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Species Diversity and Distribution Pattern of Saxicolous Lichens in Serekitaxi Region of Taxkorgan Nature Reserve, China

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Abstract

Based on field surveys across 15 sampling sites spanning five elevational belts in the Serekitaxi area of Taxkorgan Nature Reserve (eastern Pamir Plateau), we constructed a species-site coverage matrix to systematically explore the diversity and elevational patterns of saxicolous lichens. A total of 24 saxicolous lichen species were documented, belonging to 13 genera within 8 families; *Acarospora* and *Aspicilia* represented the most species-rich genera. Based on relative coverage, *Rusavskia elegans* (Link) S.Y. Kondr. & Kärnefelt and *Candelariella oleifera* were identified as the dominant taxa. Species richness per elevational belt ranged from 10 to 18, peaking at 4316 m. One-way ANOVA detected significant elevational differences in α-diversity ($p < 0.01$), whereas Pielou's evenness indices did not differ significantly among belts ($p > 0.05$). Analyses of Bray-Curtis dissimilarity, Jaccard similarity, PERMANOVA, and NMDS ordination further demonstrated pronounced compositional differentiation of saxicolous lichens along the elevation gradient. The 4316 m belt harboured the highest species count and exhibited markedly higher species turnover compared with neighbouring elevational zones. We conclude that saxicolous lichens in Sereketaxi display strong nonlinear elevational variation. Mid-elevation zones constitute biodiversity hotspots, presumably driven by balanced substrate stability, light availability and heterogeneous microhabitats. This work establishes baseline data for saxicolous lichen resource surveys and conservation on the Pamir Plateau, and provides empirical support for future broad- and fine-scale ecological studies of lichens.

Keywords

Saxicolous Lichen, Species Composition, Elevation Gradient, Pamir Plateau

1. Introduction

Lichens are stable extracellular symbiotic life systems formed by lichen-forming fungi as the constructive species, with algae or cyanobacteria as associated symbionts, also known as mycobiont-photobiont symbionts [1] [2]. Beyond the core constructive and associated symbiotic species, stable lichen mycobiont-photobiont communities host a diverse array of epiphytic microorganisms; accordingly, lichens are regarded as miniature microecosystems and a typical manifestation of widespread biodiversity in nature [2]. The origin of lichens dates back to the Early Devonian, approximately 400 million years ago, making them one of the earliest symbiotic organisms to colonize terrestrial habitats on Earth [3] [4]. According to estimations lichen-dominated vegetation covers around 8% of the global land surface [3] [5].

Saxicolous lichens refer to lichen taxa colonizing stable surfaces of rocks and various mineral substrates, mainly divided into two categories: epilithic lichens and endolithic lichens [3]. Their distinctive thallus structures endow them with exceptionally high and unique ecological functions. In alpine high-elevation zones, saxicolous lichens participate in regional water regulation and nutrient accumulation, and are critical to sustaining the structure and stability of alpine ecosystems. As classic pioneer organisms, they accelerate rock weathering and soil formation on high-altitude plateaus, optimize the microhabitat environment, and lay a foundation and favorable conditions for the primary succession of plant communities [6] [7].

Climate projection data predict a global temperature rise of 4˚C by 2100, accompanied by dramatic shifts in precipitation patterns [8]. Against the backdrop of global climate change, climatic conditions, soil properties and precipitation regimes in alpine high-elevation regions are undergoing corresponding transformations, which substantially alter the community composition and species diversity patterns of lichens [9] [10]. While saxicolous lichens exhibit extreme environmental tolerance, capable of surviving harsh habitats with intense solar radiation, severe drought and high temperatures, certain species are highly sensitive to environmental fluctuations. Therefore, species richness and community diversity of saxicolous lichens can serve as excellent bioindicators of climate change in alpine regions [11] [12]. In summary, saxicolous lichens are key pioneer organisms in extreme habitats characterized by cold alpine conditions, aridity and intense ultraviolet radiation, and they perform irreplaceable vital functions in ecological processes including ecosystem succession, pedogenesis, and the conservation of regional biodiversity.

Since the 21st century, research on the impacts of climate change on biodiversity has become a core focus in ecological research. In recent years, affected by global climate change, the temperature and precipitation in the Eastern Pamir Plateau have shown a continuous increasing trend, leading to accelerated glacier melting. From 1972 to 2011, the glacier area and storage in this region decreased by 5.79% and 6.69%, respectively, which has posed certain threats to regional hab-

itat environments and biodiversity [13] [14]. Located in the eastern Pamir Plateau, the Taxkorgan Nature Reserve of China sits at the junction of the Tianshan, Kunlun, Karakoram, and Hindu Kush mountains. It connects two global wildlife biodiversity hotspots—the Himalayas and Central Asian mountains—making it one of the critical species gene pools and an ecologically vital area for biodiversity conservation [15].

The reserve's distinctive geographic position and natural environmental conditions create ideal habitats for saxicolous lichens. As a result, this area has become a natural experimental platform and core research hotspot for lichen diversity, drawing widespread interest from lichenologists and ecologists worldwide. While climate warming and glacial retreat have enlarged the extent of exposed bedrock and generated additional suitable microhabitats for saxicolous lichens, the mechanisms driving their impacts on lichen species diversity and community structure remain poorly understood. In this context, investigations into saxicolous lichen diversity within the region can supply fundamental empirical data to unravel community assembly and diversity maintenance mechanisms of saxicolous lichens across arid zone of northwestern China. Against this backdrop, the present study aims to characterize the species diversity of saxicolous lichens and document their distribution patterns along elevational gradients within the reserve.

