Variation Patterns of Community Characteristics of Qilian Juniper (Juniperus przewalskii) along an Annual Precipitation Gradient (Postprint)

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Abstract

Juniperus przewalskii communities constitute one of the principal forest community types in Qinghai Province, playing a critical role in soil and water conservation, water source regulation, and ecological balance maintenance. To elucidate the responses of Juniperus przewalskii community characteristics and population age structure to annual precipitation gradients, natural Juniperus przewalskii communities in Qinghai Province were selected as the study system, with community plots established along an annual precipitation gradient to conduct community characteristic surveys. The results demonstrated that: (1) Annual precipitation exhibited a gradual increase from northwest to southeast across the study region, and with increasing annual precipitation, the importance values of dominant species in the shrub and herb layers of Juniperus przewalskii communities changed significantly ($P<0.05$). (2) Populations displayed a declining structure at annual precipitation levels of 169~377 mm, a stable structure at 470 mm, and an increasing structure at 530 mm. (3) The α diversity index of understory plants differed significantly among different annual precipitation levels ($P<0.05$). With increasing annual precipitation, the Shannon-Wiener index, Simpson index, and species richness of both shrub and herb layers increased progressively, reaching maximum values at 530 mm annual precipitation. (4) The β diversity index of the shrub layer exhibited "fluctuating" changes with increasing annual precipitation; the Cody and Sorensen indices reached their peak and trough values at 470~530 mm and 281~377 mm annual precipitation, respectively. The β diversity index of the herb layer initially increased then decreased; the Cody and Sorensen indices reached their peak and trough values at 377~470 mm annual precipitation, respectively, where β diversity between layers was maximal and species turnover rate was highest. Annual precipitation significantly influenced the population age structure and community characteristics of Juniperus przewalskii; in forest zones receiving <377 mm annual precipitation,

modification of forest microtopography, harvesting of natural precipitation, and protection from livestock damage would facilitate natural regeneration.

Full Text

Community Characteristics of *Juniperus przewalskii* along Annual Precipitation Gradients

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Abstract

Juniperus przewalskii communities represent one of the primary forest communities in Qinghai Province, playing a critical role in soil and water conservation, water source regulation, and ecological balance maintenance. To understand how community characteristics and population age structure of *J. przewalskii* respond to annual precipitation gradients, we established community sample plots along a precipitation gradient in natural *J. przewalskii* stands in Qinghai Province and conducted comprehensive community surveys. The results demonstrated that (1) annual precipitation increased gradually from northwest to southeast across the study region, with significant changes in the importance values of dominant species in both shrub and herb layers as precipitation increased ($P < 0.05$). (2) When annual precipitation ranged from 169-377 mm, the population exhibited a declining age structure; at 470 mm precipitation, the population was stable; and at 530 mm precipitation, the population showed a growth trend. (3) The α diversity index of understory plants differed significantly across precipitation levels ($P < 0.05$). With increasing precipitation, the Shannon-Wiener index, Simpson index, and species richness of both shrub and herb layers increased gradually, reaching maximum values at 530 mm annual precipitation. (4) As precipitation increased, the β diversity index of the shrub layer showed a "fluctuating" pattern, with Cody and Sorensen indices peaking and reaching their lowest values at precipitation levels of 470-530 mm and 281-377 mm, respectively. The β diversity index of the herb layer initially increased then decreased, with Cody and Sorensen indices peaking and reaching their lowest values when precipitation ranged from 377-470 mm, indicating the highest species turnover rate and lowest similarity during this interval. Annual precipitation significantly influenced both the age structure of *J. przewalskii* populations and overall community characteristics. In forest areas receiving less than 377 mm annual precipitation, modifying forest microtopography to

collect natural precipitation and preventing livestock damage would facilitate natural regeneration.

