

Postprint: Changes in the Distribution of *Cenchrus pauciflorus* in China Under Climate Change Scenarios

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Abstract

Cenchrus spinifex is one of the invasive plant species in China, which severely affects livestock farming in pastures and grasslands. Predicting changes in the suitable distribution areas of *Cenchrus spinifex* under future climate change scenarios will provide important theoretical basis and control measures for managing invasive plant species in China. This study employs the MaxEnt model, utilizing 103 geographic distribution records of *Cenchrus spinifex* and 19 climatic environmental variables, to analyze and predict the suitable distribution areas of *Cenchrus spinifex* across China under two climate change scenarios (RCP 4.5 and RCP 8.5) for the 2050s and 2070s. The results indicate that: (1) The current suitable distribution area of *Cenchrus spinifex* accounts for 4.00% of the study region, primarily distributed in the northeastern region at the junction of Inner Mongolia Autonomous Region, Jilin Province, and Liaoning Province. (2) The suitable distribution area of *Cenchrus spinifex* will increase in the future, with the moderately suitable zone exhibiting the greatest expansion, reaching 38.26%. (3) Annual mean temperature, standard deviation of temperature seasonality, and precipitation in the wettest quarter are the primary climatic factors influencing the distribution of *Cenchrus spinifex*. (4) The distribution centroid of *Cenchrus spinifex* will shift westward overall in the future. These results demonstrate that, currently within China, the invaded area of *Cenchrus spinifex* is far smaller than the potentially invadable area, and it may further spread into the arid and semi-arid regions of China in the future. To mitigate the harm caused by large-scale expansion of *Cenchrus spinifex* in northern China, future emphasis should be placed on preventive measures and monitoring of its invasion dynamics.

Full Text

Distribution Area Changes of *Cenchrus spinifex* in China Under Climate Change Scenarios

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Abstract

Cenchrus spinifex is one of the invasive plant species in China that seriously affects livestock farming on pastures and rangelands. Predicting changes in its suitable distribution areas under future climate change scenarios will provide important theoretical foundations and control measures for managing invasive plants in China. Based on the MaxEnt model, this study utilized 103 geographic distribution records of *C. spinifex* and 19 climatic and environmental factors to analyze and predict its suitable distribution areas across China during the 2050s and 2070s under two climate change scenarios (RCP 4.5 and RCP 8.5). The results showed that: (1) The current suitable distribution area of *C. spinifex* accounts for 4.00% of the study region, primarily distributed in the northeastern region where Inner Mongolia, Jilin, and Liaoning provinces meet. (2) Future suitable distribution areas will expand, with medium-suitability areas showing the greatest expansion at 38.26%. (3) Annual mean temperature, standard deviation of seasonal temperature variation, and precipitation in the wettest season are the main climatic factors affecting *C. spinifex* distribution. (4) The distribution centroid of *C. spinifex* will shift westward overall. These results indicate that currently invaded areas in China are far smaller than potentially invadable areas, and the species may further spread into arid and semi-arid regions of the country. To prevent the harm caused by large-scale diffusion of *C. spinifex* in northern China, future prevention measures and invasion monitoring require focused attention.

Keywords: *Cenchrus spinifex*, climate change, MaxEnt model, distribution prediction, distribution centroid

Over the past century, under the influence of global warming, near-surface temperatures in China have shown a significant upward trend, making climate change one of the major challenges facing human society today [?]. Climate is considered a critical environmental factor affecting species reproduction, development, distribution, and biodiversity [?, ?, ?, ?], and climate change will alter biodiversity patterns and biogeographic distributions [?]. The effects on

biological invasions are particularly complex. On one hand, changes in temperature and precipitation patterns can alter interactions with natural enemies and weaken ecosystem resistance [?, ?]. On the other hand, climate change may improve habitat suitability in regions previously unsuitable for invasive organisms, thereby enhancing their competitive ability [?, ?]. Research by Zhang et al. [?] on the worldwide weed *Lantana camara* demonstrated that warming enhances its assimilation and environmental competitiveness, making global warming a crucial factor in its range expansion. Since invading Xinjiang, *Solanum rostratum* has shown strong comprehensive adaptability in three habitat types—oases, desert steppes, and deserts—particularly in oases, and is currently in a rapid spread phase [?]. In terms of overall speed and scale, climate change has already triggered global biological responses [?], with organisms in marine, freshwater, and terrestrial ecosystems accelerating shifts in their distribution ranges to seek more suitable environmental conditions [?, ?, ?, ?]. Based on meta-analysis, Chen et al. [?] estimated that species distributions are currently shifting to higher elevations at a median rate of 11.0 m per decade and to higher latitudes at 16.9 km per decade.

