between assessment factors, and formed a judgment matrix. Secondly, according to the judgment matrix, the relative weight vector of each factors at the same level was calculated by using the root method, and the relative importance weight vector (combined weight) to the criteria layers of all indices was calculated too (Table 2). Finally, we carried out the consistency check of judgment matrix, in other words, we calculated consistency index (CI) and found the appropriate mean random index (RI), and then obtained consistency ratio (CR) = CI/RI. When CR < 0.1, we generally consider the judgment matrix to be of satisfactory consistency, while when CR $\geq$ 0.1, we need to adjust the judgment matrix until we are satisfied. Under the general situation, the first order and second order matrix is always consistent and CR equals to 0. In this study, for the criterion layer, we found CI = 0, RI = 1.12, and CR = 0 < 0.1, so the judgment matrix had satisfactory consistency.

In this study, as illustrated in Table 2, apparently wind-break and sand-fixation combination weight is the largest (0.42), biodiversity is second (0.25), that is to say, consulting experts believed that windbreak and sand-fixation efficiency and biodiversity are the most important functions in sandy land ecosystem service function assessment system.

2.4. Data Analysis

2.4.1. Data Preparation

According to Table 2, we calculated the aboveground biomass per unit area of shrub (*ABS*) and herb (*ABH*) using Equations (1) and (2), respectively, and calculated importance values (*IVs*) and the various relevant diversity indices, including richness index (*R*), Simpson index (*D*), and Shannon–Wiener index (*H*), using Equations (3)–(6), respectively.

$$ABS = \left(\sum biomass_s\right)/25 \quad (1)$$

$$ABH = \sum biomass_h \quad (2)$$

$$IVs = (Relative\ density + Relative\ frequency + Relative\ coverage)/3 \quad (3)$$

$$R = S \quad (4)$$

$$D = 1 - \sum P_i^2 \quad (5)$$

$$H = -\sum P_i \lg P_i \quad (6)$$

In Equation (1), $biomass_s$ ($g \cdot m^{-2}$) is aboveground biomass of each shrub individual, s is the number of individuals of the shrub, and in Equation (2), $biomass_h$ ($g \cdot m^{-2}$) is the aboveground biomass of each herb individual, h is the number of species of the herb. The relative density of this species is equal to the abundance of this species divided by the total abundance of all the species, the relative frequency and relative coverage of this species were calculated in the same way, *IVs* have a range 0–1. S is the number of species within 1 m^2, $P_i = n_i/N$, n_i is the number of individuals of each species, i is the species i, and N is the total individual number of all species.

2.4.2. Un-Dimensioned of Data and Calculated the Final Assessment Value

Because all the data had different dimensions, the dimensionless method was applied to all data before assessment. Positive and negative indices were calculated using Equations (7) and (8), respectively. The final assessment value (Y_k) was obtained using Equation (9).

$$X'_{kj} = X_{kj}/X_{\max} \times 100\left(X_{kj} \leq X_{\max}\right) \quad (7)$$

$$X'_{kj} = X_{\min}/X_{kj} \times 100\left(X_{kj} \geq X_{\min}\right) \quad (8)$$

$$Y_k = \sum_{j=1}^{m} w_j X'_{kj} \quad (9)$$

Here, k is the sample plot k; j is the ecosystem services function index j; X is the values of the 10 indices in any sample plot; X_{kj} is a measuring value of the ecosystem services function index j in the sample plot k; $X_{\max}$ is the maximum value of an ecosystem services function index; $X_{\min}$ is the minimum value of an ecosystem services function index; X'_{kj} is a dimensionless value of the ecosystem services function index j in the sample plot k; Y_k is the final assessment value of the sample plot k; w_j is the combined weight of the ecosystem services function index j (Table 2); and m is the number of the ecosystem services function index (equal to 10).

