Postprint: Community Characteristics of Saxicolous Macrolichens in the Barluk Mountain National Nature Reserve

Authors: Dolathan Tohtisin, Rahangguli Maimaiti Ali, Yong Haiying, Enwer Tömür

Date: 2024-12-15T00:00:00+00:00

Abstract

To investigate the community characteristics of saxicolous macrolichens and the relationship between species distribution and environmental factors in the Barluk Mountain National Nature Reserve, this study employed Two-Way Indicator Species Analysis (TWINSPAN) for quantitative classification of saxicolous macrolichen communities and Canonical Correspondence Analysis (CCA) for ordination. The results showed that: (1) A total of 30 species (including 2 varieties) of saxicolous macrolichens were distributed in the reserve, belonging to 6 families and 14 genera. Among them, Parmeliaceae, Physciaceae, and Verrucariaceae were the dominant families, containing 25 species, which accounted for 83.3% of the total saxicolous macrolichen species in the region. (2) Based on TWINSPAN analysis, the saxicolous macrolichens in the reserve were divided into 5 associations. Association 1: Dermatocarpon miniatum + Dermatocarpon miniatum var. complicatum + Dermatocarpon arnoldianum Association; Association 2: Umbilicaria grisea + Physcia caesia Association; Association 3: Xanthoria parietina + Xanthoria wyomingica Association; Association 4: Umbilicaria vellea + Phaeophyscia ciliata Association; Association 5: Heterodermia leucomelos + Melanelia exasperatula Association. (3) The α diversity index showed that Association 3 had the highest diversity, while Association 5 had the lowest diversity; the β diversity index among associations was relatively low. (4) CCA ordination results indicated that environmental factors such as altitude, slope, human disturbance, and rock size had significant effects on the distribution of saxicolous macrolichen species, while air relative humidity and rock pH had no significant effects on lichens; aspect and light intensity were negatively correlated with lichen distribution. Comprehensive analysis showed that the saxicolous macrolichen community structure in the reserve was relatively complex, species distribution was influenced by both natural and anthropogenic factors, and differences in saxicolous macrolichen species among

different altitudes were not significant.

Full Text

Saxicolous Macrolichen Communities Characteristics in the Barluk Mountain National Nature Reserve, Xinjiang, China

TOKSUN Dolathan, MAMATALI Rehanguli, YONG Haiying, TUMUR Anwar*

College of Life Sciences and Technology, Xinjiang University, Urumqi 830017, China

Abstract

This study investigated the characteristics of saxicolous macrolichen communities and their relationships with environmental factors in the Barluk Mountain National Nature Reserve. Using two-way indicator species analysis (TWINSPAN) for numerical classification and canonical correspondence analysis (CCA) for ordination, we examined community structure and species distribution patterns. Our results revealed: (1) A total of 30 saxicolous macrolichen species (including two varieties) belonging to 6 families and 14 genera were identified, with Parmeliaceae, Physciaceae, and Verrucariaceae as dominant families comprising 25 species (83.3% of the total). (2) TWINSPAN classified the communities into five associations: Association 1—*Dermatocarpon moulinsii* + *Dermatocarpon miniatum* var. *imbricatum* + *Dermatocarpon arnoldianum*; Association 2—*Umbilicaria virginis* + *Physcia caesia*; Association 3—*Xanthoparmelia somloensis* + *Xanthoparmelia wyomingica*; Association 4—*Umbilicaria aprina* + *Phaeophyscia ciliata*; Association 5—*Physcia phaea* + *Melanelia stygia*. (3) Alpha diversity indices indicated that Association 3 exhibited the highest diversity, while Association 5 showed the lowest, with relatively low beta diversity between associations. (4) CCA ordination demonstrated that altitude, slope, human disturbance, and rock size significantly influenced species distribution, whereas air relative humidity and rock pH showed no significant effects. Aspect and light intensity were negatively correlated with lichen distribution. Overall, the saxicolous macrolichen communities exhibited complex structure, with species distribution shaped by both natural and anthropogenic factors, though differences between altitudinal zones were not significant.

