Near-Natural Vegetation Spatial Configuration Patterns for Ecological Restoration of Abandoned Mines in Ulashan: Postprint

Authors: Zhang Zeyu1, Wu Xiaojing 2, Liang Yipeng[1], Zhang Xiaoxia[3], Zha Tonggang 1,4

Date: 2023-08-25T00:00:00+00:00

Abstract

This study examines the relationship between site types and vegetation community characteristics in abandoned mines, exploring spatial configuration of vegetation communities based on near-natural restoration theory to provide theoretical basis and reference for vegetation restoration during ecological restoration of abandoned mining areas. The study area is located in the Wulashan abandoned mine in Inner Mongolia. Site types were classified using principal component analysis, correlation analysis, and cluster analysis to investigate plant community characteristics under different site types, thereby obtaining the optimal spatial configuration ratio for near-natural vegetation restoration. The results indicate that slope, slope position, and soil hardness are the dominant factors, based on which the region was divided into 9 site types. Among them, the gentle-slope mid-slope medium-texture soil site type and the steep-slope mid-slope medium-texture soil site type exhibited higher values than other site types in biomass, vegetation coverage, Margalef richness index, and Shan non-Wiener diversity index. Regarding vegetation configuration patterns, for site types with poor habitats such as the gentle-slope lower-slope soft-texture soil site type, a herbaceous configuration model is recommended (configuration ratio of perennial herbaceous annual herbaceous = 6 4); for other areas with better site conditions, a shrub-grass configuration model is recommended.

Full Text

Spatial Allocation Pattern of Near-Natural Vegetation for Ecological Restoration of Abandoned Mines in the Wula Mountains

ZHANG Zeyu[1], WU Xiaojing[2], LIANG Yipeng[1], ZHANG Xiaoxia[3], ZHA Tonggang[1],[4]

[1]School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China

[2]Beijing Badaling Forest Farm, Beijing 102112, China

[3]The Third Construction Co., Ltd. of China Construction First Group, Beijing 100161, China

[4]Jixian County National Forest Ecosystem Observation and Research Station, Beijing Forestry University, Beijing 100083, China

Abstract

This study addresses the insufficient trade-offs between regional vegetation diversity and topographic differentiation during vegetation restoration in abandoned mines. Based on the principles of near-natural restoration theory, we examined the primary factors determining site type classification, clarified spatial distribution patterns of vegetation, and identified optimal near-natural vegetation configuration modes under various site types to provide a theoretical foundation for ecological restoration in abandoned mining areas. The study area was located in abandoned mines of the Wula Mountains in Inner Mongolia. Using principal component analysis, correlation analysis, and cluster analysis, we classified site types and investigated plant community characteristics under different site types to determine the optimal spatial allocation ratio for near-natural vegetation restoration. The results indicated that slope gradient, slope position, and soil hardness were the dominant factors, based on which the region was classified into nine site types. Among these, the gentle slope-mid slope-medium hardness soil type and the slope-mid slope-medium hardness soil type exhibited greater biomass, vegetation coverage, Margalef richness index, and Shannon-Wiener diversity index than other site types. Regarding vegetation configuration modes, we recommend a herbaceous mode (configuration ratio of perennial herb:annual herb = 4:1) for site types with poorer habitats such as the gentle slope-lower slope-soft soil type. For other areas with better site conditions, we recommend a shrub-grass mode.

Keywords: abandoned mine; site type; principal component analysis; cluster analysis; plant community characteristics

1 Materials and Methods

1.1 Study Area Overview

The study area is located in the Wula Mountains within the Wuliangsuhai watershed of Inner Mongolia, spanning 40°47 –41°03 N and 108°43 –108°57 E. The region contains 42 mineral deposits of coal, iron, gold, copper, and other resources. The typical abandoned mining area on the northern foothills of the Wula Mountains, an abandoned iron mine, covers approximately 4.5 km^2. This area experiences a temperate arid western monsoon climate with average precipitation of 250 mm, concentrated primarily in summer, and annual evaporation potential of 2167–2500 mm, far exceeding precipitation. Herbaceous plants are dominated by *Allium mongolicum*, *Tripogon chinensis*, and *Peganum harmala*, while shrub species are mainly *Convolvulus tragacanthoides* and *Caragana stenophylla*. Soils are predominantly sandy, with more than 70% sand content. Soil types are primarily gray-cinnamon soil and chestnut soil, mainly affected by combined wind and water erosion, resulting in a fragile ecological environment.