2.4.3. Statistical Analysis

The assessment indices were analyzed in Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA, USA). And to assess how service indices changed with the increase in years since aerial seeding, we conducted one-way ANOVA analysis, used least-significant-difference (LSD) tests to determine which values had significant differences, and believed that the value was significantly different at $P < 0.05$. We also calculated Pearson correlation coefficients to test for relationships between the ecosystem function service indices. All statistical analysis was conducted using SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Community Species Importance Values Change

With the increase in aerial seeding duration, the importance value of *H. laeve* decreased from 0.9502 (14a) to 0.6255 (30a), and finally, to 0.4994 (38a), while the importance value of *A. ordosica* increased from 0.0498 (14a) to 0.3745 (30a), and finally, to 0.5006 (38a) (Table 3), succession after aerial seeding was moving in the direction towards native vegetation (*A. ordosica* community, Table 3). Contrasted with control, vegetation restoration was evident, and control had not even shrub. Moreover, with the increase in aerial seeding duration, the grass species that appeared in the herb layer, such as *Poa sphondylodes* (30a) and *Leymus chinensis* (38a), were signs of a more stable community, resembling to the local natural vegetation.

Table 3. Plant species importance values (*IVs*) of sample plots in Mu Us Sandy Land, China.

Species	Control	Elapsed Time after Aerial Seeding (a)			Local Natural Vegetation
		14	30	38	
Shrub layer					
H. laeve Maxim.	-	0.9502	0.6255	0.4994	-
A. ordosica Krasch	-	0.0498	0.3745	0.5006	1.0000
Herb layer					
Bassia dasyphylla (Fisch. et Mey.) O. Kuntze	0.0858	0.4644	0.0449	0.0245	-
Corispermum mongolicum Iljin	0.9142	0.3471	0.1849	-	0.5620
Ixeridium graminifolium (Ledeb.) Tzvel.	-	0.1123	0.0105	0.0431	0.0569
Setaria viridis (L.) Beauv.	-	0.0319	0.2553	-	-
Incarvillea sinensis Lam.	-	0.0177	-	-	-
Cynanchum thesioides (Freyn) K. Schum.	-	0.0098	-	0.0077	0.0813
Sonchus brachyotus DC.	-	0.0091	-	-	-
Heteropappus altaicus (Willd.) Novopokr.	-	0.0078	-	0.0409	-
Euphorbia humifusa Willd. ex Schlecht.	-	-	0.1557	-	-
Chenopodium aristatum L.	-	-	0.1444	-	-
Chenopodium glaucum L.	-	-	0.1364	0.0084	-
Euphorbia esula L.	-	-	0.0449	0.0388	-
Silene jenisseensis Willd.	-	-	0.0101	0.0222	-
Poa sphondylodes Trin.	-	-	0.0130	-	-
Artemisia hedinii Ostenf. et Pauls.	-	-	-	0.0188	-
Eragrostis minor Host	-	-	-	0.0448	0.0569
Allium mongolicum Regel	-	-	-	0.0374	-
Leontopodium leontopodioides (Willd.) Beauv.	-	-	-	0.0215	-
Leymus chinensis (Trin.) Tzvel.	-	-	-	0.5117	0.2429
Tribulus terrester L.	-	-	-	0.0060	-
Cynanchum hancockianum (Maxim.) Al. Iljinski	-	-	-	0.0398	-
Artemisia sphaerocephala Krasch.	-	-	-	0.0191	-
Inula salsoloides (Turcz.) Ostenf.	-	-	-	0.0263	-
Thalictrum petaloideum L.	-	-	-	0.0691	-
Salsola collina Pall.	-	-	-	0.0200	-

3.2. Ecosystem Services Function Change

As illustrated in Figure 2, all indicators except wind erosion spile height change (*WEC*) mainly significantly increased with the increase in aerial seeding duration, *WEC* was the only negative indicator (implying that bigger is worse), in other words, all indicators were moving in the better direction. All indicators except *WEC* of control were the lowest. In addition, the values of *R*, *D*, *H*, *SOM* and *SAK* were significantly higher in 38a than in the local natural vegetation ($p < 0.05$) (Figure 2b–e,h), the values of *SM* was significantly lower, while the values of aboveground biomass per unit area of shrub (ABS) + aboveground biomass per unit area of herb (ABH) (ABSH), *TN*, *SAP* and *WEC* were not significantly different (Figure 2a,f,g,j).

