Postprint: Relationships Between Plant Community Species Diversity and Soil Factors Along Elevational Gradients in the Balguntay Region, Southern Slope of the Central Tianshan Mountains

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Abstract

To investigate the distribution characteristics of plant community species diversity along an elevation gradient and its relationship with soil environmental factors in the Baluntai region on the southern slope of the middle Tianshan Mountains, this study employed field survey methods, establishing 34 sample plots across the elevation range in the Baluntai area of Hejing County to conduct investigations of plant diversity and soil factors, along with statistical analysis of laboratory-measured indicators. The results showed that: (1) A total of 134 species belonging to 75 genera and 30 families were recorded in the study area, with the herb layer being the dominant stratum. Soil physicochemical indices exhibited heterogeneity across different elevations, with soil water content, total salt, organic matter, total nitrogen, total potassium, available nitrogen, and available potassium showing significant differences ($P<0.05$). Except for total potassium, the contents of other soil factors were higher at mid-elevations than at low and high elevation zones. With increasing elevation, the evenness index of plant communities was higher at low and high elevation segments; Patrick richness of shrub layer species was lower; Shannon-Wiener index and Simpson index of herb layer species first increased and then decreased with elevation. (2) RDA analysis indicated that the main environmental factors affecting plant community species diversity were elevation, soil water content, total salt, organic matter, total nitrogen, and available nitrogen. Elevation, as the dominant factor, was positively correlated with various species diversity indices of the herb layer and overall community, but negatively correlated with those of the shrub layer; total salt was the primary soil factor inhibiting the Simpson index of overall plant community species; nitrogen element limited the growth of shrub and

semi-shrub species to a certain extent, indicating that soil factors exert a certain filtering effect on the formation of diversity for different life-form species and that different species have different adaptive strategies to environmental changes.

Full Text

Preamble

Relationship between Species Diversity of Plant Communities and Soil Factors at Different Elevations in Baluntai Area, the Southern Slope of Mid-Tianshan Mountains

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Abstract

To investigate the distribution characteristics of plant community species diversity along elevation gradients and its relationship with soil environmental factors on the southern slope of the mid-Tianshan Mountains, this study conducted field investigations in the Baluntai area of Hejing County. Thirty-four sample plots were established across the elevation range to survey plant diversity and soil factors, followed by statistical analysis of laboratory metrics. The results showed: (1) A total of 134 plant species belonging to 75 genera and 30 families were recorded in the study area, with the herbaceous layer as the dominant stratum. Soil physicochemical indices exhibited heterogeneity across different elevations, with significant differences ($P<0.05$) in soil water content, total salt, organic matter, total nitrogen, total potassium, available nitrogen, and available potassium. Except for total potassium, all other soil factors showed higher contents at middle elevations compared to low and high elevations. With increasing elevation, the plant community exhibited higher evenness indices at low and high elevation zones; the Patrick richness of shrub layer species was relatively low; the Shannon-Wiener and Simpson indices of herbaceous layer species first increased and then decreased with elevation. (2) RDA analysis indicated that the main environmental factors affecting plant community species diversity were elevation, soil water content, total salt, organic matter, total nitrogen, and available nitrogen. As the dominant factor, elevation was positively correlated with diversity indices of the herbaceous layer and overall community, but negatively correlated with those of the shrub layer. Total salt was the primary soil factor inhibiting the Simpson index of the overall plant community. Nitrogen element limited the growth of shrub and semi-shrub species to some extent, demonstrating that soil factors exert a screening effect on the formation of diversity among different life forms and that different species employ distinct adaptive strategies to environmental changes.