The Wula Mountains constitute the "mountain" component in the "mountain-water-forest-field-lake-grassland" ecological system of the Wuliangsuhai watershed. In recent years, the area has faced severe grassland vegetation degradation, expanding desertification, deteriorating water environments, soil desertification and salinization, and excessive mining development. Numerous abandoned mines exist throughout the study area. Current ecological restoration primarily employs "terrain remediation + grass seed aerial seeding" methods. However, after terrain remediation, the exposed topsoil faces extreme risks of soil erosion, which is already severe. The region contains approximately 80 plant species, representing relatively rich species resources. However, mine ecological restoration has been limited to a few stress-resistant and readily available species such as alfalfa and *Elymus dahuricus*, resulting in relatively single populations, low species diversity, and poor community stability. Additionally, constrained by rainfall conditions and severe wind erosion, vegetation restoration in the Wula Mountains abandoned mining area remains poor.

1.2 Sample Plot Layout

From July to August 2021, we used typical sample plot survey methods to investigate natural grasslands with similar site conditions adjacent to the abandoned mining area. We established 45 sample plots of 10 m × 10 m. As no trees were present within the survey range, each plot contained three shrub-grass subplots (2 m × 2 m). Within each subplot, we measured vegetation species, coverage, height, and plant number, collected aboveground vegetation portions for oven-drying and weighing in the laboratory, and calculated biomass. Since sample plots were relatively concentrated with minimal altitude variation, the impact of altitude on ecological factors such as light, temperature, water, and heat was minor. Therefore, our survey indicators included slope gradient (X_1), slope position (X_2), slope aspect (X_3), available phosphorus content (X_4), total phosphorus content (X_5), available potassium content (X_6), soil hardness (X_7), soil layer thickness (X_8), and soil texture (X_9). Soil texture was numerically represented by gravel content (particle size >2 mm). Specific factor classification and assignment are shown in .

1.3 Soil Sampling and Measurement

Within the shrub-grass subplots of each sample plot, we used the diagonal method to select three sampling points and collected 0–20 cm soil samples. Soil samples were air-dried, ground, and sieved for preservation. Soil mechanical composition was determined using a Malvern laser particle size analyzer. Total nitrogen was measured using the semi-micro Kjeldahl method. Available phosphorus was determined by the 0.5 mol/L $NaHCO_3$ extraction-molybdenum antimony colorimetric method. Available potassium was measured using the 1 mol/L NH_4OAc extraction-flame photometry method.

1.4 Data Analysis

We used the Margalef richness index (Ma), Pielou evenness index (Ea), Shannon-Wiener diversity index (H), and Simpson diversity index (D) to characterize plant diversity characteristics under different microtopographies. These indices were calculated as follows:

- **Margalef richness index**, reflecting the number of species in the community:
  $Ma = (S - 1)/\ln N$
- **Pielou evenness index**, reflecting the distribution of individuals among species. Higher values indicate more uniform distribution of individual numbers among species:
  $Ea = H/\ln S$
- **Shannon-Wiener diversity index**, where higher values indicate stronger community diversity:
  $H = -\sum_{i=1}^{S} P_i \ln P_i$
- **Simpson diversity index**, representing the probability that two randomly selected individuals belong to the same species. Values closer to 1 indicate no diversity, so higher D values indicate greater diversity:
  $D = 1 - \sum_{i=1}^{S} P_i^2$

Where S is the total number of species in the sample plot, N is the total number of individuals of all species, and P_i is the proportion of individuals of the ith species.

We performed data processing using Microsoft Excel 2019. Principal component analysis, correlation analysis, cluster analysis, and significance testing were conducted using R 4.0.4 with packages "psych," "NbClust," "corrplot," and "vegan." Figures were created using Origin 2021.

