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Article

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Potential habitat suitability analysis under climate change for the native grass, *Kengyilia thoroldiana,* on the Qinghai-Tibet Plateau

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Abstract: *Kengyilia thoroldiana* is a dominant species in the desertification area of the Qinghai-Tibet Plateau. In this study, based on 88 sample points of *Kengyilia thoroldiana*, the Maximum Entropy (MaxEnt) method was used to analyze the current dominant factors of the distribution area of *Kengyilia thoroldiana* and predict its potential distribution. The results show that the training and test data area under the curve (AUC) were 0.934 ± 0.004 and 0.944 ± 0.043, respectively, which indicated the reliability of the predicted results. Based on climatic variables and the results of the "Jackknife" method, The results showed that temperature is the main cause of *Kengyilia thoroldiana* distribution. By simulating the potential distribution of *Kengyilia thoroldiana*, the highly suitable areas were mainly located in the west, south, and

southeast of Qinghai, southwest Gansu, and eastern Tibet. In future climate scenarios, the total suitable area for *Kengyilia thoroldiana* showed an expanding trend. According to the Sustainable Development (SSP126) scenario, the highly suitable areas could increase by 4.72% from 2021 to 2040 compared with the current climate scenario, and the highly suitable areas could increase by 12.71% from 2041 to 2060. An increase in the suitable areas of *Kengyilia thoroldiana* is essential for the ecological restoration of degraded grasslands.

Keywords: Maximum Entropy (MaxEnt) model; *Kengyilia thoroldiana*; potential distribution area; prediction of suitable area

1. Introduction

Climate change not only affects the growth, development, and reproduction of plants but also the geographical distribution of species (Kozak et al. 2008). Habitat is the environment on which plants depend, and climate change forces species to choose suitable habitats, which in turn determines the geographical distribution of species and the area of suitable habitats, a comprehensive understanding of the mechanisms leading to extinction will provide reliable and effective recommendations for the conservation of endangered species and biodiversity. Predicting the potential geographical distribution of species can help to understand their predict their potential survival .It is also crucial to study the potential distribution, introduction, and domestication of species to provide a theoretical basis for vegetation investigation and conservation of endangered species (Zhigila et al. 2023).

The Qinghai -Tibet Plateau is the highest altitude plateau in the world, known as the "Roof of the World". The soil particles of the Qinghai-Tibet Plateau are mainly sand, accounting for more than 70% of the total particles，Climate and NDVI values are the most important factors affecting the spatial distribution of soil texture on the Tibetan Plateau（Liu et al. 2022）. The Qinghai -Tibet Plateau is rich in resources, but due to human activities such as overgrazing, overcultivation, excessive development and utilization of water resources, and vegetation destruction, the ecosystem is fragile, mainly manifested in low temperatures, large-scale permafrost, poor soil, desertification and soil erosion in some areas（Jia et al. 2018; Liu et al. 2023; Niu et al. 2021）, and reduced biodiversity, resulting in poor plant growth ability in the Qinghai Tibet Plateau region. Therefore, it is necessary to grow plants that can survive in sandy loams, resist to droughts and sand, and grow vigorously. The dominant species of sandy loam on the Qinghai-Tibet Plateau, *Kengyilia thoroldiana* (Oliv.) J. L. Yang, C. Yen & B. R. Baum 1992 has the characteristics of drought and sand resistance. It is a native grass species suitable for growth in alpine grasslands, and studies have shown that *Kengyilia thoroldiana* has important economic and ecological value (Li et al. 2024). However, at present, the breeding technology is immature, and the seeds of *Kengyilia thoroldiana* have strong grain drop and low seed yield, therefore, it needs to be introduced and expanded. The environment of the Qinghai-Tibet Plateau is harsh, and only species that have adapted to the harsh natural environment and cold resistance can survive for a long time, and the *Kengyilia thoroldiana* shows strong adaptability in the cold, arid and barren environment, and has the characteristics of early

