Postprint: Analysis of Distribution Pattern and Key Factors of Leymus racemosus in the Junggar Basin

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Abstract

To simulate and predict the ecological suitability and spatial distribution characteristics of *Leymus racemosus*, a dune grass in the Junggar Basin of Xinjiang, and its potential responses to future climate change, thereby guiding conservation efforts for this endangered plant. Based on 24 natural distribution sites of *L. racemosus* and 8 environmental factors, this study employed GIS spatial analysis and the MaxEnt model to analyze the suitable distribution range and pattern changes of *L. racemosus* under baseline climate (1970–2000) and Shared Socioeconomic Pathway SSP2 for the 2050s (2041–2060) and 2070s (2081–2100), and utilized multivariate environmental similarity surface and most dissimilar variable approaches to identify the key climatic factors influencing *L. racemosus* distribution. The results demonstrate that: (1) Under baseline climate, the suitable distribution area of *L. racemosus* comprises 5.57% of Xinjiang' s total area, primarily concentrated in low-coverage grasslands near the Irtysh River basin; (2) Compared to baseline climate, the suitable habitat area of *L. racemosus* exhibits a significant decreasing trend in the 2050s and 2070s, accounting for 0.99% and 1.33% respectively, with suitable habitats becoming highly fragmented and the centroid of suitable areas shifting toward higher latitudes and altitudes in the northwest; (3) Precipitation in the driest month, precipitation seasonality, and temperature seasonality are the key climatic factors affecting the suitable distribution of *L. racemosus* in the Junggar Basin.

Full Text

Distribution Pattern and Key Driving Factors of Leymus racemosus in the Junggar Basin

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Abstract

This study aims to simulate and predict the ecological suitability, spatial distribution characteristics, and potential responses to future climate change of the desert grass *Leymus racemosus* (Lam.) Tzvelev in the Junggar Basin of Xinjiang, to guide conservation efforts for this endangered plant. Based on 24 natural distribution points and eight environmental factors, we analyzed the suitable distribution range and pattern changes of *L. racemosus* under baseline climate (1970–2000) and future scenarios (SSP2-4.5) for the 2050 period (2041–2060) and 2070 period (2081–2100) using GIS spatial analysis and the MaxEnt model. We employed multivariate environmental similarity surface (MESS) and most dissimilar variable (MoD) analyses to identify key climatic factors influencing its distribution. Under baseline climate, the suitable distribution area of *L. racemosus* accounts for 5.57% of Xinjiang' s total area, primarily concentrated in low-cover grasslands near the Irtysh River. Compared with baseline climate, the species' suitable habitat will be significantly reduced by 0.99% and 1.33% in 2050 and 2070, respectively, with highly fragmented distribution and a centroid shift toward the northwest at higher latitudes and elevations. The precipitation of the driest month, precipitation seasonality, and temperature seasonality are the key climatic factors affecting the suitable distribution of *L. racemosus* in the Junggar Basin.

Keywords: *Leymus racemosus*; suitable distribution; MaxEnt model; driving factor; future climate change; Junggar Basin

Introduction

Climate change significantly impacts biodiversity and species spatial distribution patterns, with different plant taxa exhibiting varying response strategies to warming [1-3]. Investigating species' suitable distributions and their potential responses to future climate change is crucial for scientific management of biodiversity and effective conservation planning. Xinjiang, located in the hinterland of the Eurasian continent, features unique mountain-basin systems and distinctive arid desert plant geography. Long-term climate aridification, mountain uplift, and desert expansion have created fragmented landscapes that intensify spatial environmental heterogeneity, further influencing species distribution patterns [4-5]. Therefore, studying the geographical distribution of desert plants under climate change and landscape fragmentation is essential for understanding and conserving biodiversity in arid regions.

Leymus racemosus belongs to the genus *Leymus* in the family Poaceae and is distributed across China, Kazakhstan, Mongolia, and Russia [6]. In China, it primarily occurs on mobile or semi-fixed sand dunes in the Junggar Basin of Xinjiang [7]. The species possesses strong resistance to cold, drought, and salinity, serving as a wild relative of common wheat, ideal forage in desert regions, an excellent gene pool for wheat improvement, and a candidate species for vegetation restoration [8-9]. It also plays vital ecological and economic roles in wind prevention, sand fixation, and vegetation restoration in arid desert areas. However, due to climate change, ecological deterioration, human disturbance, low seed germination rates, and slow clonal growth, *L. racemosus* is currently endangered and listed as a Grade III protected plant in Xinjiang [10].