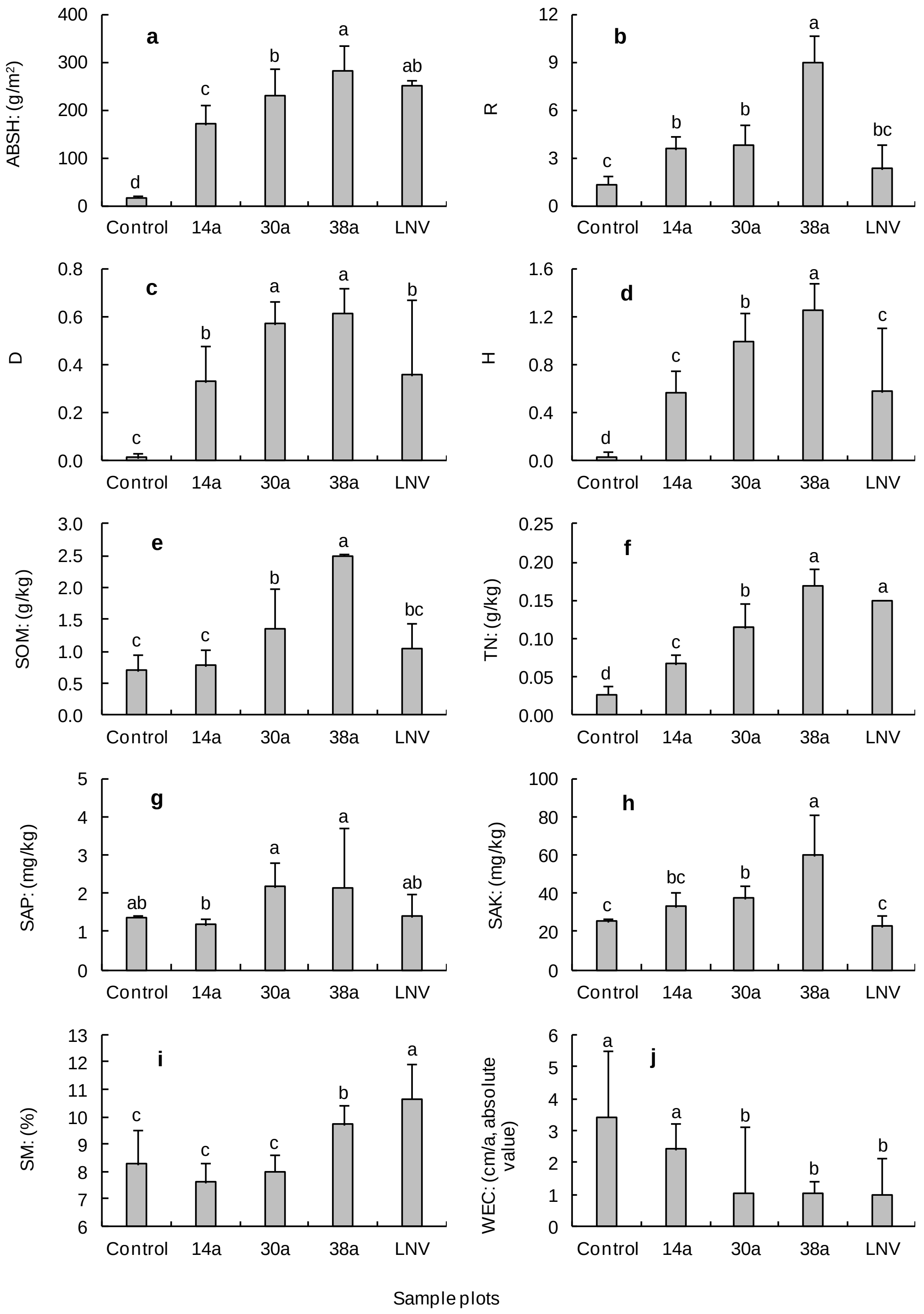

Figure 2. (**a**) Changes of *ABSH* (Aboveground biomass per unit area of shrub (*ABS*) + Aboveground biomass per unit area of herb (*ABH*)) of the sample plots; (**b**) Changes of *R* (Richness index) of the sample plots; (**c**) Changes of *D* (Simpson index) of the sample plots; (**d**) Changes of *H* (Shannon–Wiener index) of the sample plots; (**e**) Changes of *SOM* (Soil organic matter) of the sample plots; (**f**) Changes of *TN* (Total nitrogen) of the sample plots; (**g**) Changes of *SAP* (Soil available phosphorus) of the sample plots; (**h**) Changes of *SAK* (Soil available potassium) of the sample plots; (**i**) Changes of *SM* (Soil moisture) of the sample plots; (**j**) Changes of *WEC* (Wind erosion spile height change) of the sample plots; LNV means local natural vegetation.

When evaluating the ecosystem services function, we can see that the earlier the aerial seeding was conducted, the higher the assessment values were for *H. laeve* shrubs; the values were 49.02, 82.91 and 96.86 for plots in 14a, 30a and 38a, respectively (Table 4). And as we can see, the assessment value of control was the lowest, only for 29.76, and the values in 38a plots were higher than in the local natural vegetation (81.28).

Table 4. Ecosystem services function dimensionless values and assessment results of sample plots in Mu Us Sandy Land, China.

Index	Control	Elapsed Time after Aerial Seeding (a)			Local Natural Vegetation
		14	30	38	
C_1 *ABSH*	6.27	60.50	81.69	100.00	89.23
C_2 *R*	14.81	39.81	42.59	100.00	25.93
C_3 *D*	1.87	53.74	92.95	100.00	58.31
C_4 *H*	2.34	45.10	79.25	100.00	45.95
C_5 *SOM*	27.96	31.03	54.23	100.00	41.93