Species distribution models (SDMs) associate species occurrence data with environmental and geographic data to estimate species' ecological niches based on selected algorithms, reflecting habitat preferences and thereby simulating potential suitable distributions and predicting future ranges [?]. With mature climate change prediction methods, SDMs have been widely applied in studying suitable habitats for animals [?, ?], plants [?, ?, ?], and microorganisms [?] [?]. Sayit et al. [?] used the MaxEnt model to study the potential distribution patterns of the invasive plant *Xanthium spinosum* in Xinjiang, finding that its distribution had not reached saturation and showed a radial diffusion trend. Chen et al. [?] reported that the invaded area of the invasive species *Tithonia diversifolia* was far smaller than its potential invadable area, and the species would continue to spread in the future.

Cenchrus spinifex is an annual herbaceous plant in the Poaceae family, genus *Cenchrus*, native to North America and tropical coastal regions [?]. It has currently invaded the West Indies, Argentina, South Africa, and other countries, and was first discovered in China in the 1930s [?]. *C. spinifex* possesses a massive seed bank, with seed densities ranging from 213 to 14,050 seeds per square meter, averaging 5,712 seeds/m² with a coefficient of variation as high as 93% [?]. Its characteristics of drought, cold, and barren tolerance [?] enable easy survival in sandy loam soils, where it can rapidly form large monoculture populations once introduced. Additionally, its spiny burr fruits can injure the mouths and stomachs of livestock such as cattle and sheep when ingested, causing a series of animal diseases and even death from gastric perforation in severe cases [?]. As invasion intensifies, *C. spinifex* reduces biodiversity in natural grasslands [?], causing serious economic losses to agricultural and pastoral production. Conservative estimates indicate annual direct economic losses of 1.4 billion yuan in invaded areas (calculated based on losses at the time, excluding forest land) [?, ?, ?]. *C. spinifex* has become a highly destructive invasive plant in China'

s agricultural and pastoral regions. To date, most research on *C. spinifex* has focused on its physiological and biochemical characteristics, genetic mechanisms, and invasion control [?, ?, ?, ?, ?], with no reports on its geographic distribution. Given its strong adaptability and invasiveness, coupled with accelerating climate change trends, this study adopted the MaxEnt model based on two climate emission scenarios (RCP 4.5 and RCP 8.5) in northern China to address: (1) the distribution potential and key influencing factors of *C. spinifex* under current climate conditions; and (2) the impacts of future climate conditions on its suitable habitats.

1.1 Distribution Data Acquisition and Study Area Determination

By reviewing academic journals, dissertations, and reports on *C. spinifex*, and searching relevant platforms such as the Chinese Virtual Herbarium (<http://www.cvh.ac.cn/>), we collected 108 natural distribution records. Some data lacked precise geographic coordinates, which were obtained and calibrated using Google Earth. After removing ambiguous descriptions and duplicate coordinates, and to avoid overfitting, only one occurrence point was retained per 1 km × 1 km grid cell, resulting in 103 final distribution records. Sample coordinates were stored in an Excel spreadsheet and converted to CSV format for model construction.

Currently, *C. spinifex* is mainly distributed in the tri-provincial junction area of northwestern Liaoning, eastern Inner Mongolia, and southern Jilin. Based on this distribution, the study area was extended in all directions (92°13' -135°05' E, 31°1' -52°13' N), covering Inner Mongolia, Heilongjiang, Jilin, Liaoning, Hebei, Beijing, Tianjin, Shanxi, Shaanxi, Ningxia, Gansu, and Shandong.

[Figure 1: see original paper]

1.2 Environmental Variable Data

Current climate data (1970–2000) and future climate data (2050s and 2070s) were downloaded from the WorldClim Global Climate Data website (Version 1.4, <http://www.worldclim.org>), including 19 bioclimatic variables such as annual mean temperature and annual precipitation. The BCC-CSM1-1 model, which demonstrates strong simulation capability in China [?], was selected. This model includes four new emission scenarios adopted in the IPCC Fifth Assessment Report, namely Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 [?]. This study used future climate data under RCP 4.5 and RCP 8.5 scenarios to predict distributions in the 2050s and 2070s. Both current and future climate data had a spatial resolution of 30 arc-seconds. To avoid multicollinearity, highly correlated climate variables ($|\text{Pearson's } r| > 0.8$) were eliminated, resulting in seven variables for model construction: annual mean temperature (bio1), standard deviation of seasonal temperature variation (bio4), precipitation in the wettest season (bio16), isothermality (bio3), precipitation seasonality coefficient of variation (bio15), precipitation in the driest

month (bio14), and maximum temperature in the warmest month (bio5). All data were masked to the study area, projected to WGS1984 coordinate system, and converted to ASCII format.

