Postprint: Structural Characteristics and Diversity of Typical Shrub Communities in the Qilian Mountains

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Abstract

Shrub communities, as an important component of the forest ecosystem in the Qilian Mountains, play an indispensable role in maintaining ecological security in northwestern China. Systematically studying the structural characteristics of shrub communities in the Qilian Mountains is of great significance for elucidating the regeneration, succession, and stability of shrub communities, and can provide fundamental data and scientific basis for the conservation, restoration, and reconstruction of forest ecosystems in the Qilian Mountains. Five typical shrub communities distributed in the Dayekou watershed of the Qilian Mountains were selected as research objects: Caragana tangutica, Berberis diaphana, Potentilla fruticosa, Caragana jubata, and Salix gilashanica. Through field investigation and sampling combined with laboratory analysis, this study mainly examined the species composition, life-form composition, and variation patterns of species diversity of the five typical shrub communities. The results showed that: (1) The shrub community composition in the Dayekou watershed of the Qilian Mountains was relatively simple, with only 48 plant species recorded, belonging to 26 families and 38 genera, with the majority being from dominant families in the arid regions of northwestern China such as Rosaceae, Poaceae, Asteraceae, and Fabaceae. (2) The life-form spectrum was dominated by hemicryptophytes with the largest proportion at 37.09%, while chamaephytes had the smallest proportion at 4.00%. (3) Overall, the Shannon-Wiener diversity index (H) of shrub communities ranged from 1.12 to 2.26, and the Simpson diversity index (D) ranged from 0.60 to 0.74. The species diversity indices were relatively low, and species composition was relatively simple. Among different shrub communities, the H diversity index showed the pattern: Potentilla fruticosa > Caragana jubata > Berberis diaphana > Caragana tangutica > Salix gilashanica, while the D diversity index showed: Potentilla fruticosa > Caragana jubata > Salix gilashanica > Berberis diaphana > Caragana tangutica. (4) Different habitat conditions led to differences in the inter-layer structure of

community diversity. Except for the Caragana jubata community, the diversity indices were all herbaceous layer > shrub layer. In the Caragana jubata community, however, the species diversity indices of the shrub layer and herbaceous layer were relatively close, with relatively uniform species composition between shrubs and herbs.

Full Text

Structural Characteristics and Diversity of Typical Shrub Communities in Qilian Mountains

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Abstract: Shrub communities constitute a vital component of the forest ecosystem in the Qilian Mountains, playing an indispensable role in maintaining ecological security in northwestern China. Systematic investigation of shrub community structure in this region is crucial for elucidating community regeneration, succession, and stability, and can provide fundamental data and a scientific basis for the protection, restoration, and reconstruction of forest ecosystems in the Qilian Mountains. This study selected five typical shrub communities distributed in the Dayekou watershed of the Qilian Mountains as research subjects: *Caragana tangutica*, *Berberis diaphana*, *Potentilla fruticosa*, *Caragana jubata*, and *Salix gilashanica*. Through field surveys and laboratory analysis, we examined species composition, life-form composition, and patterns of species diversity in these five typical shrub communities. The results indicate that: (1) The shrub community composition in the northern piedmont of the central Qilian Mountains is relatively simple, with only 48 species belonging to 38 genera and 26 families recorded. However, most species belong to Rosaceae, Gramineae, Compositae, and Leguminosae—dominant families in the arid regions of northwestern China. (2) In terms of life-form spectra across the five typical shrub communities, ground bud plants accounted for the largest proportion (37.09%), while aboveground bud plants accounted for the smallest proportion (4.00%). (3) The Shannon-Wiener diversity index (H) and Simpson diversity index (D) of the shrub communities ranged from 1.12 to 2.26 and 0.60 to 0.74, respectively. The Shannon-Wiener diversity index of different shrub communities exhibited the following pattern: *Potentilla fruticosa* > *Caragana jubata* > *Berberis di-*

aphana > *Caragana tangutica* > *Salix gilashanica*. The Simpson diversity index showed the pattern: *Potentilla fruticosa* > *Caragana jubata* > *Salix gilashanica* > *Berberis diaphana* > *Caragana tangutica*. (4) Different habitat conditions led to variations in the interlayer structure of community diversity. Except for the *Caragana jubata* community, where the diversity index was herb layer > shrub layer, the species diversity indices of shrub and herb layers in the *Caragana jubata* community were relatively similar, with homogeneous species composition between shrubs and herbs.