Keywords: plant community, species diversity, elevation gradient, soil physicochemical index, Baluntai

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Introduction

Plant community species diversity represents a comprehensive reflection of species richness, dominance, evenness, and variation, forming the foundation for studying ecosystem structure, function, and stability (Wang et al., 2016). Changes in elevation gradients can comprehensively reflect the regular variation of ecological environmental factors affecting plant growth, such as temperature, light, humidity, and soil physicochemical properties (Liu et al., 2018). At different altitudes, changes in local microclimatic environments create distinct vertical distribution patterns of soil physicochemical properties (Ren et al., 2019), which subsequently influence plant community species diversity and its vertical distribution patterns. In recent years, numerous scholars have investigated the relationship between plant community species diversity and soil factors along elevation gradients. Studies by Zhong et al. (2019), He et al. (2020), and Gao et al. (2020) on natural secondary forests in the Qinling Mountains, the Jiangjiagou watershed in dry-hot valleys, and the Sejila Mountains in Tibet, respectively, have collectively demonstrated that different life-form plant communities respond to different environmental factors, and their vertical distribution patterns along elevation gradients vary accordingly.

Currently, these studies have primarily focused on warm temperate continental monsoon climate zones, subtropical regions, and semi-humid areas, which cannot represent the distribution patterns of plant communities in northwestern arid regions of China. Therefore, investigating plant community species diversity and its influencing soil factors along elevation gradients in the Baluntai area can provide theoretical basis for studying plant community structure types and composition in northwestern arid regions of China, as well as for scientifically assessing the coupling effects between species diversity and environmental factors (Liu et al., 2018). This research holds significant importance for maintaining and restoring ecosystem biodiversity in northwestern arid regions.

The Baluntai area in Xinjiang is located on the southern slope of the mid-Tianshan Mountains, representing an important section of the Tianshan range. The distribution of biodiversity in this region plays a crucial role in regional ecological stability. The area features a substantial relative height difference between the ridgeline (4,500–5,000 m) and foothills (700–800 m) (Liu, 2017), providing ample space for vertical differentiation of flora and natural vegetation, making it an ideal region for studying species diversity distribution patterns in arid mountainous areas. While many scholars have studied plant community types and spatial distribution characteristics on the northern slope of the Tianshan Mountains (Gong et al., 2019), research on plant diversity on the southern slope has mainly focused on the Bayinbuluke alpine grasslands and Kuqa mountainous areas (Liu et al., 2018). Previous studies in the Baluntai area have concentrated on complex geological research (Gao et al., 2018), with limited investigation into the correlation between plant community diversity and environmental factors. Meanwhile, plant diversity is gradually decreasing under the influence of global climate variability and grazing pressure (Wang et al., 2020). This study therefore examines plant communities at different elevations in the Baluntai area, systematically analyzing the relationship between plant community species diversity indices and soil factor metrics based on sample plot data. The research aims to address three scientific questions: (1) What are the patterns and causes of soil factor variation along elevation gradients in the Baluntai area? (2) What are the vertical distribution characteristics of plant community species diversity at different elevations? (3) How do elevation and soil factors influence plant community species diversity in this region? By answering these questions, this study seeks to provide theoretical foundations for the conservation and rational utilization of plant resources in the region and throughout the Tianshan Mountains, while enriching theoretical research on species diversity distribution patterns in arid mountainous areas.

1.1 Study Area Overview

Baluntai is situated in the northern mountainous area of Hejing County, Bazhou Prefecture, Xinjiang, within the canyon zone on the southern slope of the mid-Tianshan Mountains, located on the southern side of Tengger Peak between 82°06 –87°55 N and 42°05 –43°30 E. The region covers a total area of 5,002.67 km^2 and features a temperate continental climate with abundant light and heat resources, large annual temperature variations, ample sunshine, a long frost-free period, strong evaporation, and frequent dusty weather. The multi-year average temperature is 7.0 °C; the average annual frost-free period is 178 days, with a maximum of 244 days; the average annual sunshine duration is 2,400–2,700 hours; and the average annual precipitation is 150–350.7 mm, concentrated between May and August (Li, 2016).