1.3 Vector Maps and Model Sources

The China administrative division map was obtained from the National Geographic Information Public Service Platform (<http://bzdt.ch.mnr.gov.cn/>), with map approval number GS(2020)4619. MaxEnt software version 3.4.1 was used [?, ?], and ArcGIS 10.6 (Environmental Systems Research Institute, USA) was employed for geographic information processing.

1.4 Model Construction

The Maximum Entropy (MaxEnt) model is currently a well-performing and widely applied ecological niche model [?]. Based on maximum entropy theory, it makes unbiased inferences about species' spatiotemporal distributions from known occurrence data [?]. Proposed by Phillips [?], it is a general machine learning method [?]. Due to its ease of operation and high accuracy, MaxEnt has gained widespread attention in species distribution prediction studies.

In this study, filtered *C. spinifex* distribution data and environmental variables were imported into MaxEnt software. Twenty-five percent of occurrence points were selected as test data, with the remainder as training data for model construction. Response curves and jackknife analysis were selected to evaluate environmental factor correlations, with logistic output format and bootstrap replication type. The model was run 20 times with default settings for other parameters. Model outputs were imported into GIS, and predictions were reclassified based on the maximum training sensitivity plus specificity threshold (MTSS) [?] to differentiate suitability levels.

1.5 Model Prediction Accuracy

The receiver operating characteristic (ROC) curve was used for model accuracy validation, with the area under the curve (AUC) serving as the evaluation criterion based on true positive and false positive rates [?]. As AUC values are threshold-independent, they enable comparison between models and are widely applied. AUC ranges from 0 to 1, with higher values indicating better prediction performance: 0.7–0.8 is considered relatively accurate, 0.8–0.9 highly accurate, and 0.9–1.0 extremely accurate [?].

2.1 Model Validation

According to MaxEnt model results, the ROC curve is shown in [Figure 2: see original paper]. The AUC value was 0.987, significantly greater than the random prediction value of 0.5. A larger AUC value, closer to 1, indicates higher

model accuracy. This demonstrates that the MaxEnt model has high predictive accuracy for *C. spinifex* distribution.

[Figure 2: see original paper]

2.2 Current Potential Geographic Distribution of *Cenchrus spinifex*

As shown in [Figure 3: see original paper], the suitable range of *C. spinifex* in China is concentrated in northeastern and northern regions. Specifically: (1) High-suitability areas primarily include the tri-provincial junction of Inner Mongolia, Jilin, and Liaoning. In Inner Mongolia, this encompasses Tongliao City and central, eastern, and southern Chifeng City, with Tongliao having the largest high-suitability area proportion. In Jilin, high-suitability areas include southern Baicheng City, Songyuan City, and eastern Siping City. In Liaoning, small high-suitability areas occur in northeastern Chaoyang City, central and northeastern Fuxin City, and northern Jinzhou, Shenyang, and Tieling cities. High-suitability areas account for 2.10% of the study region. (2) Medium-suitability areas include northern Tongliao and eastern Chifeng in Inner Mongolia, southern Hinggan League, central and southern Baicheng and southwestern Songyuan in Jilin, and most areas of Shenyang, Tieling, Chaoyang, northern Huludao, and Jinzhou in Liaoning. Medium-suitability areas account for 1.48% of the study region. (3) Low-suitability areas surround high- and medium-suitability zones, mainly in Inner Mongolia, Jilin, and Liaoning, accounting for 0.42% of the study region.

[Figure 3: see original paper]

2.3 Climate Impact Factors on Potential Suitable Areas

Among the seven environmental variables used in MaxEnt modeling (), the top three contributors were bio1 (annual mean temperature, 35.4%), bio4 (standard deviation of seasonal temperature variation, 31.4%), and bio16 (precipitation in the wettest season, 20.3%), with a combined contribution of 87.1%. Other variables contributed: bio3 (isothermality, 9.0%), bio15 (precipitation seasonality, 2.5%), bio14 (precipitation in the driest month, 0.8%), and bio5 (maximum temperature in the warmest month, 0.5%).

