Environmental Interpretation of Saxicolous Lichen Distribution Patterns in the Shirengou Mountains, Xinjiang: Postprint

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Abstract

Lichens, as successful symbionts of fungi and green algae/cyanobacteria, are widely distributed across various habitats in terrestrial ecosystems. Saxicolous lichens, as major components of terrestrial ecosystems, play an important role in terrestrial food chains in arid and semi-arid regions, and are also significant for biological weathering of rocks and soil formation. The diversity and distribution patterns of saxicolous lichens are strongly influenced by multiple factors including altitude, humidity, temperature, precipitation, solar radiation intensity, and substrate characteristics (rock type, rock size, rock chemical composition, and nutrient content). Although saxicolous lichens are important components of terrestrial ecosystems in arid regions, there have been insufficient research reports on the effects of climatic factors on species distribution of saxicolous lichen communities in the Shirengou mountainous area of Urumqi County, Xinjiang, China. Therefore, this study established 16 sample plots in the Shirengou mountainous area of Urumqi County, measured the coverage of saxicolous lichens in the plots as well as 7 environmental factors including slope, aspect, and light intensity, and used Canonical Correspondence Analysis (CCA) to explore the relationship between species distribution patterns of each community and environmental factors. The results showed that there were 27 species of saxicolous lichens in the Shirengou mountainous area, belonging to 7 orders, 9 families, and 15 genera. Among them, Teloschistales, Lecanorales, and Pertusariales had more species, accounting for 74.07% of the total saxicolous lichens in this area. CCA ordination results indicated that slope, aspect, light intensity, humidity, and rock pH were the five main environmental factors affecting the distribution patterns of saxicolous lichen species, and showed the correspondence between saxicolous lichens and sample plots.

Full Text

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Abstract

Lichens, as highly successful symbiotic associations between fungi and green algae and/or cyanobacteria, inhabit nearly all terrestrial domains of the planet. As primary components of terrestrial ecosystems, saxicolous lichens play a pivotal role in terrestrial food chains of arid and semiarid regions and contribute significantly to rock weathering and soil formation. The diversity and distribution patterns of saxicolous lichens are strongly influenced by multiple environmental variables, including elevation, moisture, temperature, precipitation, solar radiation intensity, and substrate characteristics (rock type, size, chemical composition, and nutrient content). Although saxicolous lichens constitute important components of arid ecosystems, the influence of microclimatic factors on their distribution in rock habitats of the Shirengou Mountains in Urumqi County, Xinjiang, China, remains insufficiently investigated. To address this knowledge gap, we established 16 sampling plots in the Shirengou Mountains of Urumqi County, measuring the coverage of saxicolous lichens and recording seven environmental factors including slope gradient, aspect, and light intensity. Canonical Correspondence Analysis (CCA) was employed to examine relationships between species distribution patterns and environmental factors. Our results identified 27 saxicolous lichen species belonging to 15 genera, 9 families, and 7 orders. Teloschistales, Lecanorales, and Pertusariales were the most species-rich orders, accounting for 74.07% of the total species recorded. CCA ordination revealed that slope gradient, aspect, light intensity, humidity, and rock pH were the five primary environmental factors influencing saxicolous lichen distribution patterns, demonstrating clear correspondence between lichen species and sampling plots.

Keywords: Shirengou, saxicolous lichens, environmental factors, canonical correspondence analysis