Keywords: numerical classification, environmental factors, species distribution pattern, elevation gradient, nature reserve

Introduction

Lichens represent micro-ecosystems formed through symbiosis between fungi and photosynthetic partners (algae or cyanobacteria), harboring diverse prokaryotic and eukaryotic microorganisms [?, ?]. Macrolichens, defined as species with thalli exceeding 5 mm, constitute important epiphytic components of mountain ecosystems, with community structure and species diversity primarily governed by microclimatic conditions associated with specific habitats [?, ?]. Saxicolous lichens colonize stable rock and mineral substrate surfaces, and can be further categorized as epilithic or endolithic types [?]. In terrestrial ecosystems, saxicolous macrolichens growing on rock surfaces play crucial roles in water balance and nutrient accumulation in alpine and high-altitude regions, contributing significantly to ecosystem stability. As pioneer organisms in cold and high-altitude environments, they facilitate rock weathering and soil formation, thereby promoting primary succession of plant communities and improving microhabitat conditions [?, ?].

Species distribution and community assembly in lichens are influenced by multiple factors including climatic variables, habitat spatial structure, altitude, and substrate type [?, ?, ?, ?, ?]. Climate and altitude particularly determine species distribution patterns [?, ?, ?, ?, ?]. Different altitudinal zones exhibit distinct temperature, humidity, and solar radiation regimes [?], and species with strong competitive abilities and high tolerance to extreme conditions may dominate in harsh environments rather than in more favorable zones [?]. International research indicates that saxicolous lichen communities are affected by rock slope, aspect, light intensity, porosity, microstructure, stability, physicochemical properties, and weathering degree [?, ?, ?, ?, ?, ?]. Rock type serves as a primary driver of species composition, interacting with surface roughness, mineral composition, and internal porosity to shape community structure [?, ?]. Studies in the central-western Andes of Argentina revealed that species richness, coverage, and composition of saxicolous lichen communities vary with altitude and aspect, with mid-elevation zones showing highest richness and coverage, and aspect exerting strong effects at low elevations [?]. Research in Michigan's Upper Peninsula Huron Mountains demonstrated that solar radiation and slope/aspect indices influence species richness at mesoscales [?].

In China, altitudinal distribution patterns vary among lichen families and genera [?, ?, ?], though the generality of these differences requires further verification. Investigations in the Irtysh River Grand Canyon, Urumqi Southern Mountains, Tomur Peak National Nature Reserve, Bogda Mountain, and Shirengou Mountain areas have shown that saxicolous lichen diversity and distribution are primarily affected by slope, aspect, altitude, rock size, light intensity, air relative humidity, and rock pH, while human disturbance effects were not significant [?, ?, ?, ?, ?, ?, ?, ?]. The Barluk Mountain National Nature Reserve in Xinjiang possesses unique geographic location and natural conditions that facilitate contact, mixing, and specialization among different lichen floras, resulting in complex and distinctive communities. While macrolichen flora and

species diversity have been documented [?, ?], and saprophytic lichen communities have been examined [?], saxicolous macrolichen communities and their distribution patterns remain unstudied. Field observations confirm that saxicolous macrolichens constitute a major component of the reserve's lichen communities, yet no research has addressed their species distribution and influencing factors. This study provides baseline data for understanding community assembly mechanisms and species diversity maintenance, offers scientific reference for lichen diversity conservation, and supplies critical data for biological monitoring of environmental changes and ecosystem health in the reserve.

1.1 Study Area Description

Barluk Mountain is located in Yumin and Toli counties, Tacheng Prefecture, Xinjiang, China, forming a transitional zone between the Tianshan and Altai mountain ranges. The mountain range extends in a southwest-northeast arc, with higher elevations in the southwest and lower in the northeast, bordering Kazakhstan to the west. The main peak, Taphan Peak, reaches 3,252 m. The region experiences a typical continental temperate semi-desert climate, with humid conditions in the north and arid conditions in the southeast. Mean annual temperature is 6.2 °C, with extreme maximum of 41.8 °C and minimum of -35.9 °C. Average evaporation is 1,021 mm, relative humidity 44%, and annual precipitation 289.2 mm [?, ?]. The reserve spans 82°26 –83°13 E and 45°42 –46°03 N, covering 115,037.3 ha (89.50% in Yumin County, 10.50% in Toli County). Forest land occupies 34,614.95 ha, with 1,178 plant species belonging to 444 genera and 81 families [?, ?].

