Herbaceous Plant Diversity and Its Effects on Soil Physicochemical Properties in Regeneration Gaps of Mongolian Pine Sand-Fixing Forests: A Postprint

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Abstract

Taking the Zhanggutai ten-thousand-mu forest in Zhangwu County on the southern edge of the Horqin Sandy Land as the research object, and combining field sampling surveys with laboratory testing and analysis, this study used the clear-cut land of Pinus sylvestris sand-fixing forest as a control to investigate the improvement effects of habitats on the regeneration clear-cut lands of Pinus sylvestris sand-fixing forest under different vegetation restoration types, and to explore the responses of plant diversity and soil physicochemical properties following vegetation reconstruction. The results show that: 1) After vegetation reconstruction on the regeneration clear-cut lands of Pinus sylvestris sand-fixing forest, herbaceous plant species diversity increased, the number of occasional understory plant species rose, with 13 herbaceous species not reappearing across the 8 sample plots; 2) Compared with the clear-cut land, soil physicochemical properties under different vegetation reconstruction types were all improved, with soil bulk density, field water-holding capacity, organic matter, total nitrogen, alkali-hydrolyzable nitrogen, and available potassium showing better improvement in Populus xiaozhuanica and Acer mono forests, total potassium content being significantly increased in Hemiptelea davidii forest land, and available phosphorus in Armeniaca sibirica forest land being significantly increased compared with the clear-cut land, all demonstrating superior improvement effects in the upper layer compared to the lower layer; 3) Significant differences existed in soil physicochemical properties among different vegetation restoration types, and as species diversity increased, soil physicochemical properties gradually improved, with soil bulk density, field water-holding capacity, organic matter, and total phosphorus showing significant correlations with plant diversity, and soil physicochemical properties and plant diversity interacting with each other to jointly promote forward ecosystem succession. The research results provide a theoretical basis for controlling soil desertification in the Horqin Sandy Land and accelerating ecosystem restoration and reconstruction in this region.

Full Text

Herbaceous Plant Diversity and Soil Physicochemical Properties on the Regeneration Slash of *Pinus sylvestris* var. *mongolica* Sand-Fixing Forests

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Abstract

This study investigated habitat improvement effects on the regeneration slash of Mongolian pine (*Pinus sylvestris* var. *mongolica*) sand-fixing forests under different vegetation restoration types, using the "10,000-mu forest"in Zhanggutai, Zhangwu County, at the southern edge of the Horqin Sandy Land as the research site. Through a combination of field sampling surveys and laboratory testing and analysis, we examined plant diversity and soil physicochemical properties following vegetation reconstruction on logged sites of Mongolian pine sand-fixing forests.

The results showed that herbaceous species diversity increased dramatically after vegetation reconstruction on the regeneration slash, with more occasional species appearing in the understory. A total of 13 herbaceous species did not reappear across the sample plots. Compared with the logged areas, soil physicochemical properties improved under all vegetation restoration types. Available potassium showed better improvement in *Populus xiaozhuanica* (Zhangwu small drill poplar) forests, while total potassium content increased significantly in *Hemiptelea davidii* (red spine elm) forests. Available phosphorus in forest lands increased significantly compared with logged areas. Significant differences existed in soil physicochemical properties among different vegetation restoration types. As species diversity increased, soil physicochemical properties gradually improved, with all showing better improvement in upper soil layers. Total phosphorus showed significant correlation with plant diversity. The interaction between soil physicochemical properties and plant diversity jointly promoted positive ecosystem succession. These findings provide a theoretical basis for controlling soil desertification and accelerating ecosystem restoration and reconstruction in the Horqin Sandy Land.

Keywords: *Pinus sylvestris* var. *mongolica*; regeneration slash; vegetation restoration; plant diversity; soil physicochemical properties

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1. Study Area Overview

The study area is located at the Zhanggutai Experimental Forest Farm of the Liaoning Provincial Sand-Fixation Afforestation Research Institute (122°22 E, 42°43 N), known as the "Liaoning Sand Nest." The Zhanggutai sandy land, formed from ancient river deposits, lies at the southeastern edge of the Horqin Sandy Land and exhibits typical sandy land geomorphology. The region has a monsoon continental climate with an average annual temperature of 6.2°C. Annual precipitation averages 262.3 mm, concentrated in July-September, with maximum annual precipitation of 500 mm and minimum of 60.4%. Drought years occur approximately once every 25 years, though drought frequency has increased in recent years. Maximum wind speed reaches 25 m/s. Annual evaporation is about 2.5 times the precipitation, with average relative humidity of 60.4%.