Keywords: shrub communities; species diversity; community structure; life form; Qilian Mountains

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Community structure represents a fundamental attribute of plant communities and serves as the basis for understanding community composition, changes, and development trends. Species diversity, as an indicator for measuring the complexity of community structure and function, reflects species richness and distribution uniformity, and embodies differences in plant community structure types, species composition, stability, and habitat conditions. Shrubs play an important role in plant diversity, not only increasing sources of species productivity and improving ecological stability but also greatly enriching plant community diversity. Therefore, studying shrub diversity is of great significance. As a major component of the forest ecosystem in the Qilian Mountains, shrub communities play an extremely important role in soil and water conservation, water source regulation, and maintaining the ecological system of the Hexi Corridor and protecting China' s biodiversity. However, previous research on shrub communities in the Qilian Mountains has primarily focused on hydrological ecological functions, biomass, soil properties, and management practices, with few studies addressing shrub community structure and species diversity. Consequently, this study selected shrub community dominant species distributed across different vertical vegetation zones in the Dayekou watershed of the Qilian Mountains—*Berberis diaphana*, *Caragana tangutica*, *Potentilla fruticosa*, *Caragana jubata*, and *Salix gilashanica*—as research subjects. Through plot surveys, we investigated species composition, life-form composition, and species diversity patterns of different shrub communities to deepen understanding of plant community characteristics in the Qilian Mountains and provide theoretical foundations for sustainable management and biodiversity conservation of shrub forests in the region.

1.2 Plot Setup and Investigation

Based on principles of typicality and representativeness, we selected five typical shrub communities distributed in the study area: *Caragana tangutica*, *Berberis diaphana*, *Potentilla fruticosa*, *Caragana jubata*, and *Salix gilashanica*. Using the typical plot method commonly employed in vegetation surveys, we established survey plots within each shrub type. Due to the relatively low density

of *Caragana tangutica* communities, we used 20 m × 20 m plots for more reasonable investigation, while 30 m × 30 m plots were established for the other four shrub types. We set up 5 plots for each shrub type, and within each shrub plot, we established 1 m × 1 m herbaceous quadrats along the diagonal line. In July, we conducted surveys of shrub community structure, measuring each shrub individually and recording name, number of individuals, height, crown width, and coverage. For the herbaceous layer, we recorded each species' name, height, coverage, and number of individuals. Simultaneously, we documented detailed information on elevation, slope, and aspect for each plot. Basic plot information is presented in .

1.1 Study Area Overview

The study area is located in the Dayekou River Basin of the Xishui Forest Region in the middle section of the northern Qilian Mountains, centered at 38°31 N, 100°15 E. The watershed covers a total area of 73.32 km^2, with elevations ranging from 2590 to 4645 m. The region has a high-cold semi-arid mountain forest-steppe climate, with mean annual temperature of -0.6~2.0°C, mean annual sunshine duration of 1893 h, mean daily radiation of 110.28 $kW \cdot m^{-2}$, mean annual precipitation of 433.6 mm, and mean annual evaporation of 1081.7 mm. Mean annual relative humidity is 30%. From low to high elevations, vegetation types include forest-steppe belt, forest-shrub belt, subalpine shrub meadow belt, and alpine meadow belt. Soil types include mountain sierozem, mountain chestnut soil, mountain gray-cinnamon soil, subalpine shrub meadow soil, and alpine cold desert soil. Among these, mountain gray-cinnamon soil distributed at 2400–3300 m is the main zone for arboreal forest growth, while subalpine shrub meadow soil at 3300–4000 m is the primary zone for hygrophilous shrub forests. *Picea crassifolia* serves as the constructive species, mainly distributed on semi-shady and shady slopes at 2400–3300 m. Dominant shrub species include *Potentilla fruticosa*, *Caragana jubata*, and *Salix gilashanica*, while major herbaceous species include *Polygonum viviparum*, *Carex atrata*, and *Stipa capillata*.