2. Methods

2.1. Study Area Description

Taxkorgan Nature Reserve are located within latitude 35˚38′ - 37˚30′ N and longitude 74˚30′ - 77˚00′ E, lies in the eastern Pamir Plateau, China, with an average elevation exceeding 4000 m. The permanent snowline shows obvious aspect differentiation: 4600 - 4700 m on shaded slopes and 4800 - 5000 m on sunny slopes. Mountains above 6000 m are permanent snow-covered high peaks all year round. The reserve has a continental alpine arid desert climate [13] [16], with a mean annual temperature of around 3˚C, annual precipitation of merely 70 mm, and an extremely high evaporation capacity of 2571 mm.

Restricted by the cold and arid continental climate, the region features unique vegetation and soil properties. Its mountain vertical vegetation spectrum lacks steppe and coniferous forest belts, and alpine desert constitutes the dominant vegetation type, with alpine cushion vegetation scattered within the alpine desert zone. The main soil types in this area include alpine meadow soil, alpine meadow-steppe soil and alpine desert soil.

2.2. Field Investigation and Species Identification

In this study, five elevational transect were established along an altitudinal gradient in the Serekitaxi zone of the nature reserve, with elevations of 4168 m, 4287 m, 4316 m, 4454 m and 4486 m. Three standard 20 m × 20 m plots were laid out at 30 m intervals within each elevational transect, generating a total of 15 sampling plots [17]. At each plot, a portable 20 cm × 20 cm quadrat (divided into 100 small

grids of 2 cm × 2 cm each) was used to measure the coverage and frequency of lichens. For each plot, the following data was collected: species name of saxicolou lichens, coverage and frequency (**Appendex**: Table S1, Table S2, Table S3). We conducted the lichen survey between 10 to 25 August 2025. Photographs of the sample plots and quadrats were taken. At each plot, we identified common species in the field and took voucher specimens of all other lichens. We identified the lichen specimens morphologically and/or by microscopic examination of their ascospores, as well as by chemical-spot tests and responses to UV light [18]-[20].

2.3. Data Analysis

Each sampling plot was taken as a statistical unit to calculate α-diversity indices, including species richness (S), Shannon-Wiener diversity index (H'), Simpson dominance index (1-D), and Pielou evenness index (J) [21] [22]. Normality and homogeneity of variance tests were conducted on all diversity indices. If the data met the prerequisites for parametric tests, one-way ANOVA was adopted to identify differences in diversity indices among elevational belts, followed by post-hoc multiple comparisons using the Tukey HSD test.

To analyze the spatial differentiation of saxicolous lichen species composition, Bray-Curtis dissimilarity coefficients and Jaccard similarity coefficients were separately applied to quantify species differences across elevational gradients. PERMANOVA was performed to test the statistical significance of compositional differences among elevational transect. Furthermore, Non-metric Multidimensional Scaling (NMDS) ordination based on Bray-Curtis distances was carried out to visualize the spatial differentiation pattern of lichen communities among all sampling plots [21] [22]. Statistical software's such as SPSS 22.0 and R 4.6.0 were used for data processing and analysis.

3. Results

3.1. Saxicolous Lichens Species Composition

The results of Table 1 shows that, a total of 24 saxicolous lichen species were identified and recorded in this study, belonging to 13 genera across 8 families. According to species abundance, *Acarospora* A. Massal. and *Aspicilia* A. Massal. exhibited the highest species diversity, each containing five species, making them the dominant genera in the study area. *Lecidea* Ach., *Rhizocarpon* Ramond ex DC., and *Sarcogyne* Flot. each comprised two species. The remaining genera, namely *Candelariella* Müll. Arg., *Circinaria* Link, *Dimelaena* Norman, *Glypholecia* Nyl., *Lobothallia* (Clauzade & Cl.Roux) Hafellner 1991, *Rhizoplaca* Zopf, *Rusavskia* S.Y. Kondr. & Kärnefelt 2003, and *Xanthoria* (Fr.) Th.Fr., were monospecific genera. Overall, crustose growth forms are dominant among saxicolous lichen. This distribution pattern is highly consistent with the environmental characteristics of alpine bare rock habitats. Possessing strong drought and radiation tolerance, crustose lichens are well adapted to nutrient-poor rock substrates [3] [23] [24].

Table 1. Species composition of the saxicolous lichen in the Seriktax area of Taxkorgan Nature reserve.