Fig. 1 Distribution of study area and sample sites in Baluntai

1.3 Sample Processing

Soil samples were collected in July 2017 and August 2019 in the Baluntai, Motuosala, and Gurengou areas of Hejing County (elevation 1,500–3,700 m). Sample belts were established with 3–4 plots of 20 m × 20 m set up every 200 m elevation increase. Along each plot' s diagonal, three 5 m × 5 m shrub quadrats and three 1 m × 1 m herb quadrats were established. Plant species, quantity, height, coverage, density, and frequency were recorded in each quadrat, with herbaceous plants counted by clumps for tillering species. Photographs of plants and their surrounding environment were taken. In each plot, surface litter was removed using a five-point pattern, and 100 g of surface soil (0–20 cm) was collected from each point and mixed as one sample, placed in ziplock bags, and transported to the laboratory for processing. A total of 34 sample plots, 54 shrub quadrats, and 102 herb quadrats were established.

Soil indicators were measured using conventional methods (Li et al., 2020): soil organic matter (SOM) by potassium dichromate titration; total nitrogen (TN) by perchloric acid-sulfuric acid digestion; total phosphorus (TP) by acid dissolution-molybdenum antimony colorimetry; total potassium (TK) by acid dissolution-atomic absorption spectrometry; available nitrogen (AN) by alkali hydrolysis distillation; available phosphorus (AP) by sodium bicarbonate extraction-molybdenum antimony colorimetry; available potassium (AK) by ammonium acetate extraction-flame photometry; total salt (TS) by dry residue method; soil water content (SW) by oven-drying and weighing; and pH by Leici pH meter.

1.4 Data Processing and Analysis

Due to the simple composition and difficulty in measuring tall trees in the study area, this study only considered the importance values of shrub and herb layer plants. The calculation formulas were as follows (Park et al., 2008): shrub importance value = (relative density + relative coverage + relative height)/3; herb importance value = (relative density + relative coverage + relative height + relative frequency)/4.

The Patrick richness index (R), Pielou evenness index (E), Shannon-Wiener index (H), and Simpson index (D) were selected to analyze plant community α-diversity across 34 quadrats at different elevations. Species importance values were used as the operational unit. The calculation formulas were as follows (Luo et al., 2018): Patrick richness index: R = (S-1)/lnN; Pielou evenness index: E = H /lnS; Shannon-Wiener index: H ; Simpson index: D = (where S represents the number of species in a quadrat, N is the total number of individuals of all species, and P is the relative abundance of each species).

Routine statistical analyses were performed in Excel 2010. One-way ANOVA of soil factors and species diversity indices was conducted using SPSS 19.0. Statistical mapping of plant community species diversity indices was performed in Origin 2019. Redundancy analysis (RDA) was implemented using Canoco V 4.5

software and CanoDraw V4.0 mapping software.

2.1 Plant Community Species Composition and Types

The study area recorded a total of 134 plant species belonging to 75 genera and 30 families, including 126 herbaceous species (26 families, 70 genera) accounting for 86.67%, 93.33%, and 94.02% of total families, genera, and species, respectively. Shrub species appeared in 9 sample plots, comprising 8 species (4 families, 5 genera) accounting for 13.33%, 6.67%, and 5.98% of the total, mainly distributed at 2,300–2,900 m elevation. Based on *Flora Xinjiangensis* (Editorial Committee of Flora of Xinjiangensis, 1999) and species importance values, plant communities were classified into eight types (Table 1). Community VI exhibited the highest total species richness, distributed at 3,000–3,500 m, with dominant species including *Poa nemoralis*, *Carex melanantha*, *Carex stenocarpa*, and *Leymus racemosus*. Among the eight communities, dominant shrub species included *Ceratoides latens*, *Ephedra glauca*, *Caragana jubata*, and *Pentaphylloides parvifolia*.