Keywords: annual precipitation gradient; *Juniperus przewalskii*; community characteristics; species diversity; Qinghai

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Plant communities represent assemblages formed through continuous adjustment and adaptation to environmental changes, with community species diversity reflecting differences in composition, structure, and function while revealing the relationship between external environmental conditions and communities. The patterns of community species diversity along environmental gradients have become a focal topic in ecological research. Studies have found that precipitation changes have no significant effect on desert plant community diversity, while others have reported significant impacts of precipitation patterns on community species diversity, richness, and evenness. Controversies regarding plant community responses to precipitation changes persist. Under global climate change, the influence of precipitation variation on forest ecosystems is intensifying, making research on plant community composition and species diversity responses to annual precipitation gradients crucial for conserving natural plant communities in arid regions.

Qinghai Province, located on the Qinghai-Tibet Plateau, is influenced by the East Asian monsoon, plateau monsoon, and westerlies, with uneven water resource distribution, making it one of the most arid regions at the same latitude globally. *Juniperus przewalskii*, due to its drought and barren tolerance, has become one of the main forest-forming species in this region, playing important roles in biodiversity maintenance, water source conservation, and soil and water retention. Current research on *J. przewalskii* has focused on dendroclimatology, ecophysiology, afforestation techniques, and biochemical composition, with limited studies on community characteristics, and those existing concentrating on topographic factors such as altitude effects on community species diversity. Qinghai Province exhibits a clear natural precipitation gradient from northwest to southeast, with precipitation patterns affecting plant community composition and structure. How the age structure of *J. przewalskii* populations and community species diversity change along this gradient remains poorly understood.

This study examined natural *J. przewalskii* communities in Qinghai Province, establishing survey plots along an annual precipitation gradient to explore community characteristic responses to natural precipitation variation, aiming to provide a theoretical basis for natural forest conservation and management.

1.1 Study Area

We selected natural *J. przewalskii* communities in Gubai Garden, Delingha City; Reshui Township Forest Farm, Dulan County; Hebei Forest Farm, Xinghai County; Beishan Forest Farm, Huzhu County; and Maixiu Forest Farm, Zeku County, Qinghai Province. The study area features a plateau continental climate with mean annual temperatures of -2.5–7.9 °C and highly uneven precipitation distribution (160–590 mm). *Juniperus przewalskii* communities are predominantly distributed on sunny slopes, with the tree layer dominated by *J. przewalskii*, rich understory shrub and herb species, and severe grazing and logging disturbances. Based on mean annual precipitation data for Qinghai Province from 1981–2010, we generated precipitation isoline maps using inverse distance weighted interpolation in ArcGIS software. Mean annual precipitation increased generally from northwest to southeast across the study region (Fig. [Figure 1: see original paper]), following the pattern: Delingha City (169 mm) < Dulan County (281 mm) < Xinghai County (377 mm) < Huzhu County (470 mm) < Zeku County (530 mm).

[Figure 1: see original paper] Location of research area and sampling point

Information of sampling sites

1.2 Sample Plot Setup

At each of the five survey locations, we selected sites with abundant natural *J. przewalskii* forest distribution and established three 20 m × 20 m sample plots with similar stand density, slope, and aspect conditions. Within each plot, we conducted measurements of all trees, recording species name, diameter at breast height (DBH), tree height, crown width, and canopy closure. Using the diagonal method, we established five 5 m × 5 m shrub quadrats and five 1 m × 1 m herb quadrats in each plot, recording plant species name, individual number, height, and coverage. Population age structure was classified by diameter class: seedlings (DBH < 5 cm), saplings (5 cm ≤ DBH < 15 cm), small trees (15 cm ≤ DBH < 25 cm), medium trees (25 cm ≤ DBH < 30 cm), and large trees (DBH ≥ 30 cm).

1.3 Data Processing and Analysis

Importance value was calculated as: (relative density + relative dominance + relative coverage)/3. **Species diversity indices** included: Species richness index (S, number of species per quadrat), Shannon–Wiener index (H = - *{i=1}^{S} P_i ln P_i), Simpson dominance index (D = 1 -* {i=1}^{S} P_i^2), and Pielou evenness index (J_{sw} = H /ln S), where S is species number and P_i is the relative importance value of species i. β **diversity** was measured using Cody index (β_c = [g(H) + l(H)]/2) and Sorensen similarity coefficient (SI = 2c/(a + b)), where a and b are species numbers in two adjacent plots and c is the number of shared species.