Numbering	Family	Genus	Species
1	Acarosporaceae	*Acarospora* A. Massal.	*A. aeginaica* H. Magn.
2	Acarosporaceae	*Acarospora* A. Massal.	*A. badiofusca* (Nyl.) Th. Fr.
3	Acarosporaceae	*Acarospora* A. Massal.	*A. bohlinii* H. Magn.
4	Acarosporaceae	*Acarospora* A. Massal.	*A. invades* H. Magn.
5	Acarosporaceae	*Acarospora* A. Massal.	*A. superans* H. Magn.
6	Megasporaceae	*Aspicilia* A. Massal.	*A. bohlinii* (H. Magn.) J.C.Wei
7	Megasporaceae	*Aspicilia* A. Massal.	*A. cinerea* (L.) Körb.
8	Megasporaceae	*Aspicilia* A. Massal.	*A. cupulifera* (H. Magn.) Oxner
9	Megasporaceae	*Aspicilia* A. Massal.	*A. hartliana* (Sthr.) Hue
10	Megasporaceae	*Aspicilia* A. Massal.	*A. verrucigera* Hue
11	Candelariaceae	*Candelariella* Müll. Arg.	*C. oleifera* H. Magn.
12	Megasporaceae	*Circinaria* Link	*C. ochraceoalba* (H. Magn.) Q. Ren
13	Caliciaceae	*Dimelaena* Norman	*D. oreina* (Ach.) Norman
14	Acarosporaceae	*Glypholecia* Nyl.	*G. scabra* (Pers.) Müll. Arg.
15	Lecideaceae	*Lecidea* Ach.	*L. auriculata* Th. Fr.
16	Lecideaceae	*Lecidea* Ach.	*L. tessellata* Flörke
17	Megasporaceae	*Lobothallia* (Clauzade & Cl. Roux) Hafellner 1991	*L. alphoplaca* (Wahlenb.) Hafellner
18	Rhizocarpaceae	*Rhizocarpon* Ramond ex DC.	*R. geographicum* (L.) DC.
19	Rhizocarpaceae	*Rhizocarpon* Ramond ex DC.	*R. macrosporum* Räsänen
20	Lecanoraceae	*Rhizoplaca* Zopf	*R. melanophthalma* (DC.) Leuckert & Poelt
21	Teloschistaceae	*Rusavskia* S.Y. Kondr. & Kärnefelt 2003	*R. elegans* (Link) S.Y. Kondr. & Kärnefelt
22	Acarosporaceae	*Sarcogyne* Flot.	*S. gyrocarpa* H. Magn.
23	Acarosporaceae	*Sarcogyne* Flot.	*S. solitaria* H. Magn.
24	Teloschistaceae	*Xanthoria* (Fr.) Th.Fr.	*X. sorediata* (Vain.) Poelt

3.2. Dominant Species Analysis

The dominant species analysis results in Table 2 show that, in the study area were *Rusavskia elegans* (Link) S.Y. Kondr. & Kärnefelt and *Candelariella oleifera* H. Magn., accounting for 19.28% and 17.62% of the total coverage, respectively. Sub-dominant species included *Lecidea tessellata* Flörke, *Dimelaena oreina* (Ach.) Norman, *Lobothallia alphoplaca* (Wahlenb.) Hafellner, and *Rhizocarpon geographicum* (L.) DC. Notably, the two most dominant species occurred in all 15 sampling plots, indicating their broad ecological amplitude and exceptional adaptability to the extreme alpine, arid, oligotrophic bare rock environment of the research region.

Table 2. The top 10 dominant species by relative coverage in the study area.

Dominant species	Relative coverage (%)	Frequency
Rusavskia elegans (Link) S.Y. Kondr. & Kärnefelt	19.28	15
Candelariella oleifera H. Magn.	17.62	15
Lecidea tessellata Flörke	6.31	12
Dimelaena oreina (Ach.) Norman	5.85	8
Lobothallia alphoplaca (Wahlenb.) Hafellner	5.46	9
Rhizocarpon geographicum (L.) DC.	4.64	6
Glypholecia scabra (Pers.) Müll. Arg.	4.37	9
Xanthoria sorediata (Vain.) Poelt	3.84	6
Circinaria ochraceoalba (H. Magn.) Q. Ren	3.69	7
Rhizoplaca melanophthalma (DC.) Leuckert & Poelt	3.25	6

3.3. Diversity Analysis in Different Elevation

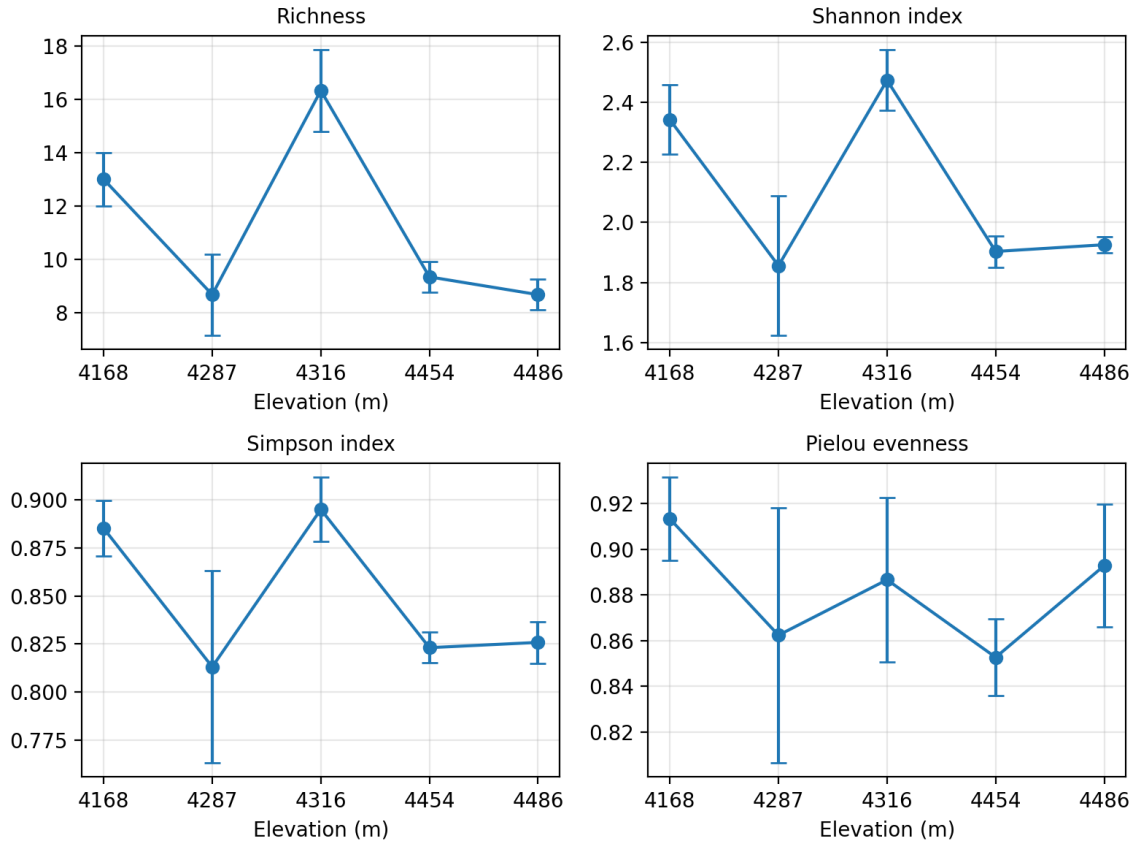

Figure 1. Diversity of saxicolous lichens at different elevational belts.