C_6 *TN*	15.99	39.99	67.74	100.00	88.43
C_7 *SAP*	63.83	54.74	100.00	99.17	64.83
C_8 *SAK*	42.11	54.94	62.49	100.00	38.14
C_9 *SM*	77.49	71.52	75.15	91.27	100.00
C_{10} *WEC*	29.13	41.38	96.77	96.00	100.00
Assessment Value (X_i)	29.76	49.02	82.91	96.86	81.28

3.3. Ecosystem Service Function at Different Slope Positions

As illustrated in Figure 3, all indicators except *WEC* mainly increased as the slope position decreased, WEC was the only negative indicator (implying that bigger is worse), in other words, all indicators were moving in the better direction as the slope position decreased. However, the values of *ABSH*, *R*, *D*, *H*, *SOM*, *TN*, *SAP*, *SAK* and *SM* were not significantly different among down-slope, middle-slope and up-slope (Figure 3a–i); only the *WEC* value was significantly lower at down-slope than at middle-slope ($p < 0.05$) and was significantly lower at middle-slope than at up-slope ($p < 0.05$) (Figure 3j). In other words, wind-break and sand-fixation benefits increased as the slope position moved downwards.

The assessment values of *H. laeve* shrubs increased from 66.90 at the upper end to 99.67 at the lower end of the slope (Table 5).

Table 5. Dimensionless values and assessment results of ecosystem service function at different slope positions in Mu Us Sandy Land, China.

Index	Slope Positions		
	Up	Middle	Down
C_1 *ABSH*	93.49	100.00	99.62
C_2 *R*	91.35	87.10	100.00
C_3 *D*	94.55	94.55	100.00
C_4 *H*	98.11	97.17	100.00
C_5 *SOM*	93.80	90.70	100.00
C_6 *TN*	100.00	90.91	90.91
C_7 *SAP*	85.25	100.00	97.81
C_8 *SAK*	84.75	100.00	92.75
C_9 *SM*	99.65	96.04	100.00
C_{10} *WEC*	26.61	37.91	100.00
Assessment Value (X_i)	66.90	71.11	99.67