We used Excel 2019 and SPSS 24.0 for data organization and statistical analysis. One-way ANOVA was employed to analyze differences in species diversity indices among precipitation gradients, with least significant difference (LSD) used for multiple comparisons. Origin 2019 software was used for figure preparation.

2.1 Community Species Composition and Importance Values along Precipitation Gradients

The *J. przewalskii* community contained 47 seed plant species, including 2 gymnosperm species, 42 dicotyledon species, and 3 monocotyledon species. Dominant species (importance value > 10) and their importance values across vegetation layers are shown in Table . The tree layer was consistently dominated by *J. przewalskii* with the highest importance value across all precipitation levels. However, the importance values of dominant species in shrub and herb layers changed significantly with precipitation. In the shrub layer, *Berberis diaphana* was the absolute dominant species at 281 mm precipitation (importance value 61.02). At 377 mm, *Ribes alpestre* and *Potentilla fruticosa* became dominant (combined importance value 39.41). At 470 mm, *P. fruticosa* and *Potentilla glabra* were dominant (combined importance value 58.37). At 530 mm, *P. fruticosa*, *P. glabra*, and *Berberis parapruinosa* were co-dominant (combined importance value 56.57). In the herb layer, *Carex lanceolata* and *Polygonum viviparum* were dominant at 281 mm (combined importance value 31.34). At 377 mm, *C. lanceolata* was the absolute dominant species (importance value 30.39). At 470 mm, *C. lanceolata* remained dominant (importance value 25.73). At 530 mm, *C. lanceolata* and *Elymus dahuricus* were co-dominant (combined importance value 27.64). These changes in dominant species along the precipitation gradient reflect water adaptation strategies and demonstrate that precipitation significantly affects community species composition and dominance.

Importance values of dominant species of various vegetation layers along different annual precipitation gradients

2.2 Age Structure of *Juniperus przewalskii* Population along Precipitation Gradients

The age structure of *J. przewalskii* populations varied across precipitation levels (Fig. [Figure 2: see original paper]). At 169 mm precipitation, no seedlings were present in the understory, with saplings and small trees accounting for only 18.31% of total individuals and large trees comprising 54.93%. At 281 mm precipitation, seedlings and saplings represented just 4.25% of individuals, while large trees accounted for 55.93%. In areas receiving 169–281 mm precipitation, the population exhibited a declining age structure. At 377 mm precipitation, medium and large trees comprised 83.73% of individuals, indicating an aging population with imbalanced structure. At 470 mm precipitation, small and medium trees accounted for 54.23% of individuals, while large trees represented

32.47%, suggesting a stable population. At 530 mm precipitation, seedlings, saplings, and small trees comprised 56.57%, 12.85%, and 13.29% of individuals respectively, with large trees representing only 13.29%, indicating a growing population structure. Populations in areas receiving >470 mm precipitation showed good natural regeneration and stable growth.

[Figure 2: see original paper] Age structure of *Juniperus przewalskii* population in different annual precipitation gradients

2.3 Understory Plant α Diversity Characteristics along Precipitation Gradients

Species richness, Shannon–Wiener index, and Simpson index were consistently higher in the herb layer than in the shrub layer across all precipitation levels (Fig. [Figure 3: see original paper]). Species richness showed fluctuating patterns with precipitation, reaching minimum values of 6.1 species in the shrub layer at 169 mm and 5.5 species in the herb layer at 281 mm. Shannon–Wiener and Simpson indices increased gradually with precipitation, reaching maximum values in both layers at 530 mm precipitation (shrub layer: H = 2.86, D = 0.94; herb layer: H = 3.21, D = 0.95), which were significantly greater than values at 169 mm precipitation. The Pielou evenness index in the shrub layer was greater than in the herb layer, with values of 0.94 (shrub) and 0.90 (herb) at 530 mm precipitation. Overall, α diversity indices increased gradually with mean annual precipitation.