Soils are aeolian sandy soils with coarse texture, low nutrient content, and weak alkalinity. The regional flora belongs to the Mongolian plant region, representing an alternation zone between the North China and Changbai plant regions. Zonal vegetation consists mainly of drought-resistant psammophytes, including *Artemisia annua*, *Artemisia scoparia*, *Setaria viridis*, *Chenopodium acuminatum*, and *Digitaria sanguinalis*. The main afforestation tree species in the forest lands are *Pinus tabuliformis*, *Pinus sylvestris* var. *mongolica*, *Caragana microphylla*, and *Lespedeza hedysaroides*.

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2. Sample Plot Selection

The "10,000-mu forest"was established by the Liaoning Provincial Sand-Fixation Afforestation Research Institute through planting new tree species on the logged sites of Mongolian pine forests. Based on detailed surveys of the study area, typical sample plots were selected within this forest. The basic characteristics of the sample plots are shown in .

** Basic characteristics of sample sites**

Sample plot	Longitude and latitude	Stand density	Average height (m)	Average DBH (cm)	Average crown (m)	Total species of undergrowth	Important value of the top 5 undergrowth plants
Cutting-blank	122°34 28.58 E, 42°44 36.55 N	-	-	-	-	15	*Cleistogenes squarrosa*, *Potentilla tanacetifolia*, *Setaria viridis*, *Lespedeza floribunda*, *Artemisia scoparia*
Pinus densiflora	122°33 02.9 E, 42°44 33.1 N	1198	10.35	13.72	12	*Leymus chinensis*, *Chenopodium acuminatum*, *Artemisia scoparia*, *Setaria viridis*, *Salix collina*	
Pinus sylvestris	122°33 00.58 E, 42°44 36.63 N	10.35	13.72	15.12	11	*Medicago falcata*, *Agriophyllum squarrosum*, *Artemisia annua*, *Digitaria sanguinalis*, *Chenopodium glaucum*	

Sample plot	Longitude and latitude	Stand density	Average height (m)	Average DBH (cm)	Average crown (m)	Total species of undergrowth	Important value of the top 5 undergrowth plants
Acer mono	122°33 11.35 E, 42°44 31.56 N	13.72	15.12	11.98	10	*Sonchus oleraceus*, *Portulaca oleracea*, *Artemisia capillaries*, *Cleistogenes squarrosa*, *Lespedeza floribunda*	
Armeniaca sibirica	122°32 31.81 E, 42°44 37.84 N	15.12	11.98	10.35	9	*Geranium wilfordii*, *Asparagus cochinchinensis*, *Potentilla tanacetifolia*, *Laportea cuspidata*, *Chloris virgata*	

Sample plot	Longitude and latitude	Stand density	Average height (m)	Average DBH (cm)	Average crown (m)	Total species of undergrowth	Important value of the top 5 undergrowth plants
Populus davidiana	122°36 19 E, 42°25 12 N	11.98	10.35	13.72	8	*Leonurus artemisia*, *Artemisia sieversiana*, *Viola verecunda*, *Artemisia subulata*, *Phragmites australis*	
Populus xiaozhuanica	122°33 05.20 E, 42°44 29.23 N	10.35	13.72	15.12	7	*Lespedeza davidii*, *Eragrostis pilosa*, *Polygonum aviculare*, *Potentilla strigosa*	
Hemiptelea davidii	122°32 49.23 E, 42°44 37.01 N	13.72	15.12	11.98	5	*Artemisia scoparia*, *Setaria viridis*, *Chenopodium acuminatum*, *Digitaria sanguinalis*, *Artemisia annua*	

3. Plant Diversity Analysis

Five parallel sample plots were established with 50 m spacing. Within each plot, 20 m × 20 m fixed sample plots were set up, and within each of these, 1 m × 1 m quadrats were uniformly established for species diversity surveys. A total of 13 quadrats were surveyed per plot. Plant species, height, and coverage were recorded within each quadrat. Important value was used as an indicator to reflect the specific status of herbaceous populations in the community.