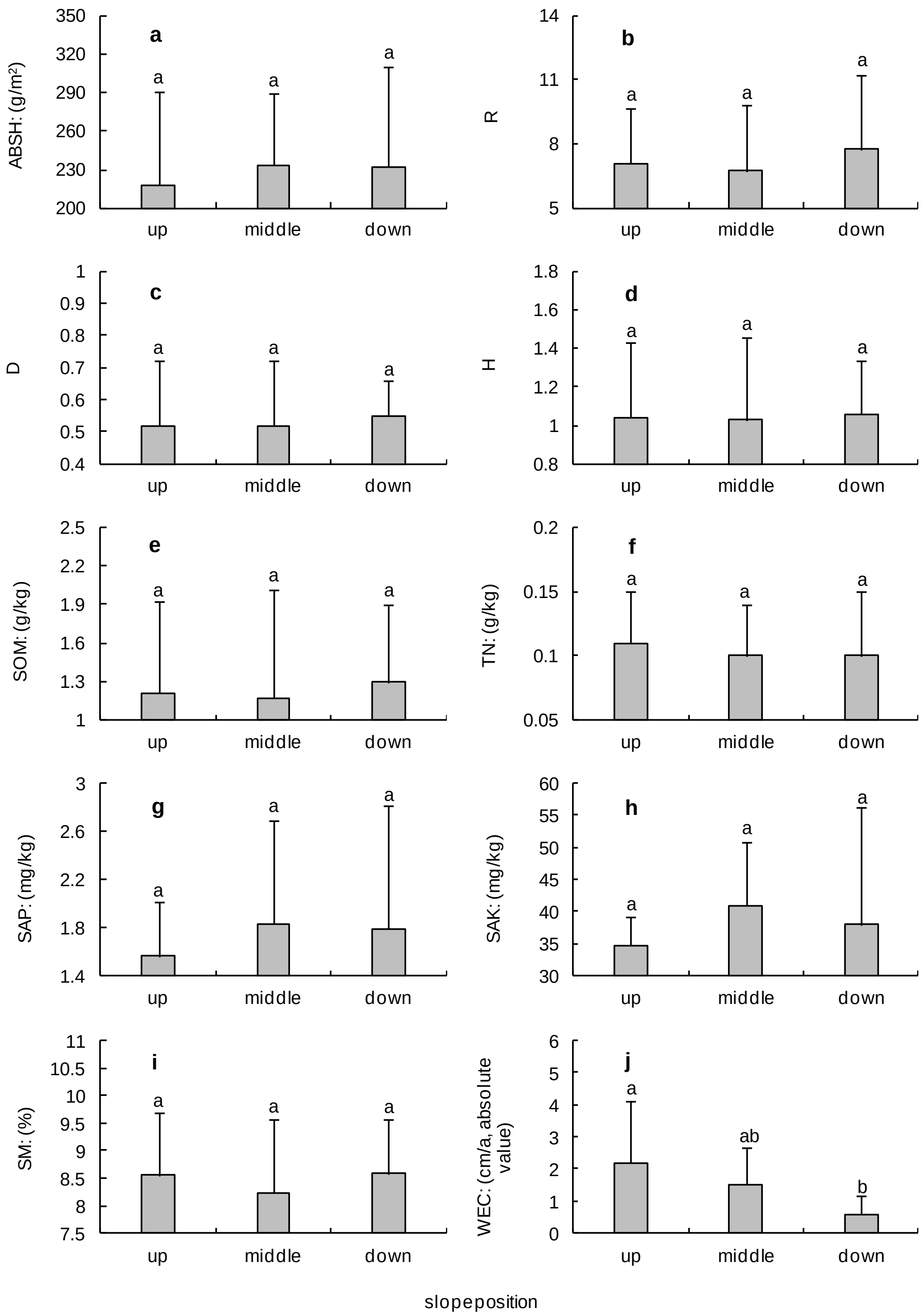

Figure 3. (**a**) Changes of *ABSH* (Aboveground biomass per unit area of shrub (*ABS*) + Aboveground biomass per unit area of herb (*ABH*)) at different slope positions for *H. laeve* shrubs; (**b**) Changes of *R* (Richness index) at different slope positions for *H. laeve* shrubs; (**c**) Changes of *D* (Simpson index) at different slope positions for *H. laeve* shrubs; (**d**) Changes of *H* (Shannon–Wiener index) at different slope positions for *H. laeve* shrubs; (**e**) Changes of *SOM* (Soil organic matter) at different slope positions for *H. laeve* shrubs; (**f**) Changes of *TN* (Total nitrogen) at different slope positions for *H. laeve* shrubs; (**g**) Changes of *SAP* (Soil available phosphorus) at different slope positions for *H. laeve* shrubs; (**h**) Changes of *SAK* (Soil available potassium) at different slope positions for *H. laeve* shrubs; (**i**) Changes of *SM* (Soil moisture) at different slope positions for *H. laeve* shrubs; (**j**) Changes of *WEC* (Wind erosion spile height change) at different slope positions for *H. laeve* shrubs.

3.4. Relationships between the Service Indices

There were positive significant correlations between *ABSH* and *R*, *D*, *H*, *SOM*, *SAK*, and *SM*, between *R* and *D*, *H*, *SOM*, *SAP*, *SAK*, and *SM*, between *D* and *H*, *SOM*, *TN*, *SAP*, and *SM*, and between *H* and *SOM*, *TN*, *SAP*, *SAK*, and *SM*, but there were negative significant correlations between *H* and *WEC* (Table 6). In addition, positive significant correlations were also found between *SOM* and *SAP*, *SOM* and *SAK*, *TN* and *SM*, and *SAP* and *SAK*. It was observed that the various relevant diversity indices (*R*, *D*, *H*) were all positively correlated with *ABSH*, *SOM*, *SAP* and *SM*.

Table 6. Pearson correlation coefficients between the ecosystem function service indices in Mu Us Sandy Land, China.

	ABSH	*R*	*D*	*H*	*SOM*	*TN*	*SAP*	*SAK*	*SM*	*WEC*
ABSH	1									
R	0.651 **	1								
D	0.371 *	0.387 *	1							
H	0.441 **	0.529 **	0.959 **	1						
SOM	0.429 *	0.711 **	0.532 **	0.652 **	1					
TN	0.185	0.258	0.599 **	0.610 **	0.265	1				
SAP	0.325	0.418 *	0.479 *	0.545 **	0.506 **	0.391	1			
SAK	0.399 *	0.676 **	0.334	0.423 *	0.600 **	0.267	0.490 **	1		
SM	0.439 **	0.667 **	0.471 **	0.524 **	0.376	0.406*	0.095	0.12	1	