1.2 Field Methods

Field surveys were conducted from June 2022 to September 2023 at 47 sampling sites in the Barluk Mountain National Nature Reserve, with saxicolous macrolichens present at 29 sites. Geographic coordinates and altitude were recorded using handheld GPS. Slope and aspect of each rock were measured with a clinometer, light intensity with an illuminometer, and air relative humidity, rock size, disturbance type, and rock weathering degree were documented. Rock pH was measured in the laboratory (Table 1).

Within the 29 saxicolous macrolichen sites, four 20 m × 20 m quadrats were established (totaling 116 quadrats). Coverage of each saxicolous macrolichen species was quantified using custom-made frames of 20 cm × 20 cm, 30 cm × 30 cm, and 50 cm × 50 cm. Species identification was based on thallus morphology, internal anatomy, and chemical spot tests [?, ?, ?].

1.3 Data Analysis

Community classification employed WinTWINS 2.3 software for two-way indicator species analysis (TWINSPAN) [?, ?]. ComEcoPac software calculated alpha diversity indices (Shannon-Weiner, Simpson's, Patrick's, Margalef, Pielou's

evenness) and Jaccard's beta diversity index [**?**, **?**].

Results

2.1 Species Composition of Saxicolous Macrolichens

The reserve harbored 30 saxicolous macrolichen species (including two varieties) belonging to 6 families and 14 genera (Table 2). Parmeliaceae (12 species), Physciaceae (7 species), and Verrucariaceae (6 species) were dominant, representing 83.3% of total species. Single-species families included Ramalinaceae (1 species) and Collemataceae (1 species). At the generic level, *Xanthoparmelia* (5 species), *Dermatocarpon* (3 species, 2 varieties), *Melanelia* (4 species), *Physcia* (4 species), and *Umbilicaria* (3 species) comprised 21 species (70% of the total). Nine genera—*Arctoparmelia*, *Evernia*, *Montanelia*, *Ramalina*, *Normandina*, *Phaeophyscia*, *Physconia*, *Collema*, and *Heterodermia*—were monotypic.

2.2 Numerical Classification of Saxicolous Macrolichen Communities

Based on coverage data for 30 species across 29 sites, TWINSPAN analysis identified five distinct associations (Figure 1 [Figure 1: see original paper]):

Association 1: Comprised sites 4, 10, 34, and 37 at 1,098–1,380 m elevation, characterized by relatively dry conditions, moderate light intensity, low human disturbance, northwest/west/northeast aspects, rock sizes of 50–250 cm, and neutral pH (7.23–7.48). Dominant species included *Dermatocarpon arnoldianum*, *D. miniatum* var. *imbricatum*, *D. moulinsii*, *D. miniatum*, *Normandina pulchella*, *Physconia kansuensis*, *Xanthoparmelia wyomingica*, *X. somloensis*, *Physcia dubia*, *P. caesia*, *P. phaea*, *Umbilicaria aprina*, and *Ramalina intermedia* (13 species, total coverage 55.85%). *Dermatocarpon miniatum* var. *complicatum* showed maximum coverage (26.40%). This association was designated as *Dermatocarpon moulinsii* + *Dermatocarpon miniatum* var. *imbricatum* + *Dermatocarpon arnoldianum*.

Association 2: Included sites 15 (2,081 m), 25 (1,184 m), and 36 (1,103 m), with weak light intensity and low disturbance. Dominant species were *Dermatocarpon miniatum*, *Umbilicaria virginis*, *Physcia caesia*, *Umbilicaria aprina*, *Melanelia glabra*, and *Heterodermia speciosa* (6 species, total coverage 30.35%). *Umbilicaria virginis* exhibited maximum coverage (12.50%). Designated as *Umbilicaria virginis* + *Physcia caesia*.

Association 3: Encompassed 16 sites (1, 2, 3, 5, 6, 9, 12, 18, 27–33, 35) at 969–1,396 m elevation, with strong light intensity, rock pH 6.88–7.81, moderate weathering, and low disturbance. Twenty-one species dominated, including *Physcia phaea*, *P. dubia*, *P. caesia*, *P. biziana*, *Physconia kansuensis*, *Heterodermia speciosa*, *Xanthoparmelia mexicana*, *X. wyomingica*, *X. viriduloumbrina*, *X. somloensis*, *X. durietzii*, *Melanelia stygia*, *M. glabra*, *M. incolorata*, *M. panniformis*, *Montanelia disjuncta*, *Ramalina intermedia*, *Collema subconveniens*, *Dermatocarpon moulinsii*, and *Umbilicaria proboscidea* (total coverage

169.42%). *Xanthoparmelia somloensis* showed maximum coverage (57.90%). Designated as *Xanthoparmelia somloensis* + *Xanthoparmelia wyomingica*.