The results of this study showed that the species richness of saxicolous lichens fluctuated from 10 to 18 species across different elevational belts. The 4316 m elevation harbored the highest species number (18 species), followed by the 4168 m elevation (14 species) and the 4454 m elevation (11 species), while both the 4287

m and 4486 m elevation presented the lowest species count of 10 species. Diversity of saxicolous lichens at different elevational belts in Figure 1 show that, the plot-averaged values, species richness, Shannon diversity index, and Simpson diversity index all peaked at the elevation of 4316 m and declined with increasing elevation thereafter. This indicates that the saxicolous lichen diversity in the study area exhibits a distinct mid-altitude peak pattern along the elevational belts.

One-way ANOVA result in Table 3 show that, there are significant differences in species richness ($F = 27.184$, $p < 0.001$), Shannon-Wiener index ($F = 15.172$, $p < 0.001$), and Simpson index ($F = 7.026$, $p = 0.006$) among elevational belts, whereas no significant difference was detected in the Pielou evenness index ($F = 1.538$, $p = 0.264$). These results indicate that the altitudinal gradient mainly regulates species diversity and dominance distribution patterns of saxicolous lichen communities, while exerting a weak effect on the relative evenness among species.

Table 3. One-way ANOVA of diversity indices across elevational belts.

Diversity Indices	F value	p value
Species richness	27.184	<0.001
Shannon-Wiener index	15.172	<0.001
Simpson index	7.026	0.006
Pielou evenness index	1.538	0.264

3.4. Similarity Analysis between Elevation

Analysis based on the Bray-Curtis dissimilarity index in Figure 2 revealed significant differentiation in species composition of saxicolous lichen across elevation belts. The highest dissimilarity value (0.676) occurred between the 4287 m and 4316 m elevation, followed by the pair of 4168 m and 4287 m with a dissimilarity of 0.665. The two pairs with the lowest dissimilarity were 4287 m vs. 4454 m (0.390) and 4287 m vs. 4486 m (0.391). These results indicate that compositional differences in saxicolous lichen communities of the study area do not follow a simple linearly increasing trend with elevation difference. Spatial differentiation of communities is more likely driven jointly by turnover of dominant species, variations in rock substrate types, and local microhabitat conditions. The Jaccard similarity index calculated from presence-absence matrices showed that in Table 4, the pair of 4168 m and 4316 m elevation belts shared the highest proportion of common species, with a similarity coefficient of 0.524.

By contrast, the species similarity between 4168 m and 4287 m was the lowest at only 0.200. Combined with the results of species diversity analysis, suggests that the 4316 m elevation belt harbors relatively high species richness and undergoes intense species turnover with adjacent elevation belts, making it the critical elevation segment it could be that lower-most species and top species share this elevation in the study area.

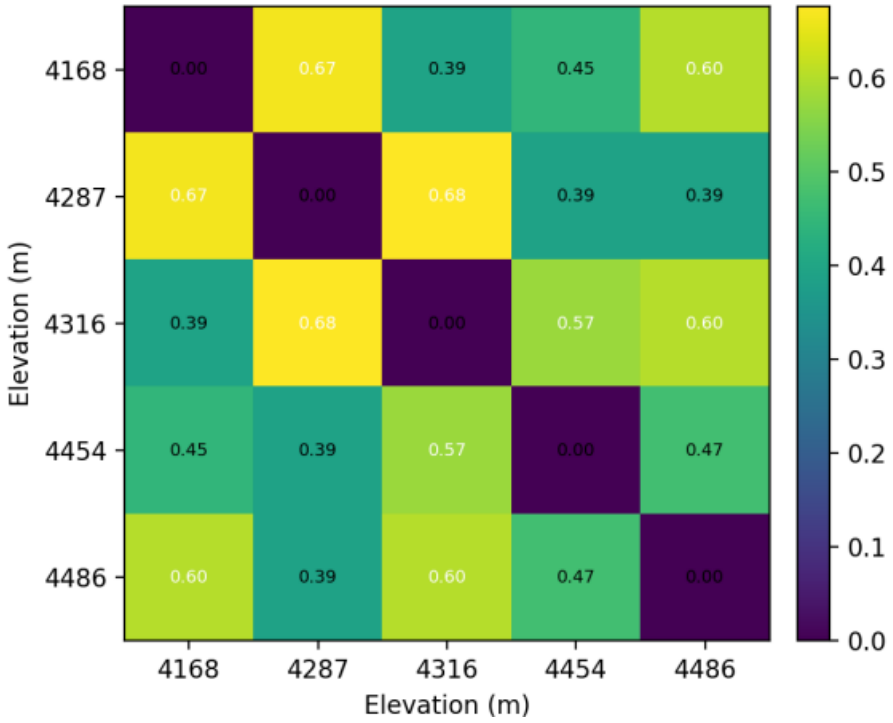

Figure 2. Bray-Curtis dissimilarity between among elevational belts.