Table 1 The plant community types and their structure in Baluntai area

Community	Elevation (m)	Major dominant species	Companion species
I	<2,500	*Ceratoides latens*, *Achnatherum splendens*, *Silene conoidea*	*Seriphidium kaschgaricum*, *Elymus dahuricus*
II	<2,500	*Ephedra glauca*, *Leymus racemosus*, *Astragalus lepsensis*	*Artemisia frigida*, *Achnatherum splendens*
III	2,500–3,000	*Elymus dahuricus*, *Leymus racemosus*	*Caragana jubata*, *Pentaphylloides parvifolia*
IV	2,500–3,000	*Thalictrum minus*, *Achnatherum splendens*, *Stipa capillata*	*Rumex acetosa*, *Ligularia macrophylla*
V	2,500–3,000	*Poa supina*, *Leymus racemosus*, *Androsace maxima*	*Leontopodium leontopodioides*, *Potentilla bifurca*
VI	3,000–3,500	*Poa nemoralis*, *Carex melanantha*, *Carex stenocarpa*, *Leymus racemosus*	*Polygonum viviparum*, *Astragalus frigidus*, *Potentilla sericea*
VII	3,000–3,500	*Poa nemoralis*, *Saussurea chondrilloides*, *Potentilla bifurca*	*Potentilla sericea*, *Carex stenocarpa*
VIII	>3,500	*Poa nemoralis*, *Rhodiola coccinea*, *Alchemilla tianschanica*	*Papaver canescens*, *Aster altaicus*

Note: Community names follow the format: Ass. [Dominant species].

2.2 Soil Factor Distribution Characteristics at Different Elevations

Soil physicochemical properties and parent materials create different microenvironments for plant growth at various elevations. As shown in Table 2, except for soil pH, total phosphorus, and available phosphorus ($P>0.05$), all other soil factors showed significant differences across elevations ($P<0.05$), indicating spatial heterogeneity in soil factor distribution along the vertical gradient in the study area. Total salt and total phosphorus reached extreme values in the middle elevation zone (2,500–3,500 m), suggesting substantial variation in these soil factors within this elevation range. Soil water content differed significantly between middle-high and low elevation zones ($P<0.05$), indicating relatively abundant rainfall and humid climate in middle-high elevation areas with soil texture more suitable for plant growth.

Table 2 Distribution characteristics of soil environmental factors at different elevations

Elevation	SW ($g \cdot kg^{-1}$)	pH	TS ($g \cdot kg^{-1}$)	SOM ($g \cdot kg^{-1}$)	TN ($g \cdot kg^{-1}$)	TP ($g \cdot kg^{-1}$)	AN ($mg \cdot kg^{-1}$)	AP ($mg \cdot kg^{-1}$)	AK ($mg \cdot kg^{-1}$)
<2,500	36.499±2.835^{a}	7.736±0.032^{a}	5.243±1.880^{a}	40.018±0.853^{a}	2.139±0.446^{a}	0.859±0.040^{a}	13.518±0.399^{a}		
3, 500	66.184±1.457^{b}	7.881±0.027^{a}	2.516±0.893^{b}	56.283±2.663^{a}	3.018±0.288^{a}	0.773±0.071^{a}	13.669±1.		

Note: Different lowercase letters in the same column indicate significant differences in soil nutrient content among elevations at the 0.05 level.

2.3 Plant Community Species Diversity Characteristics at Different Elevations

As shown in Fig. 2, species diversity in different layers of plant communities exhibited distinct patterns along the elevation gradient. Shrub layer species primarily occurred below 3,000 m, with low and non-significant differences in diversity indices across elevation gradients ($P>0.05$). The herbaceous layer dominated the study area. The Shannon-Wiener index of herbaceous layer species differed significantly among elevations ($P<0.05$), with higher values in the middle elevation zone, indicating richer herbaceous species and more complex community composition. In contrast, low and high elevation zones had fewer herbaceous species and simpler community structure due to human disturbance and natural conditions. The Pielou evenness index of the overall community was significantly greater at high elevations than other zones ($P<0.05$), showing the most uniform species distribution. The overall community Pielou evenness and Shannon-Wiener indices first decreased then increased with elevation.

Note: Different lowercase letters indicate significant differences in species diversity indices of the same life form across elevations at the 0.05 level.

Fig. 2 Distribution of species diversity indices of plant communities at different elevations

2.4 RDA Ordination Analysis of Plant Community Species Diversity and Environmental Factors

RDA ordination analysis of shrub layer, herbaceous layer, and overall community diversity indices with environmental factors for 34 quadrats in Baluntai effectively explained multiple environmental indicators along environmental gradients. Monte-Carlo tests showed all ordination axes were highly significant (F=3.913, P=0.002). The cumulative explanation rates for diversity variables and diversity-environment relationships reached 64.1% and 96.8%, respectively, indicating reliable ordination results that adequately explained relationships between community species diversity indices and environmental factors.