WEC	−0.273	−0.321	−0.215	−0.342 *	−0.277	−0.178	−0.353	−0.269	−0.173	1

* $P < 0.05$, ** $P < 0.01$ (two-tailed). *ABSH* (Aboveground biomass per unit area of shrub (*ABS*) + Aboveground biomass per unit area of herb (*ABH*)), *R* (Richness index), *D* (Simpson index), *H* (Shannon–Wiener index), *SOM* (Soil organic matter), *TN* (Total nitrogen), *SAP* (Soil available phosphorus), *SAK* (Soil available potassium), *SM* (Soil moisture), *WEC* (Wind erosion spile height change).

4. Discussion

Ascertaining the direction of vegetation restoration is very important to evaluate whether it is successful. Basically, the native vegetation is one of the key factors which are used to evaluate the success of a restoration [26]. In this study, we revealed a trend of *H. laeve* being replaced by *A. ordosica* (Table 3), which is known as the native vegetation [27]. In addition, previous studies had found that increase in nutrient supply enhanced sexual reproduction, but reduced clonal reproduction [28]. In this study, the soil nutrients were increased with the increase in aerial seeding duration (Figure 2e–h), and *H. laeve* mainly relies on clonal reproduction for population expansion, while *A. ordosica* relies on sexual reproduction [21], so this could be one of the reasons of *H. laeve* being replaced by *A. ordosica*. As time went after the seeding, ecosystem services of *H. laeve* shrubs increased with the increase in elapsed time since aerial seeding (Figure 2, Table 4), the various relevant diversity indices (*R*, *D*, and *H*) all significantly increased also (Figure 2b–d), and some species, especially grass species, appeared in the herbaceous layer (Table 3). Most important of all, all indicators of aerial seeding were significantly better than the control, and 38a sample plot was even better than the local natural vegetation. Furthermore, without human influence, the control sample was still in the initial stage of succession, the desertification was still under serious conditions (Figure 2j), and there were only two species in the herb layer and even no species in the shrub layer (Table 3). Obviously, aerial seeding of *H. laeve* was successful and had stimulated succession in Mu Us Sandy Land. Similar results had also been obtained in Australia [29], United States [12,13], Iceland [10] and Canada [30].