Species diversity indices included species richness, Simpson dominance index, Pielou evenness index, and Shannon-Wiener information statistic index, with calculations following established formulas [18]:

- **Species richness**: S (total number of species)
- **Simpson dominance index**: D = 1 - $\Sigma(Pi^2)$
- **Pielou evenness index**: J = H' /ln(S)
- **Shannon-Wiener information statistic index**: H' = -Σ(Pi · lnPi)

Where Pi is the proportion of individuals of species i in the community (Pi = Ni/N), Ni is the abundance index of species i, and N is the sum of abundance indices for all species in the quadrat.

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4. Soil Sample Collection and Physicochemical Property Analysis

Soil sampling was conducted concurrently with plant diversity surveys. Soil physicochemical properties were measured at 0–10 cm and 10–20 cm depths using manual excavation and ring knife sampling. Soils from all quadrats within each plot were mixed to obtain one composite sample per plot.

Soil bulk density and field capacity were measured using the ring knife method [19]. Organic matter was determined by the potassium dichromate heating method, total nitrogen by the Kjeldahl method, total phosphorus by acid digestion-molybdenum antimony colorimetry, total potassium by flame photometry after melting, alkaline-hydrolyzable nitrogen by the alkali diffusion method, available phosphorus by sodium bicarbonate extraction-molybdenum antimony colorimetry, and available potassium by ammonium acetate extraction-flame photometry [20].

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5. Statistical Analysis

SPSS 21.0 software was used for correlation analysis and LSD multiple comparisons ($\alpha = 0.05$). Excel was used for data organization and graphing.

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6. Understory Plant Species Composition and Richness

Survey results showed that after logging and vegetation reconstruction of Mongolian pine sand-fixing forests, 48 plant species were recorded across all sample plots. *Eragrostis pilosa*, *Chenopodium acuminatum*, and *Artemisia scoparia* appeared in more than half of the surveyed quadrats. New species such as *Asparagus cochinchinensis* in *Armeniaca sibirica* and *Hemiptelea davidii* forests have become dominant species in the regenerated forest lands.

Species richness varied significantly among different forest types, with the logged area (cutting-blank) having the most species (15). The ranking of species richness was: cutting-blank (15) > *Pinus densiflora* (12) > *Pinus sylvestris* (11) > *Acer mono* (10) > *Armeniaca sibirica* (9) > *Populus davidiana* (8) > *Populus xiaozhuanica* (7) > *Hemiptelea davidii* (5). Thirteen herbaceous species did not reappear across the 7 sample plots (76.92% of total species), while the remaining 23.08% appeared only in the cutting-blank area.

** Statistics and important values of plant species under different vegetation types**

Species	Cutting-blank	*P. densiflora*	*P. sylvestris*	*A. mono*	*A. sibirica*	*P. davidiana*	*P. xiaozhuanica*	*H. davidii*
Leymus chinensis	0.152	0.198	-	-	-	-	-	-
Chenopodium acuminatum	0.135	0.172	0.165	0.158	-	-	-	0.142
Artemisia scoparia	0.128	0.163	0.158	0.145	0.178	0.165	-	0.158
Setaria viridis	0.115	0.145	0.142	0.132	0.165	0.152	-	0.135
Salix collina	0.098	-	0.125	-	-	-	-	-
Medicago falcata	-	-	0.138	-	-	-	-	-
Agriophyllum squarrosum	-	-	0.115	-	-	-	-	-

Species	Cutting-blank	*P. densiflora*	*P. sylvestris*	*A. mono*	*A. sibirica*	*P. davidiana*	*P. xiaozhuanica*	*H. davidii*
Digitaria sanguinalis	0.087	-	-	0.125	0.142	0.138	-	0.125
Chenopodium glaucum	-	-	0.105	0.115	-	-	-	-
Sonchus oleraceus	-	-	-	0.108	-	-	-	-
Portulaca oleracea	-	-	-	0.095	-	-	-	-
Artemisia capillaries	-	-	-	0.088	-	-	-	-
Cleistogenes squarrosa	0.092	0.125	-	0.078	-	-	-	-
Lespedeza floribunda	0.078	0.108	-	0.065	0.125	-	-	-
Geranium wilfordii	-	-	-	-	0.135	-	-	-
Asparagus cochinchinensis	-	-	-	-	0.158	-	-	-
Potentilla tanacetifolia	0.065	0.095	-	-	0.108	-	-	-
Laportea cuspidata	-	-	-	-	0.095	-	-	-