Saxicolous lichens serve as key components of terrestrial ecosystems in arid and semiarid regions, facilitating material cycling and providing essential nutrients and organic matter within food chains. These organisms colonize bare, environmentally harsh rock surfaces, forming communities that weather rocks through secondary metabolites, gradually creating soil and modifying microhabitat conditions to enable colonization by other plant species and facilitate community succession (Brodo, 1973; John, 1990; John & Dale, 1990; Eldridge & Tozer, 1997; Torbjørg, 2003; Kumar et al., 2012, 2014). Substrate structure (type, roughness, hardness, relative stability, surface characteristics), water relations (moisture content, water retention capacity), and chemical properties (element types and concentrations, pH values) constitute the three major factors influencing lichen distribution (Brodo, 1973). For saxicolous lichens specifically, colonization and community formation depend not only on local climate but also on the physicochemical characteristics of the substrate (Brodo, 1973). Through both physical penetration of hyphae into the substrate and chemical processes involving respiration and organic compound production, saxicolous lichens corrode rocks and release ions from the substrate. These elements are either absorbed by the thallus or chelated into biominerals, subsequently entering the nutrient pool. When these chemical elements serve as nutrients, their deficiency can affect the development of fungal reproductive structures, underscoring the importance of rock geochemistry and mineral composition in determining saxicolous lichen species occurrence and community composition (Rajakaruna et al., 2012; Deduke et al., 2016). Previous studies have demonstrated that rock size, slope gradient, aspect, chemical properties, exposure, snow cover, rock pH, and rock type significantly influence saxicolous lichen community structure and species composition (Chen & Hans-Peter, 2002; Shimizu, 2004; Favero-Longo et al., 2011; MacDonald et al., 2011; Rajakaruna et al., 2012; Kumar et al., 2012, 2014). Brodo (1973) reported that calcicolous lichen species typically inhabit limestone with high calcium content, while silicicolous species prefer silicon-rich chert and flint. His research on North American saxicolous lichens also revealed that rocks with rough surfaces support greater species diversity than smooth-surfaced rocks (Brodo, 1973). Werner (1956) found that lichen species composition and diversity were affected by rock chemical properties when examining relationships between rock pH, silica concentration, and lichen species. Temina et al. (2015) identified dew retention time on rock surfaces as the primary factor influencing lichen species distribution in flint and limestone communities of Israel' s Negev Desert. Fodor (2015) observed that grazing and livestock excrement in the Măcin Mountains enhanced nitrogen enrichment capacity in acidic rocks, thereby reducing saxicolous lichen diversity and species coverage. Deduke et al. (2016) discovered positive correlations between certain chemical elements in the substrate and the reproductive rates of three foliose saxicolous lichen species: *Arctoparmelia centrifuga*, *Xanthoparmelia viriduloumbrina*, and *X. cumberlandia*. Shukla et al. (2017) demonstrated significant differences in secondary metabolite types among saxicolous lichens at different elevations in the Himalayas, indicating that changes in altitude, humidity, light, temperature, and rock type drive variations in lichen secondary metabolite diversity.

Domestic research on saxicolous lichen communities remains limited. Tumur and Abbas (2009, 2015) and Tumur et al. (2015, 2018) employed quantitative plant community research methods, using cluster analysis, principal component analysis, detrended correspondence analysis, and two-way indicator species analysis to numerically classify saxicolous lichen communities in the southern mountainous area of Urumqi, the Altay Two River Sources Nature Reserve, the Tomur Peak National Nature Reserve, and the Bogda Mountains. Canonical correspondence analysis was used to investigate relationships between species distribution patterns and environmental factors. Their findings revealed that saxicolous lichen community structure varied with altitude, with species composition primarily influenced by vegetation coverage, rock type, slope gradient, aspect, wind speed, wind erosion degree, light intensity, rock pH, and relative humidity.

Therefore, investigating the relationship between saxicolous lichen communities and substrates in the Shirengou Mountains of Urumqi County holds significant theoretical and practical importance for identifying environmental factors affecting saxicolous lichen distribution patterns, effectively conserving lichen species diversity in arid and semiarid regions, and elucidating the ecological functions of lichens in terrestrial ecosystems.

1 Study Area Overview

The Shirengou Mountains are located in the northern part of the central Tianshan Mountains, south of the Junggar Basin, at coordinates 87°50' E, 43°45' N. Detailed natural characteristics of the region are documented in the literature (Compilation Committee of Local Chronicles of Urumqi County, 2006; Tumur et al., 2017).

2.1 Field Survey

We randomly established 16 sampling plots (50 m × 50 m) across different landscapes in the Shirengou Mountains of Urumqi County. Within each plot, 3-5 sampling points were investigated using the quadrat method, with 20 quadrats surveyed at each point (quadrat size: 50 cm × 50 cm, spaced 2 m apart). Lichen species coverage in each quadrat was measured using the grid method, with average coverage values calculated for each sampling point (John, 1990; Tumur & Abbas, 2009, 2015; Tumur et al., 2017). Environmental factors including rock size, slope gradient, aspect, light intensity, human disturbance, rock pH, and humidity were measured for each plot (Table 1) (Tumur et al., 2015, 2017).