As shown in Table 3, elevation and available nitrogen showed extremely significant negative correlations (P<0.01) with RDA Axis 1, organic matter and total nitrogen showed significant negative correlations (P<0.05), and total salt showed an extremely significant positive correlation. Soil water content was the only factor showing an extremely significant positive correlation with Axis 2. These results indicate that among the 11 environmental factors, the primary factors influencing plant community species diversity were elevation, soil water content, total salt, organic matter, total nitrogen, and available nitrogen.

Table 3 Correlation coefficients of environmental factors with the first two RDA axes in Baluntai

Environmental Factor	Axis 1	Axis 2
Elevation	-0.757**	0.579**
Soil water content	-0.311*	-0.314*
Total salt	0.448**	-0.397**
Organic matter	-0.311*	-0.314*
Total nitrogen	-0.311*	-0.314*
Available nitrogen	-0.757**	0.579**

Note: indicates significant effect (P<0.05); ** indicates extremely significant effect (P<0.01).*

As illustrated in Fig. 3, shrub layer diversity indices showed the highest correlations with total salt and available phosphorus, and were negatively correlated with elevation. Herbaceous layer diversity indices were highly correlated with elevation, organic matter, total nitrogen, and available nitrogen, and negatively correlated with total salt. Overall community richness index (Rt) was significantly negatively correlated with soil pH, Simpson index (Dt) was significantly negatively correlated with total salt, while evenness index (Et) and Shannon-Wiener index (Ht) were both highly correlated with elevation.

Fig. 3 RDA ordination diagram of plant community species diversity indices and environmental factors

In arid and semi-arid regions, small-scale habitat heterogeneity is an important factor causing differences in community composition and species coexistence (Bergholz et al., 2017). This study found that soil SOM content in the middle elevation zone was significantly higher than in low and high elevation zones ($P<0.05$), primarily because surface SOM content is mainly influenced by plant litter and dead root systems (Dai et al., 2021). The middle elevation zone had higher herbaceous layer species diversity, and SOM entered the soil system mainly through plant-litter-soil supplementation, resulting in the highest content in this zone. Soil AN also showed significant differences across elevations ($P<0.05$), with content first increasing then decreasing with elevation. Low elevation zones had less rainfall and lower species richness, and surface soil exposed to rainwash experienced nitrogen loss, making soil AN prone to leaching and resulting in the lowest AN content (He et al., 2020). In high elevation zones, lower soil temperatures affected AN release (Wang et al., 2018), resulting in lower content. Notably, soil factor heterogeneity across elevation gradients not only affects plant community distribution patterns but also reflects and indicates ecological adaptation strategies of plant populations (Pca et al., 2019). Soil pH is a fundamental property closely related to soil fertility, salinity, and microbial activity (Luo et al., 2021). The study area' s soil pH (7.736$±0.032–7.881±$0.067) was alkaline, and as pH increased with elevation, Poaceae and forb species increased, indicating these plants are more drought-tolerant, salt-alkali resistant, and environmentally adaptable.