Association 4: Comprised sites 22 (2,015 m), 42, 44, and 46 (1,121–1,173 m), characterized by dry conditions, moderate light, high disturbance, severe weathering, and pH 7.05–7.25. Seven species dominated: *Phaeophyscia ciliata*, *Ramalina intermedia*, *Arctoparmelia separata*, *Melanelia stygia*, *M. glabra*, *Umbilicaria aprina*, and *Xanthoparmelia somloensis* (total coverage 15.19%). *Umbilicaria aprina* showed maximum coverage (4.29%). Designated as *Umbilicaria aprina* + *Phaeophyscia ciliata*.

Association 5: Included sites 7 (1,271 m) and 26 (1,286 m), with moderate weathering, south/east aspects, low disturbance, and rock sizes >250 cm. Six species dominated: *Physcia phaea*, *Melanelia stygia*, *M. glabra*, *M. incolorata*, *Xanthoparmelia wyomingica*, and *X. mexicana* (total coverage 22.16%). *Physcia phaea* showed maximum coverage (17.29%). Designated as *Physcia phaea* + *Melanelia stygia*.

Diversity, evenness, and similarity indices are presented in Tables 3 and 4 . Association 3 exhibited the highest species diversity (21 species, Shannon-Weiner = 2.856, Simpson's = 0.436, Margalef = 3.948), distributed widely across 969–1,396 m with strong light, moderate weathering, and low disturbance. Association 1 showed moderate diversity (13 species, indices: 2.745, 0.325, 2.983). Association 5 displayed the lowest diversity (6 species, indices: 1.756, 0.166, 1.465). Despite high species richness, Association 3 had the lowest evenness (0.624), likely due to intense interspecific competition. Association 4, with moderate species richness, showed highest evenness (0.901), indicating uniform species distribution.

Beta diversity between associations was generally low (Table 4). The highest Jaccard's index (0.363) occurred between Associations 1 and 3, which shared similar environmental conditions (strong light, moderate weathering, dry habitats). Associations 4 and 5 showed moderate similarity (0.200), while Associations 2 and 4 were most dissimilar (0.071). Beta diversity describes species turnover along environmental gradients [**?**]. The low values suggest minimal species replacement along the altitudinal gradient, except between Associations 1 and 3. Other associations showed limited turnover across microenvironmental variations in vegetation zones, forest canopy density, disturbance intensity, air humidity, and rock weathering.

2.3 Relationship Between Saxicolous Macrolichen Distribution and Environmental Factors

CCA ordination revealed strong relationships between community structure and environmental variables (Figure 2 [Figure 2: see original paper]). The first axis correlated positively with altitude ($r = 0.8646$, $p < 0.001$), slope, and human disturbance, indicating increasing elevation, slope steepness, and disturbance intensity along this gradient. The second axis correlated positively with weath-

ering degree (r = 0.5581), air relative humidity (r = 0.4463), and human disturbance (r = 0.3675), and negatively with light intensity, altitude, aspect, and rock pH. Altitude showed a non-significant negative correlation with the second axis (r = -0.1101). These results confirm that altitude, slope, human disturbance, and rock size significantly influence species distribution, while air relative humidity and rock pH effects were non-significant. Aspect and light intensity were negatively correlated with lichen distribution.

Species-environment correlations for the first two CCA axes were highly significant, with eigenvalues of 0.692 and 0.634, species-environment correlations of 96.1% and 92.3%, and cumulative variance contribution of 52.2% (Table 5).