Table 4. Jaccard similarity matrix among elevational belts.

Altitude/m	4168	4287	4316	4454	4486
4168	1.000				
4287	0.200	1.000			
4316	0.524	0.273	1.000		
4454	0.471	0.400	0.381	1.000	
4486	0.333	0.250	0.333	0.312	1.000

PERMA PERMANOVA tests performed on the plot-scale Bray-Curtis distance matrix verified an extremely significant difference in saxicolous lichen species composition among elevational belts (pseudo-F = 6.232, p = 0.0002). The stress value of the two- dimensional Non-metric Multidimensional Scaling (NMDS) ordination was 0.117, indicating a well-fitted ordination model with high explanatory power. The NMDS ordination plot in Figure 3, shows that elevation from distinct zones formed clearly demarcated groups: sampling points at 4316 m clustered on the negative side of the second ordination axis; plots from 4287 m and 4454 m mostly aggregated on the positive side of the second axis; while samples at 4486 m were mainly distributed along the negative direction of the first ordination axis. This pattern visually demonstrates evident differentiation of saxicolous lichen community composition along elevation gradients and associated environmental factors.

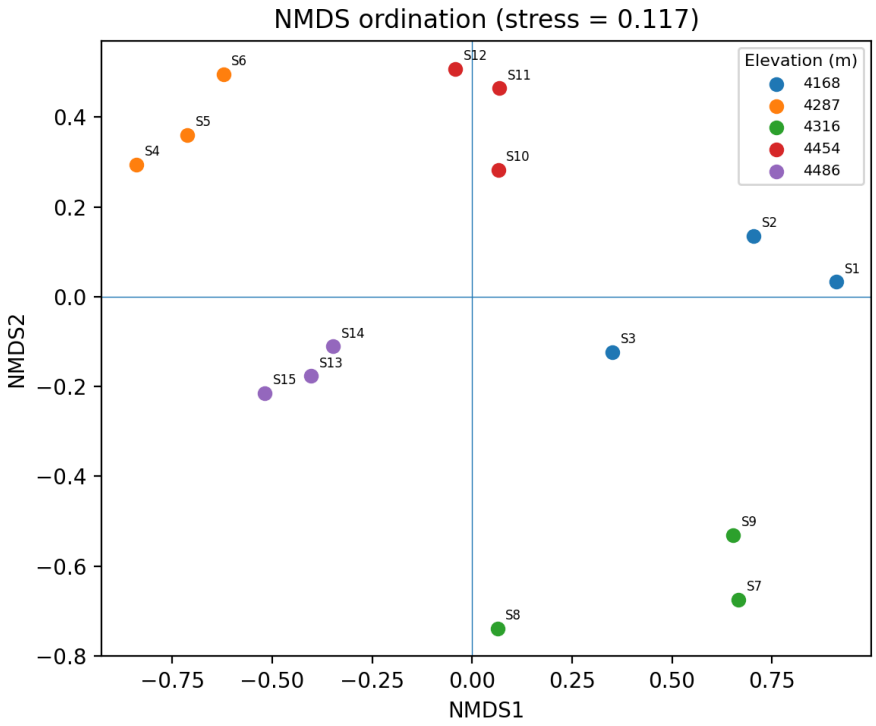

Figure 3. NMDS ordination plot.

4. Discussion

This study systematically investigated the species diversity, composition, and elevational distribution patterns of saxicolous lichens across five elevational belts in the Sereketaxi region of Taxkorgan Nature Reserve, Eastern Pamir Plateau. A total of 24 saxicolous lichen species belonging to 13 genera and 8 families were recorded, with distinct community diversity and compositional differentiation along the elevational gradient. The research results confirmed a typical mid-elevation diversity peak of saxicolous lichens at 4316 m, accompanied by significant elevational variation in species richness and community structure, while species evenness remained stable across altitudinal zones. These findings reveal unique assembly characteristics of rock-dwelling lichen communities in alpine arid plateau habitats, providing empirical evidence for understanding lichen distribution adaptation mechanisms under extreme high-altitude environments.

The relatively moderate species richness recorded in this study is comprehensively shaped by habitat characteristics, survey limitations, and taxonomic identification difficulties. Compared with the higher lichen species richness documented in the Western Tianshan Mountains with more diverse habitat types [23], the lower species number in the study area is primarily attributable to the single alpine bare-rock habitat and extreme arid-cold climatic conditions of the Eastern Pamir Plateau, which strictly filter lichen species and only allow highly stress-tolerant taxa to survive. In addition, the exclusive focus on saxicolous lichens (excluding terricolous and corticolous lichens) and the limited sampling range of high-altitude inaccessible areas further restrict the total recorded species richness.

Crucially, crustose lichens, which dominate the local community, exhibit highly similar morphological characteristics and tiny thalli, leading to great challenges in accurate morphological identification [24]. Despite the modest total species richness, the recorded lichen community is stable and well-adapted to local extreme habitats, fully representing the core characteristics of saxicolous lichen resources in the Eastern Pamir alpine desert ecosystem.