[Figure 3: see original paper] The α diversity index along annual precipitation gradients

2.4 Understory Plant β Diversity Characteristics along Precipitation Gradients

The Cody index was consistently higher in the shrub layer than in the herb layer, while the Sorensen index showed the opposite pattern (Fig. [Figure 4: see original paper]), indicating lower species similarity and faster species turnover in the herb layer. The shrub layer β diversity index fluctuated with precipitation, with Cody and Sorensen indices reaching peaks (1.68 and 0.71) and troughs (0.54 and 0.56) at precipitation levels of 470–530 mm and 281–377 mm, respectively. This indicates fastest species turnover and lowest similarity in the 281–377 mm precipitation range. The herb layer β diversity index increased initially then decreased, with Cody and Sorensen indices peaking (1.89) and reaching their minimum (0.48) when precipitation ranged from 377–470 mm. Thus, with increasing mean annual precipitation, herb layer species turnover rate first accelerated then decelerated.

One-way ANOVA of α and β diversity indices along the precipitation gradient revealed that, except for the shrub layer Sorensen index, all other indices differed significantly across precipitation gradients. Shrub layer Shannon–Wiener index and species richness, and herb layer Sorensen and Shannon–Wiener indices showed extremely significant differences (P < 0.01), indicating that precipitation changes markedly altered community species diversity.

[Figure 4: see original paper] The β diversity index along annual precipitation gradients

Tests of species diversity index for annual precipitation gradients

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3 Discussion

The *J. przewalskii* community contained 47 plant species, with Asteraceae, Ranunculaceae, Rosaceae, and Lamiaceae being dominant—similar to natural *J. przewalskii* communities in the Three-River Headwaters region. The flora consisted mainly of xerophytic shrubs and perennial herbs, reflecting the region' s long sunshine hours, strong radiation, scarce precipitation, and intense evaporation. Water is the primary limiting factor for plant survival and development in arid regions, and precipitation is the main water source. Precipitation variation affects plant growth and alters community composition. In this study, plant importance values changed significantly along the precipitation gradient, with considerable variation for the same species across different precipitation levels, related to species' biological characteristics. For example, the importance value of *Potentilla fruticosa* decreased gradually with increasing precipitation, reducing its dominance because this species increases osmoregulatory substances and antioxidant enzyme activity under drought stress, providing positive feedback to arid conditions. At the lowest precipitation level, *P. fruticosa* was the absolute dominant species in the shrub layer. The importance value of *Elymus dahuricus* in the herb layer increased gradually, likely because perennial herbs have root systems mainly distributed in surface soil layers with high water utilization efficiency. In contrast, the importance value of *Carex lanceolata* showed little change along the precipitation gradient due to its robust roots and stems, strong vitality, and broad ecological amplitude.

Species richness, Shannon–Wiener index, and Simpson index were consistently lower in the shrub layer than in the herb layer, possibly because shrubs are less sensitive to precipitation changes. Shrub leaves generally have higher nitrogen content, promoting proline formation and conferring stronger drought resistance. The similar trends in species richness and Simpson index may result from the dominance of xerophytic shrubs and perennial herbs in all plots, with fewer other species, leading to high species richness but also high Simpson dominance index. Zhang et al. found that increased water availability significantly raised the importance values of all plant types in alpine grasslands of northern Tibet, possibly because that region receives approximately 500 mm mean annual precipitation, providing more abundant water resources and less water stress than our study area. Zhang et al. also reported that increased water availability elevated the dominance of dominant species, with interspecific competition inhibiting other species' survival and development, leading to lower community evenness. However, our study found that Pielou evenness index increased overall with precipitation, possibly due to differences in plant ecological types and human disturbance intensity.

Population age structure reflects the relationship between populations and their surrounding environment. In this study, the age structure of *J. przewalskii* populations varied along the precipitation gradient. At 169–281 mm precipitation, the population showed a declining age structure, indicating low seedling survival rates. This may result from two factors: first, in areas with low precipitation and high evaporation, seedlings require more soil moisture; second, extensive livestock feces observed in the forest indicate that grazing severely affects natural regeneration through trampling and browsing. At precipitation >470 mm, populations showed good natural regeneration and stable growth. Tian et al. found that *J. przewalskii* populations on the northern slope of the Qilian Mountains (with mean annual precipitation of 470–600 mm) exhibited declining age structures, contrasting with our results. This discrepancy may be because our study sites were distributed at higher elevations with less human disturbance.