The species CCA ordination (Figure 3 [Figure 3: see original paper]) revealed distribution patterns corresponding to community gradients. Quadrant 1 species (*Phaeophyscia ciliata*, *Umbilicaria aprina*, *Physcia biziana*, *Melanelia glabra*, *Physcia phaea*) occurred at humid, highly disturbed sites. *Melanelia stygia*, *Dermatocarpon arnoldianum*, *Physcia caesia*, and *Physconia kansuensis* inhabited dry, low-slope rocks. *Umbilicaria proboscidea* occupied moderate slopes with intermediate disturbance. Quadrant 2 species (*Arctoparmelia separata*) occurred on humid, severely weathered rocks, while *Collema subconveniens*, *Melanelia incolorata*, and *Xanthoparmelia wyomingica* colonized low-elevation, undisturbed, dry, lightly weathered rocks. Quadrant 3 species (*Evernia divaricata*, *Xanthoparmelia mexicana*) grew on dry, shaded forest rocks, whereas *Dermatocarpon* spp., *Melanelia panniformis*, *Montanelia disjuncta*, *Normandina pulchella*, *Physcia dubia*, *Ramalina intermedia*, *Xanthoparmelia durietzii*, *X. somloensis*, and *X. viriduloumbrina* occupied low-elevation, low-slope sites. Quadrant 4 species included *Umbilicaria virginis* at high elevations, *Heterodermia speciosa* at mid-elevations, and *Dermatocarpon moulinsii* at lower elevations.

Discussion and Conclusion

Our study revealed significant differences in species diversity among saxicolous macrolichen associations across altitudinal gradients in the Barluk Mountain National Nature Reserve. Association 3, distributed in low-to-mid elevation sites with strong light, moderate weathering, and minimal human disturbance, supported the highest diversity, dominated by radiation- and heat-tolerant genera (*Xanthoparmelia*, *Dermatocarpon*, *Melanelia*, *Physcia*). Associations 1 and 4, at mid-elevations with dry conditions, moderate light, and low disturbance, showed moderate diversity dominated by *Xanthoparmelia*, *Physcia*, *Umbilicaria*, *Phaeophyscia*, and *Physconia*. Associations 5 and 2, in forest understories with limited rock heterogeneity and small rock sizes (<2,500 cm^2), exhibited the lowest diversity. These findings suggest that diversity differences reflect not only altitudinal effects but also morphological adaptations and environmental tolerances specific to different taxonomic groups.

Spatial heterogeneity and habitat diversity are critical determinants of species richness [**?**]. High environmental heterogeneity provides suitable niches for mul-

tiple species, enhancing diversity, whereas low heterogeneity reduces species richness. Our low beta diversity values indicate limited species turnover along altitudinal gradients, except between Associations 1 and 3. The absence of significant species replacement across microenvironmental variations in vegetation zones, disturbance intensity, humidity, and weathering suggests low habitat heterogeneity for saxicolous lichens across altitudes. We recommend increasing habitat heterogeneity across different landscapes within the reserve to enhance saxicolous macrolichen diversity and improve conservation effectiveness.

CCA results further revealed uneven community structure, with composition determined primarily by altitude, slope, human disturbance, and rock size. While air relative humidity and rock pH showed non-significant effects, aspect and light intensity were negatively correlated with distribution. These findings align with studies from Bogda Peak [**?**], Tomur Peak [**?**], Shirengou Mountain [**?**], and Haxionggou Forest Park [**?**], but contrast regarding the non-significant effects of humidity and pH. These discrepancies likely reflect differences in regional environmental conditions, rock types, forest canopy density, and lichen morphological characteristics.

In conclusion, the Barluk Mountain National Nature Reserve's unique geographic position supports rich lichen resources, with saxicolous macrolichens forming stable communities across diverse rock surfaces at various elevations, promoting soil formation and primary succession. The complex community structure and species distribution are shaped by multiple natural and anthropogenic factors, with lichen morphology and growth forms influencing habitat adaptation and community assembly. We recommend enhanced grazing management to reduce human disturbance, increased environmental heterogeneity, and establishment of a macrolichen-based environmental quality assessment and ecosystem health evaluation system for the reserve.

References

ABBAS A, WU JN, 1998. *Lichens of Xinjiang* [M]. Urumqi: Science Technology & Hygiene Publishing House of Xinjiang: 1-178.

ABDUSHALIKE N, 2013. *Universal Scientific Exploration of Barluk Mountain Nature Reserve, Xinjiang* [M]. Urumqi: Xinjiang University Press: 1-183.

AHAT P, ABBAS A, TUMUR A, 2018. Characteristics of saxicolous crustose lichen community on northern slope of Bogda Mountain in Xinjiang and its correlation with environmental factors[J]. *Journal of Plant Resources and Environment*, 27(4): 21-30.