Previous research on *L. racemosus* has focused on transgenic applications [11], wheat breeding [12], seed germination [13], and genetic diversity [14], revealing its high genetic diversity and special germplasm resources, as well as ecological adaptation strategies to desert environments. However, studies on its ecological suitability, spatial distribution characteristics, and potential responses to future climate change in the Junggar Basin remain scarce. Addressing these questions will enhance understanding of distribution patterns and environmental responses of psammophytes in Xinjiang under climate change scenarios.

Species Distribution Models (SDMs) are numerical tools that simulate species ecological niches based on distribution and environmental data [15]. With advances in ecological niche theory and technology, numerous statistical methods have been applied to describe and predict species distribution patterns, including generalized linear models (GLM), classification regression tree analysis (CART), random forest (RF), artificial neural networks (ANN), and maximum entropy (MaxEnt) models. Among these, MaxEnt is one of the most widely used SDMs, capable of achieving robust simulation results even with small sample sizes [16], and has been extensively applied in predicting potential suitable habitats for species.

Based on the suitable distribution characteristics of *L. racemosus* in the Junggar Basin, this study addresses three scientific questions: (1) What are the ecological suitability levels and spatial distribution characteristics of *L. racemosus* in Xinjiang? (2) How might its suitable distribution respond to future climate change? (3) What are the key environmental factors influencing its ecological suitability and distribution?

1. Materials and Methods

1.1 Study Area The Junggar Basin, China' s second largest inland basin, is located in northern Xinjiang between the Altai Mountains, Tianshan Mountains, and western Junggar Mountains. The terrain slopes from higher in the east to lower in the west, with the northern part slightly higher than the southern part. The Gurbantunggut Desert (China' s second largest desert) lies between the northern and southern regions. Desert soils are predominantly fixed and semi-fixed aeolian sandy soils [17]. The basin has a typical mid-temperate climate, with mean annual temperatures of 6–10°C in the north and 3–5°C in the south. Precipitation is relatively evenly distributed across seasons, primarily from westerly airflow [18]. The basin' s flora formed during the Quaternary, with rich ephemeral and xerophytic plant species [19].

1.2 Data Sources Distribution data were obtained from the Chinese Virtual Herbarium (http://www.cvh.ac.cn/), the Teaching Specimen Resource Platform (http://mnh.scu.edu.cn/), the Flora of China (http://zhiwu.cnki.net/), and the Chinese Plant Photo Library (http://www.plantphoto.cn/), supplemented by the *Flora of Xinjiang* and relevant literature [7,20-21], yielding 24 natural distribution points. We verified geographic coordinates using Google Earth and Xinjiang place name directories, then corrected spatial bias using the *biomod2* package in R, retaining one point per grid cell to ensure coverage of the species' natural and climatic range in Xinjiang. Field surveys were conducted near the Irtysh River in Fuhai, Burqin, and Habahe counties, recording plant height, coverage, soil texture, and human disturbance types to validate model predictions [Figure 1: see original paper].

Environmental factors included 19 bioclimatic variables and elevation data from the WorldClim database (http://www.worldclim.org) at 2.5 arc-minute resolution. Future climate data were derived from the MIROC6 global climate model under the shared socioeconomic pathway SSP2-4.5, representing a middle-of-the-road greenhouse gas emission scenario [22]. Slope and aspect were extracted from elevation data using ArcGIS spatial analysis tools. To reduce spatial autocorrelation, we performed Pearson correlation analysis using the *Hmisc* package in R, removing variables with correlation coefficients >0.8. Eight variables were retained: mean diurnal temperature range (Bio2), temperature seasonality (Bio4), minimum temperature of the coldest month (Bio6), precipitation of the wettest month (Bio13), precipitation of the driest month (Bio14), precipitation seasonality (Bio15), slope, and aspect. Soil texture data (1 km resolution) were obtained from the Harmonized World Soil Database, and Xinjiang land use data (2020) were from the Chinese Academy of Sciences Resource and Environmental Science Data Center (http://www.resdc.cn/) for analyzing land cover in suitable areas.