2 Results

2.1 Site Type Classification

After quantification and standardization of the nine indicator datasets from the survey plots, principal component analysis identified three principal components with eigenvalues >1, representing 76.517% of the total information. The relationships between the three principal components (F_1, F_2, F_3) and each factor were:

$F_1 = 0.277X_1 + 0.356X_2 + 0.374X_3 + 0.164X_4 + 0.205X_5 + 0.356X_6 + 0.408X_7 + 0.379X_8 + 0.331X_9$

$F_2 = 0.513X_1 + 0.144X_2 + 0.327X_3 + 0.136X_4 + 0.513X_5 + 0.513X_6 + 0.513X_7 + 0.513X_8 + 0.513X_9$

$F_3 = 0.513X_1 + 0.513X_2 + 0.513X_3 + 0.513X_4 + 0.513X_5 + 0.513X_6 + 0.513X_7 + 0.513X_8 + 0.513X_9$

The first principal component represents soil fertility status (coefficients >0.375 for X_4, X_5, X_6), the second represents terrain characteristics (coefficients for slope gradient, position, and aspect are 0.513, 0.144, and 0.327 respectively), and the third represents soil physical properties (coefficients for soil hardness, thickness, and particle composition are 0.513, 0.513, and 0.513 respectively). Although soil fertility status plays a key role in site type classification, soil nutrient content indicators cannot be directly measured through field surveys. Correlation analysis of site factors revealed that soil nutrient content is influenced by terrain factors, particularly significantly correlated with slope position ($P < 0.01$) .

Based on field surveys and combined with correlation and principal component analyses, we selected slope gradient, slope position, and soil hardness as the dominant factors for classifying abandoned mine site types. Using these three dominant factors, we performed cluster analysis using Euclidean distance on the standardized survey data [Figure 1: see original paper]. The cluster analysis results, combined with the dominant factors, divided the 45 sample plots into three site type groups and nine site types: gentle slope site type group, slope site type group, and steep slope site type group. The specific site types include: gentle slope-lower slope-soft soil type, gentle slope-lower slope-hard soil type, gentle slope-mid slope-medium hardness soil type, gentle slope-mid slope-hard soil type, gentle slope-upper slope-hard soil type, slope-mid slope-medium hardness soil type, slope-upper slope-hard soil type, steep slope-lower slope-hard soil type, and steep slope-mid slope-hard soil type.

2.2 Plant Community Characteristics Under Different Site Types

Overall, biomass and vegetation coverage showed similar trends across site types [Figure 2: see original paper], with both highest in the gentle slope-mid slope-medium hardness soil type (II_3) and slope-mid slope-medium hardness soil type (III_2), reaching 85.00 g/m^2 and 85.00% respectively, significantly higher than other site types ($P < 0.05$). The lowest biomass and vegetation coverage occurred in the steep slope-mid slope-hard soil type (III_3), accounting for only 25.59% of the maximum biomass and 25.88% of the maximum coverage.

Vegetation evenness index and species diversity index also varied significantly among different site types [Figure 2: see original paper]. The Margalef richness index and Shannon-Wiener diversity index were highest in the gentle slope-mid slope-medium hardness soil type (II_3) and slope-mid slope-medium hardness soil type (III_2), while lowest in the steep slope-mid slope-hard soil type (III_3), which was significantly lower than other site types ($P < 0.05$). The Pielou evenness index showed no significant difference among site types ($P > 0.05$). The Shannon-Wiener diversity index followed the same trend as biomass and vegetation coverage.

2.3 Near-Natural Vegetation Allocation for Different Site Types

To achieve near-natural vegetation structure, we statistically analyzed vegetation types occurring under different site types and calculated the proportions of perennial herbs, annual herbs, and shrubs. Based on these proportions, we derived near-natural vegetation configuration modes . The results show that the gentle slope-lower slope-soft soil type (I_1), gentle slope-upper slope-hard soil type (II_5), and steep slope-mid slope-hard soil type (III_3) are pure herbaceous modes. The remaining six site types are shrub-grass modes.

---

3 Discussion

Near-natural restoration focuses on natural ecological processes supplemented by scientifically sound artificial management measures to restore degraded ecosystems to a state where ecological service functions (species composition, diversity, and community structure) approximate those of zonal ecosystems, achieving diversity, stability, and sustainability in ecosystem structure and function. Habitat is a key element in plant community formation, and different habitats support different plant species. This study classified different habitats and productivity levels through site type classification. Using principal component analysis, we identified slope gradient, slope position, and soil hardness as dominant factors, consistent with findings from Yang Yuping and Liu Ying in abandoned mine studies. Therefore, based on these three dominant factors, we classified the abandoned mine into three site type groups and nine site types. Using statistical methods to analyze plant species and their growth status for different site types, we achieved near-natural vegetation spatial allocation in abandoned mining areas based on the principle of matching species to sites.