Changes in microenvironments at different elevations alter plant ecological and physiological characteristics, thereby affecting community structure and vertical distribution. This study found that herbaceous plants dominated, accounting for 94.02% of total species, while shrubs were scarce above 2,919 m. This is likely because elevation, as a topographic factor, critically affects temperature changes —higher elevations create harsh conditions dominated by low temperatures that reduce shrub photosynthesis and limit shrub layer growth (Kang et al., 2020). Compared with plant community diversity surveys in the Kuqa mountainous area (Chang et al., 2018), although both regions share similar latitudes and are located on the southern slope of the mid-Tianshan Mountains, Baluntai has richer herbaceous and shrub species. This is because Kuqa has a drier climate with less precipitation and greater evaporation, while Baluntai, situated on the sunny side of the Tianshan Mountains, has abundant light and heat resources with annual precipitation more than double that of Kuqa. Plants are regulated by the combination of heat and water, growing more abundantly in Baluntai where hydrothermal resources are more suitable. Overall community richness index (Rt) showed a hump-shaped pattern along the elevation gradient. Low elevation mountains have extremely arid climates—although temperatures are high, water is relatively scarce, making it the primary limiting factor for plant distribution. Many plants cannot complete their life cycles in such extremely dry environments, and combined with human disturbance and grazing impacts, the vegetation consists mainly of xerophytic shrubs and a few herbaceous species, resulting in lower species richness. High elevation zones are primarily limited by heat, with large diurnal temperature variations and reduced soil fertility severely affecting plant growth and development (Zhang et al., 2020), resulting in mainly cold-tolerant herbs and reduced species richness. Middle elevation zones have relatively better environmental conditions more suitable for plant growth, thus exhibiting higher species richness. This differs from the elevation gradient pattern of species richness in *Bromus inermis* communities on the northern slope of the Tianshan Mountains (Gong et al., 2019). Factors influencing species diversity are multifaceted, including large-scale regional differences and small-scale elevation variations. The Tianshan Mountains' southern and northern slopes differ in climate, hydrology, soil environment, and other environmental factors (Qin et al., 2021), leading to different responses of plant communities to elevation.

Overall community Pielou evenness index (Et) showed a decreasing-then-increasing pattern with elevation. This may be because soil TS and TP contents reached their maximum (6.929$\pm$1.887 $g \cdot kg^{-1}$ and 1.055$\pm$0.244 $g \cdot kg^{-1}$) and minimum (2.036$\pm$0.333 $g \cdot kg^{-1}$ and 0.884$\pm$0.050 $g \cdot kg^{-1}$) values, respectively, in the middle elevation zone, creating large variation in the soil environment where plants survive. This elevation zone also had more species and complex microhabitats, with complex interspecific relationships leading to lower overall community evenness, while low and high elevation zones showed more uniform community distribution. Dominant herbaceous layer species richness (Rh), Shannon-Wiener (Hh), and Simpson indices (Dh) first increased then decreased with elevation, consistent with the unimodal distribution pattern of seed plant flora vertical distribution in the middle section of the southern Tianshan Mountains (Liu et al., 2018). Unimodal patterns are common in arid and semi-arid regions of northwestern China. The study area has a temperate continental climate—compared with warm temperate continental monsoon, subtropical, and semi-humid regions (Zhong et al., 2019; He et al., 2020; Gao et al., 2020), the study sites are far from oceans or blocked by terrain, preventing moist air masses from reaching them, resulting in dry, rainless conditions with an extremely continental climate. With average annual precipitation below 500 mm, severe soil erosion and desertification, overall species diversity is strongly regulated by water and temperature. At the small scale, middle elevations have relatively suitable temperature and precipitation, with soil texture and hydrothermal conditions more favorable for dominant herbaceous layer growth, thus forming a peak species diversity zone.

As the primary topographic factor, elevation influences the spatial gradient changes in plant community species diversity by affecting the geographical structure and hydrothermal processes of mountain ecosystems. The study area has complex geological structures and rich soil parent materials. Along the elevation gradient, interactive effects of various environmental factors influenced plant community species diversity, consistent with Wu et al. (2019) findings that species diversity changes in alpine grasslands in northern Tibet are regulated by heat and water, with different soil factors explaining elevation gradient patterns differently. RDA results showed that among soil physicochemical indicators, SW, AN, and TS significantly affected plant community species diversity. SW is a necessary environmental factor for plant community growth, directly affecting plant physiological conditions. This study found a positive correlation between overall community richness index (Rt) and SW, differing from studies on the northern Tianshan slope (Chen et al., 2019). The southern Tianshan slope receives less moisture from the Atlantic and Arctic Oceans than the northern slope, with lower annual precipitation and more extreme aridity, making plants more sensitive to SW, which significantly affects overall community richness. Shrub layer diversity indices showed negative correlations with AN in RDA ordination, with higher AN content in middle-high elevation zones but fewer shrub species. This aligns with Pan (2017), who found excessive nitrogen significantly reduced shrub and semi-shrub species numbers, as high N content intensifies interspecific competition and suppresses weaker populations. While many studies have found soil TS plays a minor role in species diversity distribution patterns on Tianshan slopes (Chen et al., 2019), this study differed—RDA showed TS was negatively correlated with overall community diversity indices and significantly affected distribution patterns, mainly because sample plots had relatively high salt content (Naqinezhad et al., 2009). Under dry, water-deficient conditions, excessive soluble salts in soil create physiological drought for plants, thereby affecting overall community species diversity.