regreening, and is the native grass species suitable for growth in the alpine grassland. *Kengyilia thoroldiana* is a perennial herb of Poaceae, mainly distributed in high-altitude areas (3700–5200 m) in Central Asia. In China, *Kengyilia thoroldiana* is concentrated in Qinghai, Tibet, Xinjiang, and Sichuan (Li et al. 2009; Yang et al. 1992). It is mainly distributed in the Qinghai-Tibet Plateau. Because *Kengyilia thoroldiana* exhibits strong soil retention, root extension, strong soil fixation, and cold, drought, salt, alkali, and sand resistance, as well as early greening, multiple tillers, and flower growth. It is a suitable native and ecological grass species for the growth of alpine grasslands in the Sanjiangyuan region (Shi et al. 2003; Li et al. 2010a). The soil type of *Kengyilia thoroldiana* is mainly warm sand soil without grass cortex, which is not conducive to the growth and development of most plants, and the growth process is slow. However, in barren dune soil at an extremely high altitude, *Kengyilia thoroldiana* can still maintain its height, cover, and yield (Li et al. 2009), which is of great significance for alleviating the lack of suitable grass species in the Sanjiangyuan alpine sand region and restoring the ecology of the Qinghai-Tibet Plateau. A large number of studies have shown that artificial grassland planting is the main means of ecological restoration of severely and extremely degraded grasslands, and so far, no forage varieties suitable for alpine grassland planting and ecological grass species for vegetation restoration have been selected, and the extreme lack of suitable grass species has made no significant progress in the vegetation restoration of degraded grassland in alpine grassland.Therefore, it is important to study the distribution of *Kengyilia thoroldiana* and understand the leading environmental factors that restrict its growth. Due to the

overgrazing, lagging grassland management technology and other inappropriate human disturbances in the Qinghai-Tibet Plateau, grassland degradation to varying degrees, because Solo grass is cold-tolerant, drought-tolerant and adaptable, and can show strong vitality in high-altitude areas, so it is necessary to introduce and expand the vegetation, which has a significant impact on grassland ecological restoration.This study provides a theoretical basis for the cultivation of ecological grass species and environmental restoration By predicting the suitable habitat of Halomyrtle, this study is helpful for the cultivation and propagation of Chorax vulgaris, and provides a theoretical basis for ecological grass cultivation and environmental restoration on the Qinghai-Tibet Plateau.

Through the development of geographic informatization, the sharing of global data resources, and the joint application of ecological niche models and geographic information systems, it is possible to accurately calculate the distribution of species and predict suitable areas for them. Under environmental changes, The Maximum Entropy Model (MaxEnt) can quantitatively analyze environmental factors and predict suitable areas for species by generating species response curves without any influence from the sample size. MaxEnt is the most accurate and widely used species distribution model. The maximum entropy model is based on the principle of maximum entropy, when predicting the probability distribution of a sample or event, all the known constraints should be met first, and then no subjective assumptions should be made about the unknown situation, so that the probability distribution is the most uniform and the prediction risk is minimized. The maximum entropy model is widely used in practical problems such as species distribution, and predicts the distribution of species by

112 modeling the probability distribution of species occurrence. MaxEnt has been used in
113 many related studies, such as the prediction and suitability evaluation of various
114 animals and plants (Aouinti et al. 2022; Hou et al. 2023; Soilhi et al. 2022). Species
115 distribution models (SDMs) are models that predict the potential distribution area of
116 species based on species distribution information and corresponding environmental
117 variable data. It is one of the most frequently used species distribution models, so the
118 maximum entropy model (MaxEnt) recommended in Appendix C of the Habitat
119 Assessment Method of the Technical Guidelines for Environmental Impact
120 Assessment (HJ19-2022) was used to predict the suitable habitat of *Kengyilia*
121 *thoroldiana.* Currently, research on *K. thoroldiana* mainly focuses on seed germination
122 (Li et al. 2010b), genetic analysis (Jiang et al. 2005), cultivation methods (Xie, 2007),
123 adversity response (Sun et al. 2010), and vegetation restoration applications (Chen et
124 al. 2006), but the analysis of the main influencing factors and potential distribution
125 areas is lacking. With the continuous improvement of grassland ecological restoration
126 and the promulgation of relevant regulations, the demand for high-quality grass seeds
127 has increased sharply, and it is predicted that the suitable habitat of Thoroughtis grass
128 will play an important role in its cultivation, propagation and further scientific and
129 sustainable development. Considering the changeable weather situation, the suitable
130 growth environment for *Kengyilia thoroldiana* was predicted in advance according to
131 future climate environmental factors to provide theoretical support for resource
132 investigation and introduction cultivation. The current and future potential distribution
133 areas of *Kengyilia thoroldiana* were predicted using the MaxEnt model. The evaluation

of the dominant climatic factors affecting *Kengyilia thoroldiana* provides a scientific basis for protecting the stability of the ecosystem on the Qinghai-Tibet Plateau under climate change conditions.