Community composition analysis verified that crustose lichens are absolutely dominant in the study area, consistent with the universal distribution rule of saxicolous lichens in alpine arid mountain regions [25] [26]. Genera including Acarospora and Aspicilia constitute the dominant species pool, which is closely related to the unique adaptive traits of crustose lichens. Crustose lichens tightly adhere to rock substrates, effectively resisting strong alpine ultraviolet radiation, extreme drought, severe temperature fluctuations, and wind erosion [3]. Their special thallus structure enables efficient utilization of limited water vapor and mineral nutrients on barren rock surfaces, making them the pioneer and dominant organisms colonizing high-altitude bare rocks. At the species level, *Rusavskia elegans* and *Candelariella oleifera* occurred in all sampling plots with the highest relative coverage, demonstrating their absolute dominant position in the local lichen community. This study further confirms that these two species have extremely wide ecological amplitude and strong environmental adaptability to alpine arid oligotrophic habitats [27] [28]. The stable existence of widespread dominant species is the core foundation for maintaining the structural stability of saxicolous lichen communities in extreme plateau habitats, and these species can serve as key bioindicators for monitoring environmental changes in the Eastern Pamir region.

A core finding of this study is the significant nonlinear elevational pattern of saxicolous lichen diversity, with a prominent mid-elevation diversity hotspot at 4316 m. The species richness, Shannon-Wiener diversity index, and Simpson dominance index all peaked at this elevation, presenting a typical unimodal elevational distribution pattern. This pattern is highly consistent with the lichen diversity distribution rules observed in the Himalayan Arc, Western Tianshan Mountains, and Argentine alpine mountainous regions [23] [29] [30], indicating that the mid-elevation peak is a universal diversity pattern for mountain saxicolous lichens across different arid and alpine regions. We propose two synergistic mechanisms to explain this core distribution pattern: microhabitat heterogeneity and environmental filtering balance.

First, the 4316 m elevational belt exhibits the highest microhabitat heterogeneity. Compared with the low-elevation zone (4168 - 4287 m) with relatively single rock substrate and severe drought stress, and the high-elevation zone (4454 - 4486 m) with intense ultraviolet radiation, low temperature, and frequent strong winds, the mid-elevation belt features balanced light availability, moderate temperature and humidity conditions, and diverse rock microhabitats. Such heterogeneous microenvironments can accommodate lichen species with different environmen-

tal adaptation strategies, supporting higher species richness and community diversity. Second, this elevation forms a balanced environmental filtering threshold. Low-elevation habitats are constrained by extreme aridity and substrate barrenness, limiting the survival of sensitive lichen species; high-elevation habitats are governed by low temperature and strong radiation stress, eliminating species with weak stress resistance. In contrast, the mid-elevation zone avoids extreme environmental constraints, forming a suitable habitat for most local saxicolous lichens, thus shaping the regional biodiversity hotspot.

NMDS ordination, PERMANOVA test, and β-diversity analysis collectively verified significant compositional differentiation and species turnover of saxicolous lichen communities along the elevational gradient, which is a key innovative finding of this study. The community composition of each elevational belt formed independent clustered groups in the NMDS analysis, confirming distinct community segmentation driven by elevation. Notably, the highest species dissimilarity and strongest species turnover occurred between the 4287 m and 4316 m belts, rather than between distant elevational zones, indicating that lichen community differentiation does not follow a simple linear elevational variation pattern. We hypothesize that local microhabitat conditions override pure elevational differences in driving community differentiation. The slight differences in rock substrate properties, slope aspect, micro-scale temperature and humidity, and vegetation coverage between adjacent elevational belts trigger significant species replacement, resulting in abrupt community compositional changes at the 4287 - 4316 m elevation transition zone.

Additionally, this study found a typical overlapping distribution phenomenon of low- and high-elevation species at the 4316 m hotspot belt, which is a very common ecological pattern in mountain elevational gradient research. The mid-elevation zone not only accommodates endemic mid-altitude lichen species but also allows partial low-elevation drought-tolerant species and high-elevation radiation-resistant species to coexist, further explaining the highest species richness and unique community characteristics at this elevation. Meanwhile, the non-significant difference in Pielou evenness index across all elevational belts indicates that although elevation and microhabitat differences significantly regulate species richness and community composition, they have a weak regulatory effect on the relative distribution uniformity of individual species. The stable evenness further proves that dominant species such as *Rusavskia elegans* and *Candelariella oleifera* can stably occupy niche spaces in all habitats, maintaining the relative balance of community structure in different elevational environments.

Under the background of ongoing global climate warming, the Eastern Pamir Plateau is experiencing continuous temperature rise, increased precipitation, and accelerated glacier retreat [13] [14]. Glacier melting exposes a large number of new bare-rock substrates, providing potential new habitats for saxicolous lichens. However, the specific mechanisms by which climate change alters microhabitat conditions, drives species turnover, and reshapes lichen community elevational

patterns remain unclear. Combined with the findings of this study, we infer that future climate warming may further expand suitable habitats for saxicolous lichens, but excessive temperature rise and hydrological changes may break the mid-elevation environmental balance, potentially shifting the diversity hotspot and altering existing community differentiation patterns.

This study has certain limitations. First, we only set fixed elevation sampling belts and did not conduct continuous gradient monitoring, failing to capture fine-scale dynamic changes of lichen communities. Second, this study only analyzed the macroscopic elevational distribution pattern of lichen diversity but did not quantify the driving effects of microhabitat factors (substrate physicochemical properties, micro-temperature and humidity, radiation intensity) on community assembly. Finally, the lack of species accumulation curve analysis cannot fully evaluate the sufficiency of the current sampling design, and a small number of rare species may not be fully captured.

In summary, this study systematically clarified the species composition, diversity characteristics, and elevational differentiation pattern of saxicolous lichens in the Sereketaxi region, revealing that the coupling of macro environmental filtering and microhabitat heterogeneity is the core driving mechanism of lichen community distribution. The research results fill the gap in basic data of saxicolous lichen diversity in the Eastern Pamir Plateau and provide a theoretical basis for lichen resource conservation and biodiversity maintenance research in arid zone of northwest China. Future research should supplement species accumulation curve analysis to optimize sampling reliability, integrate multi-dimensional microenvironmental monitoring data, and further explore the response mechanisms of saxicolous lichen community assembly to climate change and microhabitat variation on the alpine plateau.