To further explore climate factor effects, response curves were generated for the top four contributing factors (cumulative contribution 87.1%) to analyze species occurrence probability responses ([Figure 4: see original paper]) and annual mean precipitation in distribution areas under each scenario ([Figure 5: see original paper]). Results showed that occurrence probability peaked at approximately 0.7 when annual mean temperature (bio1) was 6–7°C, decreasing rapidly with higher temperatures and reaching zero above 10°C. At around -8°C, occurrence probability gradually increased, stabilizing at approximately 0.3 at -10°C. For temperature seasonality (bio4), maximum survival probability reached 0.7 at 1,350, decreasing rapidly to 1,500. Precipitation in the wettest season (bio16) showed higher occurrence probability at 300 mm, but survival probability

decreased rapidly with increasing rainfall. Isothermality (bio3) showed highest survival probability at 26°C. Under current climate, suitable distribution areas are mainly around the 400 mm isohyet, with annual precipitation ranging 359–660 mm ([Figure 5: see original paper]). Under RCP 4.5, future suitable areas have annual precipitation of 15–1,417 mm, while under RCP 8.5, this ranges 39–1,212 mm. Overall, *C. spinifex* demonstrates good cold tolerance and strong adaptability to northern cold environments. Regarding precipitation, future potential distribution areas under both scenarios are mainly in regions with annual precipitation of 15–700 mm, primarily in Inner Mongolia's temperate continental monsoon climate zone where the species' growth cycle aligns closely with the rainfall pattern.

[Figure 4: see original paper]

[Figure 5: see original paper]

Jackknife analysis was used for regularized variable testing. As shown in [Figure 6: see original paper], when using single environmental variables, those with the greatest impact on regularized training gain were annual mean temperature (bio1), temperature seasonality (bio4), and maximum temperature in the warmest month (bio5), with bio1 being the most important factor for current suitable distribution.

[Figure 6: see original paper]

2.4 Prediction of Climate Change Impacts on Distribution Range

Based on future climate scenarios RCP 4.5 (medium emission) and RCP 8.5 (high emission), MaxEnt modeling simulated *C. spinifex* geographic distribution in the 2050s and 2070s. Using the model-derived threshold (MTSS = 0.157), predictions were resampled to classify habitat suitability into four categories: unsuitable (<MTSS), low-suitability (MTSS–0.2), medium-suitability (0.2–0.4), and high-suitability (>0.4). Spatial distributions ([Figure 7: see original paper]) and suitable habitat areas () were obtained for each scenario.

[Figure 7: see original paper]

Under both RCP 4.5 and RCP 8.5 scenarios in the 2050s and 2070s, *C. spinifex* distribution shows expansion trends, with high-suitability areas expanding significantly compared to current distribution. In the 2050s, high-suitability habitats account for 27.03% (RCP 4.5) and 12.69% (RCP 8.5) of the area. Under RCP 4.5, high-suitability areas expand from three provinces to include Heilongjiang, Hebei, Shandong, Shanxi, Shaanxi, Gansu, Ningxia, Beijing, and Tianjin, with Inner Mongolia remaining the most severely invaded region. In the 2070s, high-suitability areas account for 11.56% (RCP 4.5) and 10.85% (RCP 8.5), decreasing compared to the 2050s and existing only in small regions of Inner Mongolia, Liaoning, Hebei, and Shandong, with very small areas in Jilin and Shanxi.

Current medium-suitability areas (0.2-0.4) account for 1.48%, expanding to 25.02% (RCP 4.5) and 34.40% (RCP 8.5) in the 2050s, and 39.74% (RCP 4.5) and 39.72% (RCP 8.5) in the 2070s. Low-suitability areas (MTSS-0.2) currently account for 0.42%, increasing to 10.34% (RCP 4.5) and 9.79% (RCP 8.5) in the 2050s, and 9.88% (RCP 4.5) and 14.96% (RCP 8.5) in the 2070s. Low-suitability areas surround medium- and high-suitability zones, extending north to the Greater Khingan Mountains in Heilongjiang, west to Jiuquan City in Gansu, and south to Hanzhong City in southern Shaanxi.

Under RCP 4.5, from the 2050s to 2070s, both high- and low-suitability areas decrease to some extent, with high-suitability areas shrinking by nearly 15.47%, while medium-suitability areas expand by approximately 14.72%. Under RCP 8.5, high-suitability areas decrease by 1.84% from 2050 to 2070, while medium- and low-suitability areas show expansion trends, with medium-suitability areas increasing by about 5.52% and low-suitability areas by 5.17%. In the 2050s under RCP 4.5, *C. spinifex* invasion is most severe across most of Inner Mongolia, with the largest high-suitability area proportion.