AHAT P, ABBAS A, TUMUR A, 2018. Species diversity and distribution characteristics of macrolichens around the Bogda Mountains, Xinjiang, China[J]. *Mycosystema*, 37(7): 907-918.

ANSTETT D, 2010. The influence of wind and light exposure on the extent of lichen coverage in an alpine environment[J]. *Journal of Undergrad Life Science*,

4: 8-41.

ARMSTRONG R, 1974. The descriptive ecology of saxicolous lichens in an area of South Merionethshire, Wales[J]. *Journal of Ecology*, 62(1): 33-45.

ARMSTRONG RA, WELCH AR, 2007. Competition in lichen communities[J]. *Symbiosis*, 43: 1-12.

BRODO IM, 2016. *Keys to Lichens of North America: Revised and Expanded* [M]. New Haven: Yale University Press: 1-427.

BRODO IM, SHARNOFF SD, SHARNOFF S, 2001. *Lichens of North America* [M]. New Haven: Yale University Press: 118-145.

CHEN J, BLUME HP, BEYER L, 2000. Weathering of rocks induced by lichen colonization—a review[J]. *Catena*, 39: 121-146.

COSTAS SM, CANTON N, RODRIGUEZ JM, 2021. The relative effect of altitude and aspect on saxicolous lichen communities at mountain summits from central-west of Argentina[J]. *Rodriguesia*, 72: e00282020.2021.

GUO SL, YU J, CHEN GQ, 2015. *Ecological Data Analyses: Methods, Programs and Software* [M]. Beijing: Science Press: 103-175.

HALE ME, 1974. *The Biology of Lichens* [M]. London: Edward Arnold: 84-96.

HUANG MR, 2010. Altitudinal patterns of *Stereocaulon* (Lichenized Ascomycota) in China[J]. *Acta Oecologica*, 36: 173-178.

HUANG MR, 2011. An analysis on the altitudinal pattern of *Stereocaulon* in China[M]// LIU HJ, JIA ZF, REN Q, ZHOU QM. *The Present Status and Potentialities of the Lichenology in China—A Collection of Lichenological Papers in Congratulation of the Eightieth Birthday of CAS member, Dr. Sc. Prof. Wei Jiangchun*. Beijing: Science Press: 289-298.

ISSAK M, TUMUR A, 2021. Study of the characteristics of saxicolous lichen communities on the Southern slope of Bogda Peak, Xinjiang, China[J]. *Journal of Xinjiang University (Natural Science Edition)*, 38(5): 576-587.

ISSAK M, TUMUR A, 2020. Species diversity and community structure of saxicolous lichens in Haxionggou Forest Park[J]. *Journal of Arid Land Resources and Environment*, 34(3): 124-129.

JACKSON TA, 2015. Weathering, secondary mineral genesis, and soil formation caused by lichens and mosses growing on granitic gneiss in a boreal forest environment[J]. *Geoderma*, 251/252: 78-87.

JIA XN, CHENG JM, WANG HE, 2007. Application present situation of DCA, CCA and DCCA ordination of grassland vegetation communities in China[J]. *Chinese Agricultural Science Bulletin*, 23(12): 391-395.

JIANG ZC, ZHANG T, ABBAS A, et al., 2014. Quantitative classification of saxicolous lichen communities in Ergis River gorge, Xinjiang[J]. *Journal of Arid*

Land Resources and Environment, 28(8): 167-171.

JOHN EA, DALE MRT, 1990. Environmental correlates of species distributions in a saxicolous lichen community[J]. *Journal of Vegetation Sciences*, 1(3): 385-392.

JOHN EA, 1990. Fine scale pattern of species distribution in a saxicolous lichen community at Jonas rockslide, Canadian Rocky Mountains[J]. *Holarctic Ecology*, 13: 187-194.

KÖRNER C, 2007. The use of altitude in ecological research[J]. *Trends in Ecology & Evolution*, 22: 569-574.

LIU HJ, HUANG MR, WU QF, et al., 2011. An analysis on the altitudinal pattern of *Peltigera* in China[J]. *Mycosystema*, 30(6): 955-964.