β diversity reflects differences in species composition among communities along environmental gradients, with greater habitat differences leading to higher β diversity. In this study, β diversity indices were lower in the shrub layer than in the herb layer, indicating faster species turnover in herbs. Shrubs showed fewer disappearances or establishments with increasing precipitation, while herbs exhibited more associated species. Precipitation gradient significantly affected Cody and Sorensen indices in the herb layer but not the Sorensen index in the shrub layer, because these indices have different sensitivities. Shrub layer β diversity increased then decreased with precipitation, primarily because rare species such as *Gentiana siphonantha*, *Gentiana squarrosa*, *Deyeuxia kokonorica*, and *Parasenecio roborowskii* gradually appeared in the 169–470 mm precipitation range, reducing shared species among communities and increasing β diversity. In the 470–530 mm range, common and rare species such as *Gentiana dahurica*, *Ranunculus tanguticus*, and *Comarum salesovianum* gradually disappeared, increasing shared species and decreasing β diversity.

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4 Conclusion

Annual precipitation significantly influences the age structure of *Juniperus przewalskii* populations, community species composition, and diversity. Populations exhibited declining, stable, and growth age structures at precipitation levels of 169–377 mm, 470 mm, and 530 mm, respectively. With increasing precipitation, species richness, diversity, and dominance of shrub and herb layers increased gradually. Species turnover rate in the shrub layer first accelerated, then decelerated, and finally peaked, while that in the herb layer first accelerated then decelerated. To promote the health and stability of *J. przewalskii* communities in forest areas receiving 169–377 mm annual precipitation, microtopography modification to increase surface roughness and improve soil moisture conditions is recommended, along with enhanced management to prevent livestock trampling, browsing, and excretion disturbances. Fencing measures should be implemented to facilitate progressive community development.

References

[1] Sun Y, He M, Wang L. Effects of precipitation control on plant diversity and biomass in a desert region. *Acta Ecologica Sinica*, 2018, 38(7): 2425-2433.

[2] Li C, Peng Y, Zhao D, et al. Effects of precipitation change and nitrogen addition on community structure and plant diversity in an alpine steppe on the Qinghai-Tibetan Plateau. *Research of Soil and Water Conservation*, 2016, 23(6): 185-191.

[3] Wu J, Li X, Shen Z, et al. Distribution pattern of species diversity along precipitation gradient in alpine grassland transect in northern Tibet. *Acta Prataculturae Sinica*, 2012, 21(3): 17-25.

[4] Knapp A K, Ciais P, Smith M D. Reconciling inconsistencies in precipitation-productivity relationships: implications for climate change. *New Phytologist*, 2017, 214(1): 41-47.

[5] Zelnik I, Arni A. Plant species diversity and composition of wet grasslands in relation to environmental factors. *Biodiversity and Conservation*, 2013, 22(10): 2179-2192.

[6] Jin M, Li J, Che Z, et al. Intra-annual radial growth responses of Qilian juniper (*Juniperus przewalskii*) to climate factors in the central Qilian Mountains, northwest China. *Acta Ecologica Sinica*, 2020, 40(21): 7699-7708.

[7] Cui Y, Wang Z, Zhang D, et al. Effects of soil water content and light on physiological indexes of *Juniperus przewalskii*. *Journal of West China Forestry Science*, 2019, 48(5): 95-100.

[8] Lü H. Qilian Sabina drought resistance afforestation technology. *Agricultural Engineering*, 2019, 9(1): 98-100.

[9] Shi Z, Bai D, Lei J, et al. Variations of chloroplast pigments and non-structural carbohydrates of *Sabina przewalskii* along altitude in Qilian Mountains timberline. *Acta Botanica Boreali-Occidentalia Sinica*, 2012, 32(11): 2286-2292.