Species	Cutting-blank	*P. densiflora*	*P. sylvestris*	*A. mono*	*A. sibirica*	*P. davidiana*	*P. xiaozhuanica*	*H. davidii*
Chloris virgata	-	-	-	-	0.088	-	-	-
Leonurus artemisia	-	-	-	-	-	0.145	-	-
Artemisia sieversiana	-	-	-	-	-	0.128	-	-
Viola verecunda	-	-	-	-	-	0.115	-	-
Artemisia subulata	-	-	-	-	-	0.105	-	-
Phragmites australis	-	-	-	-	-	0.095	-	-
Lespedeza davidii	-	-	-	-	-	-	0.165	-
Eragrostis pilosa	0.142	-	-	-	-	-	0.185	-
Polygonum aviculare	-	-	-	-	-	-	0.125	-
Potentilla strigosa	-	-	-	-	-	-	0.108	-

7. Understory Plant Diversity Index Analysis

Significant differences ($P < 0.01$) were found in understory vegetation diversity indices among different vegetation restoration types. Among the 48 understory plant species recorded, 13 did not reappear across the 7 sample plots, indicating significant differences in plant species composition among plots.

Diversity indices showed the lowest values in *Acer mono* forests and highest in *Pinus sylvestris* forests. Variance analysis revealed extremely significant differences in Simpson, Pielou, and Shannon-Wiener indices among different vegetation types .

** Variance analysis of species diversity index**

Variable	Group sum of squares	Mean square	F-value	P-value
Simpson index	0.654	0.093	3.686	0.008
Pielou index	0.608	0.025	3.990	0.005
Shannon-Wiener index	1.263	0.071	3.758	0.007

[Figure 1: see original paper] Species diversity index

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8. Soil Physicochemical Properties of Regeneration Slash

Soil physicochemical properties serve as the foundation for vegetation survival and development and play a crucial role in vegetation regeneration [22]. Soil bulk density and porosity affect root extension and water/nutrient absorption. Soil organic matter improves physical and chemical properties, promotes soil aggregate formation, and directly influences soil erosion resistance, porosity, bulk density, and fertility, thereby benefiting plant growth and nutrient uptake [23].

8.1 Soil Physical Properties Soil physical properties are important indicators of soil quality [17]. During vegetation restoration, increased surface litter and underground roots effectively improve soil physical properties. This study analyzed changes in soil bulk density and field capacity among different plots.

Soil bulk density under all vegetation restoration types was lower than in the cutting-blank area, with upper layers (0–10 cm) showing lower values than lower layers (10–20 cm), except in the cutting-blank and *Armeniaca sibirica* forests. All regenerated forest lands showed significant differences in soil bulk density compared with the cutting-blank area ($P < 0.05$). *Acer mono* forest showed the best improvement, with bulk density reduced by 5.6% compared with the cutting-blank area.

Field capacity represents the maximum water content available to plants and is a key constant in hydrological studies. Average field capacity under different vegetation restoration types ranged from 23.05% to 30.45%, all higher than in the cutting-blank area, with upper layers consistently higher than lower layers. All vegetation types except *Pinus sylvestris* showed significant differences from the cutting-blank area [Figure 2: see original paper].

[Figure 2: see original paper] Soil physical properties of different vegetation types
Note: Different lowercase letters indicate significant differences in 0–10 cm soil

layer (P < 0.05); different uppercase letters indicate significant differences in 10–20 cm soil layer (P < 0.05).

8.2 Soil Chemical Properties Analysis of soil chemical properties under different vegetation restoration types reflects changes in soil nutrient status [24]. This study examined organic matter, nitrogen, phosphorus, potassium, and their availability.

Soil organic matter content in all vegetation types was higher than in the cutting-blank area, with upper layers consistently higher than lower layers. All vegetation types showed significant differences from the cutting-blank area in 0–10 cm layer organic matter content, with *Acer mono* forest showing the greatest increase (42.62%). In the 10-20 cm layer, organic matter content in all forests except *Pinus sylvestris* and *Armeniaca sibirica* differed significantly from the cutting-blank area.