5. Conclusions

(1) A total of 24 saxicolous lichen species belonging to 13 genera within 8 families were recorded in the Sereketaxi Zone of Taxkorgan Nature Reserve. The genera with the highest species numbers are *Acarospora* A. Massal. and *Aspicilia* A. Massal., while *Rusavskia elegans* (Link) S.Y. Kondr. & Kärnefelt and *Candelariella oleifera* H. Magn. represent the dominant species in the study area.

(2) Significant differences in saxicolous lichen diversity were detected across elevation bands. Both the total species number of transects and diversity indices at the sampling plot scale indicated that the elevation band at 4316 m was the diversity hotspot for saxicolous lichens in this study, presenting an overall mid-elevation peak pattern.

(3) Pronounced differentiation in community composition existed among elevation bands. The combined results of Bray-Curtis dissimilarity, Jaccard index, PERMANOVA and NMDS ordination revealed significant species turnover and community segregation between different elevation bands. The 4316 m elevation band possessed both high species richness and strong community uniqueness.

Overall, the species composition and distribution of saxicolous lichen at different altitudinal zones in the Sereketaxi Zone of Taxkorgan Nature Reserve can be generalized as a dual regulation model driven by "macro environmental filtering and microhabitat heterogeneity modulation". Future research could further integrate multi-dimensional datasets including chemical properties of rock substrates, microscale dynamic monitoring of temperature and humidity, slope gradient and aspect of sampling sites, to thoroughly unravel the community assembly mechanisms of saxicolous lichens on the eastern Pamir Plateau and their response patterns to global climate change.

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Author Contributions

Liming Liu (writing original draft, formal analysis); Fenghui Guo (formal analysis); Maierhaba Aimudula (data curation); Wukelai Duosimubayi (data curation); Ainiwaer Tumier (formal analysis, project administration, supervision, writing-review & editing).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table S1. The coverage of 24 saxicolous lichens on 15 sampling plots.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Sp1	0.24	0.09	1.24	0.00	0.00	0.00	0.00	0.00	0.00	1.18	0.35	0.65	0.00	0.00	0.00
Sp2	0.00	0.00	0.00	3.25	0.00	1.09	0.00	0.00	0.58	0.69	0.00	0.00	0.00	0.00	0.00
Sp3	0.00	0.00	0.00	0.57	0.00	0.28	0.00	0.00	0.00	1.02	0.00	0.25	0.00	0.00	0.00
Sp4	2.15	1.18	0.59	0.00	0.00	0.00	0.05	0.65	0.14	0.00	0.00	0.00	0.00	0.00	0.00
Sp5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.47	1.24	1.08	0.98	1.75
Sp6	0.00	0.00	0.00	5.24	1.28	3.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp7	0.87	0.00	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.45	0.00	0.00	0.00	0.00
Sp8	0.00	0.00	0.00	0.58	0.00	1.28	0.00	0.00	0.00	0.00	0.00	0.00	2.05	0.00	0.54
Sp9	0.87	0.54	0.00	0.00	0.00	0.00	1.54	0.00	0.88	0.00	0.00	0.00	0.00	0.00	0.00
Sp10	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Sp11	0.25	0.54	4.25	2.10	2.05	1.95	1.14	3.17	0.58	0.99	3.65	2.58	4.18	2.58	4.25
Sp12	3.21	0.00	0.00	0.00	0.00	0.00	0.54	0.00	5.21	2.38	1.58	0.00	0.00	0.00	0.00
Sp13	0.00	0.00	0.00	0.58	0.00	5.21	0.00	3.25	0.00	4.17	2.28	0.54	0.00	0.00	0.00
Sp14	2.14	0.00	3.21	0.00	0.00	0.00	0.98	0.00	1.12	0.00	0.00	0.00	1.12	0.45	2.17
Sp15	0.00	0.00	0.00	0.00	0.00	0.00	1.18	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp16	2.14	1.18	0.58	0.00	0.00	0.00	0.00	0.00	1.28	2.25	0.00	3.54	0.00	0.87	0.00
Sp17	0.54	3.24	0.00	0.57	0.00	2.17	0.00	0.00	0.00	0.57	1.14	0.58	0.00	0.00	0.00
Sp18	0.00	0.00	0.00	3.58	0.00	2.14	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	3.25
Sp19	1.28	0.00	2.58	0.00	0.00	0.00	0.65	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp20	0.00	0.00	0.00	0.00	0.00	0.00	3.54	0.00	3.25	0.00	0.00	0.00	1.08	0.58	0.39
Sp21	2.35	1.25	3.25	0.57	1.17	2.28	1.65	0.54	1.08	3.26	4.21	1.28	3.33	6.25	1.28
Sp22	6.24	0.00	2.14	0.00	0.00	0.00	0.25	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00
Sp23	0.00	0.00	0.00	0.00	0.00	0.81	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp24	0.14	0.00	0.28	0.00	0.00	0.00	2.14	0.00	3.51	0.00	0.00	0.00	0.00	0.00	0.00

Table S2. Prequency of 24 saxicolous lichens on 15 sampling plots.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Sp1	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00
Sp2	2.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp3	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp4	2.00	1.00	1.00	0.00	0.00	0.00	1.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp5	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	2.00	0.00	1.00
Sp6	0.00	0.00	0.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp7	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	0.00	0.00	0.00