Conclusions

4.1 The study area recorded 134 plant species belonging to 30 families and 75 genera, classified into eight community types. Plant communities were most species-rich at middle elevations and more uniformly distributed at low and high elevations, indicating that middle elevation zones have more complex community structure and higher stability, providing suitable conditions for plant growth.

4.2 Across different elevations, soil water content, organic matter, and available nitrogen first increased then decreased. The primary factors affecting plant community species diversity were elevation, soil water content, and total salt, followed by organic matter, total nitrogen, and available nitrogen.

In summary, both plant community composition and soil factors in the study area were significantly affected by elevation gradients. Plants adopted different survival strategies to adapt to microhabitats at different elevations. The distribution patterns of overall community species diversity indices were largely consistent with soil nutrient and water distribution, reflecting the role of environmental filtering in shaping plant community species diversity and the adaptive strategies of different species to environmental changes.

References

Bergholz, May, Giladi, et al., 2017. Environmental heterogeneity drives fine-scale species assembly and functional diversity of annual plants in a semi-arid environment[J]. *Perspect Plant Ecol*, 24: 138-146.

Chang F, Liu B, Liu RK, et al., 2018. Plant community diversity and environmental interpretation of adaptive region of *Gentianella turkestanorum* in Kuche Mountain area[J]. *Acta Agr Sin*, 26(5): 1084-1090.

Chen YS, Sun HR, Li NN, et al., 2019. Plant community diversity in grazed *Seriphidium* semidesert grassland and its relationships with environmental factors[J]. *Acta Pratact Sci*, 28(11): 1-11.

Dai WX, Lou CY, Xu DM, et al., 2021. Spatial distribution of litter yield in an evergreen broadleaf forest and its effects on the heterogeneity of soil nutrients[J]. *Acta Ecol Sin*, 41(2): 513-521.

Editorial Committee of Flora of Xinjiangensis, 1999. *Flora Xinjiangensis*[M]. Urumqi: Xinjiang Science Technology and Health Press.

Gao H, Liu LJ, Fang JP, 2020. Distribution pattern and environmental interpretation of forest communities along elevation gradients in Sejila Mountain[J]. *J Hunan Norm Univ (Nat Sci Ed)*, 43(5): 43-51+68.

Gao LJ, Zhao BB, Xing XM, et al., 2018. Short term anomalies detected at Balguntay station's component borehole strain before the Hutubi Ms6.2 earthquake, Xinjiang, China[J]. *J Geod Geodyn*, 38(8): 102-106.

Gong K, Jin GL, Yue YH, et al., 2019. Community characteristics of *Bromus inermis* on the northern slope of Tianshan Mountains[J]. *Xinjiang Agric Sci*, 56(3): 561-570.

He JW, Liu Y, Li SY, et al., 2020. Relationship between shrub plant communities and soil at different altitudes in Jiangjiagou watershed[J]. *Guihaia*, 40(8): 34-42.

Kang HM, Li HH, Xu DH, et al., 2020. Effects of elevated CO_2 and temperature on *Caragana jubata* (Alpine shrub) growth and antioxidant systems[J]. *Acta Ecol Sin*, 40(1): 367-376.

Li MF, Ma YC, Liu GH, et al., 2020. Pattern and drivers of phylogenetic diversity in Xinjiang grassland[J]. *Acta Ecol Sin*, 40(7): 2285-2299.

Li LG, 2016. *The Grand Ceremony of the People' s Republic of China, Xinjiang Uygur Autonomous Region Volume*[M]. Beijing: China Social Press.