1.3 Data Calculation

Important Value Calculation. Based on statistics of species height, coverage, and frequency in each quadrat, we calculated species important values using the following formula: Important Value = (relative frequency + relative coverage) / 2.

Life-Form Classification. Following the life-form classification system of Danish botanist Raunkiaer, plant life forms mainly include phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes.

Species Diversity Indices. Based on the ability of species diversity indices to reflect community biodiversity status and their wide application, we selected Shannon-Wiener diversity index (H), Simpson diversity index (D), Pielou even-

ness index (J), Simpson dominance index (C), and Margalef richness index (M) to measure shrub community species diversity. The calculation formulas are as follows:

Simpson diversity index (D):

$$D = 1 - \sum_{i=1}^{S} \left(\frac{N_i}{N} \right)^2$$

Shannon-Wiener diversity index (H):

$$H = -\sum_{i=1}^{S} \frac{N_i}{N} \ln \left(\frac{N_i}{N} \right)$$

Pielou evenness index (J):

$$J = \frac{H}{\ln S}$$

Simpson dominance index (C):

$$C = \sum_{i=1}^{S} \left(\frac{N_i}{N} \right)^2$$

Margalef richness index (M):

$$M = \frac{S - 1}{\ln N}$$

Where: S is the number of species in the quadrat; N is the total number of individuals of all species in the quadrat; and N_i is the important value of species i in the quadrat.

2.1 Community Species Composition

The species composition and patterns of family variation differed among the five shrub communities, thereby affecting community structure (Table 2). Results showed that the *Caragana tangutica* community contained 15 species belonging to 14 genera, with Rosaceae being most abundant (4 species, accounting for 26.67% of the total), followed by Gramineae (3 species, 20.00%). Compositae and Leguminosae each had 2 species, accounting for 13.33%, while remaining families had only 1 species each. The *Berberis diaphana* community contained 20 species belonging to 15 genera, with Rosaceae dominant (5 species, 25.00%), followed by Gramineae and Leguminosae (4 species each, 20.00%). Compositae had 3 species (15.00%), while other families had only 1 species each. The *Potentilla fruticosa* community contained 24 species belonging to 20 genera, with Rosaceae dominant (6 species, 25.00%), followed by Gramineae (5 species,

20.83%). Compositae had 4 species (16.67%), while other families had only 1 species each. The *Caragana jubata* community contained 11 species belonging to 10 genera, with Leguminosae, Rosaceae, and Labiatae each having 2 species (18.18%), while other families had only 1 species each. The *Salix gilashanica* community contained 11 species belonging to 11 genera, with Salicaceae having 2 species (18.18%), while other families had only 1 species each. Overall, the five typical shrub communities in the northern piedmont of the Qilian Mountains had relatively simple composition, with only 48 species belonging to 38 genera and 26 families recorded. Among these, Cyperaceae and Leguminosae appeared in all five communities, Rosaceae was dominant in *Caragana tangutica*, *Berberis diaphana*, and *Potentilla fruticosa* communities, and Gramineae was also common in these three communities.

2.2 Community Life-Form Composition

The life-form spectra of the five typical shrub communities reflected the characteristics of the study area (Table 4). In the *Caragana tangutica* community, hemicryptophytes were most numerous, accounting for 53.33% of the total and showing absolute dominance. Phanerophytes, cryptophytes, and therophytes each accounted for 13.33%, while chamaephytes were least abundant at only 6.67%. In the *Berberis diaphana* community, hemicryptophytes were most numerous (45.00%), followed by cryptophytes and therophytes (30.00% and 10.00%, respectively), with a small number of chamaephytes present. In the *Potentilla fruticosa* community, hemicryptophytes were most numerous (41.67%), followed by cryptophytes (25.00%). Therophytes accounted for 16.67%, while phanerophytes and chamaephytes were less numerous (8.33% each). In the *Caragana jubata* community, phanerophytes were most numerous (36.36%), while hemicryptophytes and cryptophytes each accounted for 27.27%. Therophytes were less numerous (9.09%), and no chamaephytes were present. In the *Salix gilashanica* community, cryptophytes were most numerous (36.36%), followed by phanerophytes (27.27%). Therophytes and hemicryptophytes each accounted for 18.18%, while no chamaephytes were present. Analysis of shrub community life forms overall reflects the high-cold semi-arid mountain climate of the study area.