The centroid of suitable distribution areas quantitatively describes distribution changes ([Figure 8: see original paper]). Under current climate, the distribution centroid is in Tongliao City, Inner Mongolia. Under future scenarios, the centroid shifts substantially. Under RCP 4.5, it migrates westward from Tongliao to Fengning Manchu Autonomous County in Chengde City, Hebei in the 2050s, then further west to Zhangbei County in Zhangjiakou City, Hebei in the 2070s. Under RCP 8.5, the centroid first shifts westward from Tongliao to Guyuan County in Zhangjiakou City, Hebei in the 2050s, then northeastward to western Duolun County in Xilingol League, Inner Mongolia in the 2070s.

[Figure 8: see original paper]

3.1 Changes in Spatial Distribution Under Climate Change

Based on MaxEnt modeling with 103 occurrence records and seven climate factors, this study demonstrates the potential distribution of the invasive plant *C. spinifex* across northern China under baseline (current) and future climate (RCP 4.5, RCP 8.5) conditions. Results indicate that *C. spinifex* distribution in China has not reached saturation and is gradually expanding, radiating outward from Tongliao City, Inner Mongolia. This aligns with field survey results from Sun et al. [?] showing rapid spread in occurrence area through point, belt, and patch patterns within small ranges, severely affecting northern agricultural-pastoral industries and ecological environments. Under future climate scenarios, China's semi-humid regions are highly likely to be invaded. Climate change impacts vary among species—some face endangerment or extinction [?], while others benefit and expand their ranges [?]. This study shows *C. spinifex* clearly belongs to the latter category, consistent with studies on *Solanum rostratum* in Xinjiang [?] and *Ambrosia trifida* [?], where invasive species with strong adaptability rapidly expand their survival ranges under altered climate conditions to

become community dominants.

Research has shown that *C. spinifex* reproduces rapidly and has strong drought tolerance, making it suitable for propagation in arid and semi-arid sandy lands of China's agricultural-pastoral ecotone [?]. China has extensive desertified land types covering 13.45% of its territory, widely distributed across 30 provinces (autonomous regions) except Taiwan and Shanghai [?]. Xu et al. [?, ?] predicted that under RCP 4.5 and RCP 8.5 scenarios, low to moderate desertification sensitivity would dominate in North China, with high-sensitivity areas decreasing but becoming more sensitive in Xinjiang and Gansu. Additionally, desertification 重心 in North China shifted from high to low latitudes between 2001–2015 [?]. However, recent trends show decreasing desertification intensity, with weakening severity more pronounced south than north of the Yangtze River [?]. These changing desertification patterns alter *C. spinifex* invasion directions, and if invasion occurs, it will seriously affect grassland health [?]. This suggests that future westward and southward expansion under climate change scenarios may result from global warming, frequent extreme climate events, vegetation cover changes, and intensified human activities, while desertification and landscape pattern changes in northwestern China influence invasion direction.

3.2 Relationship Between *Cenchrus spinifex* and Environmental Factors

Model results show that annual mean temperature (bio1), temperature seasonality (bio4), and precipitation in the wettest season (bio16) are the top three contributing factors, indicating that precipitation and temperature are critical constraints on future distribution. Under RCP 4.5 and RCP 8.5 scenarios, potential distribution areas will expand substantially in the 2050s and 2070s, invading regions with increased annual mean precipitation. Under future climate scenarios, the North China Plain and northern Shandong have annual precipitation of 400–700 mm with relatively abundant rainfall, while central-northern Inner Mongolia, Shaanxi, Shanxi, northern Ningxia, and central Gansu have 15–450 mm annual precipitation—far below evaporation rates. With wind erosion, sandy soils, and simple vegetation structure, these regions provide suitable growth conditions for *C. spinifex*. Investigations of *C. spinifex* biological characteristics [?, ?] indicate that under appropriate temperatures and sufficient moisture, it can germinate year-round, with its life cycle closely matching the rainy season. This demonstrates that rainfall and temperature strongly influence its potential distribution. In addition to temperature and precipitation, factors such as light intensity, soil texture, and interspecific interactions also affect plant distribution. Future studies should incorporate more influencing factors to obtain more precise results and further analyze *C. spinifex* distribution responses to climate change, providing theoretical support and practical guidance for invasive plant management in China.

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