2. Materials and Methods

2.1. Collection of existing geographic distribution data of *Kengyilia thoroldiana*

Combined with local flora and literature reports, we obtained 96 where *Kengyilia thoroldiana* resources were previously reported in the Chinese Virtual Herbarium (https://www.cvh.ac.cn/) and The Global Biodiversity Information Facility database (https://www.gbif.org/zh/). After removing duplicate sample points, we selected 88 distribution points as experimental data (Figure 1).

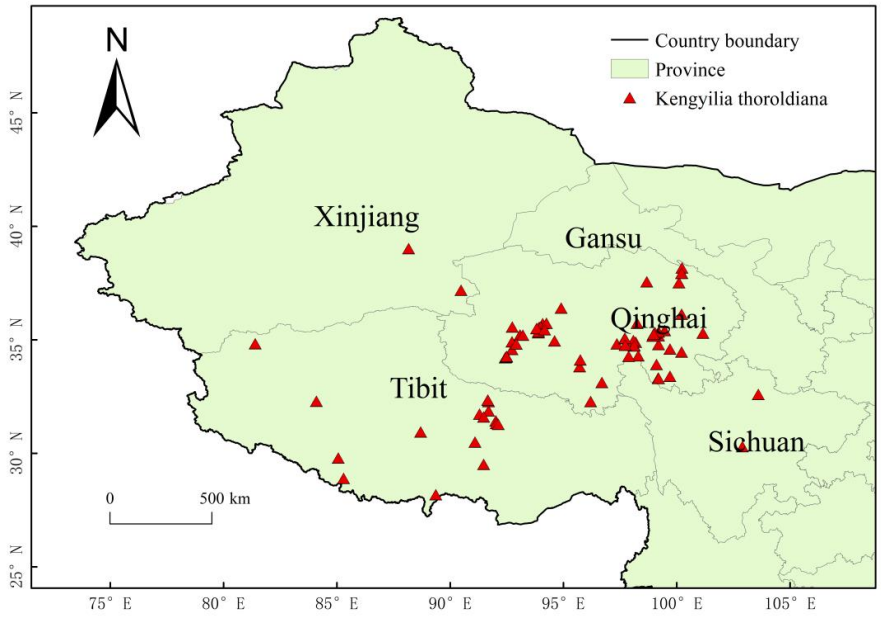


Figure 1. Distribution of *Kengyilia thoroldiana.*

2.2. Acquisition of climate data

Climate data were obtained from the latest climate data layer provided by the WorldClim website (http://www.worldclim.org/). In January 2020, the website

149 released climate data such as rainfall, temperature, solar radiation, and wind speed
150 from 1970 to 2000, as well as data on 19 bioclimatic variables (Table 1). Bioclimatic
151 variables were derived from monthly temperature and rainfall values to generate
152 biologically meaningful variables. They are often used in species distribution
153 modeling and related ecological modeling techniques. All climate variable data layers
154 adopt a spatial resolution of 30″ (about 1km). The World Climate Research
155 Programme (WCRP) has successfully organized five International Coupled Model
156 Intercomparison Programs (CMIP) sessions, increasing the number of models
157 participating in the CMIP from 10 (CMIP1) to more than 40 (CMIP5), increasing the
158 number of Chinese models participating in the program from one to five, and
159 officially launching the CMIP 6 experiment in 2018. Future Climate Data (2021-
160 2040, 2041-2060) were based on the Couple Model Intercomparison Project Phase 6
161 (CMIP 6). Shared Socioeconomic Pathways (SSPs) were applied to the scenario
162 pattern comparison scheme, which is a critical component of CMIP 6. The SSPs
163 contain four emission scenarios in the IPCC Sixth Assessment Report, and we
164 selected the Sustainable Development (SSP126) scenario (Pierce et al. 2022). After
165 the Chinese region was obtained by mask extraction in ArcGIS 10.8, each
166 environmental variable was converted to the ASCII format.