Continued

Sp8	0.00	0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	2.00
Sp9	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00	1.00	0.00
Sp10	0.00	0.00	0.00	0.00	0.00	0.00	2.00	4.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp11	2.00	4.00	3.00	5.00	1.00	2.00	3.00	4.00	8.00	5.00	1.00	4.00	6.00	3.00	3.00
Sp12	2.00	1.00	0.00	0.00	0.00	0.00	1.00	2.00	3.00	1.00	1.00	0.00	0.00	0.00	0.00
Sp13	0.00	0.00	0.00	0.00	1.00	3.00	0.00	1.00	2.00	4.00	1.00	0.00	0.00	0.00	0.00
Sp14	2.00	1.00	0.00	0.00	0.00	0.00	1.00	4.00	2.00	0.00	0.00	0.00	1.00	3.00	2.00
Sp15	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp16	4.00	1.00	2.00	0.00	0.00	0.00	2.00	1.00	4.00	1.00	2.00	3.00	2.00	1.00	1.00
Sp17	1.00	2.00	1.00	2.00	1.00	1.00	0.00	0.00	0.00	1.00	3.00	4.00	0.00	0.00	0.00
Sp18	0.00	0.00	0.00	1.00	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	4.00	2.00
Sp19	1.00	2.00	4.00	0.00	0.00	0.00	4.00	5.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp20	0.00	0.00	0.00	0.00	0.00	0.00	1.00	2.00	4.00	0.00	0.00	0.00	1.00	2.00	1.00
Sp21	4.00	2.00	5.00	3.00	6.00	7.00	4.00	2.00	6.00	2.00	5.00	7.00	6.00	2.00	4.00
Sp22	2.00	3.00	1.00	0.00	0.00	0.00	4.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp23	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp24	3.00	4.00	5.00	0.00	0.00	0.00	4.00	2.00	6.00	0.00	0.00	0.00	0.00	0.00	0.00

Table S3. Important value of 24 saxicolous lichens on 15 sampling plots.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Sp1	4.64	9.12	6.44	0.00	0.00	0.00	0.00	0.00	0.00	7.04	2.17	6.10	16.00	0.00	0.00
Sp2	7.14	0.00	0.00	19.07	0.00	5.28	3.03	0.00	3.15	4.12	0.00	0.00	0.00	0.00	0.00
Sp3	0.00	0.00	0.00	10.01	0.00	1.36	0.00	5.56	2.13	6.09	0.00	2.35	0.00	0.00	0.00
Sp4	16.73	18.71	7.41	0.00	0.00	0.00	3.38	12.38	2.89	0.00	0.00	0.00	0.00	0.00	0.00
Sp5	0.00	0.00	0.00	0.00	0.00	0.00	3.03	0.00	2.13	1.49	2.91	11.63	16.05	8.37	19.09
Sp6	0.00	0.00	0.00	37.42	42.73	16.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sp7	7.45	8.00	5.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.33	10.00	0.00	0.00	0.00
Sp8	0.00	0.00	0.00	16.74	7.14	6.20	0.00	0.00	0.00	0.00	0.00	0.00	23.29	5.88	16.46
Sp9	7.45	6.73	4.35	0.00	0.00	0.00	13.88	0.00	9.03	0.00	0.00	0.00	0.00	5.88	0.00
Sp10	0.00	0.00	0.00	0.00	0.00	0.00	9.86	11.11	3.48	0.00	0.00	0.00	0.00	0.00	0.00
Sp11	8.26	22.73	35.13	45.66	52.70	21.94	17.12	44.41	20.17	41.62	29.77	44.20	55.17	39.68	49.93
Sp12	21.46	4.00	0.00	0.00	0.00	0.00	6.83	5.56	34.67	21.34	16.94	0.00	0.00	0.00	0.00
Sp13	0.00	0.00	0.00	3.40	7.14	43.97	0.00	36.92	4.26	53.45	21.28	5.07	0.00	0.00	0.00
Sp14	16.69	4.00	16.68	0.00	0.00	0.00	9.93	11.11	10.34	0.00	0.00	0.00	12.35	21.49	28.42
Sp15	0.00	0.00	0.00	0.00	0.00	0.00	11.34	5.40	2.13	0.00	0.00	0.00	0.00	0.00	0.00
Sp16	23.83	18.71	11.71	0.00	0.00	0.00	6.06	2.78	15.46	20.57	14.29	48.21	8.00	13.31	6.25
Sp17	5.98	48.40	4.35	16.68	7.14	16.75	0.00	0.00	0.00	10.54	28.50	25.44	0.00	0.00	0.00

Continued

Sp18	0.00	0.00	0.00	27.68	14.29	29.11	0.00	0.00	0.00	0.00	0.00	0.00	8.25	23.53	36.34
Sp19	9.28	8.00	30.80	0.00	0.00	0.00	16.70	24.29	4.26	0.00	0.00	0.00	0.00	0.00	0.00
Sp20	0.00	0.00	0.00	0.00	0.00	0.00	27.96	5.56	26.15	0.00	0.00	0.00	12.05	16.72	9.11
Sp21	24.77	23.59	38.63	23.35	68.86	54.79	23.74	11.23	18.63	33.74	61.81	47.01	48.83	65.14	34.39
Sp22	34.98	12.00	15.47	0.00	0.00	0.00	13.88	2.78	7.19	0.00	0.00	0.00	0.00	0.00	0.00
Sp23	0.00	0.00	0.00	0.00	0.00	3.92	6.06	15.37	2.13	0.00	0.00	0.00	0.00	0.00	0.00
Sp24	11.34	16.00	23.19	0.00	0.00	0.00	27.19	5.56	31.82	0.00	0.00	0.00	0.00	0.00	0.00