1.3 Model Construction and Environmental Factor Analysis We used MaxEnt version 3.4.1 to simulate potential distributions for baseline and future periods. Model runs employed 75% of distribution data for training and 25% for testing, with 10 replicates and default settings. Model accuracy was assessed using the area under the receiver operating characteristic curve (AUC); values $ $0.85 indicate satisfactory performance [23]. Suitable areas were classified using the natural breaks method into unsuitable, low-suitability, moderate-suitability, and high-suitability zones. Jackknife tests evaluated variable importance, while contribution rates and permutation importance values assessed each factor' s influence [24]. As *L. racemosus* prefers sandy habitats, soil texture was used as a limiting factor to refine baseline distribution analysis.

1.4 Multivariate Environmental Similarity Surface and Most Dissimilar Variable We employed multivariate environmental similarity surface (MESS) and most dissimilar variable (MoD) analyses to investigate climate change magnitude and identify key climatic factors causing distribution pattern shifts [25]. Using MaxEnt' s density.tools.novel function, we calculated similarity (S) between baseline and future periods. S values range from -100 to 100, where S = 100 indicates no difference, S = 0 indicates at least one variable exceeds the reference range, and negative values indicate extreme environmental differences. MoD analysis identified which variables contributed most to dissimilarity. Visualization was performed in ArcGIS 10.2.

2. Results and Analysis

2.1 Suitable Distribution Under Baseline Climate MaxEnt modeling achieved AUC values $ $0.85, indicating high simulation accuracy. Under baseline climate, the suitable distribution area of *L. racemosus* accounts for 5.57% of Xinjiang' s total area, concentrated in the Irtysh River basin, northwestern Junggar Basin, southern Altai slopes, northern Tianshan slopes, and the Ili River Valley [Figure 2: see original paper]. High-suitability areas comprise only 0.71% of the study area, located in the middle and lower Irtysh River basin. Moderate-suitability areas account for 3.86%, while low-suitability areas cover 1.00% .

Soil texture refinement removed 0.05% of the simulated suitable area [Figure 2: see original paper], primarily fragmented habitats near Ulungur Lake, Ebinur Lake, and the northeastern Junggar Basin, as these areas lack suitable sandy substrates.

2.2 Suitable Distribution Under Future Climate Scenarios Compared with baseline climate, suitable habitats will be significantly reduced by 0.99% and 1.33% in 2050 and 2070, respectively, with increasing fragmentation and a northwestward centroid shift toward higher latitudes and elevations [Figure 2: see original paper]. In the 2050 period, reduced habitat will primarily occur in low-suitability areas of central and eastern Junggar Basin and moderate-high suitability areas along the middle-lower Irtysh River. By 2070, suitable areas will further contract and fragment. High-suitability habitat in the lower Irtysh River will shrink, while expansion will occur near the Emin River and western Bogda Mountains, transforming the distribution from a single center (Irtysh River) to multiple centers (Irtysh, Emin, and Bogda) [Figure 2: see original paper].

2.3 Environmental Driving Factors of Suitable Distribution MaxEnt simulation revealed that precipitation of the driest month and temperature seasonality contributed most to the model, with a cumulative contribution of 76.4%

. Permutation importance showed stronger dependence on precipitation seasonality (10.5%) and mean diurnal temperature range. Jackknife tests indicated precipitation of the driest month had the greatest impact on AUC, regularized training gain, and test gain, followed by precipitation seasonality and temperature seasonality. Precipitation factors contributed more than temperature factors across all metrics. Therefore, precipitation of the driest month, temperature seasonality, and precipitation seasonality are key climatic factors.

MESS analysis showed significant climate fluctuations across most of the study area in future periods. Areas with similarity values <0 account for 7.01% and 10.20% in 2050 and 2070, respectively, concentrated in southwestern Junggar and Tarim basins [Figure 4: see original paper]. Mean similarity values at the 24 distribution points are 45.32 (2050) and 39.45 (2070). Areas with changing suitability will experience notable climate fluctuations: reduced areas show similarity values of 10–20 (e.g., northern Junggar Basin), while increased areas show values of 20–30 (e.g., southern Altai and northern Betula slopes) [Figure 4: see original paper].