Among many other potential reasons for the successful implication of aerial seedling, we want to demonstrate the usage of endemic species, which are well acclimated to the local environment conditions. Besides, using local species can avoid the loss of native species and bring about the threat of invasion when non-native trees are being used [31]. For instance, Cao et al. [16] found that China's Grain for Green Project, in which non-native trees had been planted in large quantities, had accelerated water shortages and had a negative impact on local biodiversity. Therefore, our results support our first hypothesis that aerial seeding of endemic species can stimulate vegetation succession to local vegetation climax, especially in the adverse environmental conditions, where soil seed banks were scarce.

In this study, as illustrated in Figure 3 and Table 5, the overall values of ecosystem services increased as the slope position decreased, despite the fact that most single index values showed no significant differences (Figure 3). This must be related to the low elevation of the slope not enough to make a significant difference, so our second hypothesis is not true. Compared with mountainous regions [32,33], sandy land as a relatively flat terrain, the relatively smooth topography, however, it can still regulate the hydrothermal processes [34,35]. As we know, water is the most important limiting factor in arid environment, which can promote crust and vegetation growth especially in desert and sandy land [34]. Gamfeldt et al. [36] also indicated that higher levels of multiple ecosystem services were found in forests with more tree species. Thus, the lower end of the slope provides higher levels of ecosystem services, possibly due to the higher biodiversity and soil moisture found down-slope (Figure 3). Similar results were also found on the loess plateau (to the south of our study area) of China [37]. In addition, we explored the relationship between biodiversity and other indices. Isbell et al. [38] confirmed that high plant diversity was needed to maintain ecosystem services. Balvanera et al. [39] also believed that biodiversity generally had a positive impact on ecosystem services. We saw similar results in the aerial seeding of *H. laeve* in Mu Us Sandy Land, China (Table 6). These could be also the reason that ecosystem services assessment values in 38a sample plot were significantly better than the local natural vegetation (Table 4), because 38a sample plot had higher diversity indices (Figure 2b–d). Therefore, our results are credible in the study area. Given that the relationship between biodiversity and ecosystem functioning has long been topic of concern [40–42], there are still many uncertainties due to the complexity of the relationship [15,41,42].

This study has significant practical implications. Our results indicated that the practice of aerial seeding had stimulated vegetation restoration in the Mu Us Sandy Land, China, and indicated positive succession was occurring towards locally native vegetation. Therefore, we propose that aerial seeding of endemic species be generalized to more ecosystems with vegetation degradation problems, where soil seed banks were scarce.

5. Conclusions

To assess the ecosystem service function after different aerial seeding time (14a, 30a, 38a) in Mu Us Sandy Land, we calculated ecosystem service function metrics, including the carbon sequestration ability, biodiversity, physical and chemical properties of soil, and wind-break and sand-fixation on a typical windward slope. The main conclusions are as follows: (1) ecosystem services mainly increased with the number of elapsed years after aerial seeding, and therefore there is no need for human intervention after aerial seeding occurs in the future; (2) the overall assessment values of ecosystem services increased as the slope position moved downwards, despite the fact that most single index values showed no significant differences among the slope positions; and (3) the importance value of *H. laeve* decreased with increasing years after aerial seeding, while the importance value of *A. ordosica* increased, indicating that *H. laeve* was being replaced by *A. ordosica*, indicating that the vegetation was undergoing a continuous succession towards native climax of vegetation.

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