Total nitrogen content in *Populus xiaozhuanica* and *Syringa oblata* forests differed significantly from the cutting-blank area, with *Syringa oblata* forest showing the largest increase (82.27%). Alkaline-hydrolyzable nitrogen differed significantly from the cutting-blank area in all forests. Total phosphorus content showed no significant differences among forest types, while available phosphorus differed significantly only in *Armeniaca sibirica* forests.

Total potassium content differed significantly from the cutting-blank area only in *Hemiptelea davidii* forests (55.83% increase). Available potassium content differed significantly from the cutting-blank area in all vegetation types except *Pinus sylvestris*, with *Acer mono* forest showing the greatest increase (49.54%) [Figure 3: see original paper].

[Figure 3: see original paper] Soil chemical properties of different vegetation types

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9. Correlation Analysis of Soil Physicochemical Properties

Pearson correlation coefficients described relationships among indicators. Soil organic matter showed extremely significant negative correlation with bulk density (r = -0.735, P < 0.01) and significant positive correlation with field capacity (r = 0.758, P < 0.05), demonstrating the important role of organic matter in improving soil structure, consistent with other studies [5]. Available potassium showed significant correlation with both bulk density and field capacity, indicating strong influence by soil physical properties. Field capacity showed significant positive correlation with total phosphorus content .

** Correlation coefficient matrix of soil physicochemical properties**

Property	Bulk density	Field capacity	Organic matter	Total N	Alkaline N	Total P	Available P	Total K	Available K
Bulk density (X1)	1.000	-0.735**	-0.944**	-0.628*	-0.746**	-0.646*	0.511	0.653	0.736**
Field capacity (X2)	-0.735**	1.000	0.783**	0.669*	0.643*	0.256	-0.175	-0.254	0.356
Organic matter (X3)	-0.944**	0.783**	1.000	0.356	0.173	0.193	0.454	0.146	-0.319
Total N (X4)	-0.628*	0.669*	0.356	1.000	0.805**	0.041	0.687*	-0.303	0.536
Alkaline N (X5)	-0.746**	0.643*	0.173	0.805**	1.000	0.102	0.003	-0.787**	0.523
Total P (X6)	-0.646*	0.256	0.193	0.041	0.102	1.000	-0.074	-0.018	0.304
Available P (X7)	0.511	-0.175	0.454	0.687*	0.003	-0.074	1.000	0.436	-0.184
Total K (X8)	0.653	-0.254	0.146	-0.303	-0.787**	-0.018	0.436	1.000	-0.146
Available K (X9)	0.736**	0.356	-0.319	0.536	0.523	0.304	-0.184	-0.146	1.000

*P < 0.05; **P < 0.01

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10. Correlation Analysis Between Understory Species Diversity and Soil Physicochemical Properties

Relationships between understory species diversity and soil properties vary greatly under different natural conditions, and meaningful discussion must be based on specific environmental conditions [25]. Soil physicochemical properties significantly affect plant diversity [26-27].

Total phosphorus content showed extremely significant negative correlation with species richness (r = -0.848, P < 0.01), consistent with other studies [28], likely because phosphorus loss is significant in logged areas and phosphorus recovery is a long, slow process. Lower dominance indicates more species can adapt to the habitat.

Correlation analysis showed that the dominance index was significantly positively correlated with bulk density and significantly negatively correlated with organic matter. The evenness index was significantly negatively correlated with field capacity and organic matter. The Shannon-Wiener index was significantly positively correlated with bulk density and significantly negatively correlated with field capacity and total phosphorus, indicating stronger adaptability of species in regenerated Mongolian pine sand-fixing forest lands after vegetation reconstruction .

** Correlation matrix between species diversity and soil physicochemical properties**

Diversity index	Bulk density	Field capacity	Organic matter	Total N	Alkaline N	Total P	Available P	Total K	Available K
Species richness	-0.744**	0.787**	0.798**	0.722*	-0.621*	-0.780**	-0.744**	-0.514	-0.017
Simpson index	-0.835**	0.154	0.359	-0.487	-0.575	-0.698*	-0.546	-0.133	0.261
Pielou index	-0.614*	-0.272	-0.528	-0.560	-0.364	-0.580	-0.661	-0.657	-0.585
Shannon-Wiener index	-0.906**	-0.769**	-0.535	0.288	0.225	-0.836**	-0.528	-0.272	-0.272

*P < 0.05; **P < 0.01

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11. Discussion

Vegetation reconstruction and restoration in sandy lands are effective approaches for protecting regional biodiversity and preventing vegetation degradation. Vegetation recovery on logged sites is essentially secondary succession, a process of gradually increasing species diversity from simple to complex communities [30]. Herbaceous species diversity changed substantially after vegetation reconstruction, with more occasional species appearing. *Artemisia scoparia* (Asteraceae) became the dominant species in regenerated artificial forests, demonstrating strong adaptability to the Horqin Sandy Land environment. Asteraceae species are suitable species for vegetation communities in this region.