MoD analysis revealed that minimum temperature of the coldest month and precipitation seasonality will change significantly, causing climate fluctuations in areas with $S < 0$. Precipitation seasonality and precipitation of the driest month are the primary drivers of fluctuations at the 24 distribution points. The most dissimilar variables differ between increasing and decreasing areas: increasing areas are mainly affected by precipitation of the driest month and mean diurnal temperature range, while decreasing areas are influenced by precipitation seasonality and precipitation of the driest month [Figure 4: see original paper].

3. Discussion

3.1 Suitable Distribution of Leymus racemosus Our model accurately visualized the suitable distribution and ecological suitability levels of *L. racemosus* in Xinjiang, primarily in grasslands, drylands, and Gobi near the middle-lower Irtysh River, Ulungur River, Emin River, and western Bogda Mountains [Figure 2: see original paper]. Field surveys revealed severe degradation in most natural populations due to grazing and construction activities. Populations in the middle-lower Irtysh and Ulungur Rivers show high genetic diversity [14,26], confirming these high-suitability areas as core distribution zones. The species mainly occurs in low-cover grasslands (5–20% coverage), drylands, and Gobi, with soils dominated by loam, sandy loam, and sandy clay loam, consistent with field observations.

Our soil texture refinement significantly improved simulation accuracy by filtering unsuitable habitats (e.g., areas overlapping Ulungur and Ebinur Lakes, fragmented northeastern Junggar Basin) [Figure 2: see original paper]. Previous studies demonstrate that incorporating topographic, edaphic, and vegetation indices enhances environmental heterogeneity and model sensitivity [27-28].

3.2 Potential Response of Leymus racemosus to Climate Change Climate change profoundly affects species' life habits, spatial patterns, and distribution [29-30]. Studies on other species show similar trends: suitable habitats for medicinal plants like *Schisandra sphenanthera* will decrease [31], while *Sorbus amabilis* will experience range contraction and fragmentation with upward elevation shifts [32]. Consistently, *L. racemosus* will show significant range reduction and northwestward migration to higher latitudes and elevations.

Precipitation factors primarily constrain *L. racemosus* distribution, with contribution rates exceeding those of temperature factors across all periods [Figure 5: see original paper]. MoD analysis confirms precipitation of the driest month and precipitation seasonality as the main drivers of range changes. The suitable range of precipitation values will contract substantially: precipitation seasonality will narrow from 22.665–140.413 mm (baseline) to 23.218–142.685 mm (2050) and 0–26 mm (2070), while precipitation of the driest month will shrink from 0–20 mm (baseline) to 0–26 mm (2050) and 0–20 mm (2070). Consequently, high-suitability areas along the Ulungur and Irtysh Rivers will experience significant climate fluctuations and habitat loss, threatening genetically important populations. These areas, particularly populations in Altay City and Burqin County, should be prioritized for conservation. Other factors like species interactions, dispersal capacity, and adaptive potential also warrant consideration [33].

4. Conclusion

This study used MaxEnt to simulate and predict the suitable distribution of *L. racemosus* in the Junggar Basin under baseline, 2050, and 2070 climate scenarios. Key findings include:

1) The suitable distribution of *L. racemosus* is concentrated in the Irtysh River basin. Under future climate change, suitable areas will significantly decrease, with the distribution centroid shifting toward higher latitudes and elevations. Precipitation (precipitation of the driest month, precipitation seasonality) is the key climatic factor influencing its distribution.

2) Northwest China is among the most arid regions globally at similar latitudes, where precipitation is the decisive environmental factor for xerophyte growth. Climate change in Xinjiang over the next century will feature rising temperatures, increased precipitation, and higher aridity [34]. In water-deficient areas like desert steppes and mobile/semi-fixed dunes, increased evaporation will exacerbate soil moisture deficits, making water availability the critical limiting factor for forage growth.

3) Integrating field surveys of human disturbance intensity and population genetic diversity studies identifies the middle-lower Irtysh and Ulungur River regions as priority areas for population recovery and natural regeneration. These results enhance understanding of distribution, evolution, and conservation for psammophytes in Xinjiang.

However, this study did not account for uncertainties from different SDM algorithms or climate models, and the results represent only the potential suitable distribution of *L. racemosus* in the Junggar Basin.

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