167 Table 1. Bioclimatic variables description

Variable	Description
Bio1	Mean annual temperature
Bio2	Mean diurnal range
Bio3	Isothermality
Bio4	Temperature seasonality

Bio5	Max temperature of warmest month
Bio6	Minimum temperature of coldest month
Bio7	Temperature annual range
Bio8	Mean temperature of wettest quarter
Bio9	Mean temperature of driest quarter
Bio10	Mean temperature of warmest quarter
Bio11	Mean temperature of coldest quarter
Bio12	Annual precipitation
Bio13	Precipitation of wettest month
Bio14	Precipitation of driest month
Bio15	Precipitation seasonality
Bio16	Precipitation of wettest quarter
Bio17	Precipitation of driest quarter
Bio18	Precipitation of warmest quarter
Bio19	Precipitation of coldest quarter

168 2.3. Model construction and evaluation

169 The geographic distribution information of 88 *Kengyilia thoroldiana* and 19
170 climate data points were imported into MaxEnt 3.4.1 software for calculation. In order
171 to ensure the accuracy of the operation, the data were simulated, and the total number
172 was divided into 4 equal parts, three of which (75% of the total data) were selected as
173 the training set, and one (25%) was selected as the test subset of 10,000 iterations, 10
174 iterations, and 10 repeated training sessions. Choosing an average after ten simulations
175 improves the accuracy of the model. Select "Jackknife" to calculate the percentage
176 contribution and rank importance values for each climate, to test the restriction strength
177 of the geographical distribution of *Kengyilia thoroldiana*. The area under the curve
178 (AUC) of the model was evaluated using the receiver operating characteristic (ROC)
179 curve. The kappa statistic ranges from 0 to +1, where +1 indicates excellent agreement
180 between predictions and observations, and 0 indicates agreement no better than random
181 classification. This suggests the following ranges of agreement of the kappa statistic

(K): < 0.7, poor; 0.7–0.8, useful; 0.8–0.9, good; and > 0.9, excellent (Braunisch and Suchant 2010). The MaxEnt predictions were introduced into ArcGIS 10.8, and the species distribution of *Kengyilia thoroldiana* was divided into four grades using the natural breaks: not-suitable (< 0.09), poorly suitable (0.09-0.33), moderately suitable (0.33-0.62) and highly suitable (> 0.62) (Li et al. 2023; Y. Yang et al. 2023; Zhang et al. 2023). The ArcGIS 10.8 software is used to calculate and calculate the corresponding area of each level.

3. Results

3.1. Simulated prediction accuracy assessment

Among the 88 geographically distributed coordinates of *Kengyilia thoroldiana*, 66 were randomly selected as training samples, and the remaining 22 were used as test samples. The results showed that the AUC of the model training date was 0.934 ± 0.004, and the AUC of the test date was 0.944 ± 0.043, which were all greater than 0.9, and greater than the AUC of the random predicted distribution model. Figure 2 shows the AUC for the test date. This indicated that the potential distribution area predicted by the MaxEnt model had high accuracy, high reliability, and no randomness.

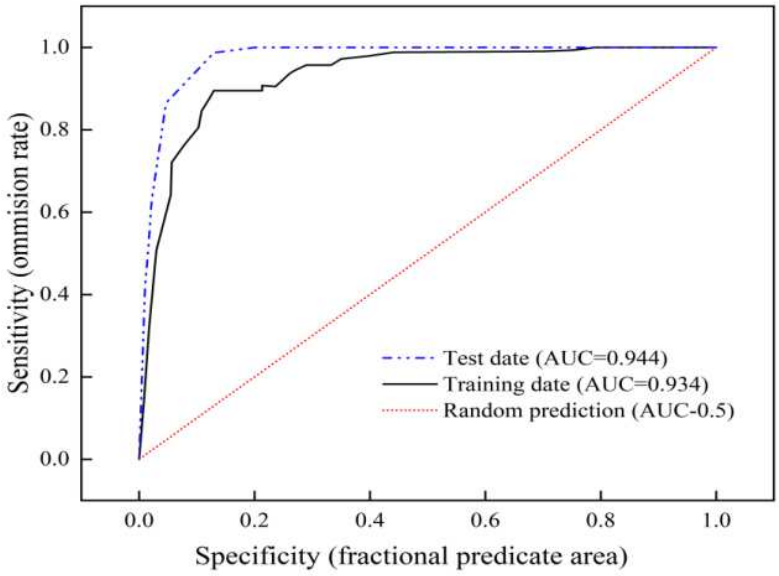


Figure 2. Subject Receiver operating characteristic curve (ROC) predicting the potential distribution of *Kengyilia thoroldiana* based on the MaxEnt model.