Table 1 Seven environmental factors in 16 sites

Notes: Humidity (5 = 50%, 4 = 40%-49%, 3 = 30%-39%, 2 = 10%-29%, 1 = 10%); Light intensity (1 = low, 2 = weak, 3 = medium, 4 = relatively strong, 5 = intense); Disturbance (1 = low, 2 = weak, 3 = medium, 4 = relatively strong, 5 = intense). NW = Northwest; S = South; SE = Southeast; SW = Southwest; N = North.

2.2 Data Analysis

Canonical Correspondence Analysis (CCA) was performed with saxicolous lichens as the analytical object, using coverage values within plots as the response variable. Environmental factors were standardized using the maximum value method, while lichen coverage data were square-root transformed. Data analysis was conducted using the international standard ecological software CANOCO for Windows 4.5, with CANODRAW 4.5 used for graphical output. Relationships between saxicolous lichen distribution and environmental factors were expressed through two-dimensional ordination (John, 1990; John & Dale, 1990; Tumur & Abbas, 2009; Tumur et al., 2017).

3.1 Saxicolous Lichen Species Diversity

We identified 27 saxicolous lichen species in the study area, belonging to 15 genera and 9 families (Table 2).

Table 2 Saxicolous lichen species composition in Shirengou, Urumqi County

Family, Genus and Species	Coverage (%)	Frequency
Acarosporaceae		
Acarospora		
A. molybdina		
A. veronensis		
A. verruculosa		
Candelariaceae		
Candelariella		
C. oleifera		
Lecanoraceae		
Lecanora		
L. argopholis		
L. muralis		
Lecidella		
L. carpathica		
L. sigmatea		
Rhizoplaca		
R. peltata		
Parmeliaceae		
Melanelia		
M. tominii		
Collemataceae		
Collema		
C. fuscovirens		
Megasporaceae		
Aspicilia		
A. asiatica		

Family, Genus and Species	Coverage (%)	Frequency
A. calcarea		
A. cinerea		
A. contorta		
A. ochraceoalba		
Lobothallia		
L. alphoplaca		
Physciaceae		
Dimelaena		
D. oreina		
Phaeophyscia		
P. sciastra		
Physcia		
P. caesia		
Teloschistaceae		
Caloplaca		
C. biatorina		
Xanthoria		
X. elegans		
X. lobulata		
X. parietina		
X. sorediata		
Verrucariaceae		
Dermatocarpon		
D. miniatum		
D. vellereum		

Notes: Species names are abbreviated using the first three letters of the genus and species names.

According to Table 1, the saxicolous lichen flora of the Shirengou area includes eight species of Teloschistales, belonging to five genera and two families, representing 22.22%, 35.71%, and 29.63% of the total families, genera, and species, respectively. Lecanorales and Pertusariales each contain six species, while Acarosporales, Verrucariales, Peltigerales, and Candelariales are less species-rich.

3.2 Correlations Among Environmental Factors and Their Influence on Lichen Species Distribution

Using sampling plots as classification objects and lichen coverage as the response variable (Table 3), CCA ordination diagrams were generated (Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper]). The first two ordination axes exhibited eigenvalues of 0.638 and 0.491, respectively, with correlation coefficients between environmental factor axes and species ordination axes reaching 0.965 and 0.947, indicating that the ordination effectively reflected species-environment relationships.

In CCA ordination diagrams, environmental factors are represented by arrows. Arrow length indicates the strength of the relationship between lichen species distribution and the environmental factor, while the angle between the arrow and ordination axis represents the degree of correlation. The arrow direction shows the gradient of environmental change. Species points projected perpendicularly onto environmental factor arrows with proximity to the arrowhead indicate strong positive correlations with that habitat factor, whereas points at the opposite end indicate strong negative correlations (Guo et al., 2002). Correlation coefficients among the seven environmental factors and with the first two species ordination axes are presented in Table 4 .

Among the seven environmental factors, aspect showed the strongest relationship with the first ordination axis (r = 0.7092), followed by slope gradient (r = 0.6354) and humidity (r = 0.4736), while light intensity exhibited a negative correlation (r = -0.4513). This indicates that the first ordination axis primarily reflects variation in saxicolous lichen species along gradients of aspect, slope gradient, humidity, and light intensity. Light intensity demonstrated the strongest correlation with the second ordination axis (r = 0.5957), followed by negative correlations with humidity (r = -0.4687) and pH (r = -0.4461), while aspect and slope gradient also influenced the second axis. Thus, the second ordination axis mainly reflects saxicolous lichen adaptation to light and rock acidity, as well as variation in slope gradient and aspect. The ordination diagrams reveal that light intensity, slope gradient, and aspect significantly influence saxicolous lichen distribution in the Shirengou area, followed by humidity and rock pH, whereas rock size and human disturbance have relatively minor effects.