LIU HJ, WU QF, LI HM, 2011. The influence of macroclimatic factors on the spatial distribution of *Peltigera* at county scale in China[M]// LIU HJ, JIA ZF, REN Q, et al. *The Present Status and Potentialities of the Lichenology in China—A Collection of Lichenological Papers in Congratulation of the Eightieth Birthday of CAS member, Dr. Sc. Prof. Wei Jiangchun*. Beijing: Science Press: 263-275.

LUNDHOLM JT, 2009. Plant species diversity and environmental heterogeneity: spatial scale and competing hypotheses[J]. *Journal of Vegetation Sciences*, 20: 377-391.

MACDONALD AM, LUNDHOLM JT, CLAYDEN SR, 2011. Saxicolous lichens on a Nova Scotian Coastal Barren[J]. *Northeastern Naturalist*, 18(4): 475-488.

MAMATALI R, YONG HY, TOKSUN D, et al., 2024. Diversity of macrolichens in the Barluk Mountain National Nature Reserve in Xinjiang, China[C]. IF-BioScFU 2024, BIO Web of Conferences 100, 02024 (2024).

MAMATALI R, KAHRIMAN, TUMUR A, 2023. Preliminary study on macrolichen flora in Barluk Mountain National Nature Reserve, Xinjiang, China[J]. *Journal of Arid Land Resources and Environment*, 37(7): 170-176.

MAMATALI R, TUMUR A, 2024. The structural characteristics and diversity of the saprophytic lichen communities on Barluk Mountain National Nature Reserve[J]. *Journal of Northeast Forestry University*, 52(6): 43-50.

MATTHES U, RYAN BD, LARSON DW, 2000. Community structure of epilithic lichens on the cliffs of the Niagara Escarpment, Ontario, Canada[J]. *Plant Ecology*, 148(2): 233-244.

RAHBEK C, 2005. The role of spatial scale and the perception of large scale species-richness patterns[J]. *Ecological Letters*, 8: 224-239.

RUTHERFORD RD, REBERTUS A, 2022. A habitat analysis and influence of scale in lichen communities on granitic rock[J]. *The Bryologist*, 125(1): 43-60.

SCARCIGLIA F, SAPORITO N, LA RUSSA MF, 2012. Role of lichens in weathering of granodiorite in the Sila uplands (Calabria, southern Italy)[J]. *Sedimentary Geology*, 280: 65-79.

TAJIGULI A, 2012. The forest ecosystem services valuation of Barlehtaw Nature Reserve[D]. Urumqi: Xinjiang University: 25-31.

TUMUR A, ZHANG T, MUHAMAT M, et al., 2013. Species distribution of saxicolous foliose lichen communities in Xiaoquzi southern mountainous area of Urumqi[J]. *Journal of Arid Land Resources and Environment*, 27(7): 142-147.

TUMUR A, ABBAS A, 2015. Quantitative classification of saxicolous lichen community in Xinjiang Tumur Peak National Natural Reserve and its correlation with environment[J]. *Journal of Plant Resources and Environment*, 24(2): 80-87.

TUMUR A, ABDULLA A, ABBAS A, 2015. Characteristics of saxicolous lichen communities in Altay two river source Nature reserve in Xinjiang[J]. *Journal of Arid Land Resources and Environment*, 29(9): 74-79.

TUMUR A, MAMUT R, ABBAS A, 2018. Community structure characteristics of saxicolous lichens in the Baogda Mountains of Xinjiang[J]. *Acta Ecologica Sinica*, 38(3): 1053-1064.

TURSUN A, ABBAS A, TUMUR A, 2018. Environmental interpretation of saxicolous lichen distribution pattern in Shirengou mountains, Xinjiang, China[J]. *Guihaia*, 38(11): 1454-1462.

VITTOZ P, CAMENISCH M, MAYOR R, et al., 2010. Subalpine nival gradient of species richness for vascular plants, bryophytes and lichens in the Swiss Inner Alps[J]. *Botanica Helvetica*, 120: 117-127.

WEI XL, DENG H, WEI JC, 2020. Evaluation on endangered grade of lichens in China[J]. *Biodiversity*, 28(1): 54-65.

ZACHARIAH SA, VARGHESE SK, 2018. The lichen symbiosis: A review[J]. *International Journal of Scientific Research and Reviews*, 7(3): 1160-1169.

ZHANG JT, 2022. *Numerical Ecology* [M]. 3rd ed. Beijing: Science Press: 124-248.

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