2.3 Community Species Diversity

The species diversity of the five typical shrub communities in the study area was generally low, with simple community structure (Table 5). Simpson diversity index (D) showed the pattern: *Potentilla fruticosa* > *Caragana jubata* > *Salix gilashanica* > *Berberis diaphana* > *Caragana tangutica*. Shannon-Wiener diversity index (H) showed the pattern: *Potentilla fruticosa* > *Caragana jubata* > *Berberis diaphana* > *Caragana tangutica* > *Salix gilashanica*. Different shrub communities exhibited variations in community environment, structure, and stability, leading to differences in community diversity. The *Caragana jubata* community had the highest Pielou evenness index (0.85), indicating uni-

form species distribution. The *Berberis diaphana* community, which occurred in patchy distributions, had the lowest evenness index (0.53). Simpson dominance index (C) showed an opposite pattern to Shannon-Wiener diversity index (H). The *Salix gilashanica* community, with low species diversity, had fewer species and higher dominance. Under normal conditions, ecosystems limited by certain environmental factors do not exhibit high species diversity levels.

2.4 Inter-Layer Distribution Characteristics of Community Species Diversity

Species diversity characteristics differed between shrub and herb layers across the five shrub communities (Table 6). In *Caragana tangutica*, *Berberis diaphana*, *Potentilla fruticosa*, and *Salix gilashanica* communities, herb layer species diversity indices were higher than those of the shrub layer, indicating herbaceous species dominance. In the *Caragana jubata* community, species diversity indices of shrub and herb layers were similar, showing homogeneous species composition between layers. Plant community vertical structure is influenced by water-heat conditions, microhabitats, species composition, and developmental stages. Overall, except for *Caragana jubata*, herb layer species diversity exceeded shrub layer diversity in the other communities, making herbs the dominant stratum. The *Caragana jubata* shrub community showed superior species diversity in the shrub layer compared to other communities, while *Potentilla fruticosa* and *Salix gilashanica* communities exhibited superior herb layer diversity. This demonstrates that different habitats and shrub types have different dominant growth forms.

3 Discussion

Life form represents the result of long-term plant adaptation to specific survival environments during development, and identical life forms reflect similar environmental adaptations. In the life-form spectra of study area shrub communities, the high proportion of hemicryptophytes indicates long winters in the Qilian Mountains, consistent with the regional climate conditions and reflecting the distinct high-cold climate characteristics of the Qilian Mountains. The low proportion of chamaephytes is primarily caused by regional environmental stress. Shrub communities at high elevations are limited by low temperatures, while those at low elevations are constrained by drought. Additionally, vegetation in the study area, particularly low-elevation shrub forests, is affected by grazing and other human activities that destroy the growth environment for chamaephytes. Overall, the five typical shrub communities were dominated by hemicryptophytes (37.09%), followed by phanerophytes (23.06%), therophytes (22.39%), and cryptophytes (13.45%), with chamaephytes being least common (4.00%). This reflects the harsh regional climate of the northern Qilian Mountains piedmont, characterized by brief summer growing seasons and long, cold winters, indicating that these five typical shrub communities are products of long-term adaptation to alpine severe cold climate.