3.3 Correlation Between Saxicolous Lichen Distribution and Environmental Factors

CCA ordination diagrams 1 and 2 illustrate relationships among the 16 sampling plots, 27 saxicolous lichen species, and seven environmental factors. Along the first ordination axis, plots 12–16 are distributed in the first quadrant, comprising seven saxicolous lichen species. *Xanthoria parietina*, *Acarospora molybdina*, and *Phaeophyscia sciastra* distributions correlate with slope gradient and aspect. *Dermatocarpon vellereum*, *Dimelaena oreina*, *Lecanora argopholis*, and *Aspicilia asiatica* distributions are somewhat influenced by human disturbance, with rock pH having minimal impact on these species.

The second quadrant includes plots 8–11, containing 10 species. *Lecidella sigmatea*, *Caloplaca biatorina*, *Lecanora muralis*, and *Collema fuscovirens* inhabit relatively small rocks with strong light intensity, low humidity, and minimal human disturbance. *Lobothallia alphoplaca*, *Xanthoria lobulata*, *Melanelia tominii*, *Physcia caesia*, *Aspicilia calcarea*, and *Aspicilia ochraceoalba* occur on small-to-medium rocks with moderate light intensity, low slope gradient, and low humidity.

In the third quadrant, plots 1, 2, and 5–7 host eight saxicolous lichen species: *Candelariella oleifera*, *Acarospora veronensis*, *Aspicilia cinerea*, *Rhizoplaca peltata*, *Dermatocarpon miniatum*, *Lecidella carpathica*, *Xanthoria elegans*, and *Acarospora verruculosa*. Species distributions in this quadrant are influenced by rock pH, with *A. verruculosa*, *L. carpathica*, and *R. peltata* occurring on moderately acidic rocks and being minimally affected by slope gradient, aspect, rock size, or human disturbance.

In the fourth quadrant, *Aspicilia contorta* occurs on relatively large rocks with moderate humidity, independent of human disturbance. *Xanthoria sorediata* exhibits broad distribution with low habitat specificity. The CCA ordination indicates that saxicolous lichen distribution in the Shirengou Mountains of Urumqi County correlates with slope gradient, aspect, light intensity, rock pH, and humidity. Slope gradient and aspect exert the strongest influence, followed by light intensity, humidity, and rock pH. Human disturbance and rock size have insignificant effects on species distribution.

4 Discussion

Canonical correspondence analysis of 27 saxicolous lichen species in the Shirengou Mountains of Urumqi County, Xinjiang, reveals that species distribution primarily correlates with rock slope gradient, aspect, light intensity, and humidity. We found that species harboring symbiotic green algae, such as *Phaeophyscia sciastra*, *Physcia caesia*, *Lobothallia alphoplaca*, *Aspicilia calcarea*, *A. contorta*, *A. asiatica*, and *Melanelia tominii*, predominantly inhabit the lower northern aspects of rocks with weak light and high moisture. Conversely, species containing coccoid green algae, including *Acarospora molybdina*, *A. veronensis*, *A. verruculosa*, *Candelariella oleifera*, *Lecidella carpathica*, *Dermatocarpon vellereum*, and *Lecanora muralis*, occur on rock surfaces with strong light and dry conditions, consistent with Monte' s (1993) findings.

Analysis of reproductive strategies reveals that species with soredia primarily inhabit rock crevices and lateral surfaces, protecting soredia from rain wash and strong wind damage, whereas species with isidia and apothecia predominantly occupy rock surface areas. Furthermore, in areas with intensive grazing activity, acidic rocks support fewer saxicolous lichen species with lower coverage, primarily due to nitrogen enrichment from livestock excrement, corroborating previous research findings (Shukla et al., 2017). In summary, slope gradient and aspect in the Shirengou Mountains determine solar radiation receipt at different rock positions, creating microenvironmental variation in humidity, temperature, and light intensity across rock surfaces, while also differentially affecting wind exposure. These factors collectively drive differences in saxicolous lichen species composition and community distribution patterns.

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