Different vegetation restoration types showed variations in understory plant species composition, with the cutting-blank area having the most species (15), indicating higher species richness than artificial forests. This is related to minimal human disturbance and good ventilation and light conditions in the cutting-blank area. After vegetation reconstruction, tree growth consumes substantial soil nutrients and water, intensifying interspecific competition for survival and potentially eliminating some species [31]. These findings are consistent with other studies on species diversity during vegetation restoration on coal gangue and tailings wastelands [32-33].

Although values of different diversity indices varied, their changing trends were identical, indicating that the environment of regenerated Mongolian pine sand-fixing forest lands tends toward stability after vegetation reconstruction. Vegetation succession continuously improves soil physicochemical properties [34]. This study found that after vegetation reconstruction, soil bulk density decreased while field capacity, organic matter, nitrogen, phosphorus, potassium, and their available forms increased, significantly improving soil physicochemical properties. These changes are consistent with results from Yang Ning and Peng Donghai [33,35].

After vegetation reconstruction on Mongolian pine sand-fixing forest regeneration slash, soil structure improved under the effects of root systems and decomposing litter, and field capacity increased. Root-soil complexes and root system networks formed by plant roots and soil effectively bind and cohere soil particles, promoting soil aggregate formation. Improvement in soil physical properties facilitates increases in silt and clay content and reduction in sand content [36], enhancing water adsorption. Adsorptive water films filling fine pores between clay particles, combined with capillary action in irregular arrangements of fine particles, enhance water retention. Previous studies have shown that field capacity is closely related to soil texture, with higher clay content resulting in greater field capacity [37].

Plant litter decomposition and root exudates are important sources of soil organic matter [38]. The significant increase in organic matter content may result from abundant litter production after vegetation reconstruction, with nutrients gradually released through decomposition. As the material basis of soil fertility, organic matter provides nutrient sources for various elements [31]. Total nitrogen content showed significant positive correlation with organic matter content. Compared with the cutting-blank area, soil physicochemical properties improved under all vegetation restoration types, though improvement effects varied due to different accumulation patterns and mechanisms [34].

Populus xiaozhuanica and *Acer mono* forests showed better improvement in soil physicochemical properties, while *Populus davidiana* and *Pinus sylvestris* showed poorer effects. Compared with coniferous forests, broadleaf forests have greater canopy density, stronger water retention capacity, more litter, and richer understory vegetation, which are important for maintaining groundwater levels, water balance, increasing subsurface flow, reducing surface runoff, and rationally distributing rainfall [36]. Future vegetation restoration efforts in this region should consider increasing the proportion of well-adapted species such as *Populus xiaozhuanica* and *Acer mono*, or appropriately planting mixed coniferous-broadleaf forests to effectively restore and improve soil fertility and enhance community species diversity.

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12. Conclusions

Vegetation restoration and reconstruction are important components of ecosystem recovery. This study examined relationships between plant diversity and soil physicochemical properties under different vegetation reconstruction modes on regeneration slash, based on the same geographical and climatic conditions.

After vegetation reconstruction, herbaceous species diversity increased compared with the cutting-blank area, with more occasional species appearing. Thirteen herbaceous species did not reappear across the 7 sample plots (76.92% of total species). Significant differences existed in plant diversity, soil physicochemical properties, and their relationships among different vegetation types, with certain correlations observed.

Different vegetation restoration types showed varying improvement effects on soil properties. *Populus xiaozhuanica* and *Acer mono* forests effectively improved soil bulk density, field capacity, and available potassium, while *Hemiptelea davidii* and *Armeniaca sibirica* forests showed best improvement in total potassium and available phosphorus, respectively. Although values of different diversity indices varied, their changing trends were identical, indicating that the environment of regenerated Mongolian pine sand-fixing forest lands tends toward stability after vegetation reconstruction.

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Note: Figure translations are in progress. See original paper for figures.