Biomass and vegetation coverage differed significantly among site types due to spatial heterogeneity in site environments created by variations in topography and soil properties, which determines natural vegetation distribution and biodiversity. Slope gradient affects vegetation primarily in two ways: first, by influencing water and nutrient loss along the slope surface, and second, by increasing wind erosion impact on soil surfaces as slope steepness increases, accelerating soil loss. Slope position changes cause variations in soil water and nutrient content, with better nutrient conditions at lower slopes than at mid and upper slopes. Research has found that medium hardness soil is most suitable for seed germination and growth, while overly soft or hard soils are unfavorable for plant development.

Among the nine site types, only the gentle slope-lower slope-soft soil type, gentle slope-upper slope-hard soil type, and steep slope-mid slope-hard soil type have poor habitats affected by soft soil, upper slope position, and steep gradients with low nutrient content, making it difficult to support extensive shrub growth. Near-natural vegetation restoration should therefore employ herbaceous modes (perennial herb:annual herb = 4:1). The remaining site types, particularly the gentle slope-mid slope-medium hardness soil type and slope-mid slope-medium hardness soil type, support good vegetation growth under medium hardness soil and gentle slope conditions, recommending shrub-grass modes (perennial herb:annual herb:shrub or semi-shrub = 5:4:1 or 7:2:1). Therefore, in ecologically fragile areas with severe soil erosion, near-natural vegetation allocation should be based on site types to form healthy ecosystems where plant communities and natural environments adapt to each other and achieve dynamic balance, thereby improving local vegetation and environmental conditions.

---

4 Conclusion

In the Wula Mountains abandoned mining area, the dominant site factors affecting vegetation growth and distribution are slope gradient, slope position, and soil hardness, based on which nine site types can be classified. Vegetation grows optimally in site types with gentle slopes, mid-slope positions, and medium soil hardness, where hydrothermal conditions are relatively favorable. Growth is relatively poor in site types with steep slopes, mid-slope positions, and hard or soft soil hardness. Therefore, when conducting near-natural vegetation allocation, the vegetation growth conditions of different site types should be considered. For example, the steep slope-mid slope-hard soil type should employ a herbaceous mode (configuration ratio of perennial herb:annual herb = 4:1). Other site types such as the gentle slope-mid slope-medium hardness soil type should employ a shrub-grass mode (configuration ratio of perennial herb:annual herb:shrub or semi-shrub = 5:4:1). Meanwhile, fertilization and irrigation can be appropriately applied according to the water and nutrient conditions of different site types, supplementing nitrogen-phosphorus-potassium compound fertilizers to promote uniform vegetation distribution and rapid establishment.

References

[1] Wei Yuan, Gu Hongbo, Xue Liang, et al. Review of studies on reclamation and ecological restoration of abandoned land of mine[J]. Science of Soil and Water Conservation, 2012, 10(2): 107-114.

[2] Yu Bao, Peng Huafu. Research on forest management measures based on natural restoration concept[J]. Journal of Southwest Forestry University (Natural Sciences), 2023, 43(1): 8-17.

[3] Bai Zhongke, Shi Xueyi, Wang Zhouwei, et al. How does artificiality support and guide the natural restoration of ecosystems[J]. China Land Science, 2020, 34(9): 1-9.

[4] Bai Shiqiang, Qiang Zhen. Problems and countermeasures of ecological rehabilitation of abandoned open pit mines: A case study of South Taihang Region of Henan Province[J]. Natural Resource Economics of China, 2022, 35(7): 36-41.

[5] Xu Wenda. Problems and solutions of ecological reconstruction and vegetation restoration of mines in Jianping County[J]. Modern Agriculture, 2020, 49(4): 87-88.

[6] Tang Yufeng, Li Xueyan, Cheng Jinpeng, et al. Plant diversity and communities characteristics of abandoned paddy field wetland of Longshu River Basin in Zhaotong City[J]. Southwest China Journal of Agricultural Sciences, 2021, 34(5): 1088-1095.

[7] He Jinsheng, Bu Haiyan, Hu Xiaowen, et al. Close nature restoration of degraded alpine grasslands: Theoretical basis and technical approach[J]. Chinese Science Bulletin, 2020, 65(34): 3898-3908.

[8] Peng Donghai, Hou Xiaolong, He Zongming, et al. Community characteristics of different vegetation restoration models in gold tailing wasteland[J]. Research of Soil and Water Conservation, 2016, 23(1): 50-55.

[9] Wei Yiling. A Preliminary study on the pattern of near nature plant allocation in mountain ecological park[J]. Contemporary Horticulture, 2021, 44(22): 182-183, 186.