3.2. Climate factors affecting the distribution of *Kengyilia thoroldiana*

Percent contribution and displacement importance are two other metrics that can be used in MaxEnt to analyze the importance of the influencing factors. Percent contribution refers to the contribution of each influencing factor to habitat selection during the training process of the MaxEnt model, whereas displacement importance is the degree of reduction in AUC values obtained from model simulations after the random replacement of climatic factors at sample sites. Based on these two values (see Table 2), the five parameters that contributed the most to the model were the mean temperature of warmest quarter (Bio10, 50.2%), isothermality (Bio3, 16.3%), temperature seasonality (Bio4, 9.5%), mean temperature of coldest quarter (Bio11, 4%), and precipitation of wettest quarter (Bio16,4%). The five most important parameters in determining the selection of suitable habitats for *Kengyilia thoroldiana* were temperature seasonality (Bio4, 52.3), precipitation of wettest quarter (Bio16, 11.7),

mean temperature of coldest quarter (Bio11, 7.8), precipitation of wettest month (Bio13, 5.8), and precipitation of warmest quarter (Bio18, 4.7).

The results of the jackknife test (Figure 3) showed that the top five climatic factors in the training gain score were the mean temperature of the warmest quarter (Bio10), maximum temperature of the warmest month (Bio05), mean temperature of the wettest quarter (Bio08), mean annual temperature (Bio1), and isothermality (Bio03). Thus, temperature is a key environmental variable affecting the distribution of *Kengyilia thoroldiana*..

Table 2. The contribution rate of climate factors to *Kengyilia thoroldiana* distribution.

Variables	Percent contribution/%	Permutation importance
Bio10	50.2	0.2
Bio3	16.3	0.7
Bio4	9.5	52.3
Bio11	4	7.8
Bio16	4	11.7
Bio12	2.8	0.9
Bio18	1.8	4.7
Bio2	1.7	4.2
Bio19	1.3	0.2
Bio7	1.3	0
Bio8	1.2	0
Bio13	1.1	5.8
Bio5	1	0.1
Bio14	0.9	0.6
Bio6	0.8	3.3
Bio17	0.7	0.1
Bio1	0.6	3.3

Bio9	0.4	4
Bio15	0.1	0

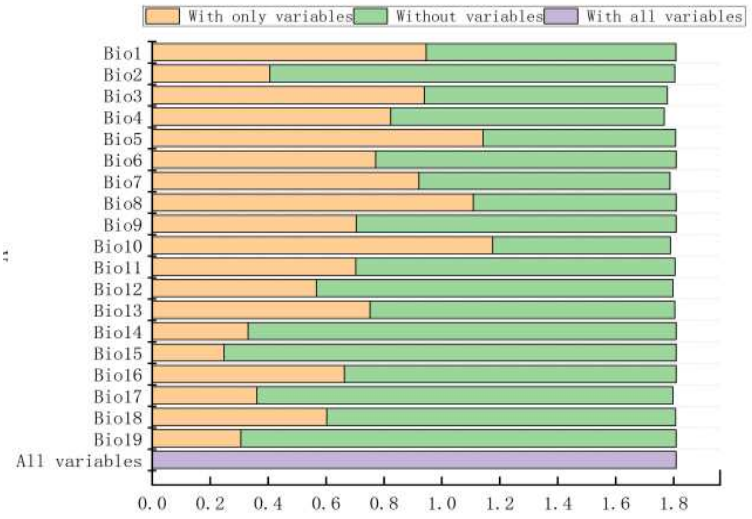


Figure 3 Jackknife-test scores for the potential distribution model.

3.3. Climate characteristics of the *K. thoroldiana* distribution area

The response curves show how the probability of occurrence varies with each climatic factor. Figure 4 shows the response curves of the above eight climatic factors to *Kengyilia thoroldiana* fitness. With an increase in the climate factor value, there is a rule of slow increase, rapid increase, rapid decline, and slow decrease. If the existence probability of *Kengyilia thoroldiana* is greater than 0.62 (Liu et al. 2020; Gun et al. 2023), it means that the numerical range of the corresponding environmental factors is conducive to growth. Therefore, the climatic characteristics of *Kengyilia thoroldiana* are: Bio01, -5.8～1.2 ℃; Bio3, 35.6～42.3; Bio04, 778～937; Bio05, 11.1～16.2 ℃; Bio08, 2.4～9.2 ℃; Bio10, 4.5～9.4 ℃; Bio11, -16.4～11.9 ℃; Bio16, 144-284 mm.