Different environmental resources and their heterogeneity constitute the primary cause of variations in community structural characteristics and plant community diversity distribution patterns. Our investigation revealed that typical shrub communities in the middle section of the northern Qilian Mountains piedmont mainly include *Caragana tangutica*, *Berberis diaphana*, *Potentilla fruticosa*, *Caragana jubata*, and *Salix gilashanica* communities. Due to differences in habitat conditions and community types, species composition varied significantly among different shrub communities. The shrub communities in the northern piedmont of the central Qilian Mountains had relatively simple composition, with only 48 species belonging to 38 genera and 26 families recorded. This is related to the special climate conditions and habitat conditions of shrub communities in the Qilian Mountains. Rosaceae, Gramineae, Compositae, and Leguminosae were dominant, consistent with Tian Chunying' s research findings in the Qilian Mountains and with the prevalence of these families as characteristic taxa in the arid regions of northwestern China. The *Potentilla fruticosa* community at middle elevations (2900 m) showed higher species diversity, likely because mid-elevation areas have more favorable water-heat conditions, higher resource utilization efficiency, and are suitable for more species growth, resulting in higher species diversity than other shrub communities. The *Salix gilashanica* community at high elevations, although receiving more precipitation and less human disturbance, has cold climate that inhibits understory plant growth. Additionally, the high shrub layer coverage limits light availability for lower herbaceous plants, resulting in lower species diversity. The *Caragana tangutica* and *Berberis diaphana* communities at low elevations (2600 m) also had low diversity because low-elevation areas in the Qilian Mountains are dry with low rainfall and poor soil fertility, allowing only a few drought-tolerant species to survive.

Our results also indicate that the five typical shrub communities in the northern piedmont of the central Qilian Mountains had relatively low species diversity indices. The maximum values of Simpson diversity index (D), Shannon-Wiener diversity index (H), and Margalef richness index (M) were 0.74, 2.26, and 1.97, respectively. Comparing shrub community diversity studies from different regions, the H diversity index of shrub communities in Urumqi ranged from 0.95 to 3.06, that in the Irtysh River basin ranged from 0.87 to 3.24, that of desertified steppe shrub communities on the Ordos Plateau ranged from 2.62 to 4.31, and that of typical shrub communities in central Guangxi ranged from 1.86 to 3.41. These comparisons indicate that species diversity indices of shrub communities in the northern piedmont of the central Qilian Mountains are relatively low, with high dominance of single-dominant communities, which is related to the special climate and fragile ecosystem of the Qilian Mountains. However, low diversity indices do not necessarily indicate poor system stability. Some communities with simple structure and single-dominant populations exhibit high stability. Nevertheless, for a fragile ecosystem, if the dominant species disappears without redundant species with similar functions to replace it, the entire ecosystem will suffer severe damage. Therefore, enhanced protection of shrub

communities is necessary.

Plant diversity distribution is influenced by biological characteristics, natural environment, and external disturbances. Different types and intensities of disturbance can alter community structure. Research shows that disturbance can reduce species diversity, and different life-form plants within the same community respond differently to external disturbance. We found that *Potentilla fruticosa*, *Caragana tangutica*, and *Berberis diaphana* communities distributed at middle and low elevations experienced varying degrees of grazing disturbance, all showing low shrub layer species diversity but high herb layer diversity. This is because these three communities were affected by cattle and sheep grazing and trampling during the growing season, resulting in slow regeneration and low species diversity in the shrub layer. However, grazing reduced the density of upper vegetation, providing more comfortable living space for lower-layer plants and limiting the ecological niches occupied by shrub species to some extent. Combined with the faster regeneration rate of herbaceous plants, these factors collectively contributed to higher herbaceous species diversity.

4 Conclusion

This study addressed the lack of research on species composition and diversity characteristics of shrub communities in the Qilian Mountains by selecting five typical shrub communities in the Dayekou watershed. Through field surveys and laboratory analysis, we deeply investigated species composition, life-form composition, and species diversity patterns, reaching the following conclusions:

The five typical shrub communities in the northern piedmont of the Qilian Mountains had relatively simple composition, with 48 species belonging to 38 genera recorded. However, most species belonged to Rosaceae, Gramineae, Compositae, and Leguminosae—dominant families in the arid regions of northwestern China. The life-form spectra of the five typical shrub communities were dominated by hemicryptophytes (37.09%), with aboveground bud plants accounting for only 4.00%, consistent with the high-cold semi-arid climate characteristics of the study area. The Shannon-Wiener diversity index (H) of the five typical shrub communities ranged from 1.12 to 2.26, and the Simpson diversity index (D) ranged from 0.60 to 0.74, indicating relatively low species diversity and high dominance of single-dominant communities. However, low species diversity does not necessarily imply poor system stability. For the fragile ecosystem of the Qilian Mountains, if dominant species disappear, it would cause extremely serious damage to ecosystem functions. Therefore, enhanced protection of shrub communities is essential.

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