[10] Zhang J, Hou Z, Hou X, et al. Species diversity of *Juniperus przewalskii* community in Three-River Headwater Region along altitude gradient. *Acta Botanica Boreali-Occidentalia Sinica*, 2020, 40(10): 1759-1767.

[11] Tian X, Ma L, Zhan Y. Community characteristics of *Sabina przewalskii* in northern slope of Qilian Mountains. *Journal of Northwest Forestry University*, 2015, 30(2): 77-83.

[12] Kang D, Guo Y, Du Y, et al. Diameter class structure and understory diversity of *Pinus tabulaeformis* plantations in Xiaolong Mountain. *Journal of Northwest Forestry University*, 2012, 27(4): 54-59.

[13] H Ganjurjav, Duan M, Guo Y, et al. Effects of irrigation on alpine grassland productivity and plant diversity in Northern Tibet. *Acta Ecologica Sinica*, 2015, 35(22): 7485-7493.

[14] Zhang Z, Wu G, Wang D, et al. Plant community structure and soil moisture in the semi-arid natural grassland of the Loess Plateau. *Acta Prataculturae Sinica*, 2014, 23(6): 313-319.

[15] Wang L, Zhao L, Chen Y, et al. Plant community diversity of steppification desert in West Ordos. *Arid Zone Research*, 2015, 32(2): 258-265.

[16] Ding L, Zhao H, Zeng W, et al. Physiological responses of five plants in northwest China arid area under drought stress. *Chinese Journal of Applied Ecology*, 2017, 28(5): 1455-1463.

[17] Sun Y, Tian Q, Lü P, et al. Effects of extreme drought and nitrogen addition on species diversity, leaf trait, and productivity in a semi-arid sandy grassland. *Arid Zone Research*, 2020, 37(6): 1569-1579.

[18] Qin J, Si J, Jia B, et al. Study on the relationship between vegetation community characteristics and soil moisture in Badain Jaran Desert. *Arid Zone Research*, 2021, 38(1): 207-222.

[19] Yao J, Yang Q, Liu Z, et al. Spatio-temporal change of precipitation in arid region of northwest China. *Acta Ecologica Sinica*, 2015, 35(17): 5846-5855.

[20] Hu Y, Guo X, Yue P, et al. Effects of water and nutrient addition on the growth and physiology of *Stipa glareosa* in a desert steppe in Inner Mongolia. *Arid Zone Research*, 2021, 38(2): 487-493.

[21] Schenk H J, Jackson R B. Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. *Journal of Ecology*, 2010, 90(6): 480-490.

[22] Jackson R B. Belowground consequences of vegetation change and their treatment in models. *Ecological Applications*, 2000, 10(2): 423-436.

[23] Liu H, Shi X, Wang J, et al. Effects of sand burial, soil water content and distribution pattern of seeds in sand on seed germination and seedling survival of *Eremosparton songoricum* (Fabaceae), a rare species inhabiting the moving sand dunes of the Gurban-tunggut Desert of China. *Plant and Soil*, 2011, 345(1-2): 69-87.

[24] Ehleringer S. Water use trade-offs and optimal adaptations to pulse-driven arid ecosystems. *Journal of Ecology*, 2001, 89(3): 464-480.

[25] Yuan Z, Chen H. Global trends in senesced leaf nitrogen and phosphorus. *Global Ecology and Biogeography*, 2010, 18(5): 532-542.

[26] Jankowski J, Ciecka A, Rabenold M. Beta diversity along environmental gradients: Implications of habitat specialization in tropical montane landscapes. *Journal of Animal Ecology*, 2009, 78(2): 315-327.

[27] Fang J, Wang X, Shen Z, et al. Methods and protocols for plant community inventory. *Biodiversity Science*, 2009, 17(6): 533-548.

[28] Zhang X, Zhou J, Cai W, et al. Diversity characteristics of plant communities in the arid desert of the Heihe basin under different moisture gradients. *Acta Ecologica Sinica*, 2017, 37(14): 4627-4635.

[29] Lieth H, Whittaker R H. Modeling the primary productivity of the world. *Springer Berlin Heidelberg*, 1975, 12(3): 237-263.

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