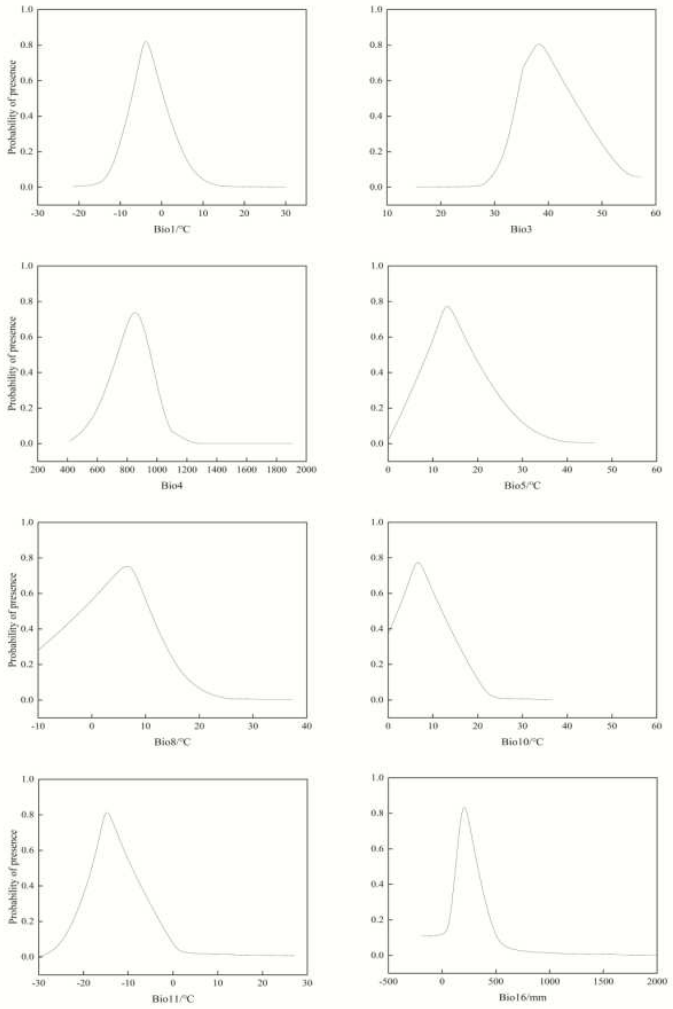


Figure 4. Probability response curves of main climatic factors.

3.4. Potential distribution area and suitability evaluation of *Kengyilia thoroldiana*

The highly suitable areas were mainly located in the western, central, southern, and southeastern parts of Qinghai; southwest Gansu; eastern Tibet; northwest Sichuan; and other regions. There were a small number of highly suitable areas in central Xinjiang (Figure 5). Based on the MaxEnt model, the highest optimal area of *Kengyilia thoroldiana* was predicted to be 67.21×10^4 km^2 (Figure 6).

The moderately suitable areas are mainly located around the highly suitable areas in southern Qinghai, southeastern Gansu, central and southern Tibet, and northern

Sichuan, and a small number are located in central Xinjiang (Figure 5). The moderate area is $82.75\times10^4 km^2$ (Figure 6).

Poorly suitable areas exist in northern Qinghai, southeastern and western Tibet, northern Sichuan, and southern Ningxia, with a few located in southwestern Xinjiang (Figure 5). The area is 159.46×10^4 km^2 (Figure 6).