Liu B, 2017. Vertical patterns in plant diversity and their relationships with environmental factors on the southern slope of the Tianshan Mountains (middle section) in Xinjiang (China)[J]. *J MT Sci-engl*, 14(4): 742-757.

Liu B, Bumaryam T, Aibibaimu K, et al., 2018. Vertical distribution patterns of the seed plant flora in the middle section on the southern slopes of the Tianshan Mountains in Xinjiang, China[J]. *Plant Sci J*, 36(2): 191-202.

Liu GC, Huang YX, Wang QG, et al., 2018. Effects of environmental factors on plant species diversity: research progress[J]. *Chin Agric Sci Bull*, 34(13): 83-89.

Liu N, Bai KY, Yang YH, et al., 2018. Effects of grazing on vegetation and soil nutrients of a desert steppe in Inner Mongolia[J]. *Pratact Sci*, 35(6): 1323-1331.

Luo QH, Sun F, Cui Y, et al., 2018. Interspecific association among main plant species in the unstable slope with high-frequency debris flow[J]. *Chin J Appl Environ Biol*, 24(4): 689-696.

Luo QY, Wang YL, Du L, et al., 2021. Plant community diversity and soil factor interpretation of adaptive region of *Deschampsia caespitosa* in the source region of the Yellow River[J]. *Acta Pratact Sci*, 30(4): 80-89.

Naqinezhad A, Jalili A, Attar F, et al., 2009. Floristic characteristics of the wetland sites on dry southern slopes of the Alborz Mts., N. Iran: The role of altitude in floristic composition[J]. *Flora*, 204(4): 254-269.

Pan ZL, 2017. The response of productivity and species diversity to warming and nitrogen addition in *Stipa breviflora* desert steppe[D]. Hohhot: Inner Mongolia Agricultural University.

Pca B, Dck C, D M J, et al., 2019. Classification, description and environmental factors of montane wetland vegetation of the Maloti-Drakensberg region and the surrounding areas[J]. *S Afr J Bot*, 25: 221-233.

Park HG, Barrelet CJ, Wu Y, et al., 2008. A wavelength-selective photonic-crystal waveguide coupled to a nanowire light source[J]. *Nat Photonics*, 2(10): 622-626.

Qin L, Shang HM, Zhang TW, et al., 2021. Response comparison of the tree-rings δ^{13}C to climate on the southern and northern slopes of Tianshan Mountain[J]. *Acta Ecol Sin*, 41(14): 5713-5724.

Ren QW, Wang X, Li LD, et al., 2019. Vertical variation of soil physical and chemical properties at different altitudes in Xiaowutai Mountain[J]. *J Soil Water Conserv*, 33(1): 241-247.

Wang L, Xu XL, Liu L, 2020. Remotely sensed dataset of grassland degradation on the Qinghai-Tibet Plateau[J]. *Acta Geogr Sin*, 69(S1): 159-163.

Wang LJ, Wang P, Sheng MY, 2018. Stoichiometric characteristics of soil nutrient elements and its influencing factors in typical karst rocky desertification ecosystems, Southwest China[J]. *Acta Ecol Sin*, 38(18): 6580-6593.

Wang JM, Dong FY, Bahai N, et al., 2016. Plant distribution patterns and the factors influencing plant diversity in the Black Gobi Desert of China[J]. *Acta Ecol Sin*, 36(12): 3488-3498.

Wu HB, Shui HW, Hu GZ, et al., 2019. Species diversity and biomass distribution patterns of alpine grassland along an elevation gradient in the northern Tibetan Plateau[J]. *Ecol Environ*, 28(6): 1071-1079.

Zhang SX, Qin RM, Yang XY, et al., 2020. Pattern of species diversity in herbaceous communities at different altitude gradient and their relationships with environmental factors in Lüliang Mountains in Shanxi Province, China[J]. *Guihaia*, 40(12): 1860-1868.

Zhong JJ, Chen J, Chen Q, et al., 2019. Quantitative classification of MRT, CCA ordination, and species diversity along elevation gradients of a natural secondary forest in the Qinling mountains[J]. *Acta Ecol Sin*, 39(1): 277-285.

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