[10] Song Anqi, Ji Xinhui, Zhao Bing. The landscape construction of the forest belt along the Yangtze River bank based on ecological restoration theory: Take the forest belt landscape planning along Yangzhou Jiangdu economic development zone riverside as an example[J]. Landscape Architecture Academic Journal, 2020, 40(3): 71-75.

[11] An Weili, Lu Yaohai, Xie Wei, et al. Mixed sowing of arbor, shrub and herbs seeds based on near natural vegetation restoration[J]. Soil and Water Conservation in China, 2021, 42(8): 40-43.

[12] Wang Saifeng, Zhao Yifan, Wu Lan, et al. Vegetation distribution and protection of Urat Front Banner[J]. Inner Mongolia Forestry Investigation and Design, 2006, 46(5): 49-52.

[13] Pensa M, Sellin A, Luud A, et al. An analysis of vegetation restoration on opencast oil shale mines in Estonia[J]. Restoration Ecology, 2004, 12(2): 200-206.

[14] Hoda ová D, Prach K. Spoil heaps from brown coal mining: Technical reclamation versus spontaneous revegetation[J]. Restoration Ecology, 2003, 11(3): 385-391.

[15] Zhang Hengshuo, Yu Yang, Zha Tonggang, et al. Assessing previous land vegetation productivity relationships on mountainous areas hosting coming Winter Olympics Games in 2022[J]. Science of The Total Environment, 2021, 788: 147870.

[16] Dai Lifei. Comprehensive Treatment of the Watershed in Wula Mountains Based on GIS and RUSLE[D]. Beijing: Beijing Forestry University, 2013.

[17] Zhao Peng, Qu Jianjun, Xu Xianying, et al. Study on the characteristics of sandy alpine grasslands and its relationship between plant distribution and microtopography in the source regions of Yangtze River[J]. Acta Ecologica Sinica, 2019, 39(3): 1030-1040.

[18] Ming Jian. Study on Micro site Division, Vegetation Characteristics and Optimal Allocation of Pingshan Gneiss[D]. Beijing: Beijing Forestry University, 2019.

[19] He Jijun, Tang Zejun, Cai Qiangguo. Study on changing laws of soil wind erosion by wind tunnel experiment in Agro-pastoral area of Inner Mongolia[J]. Journal of Soil and Water Conservation, 2010, 24(4): 35-39.

[20] Cui Ranran, Qi Shi, Wu Bingchen, et al. The influence of stand structure on understory herbaceous plants species diversity of *Platycladus orientalis* plantations in Beijing, China[J]. Forests, 2022, 13(11): 1921.

[21] Zhao Mengen, Yan Qingwu, Liu Zhengting, et al. Analysis of temporal and spatial evolution and influencing factors of soil erosion in Ordos City[J]. Arid Zone Research, 2022, 39(6): 1819-1831.

[22] Wang Junli. Effects of Slope Gradient and Position on Organic Carbon and Nitrogen Fractions and Aggregate Composition in Tobacco-growing Soil[D]. Chengdu: Sichuan Agricultural University, 2019.

[23] Yuan Xueli, Wang Yangdong, Huang Xingzhao, et al. Classification and evaluation of *Litsea cubeba* site type based on quantification theory[J]. Journal of Northwest Forestry University, 2020, 35(5): 91-96.

[24] Yang Yuping. Study on Site Classification and Characteristics of Coal Mining Bases in Lingwu Mining Area[D]. Hohhot: Inner Mongolia Agricultural University, 2020.

[25] Miao Henglu, Wang Xingtian, et al. Analysis of meteorological factors affecting drought in a desert steppe of the northern foot of Yinshan Mountain[J]. Arid Zone Research, 2021, 38(5): 327-1334.

[26] Feng Dan. Spatial Variability of Site Factors and Micro Site Classification in Arid and Barren Mountains of South Central Shandong Province[D]. Tai'an: Shandong Agriculture University, 2021.

[27] Liu Ying. Study on Site Classification and Evaluation of Dump in Wuhai Coal Mining Area[D]. Hohhot: Inner Mongolia Agricultural University, 2021.

[28] Aleksandra Glowacka, Ewelina Flis, et al. The biodiversity of weed communities of dent maize, narrow-leaved lupin and oat in relation to cropping system and weed control[J]. Annales Umcs Agricultura, 2022, 77: 3.

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