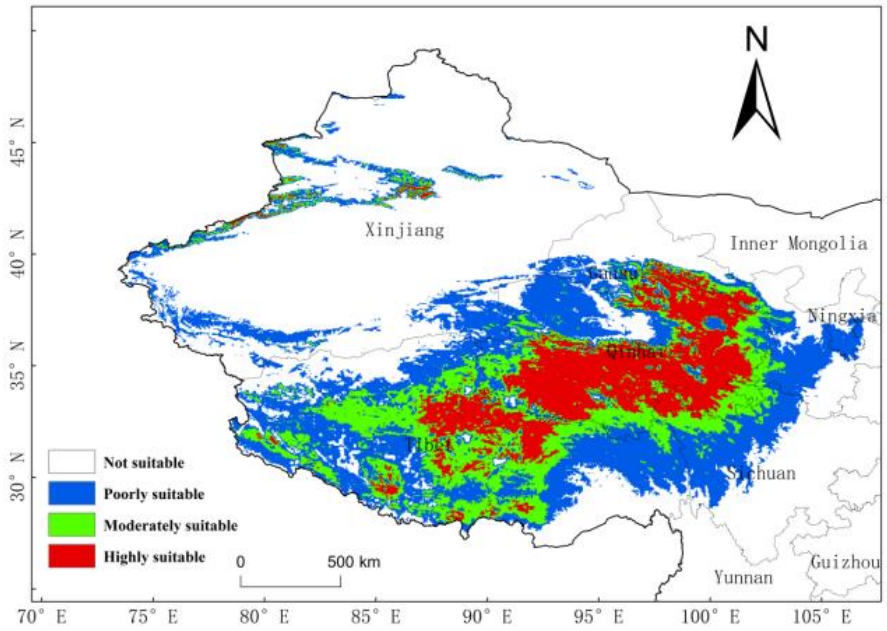


Figure 5. Schematic of the potential distribution of *Kengyilia thoroldiana* based on the MaxEnt model.

3.5. Potential distribution area of *Kengyilia thoroldiana* in the future climate

As shown in Table 3, the suitable areas can increase slightly, the highly and moderately suitable areas can increase continuously, and the poorly suitable areas can increase slightly from 2041 to 2060. Thus, all areas can increase under the current climate. Under the SSP126 scenario, the highly suitable areas of *Kengyilia thoroldiana* from 2021 to 2040 will be approximately 70.37×10^4 km^2, an increase of 4.72% over the current climate scenario. Moderately and poorly suitable areas will increase by 3.60

and 4.40%, respectively. From 2041 to 2060, the area of highly suitable areas will be approximately 75.74×10^4 km^2, an increase of 12.71% over the current climate scenario, and the area of moderately and poorly suitable areas will increase by 7.66 and 2.83%, respectively (Figure 5 and 7).

Table 3 Percentage of area change in future climate change compared to current climate

Climate scenario	Highly suitable		Moderately suitable		Poorly suitable	
	Area（×$10^4$$km^2$）	Percent（%）	Area（×$10^4$$km^2$）	Percent（%）	Area（×$10^4$$km^2$）	Percent（%）
2021-2040	70.37	4.72	85.73	3.60	166.46	4.40
2041-2060	75.74	12.71	89.09	7.66	163.97	2.83

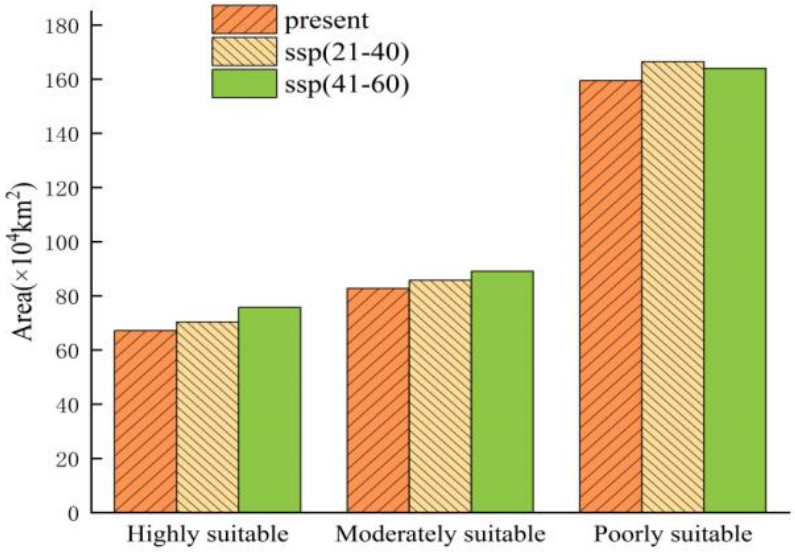


Figure 6. Potential distribution area of *Kengyilia thoroldiana* under current and future climate.

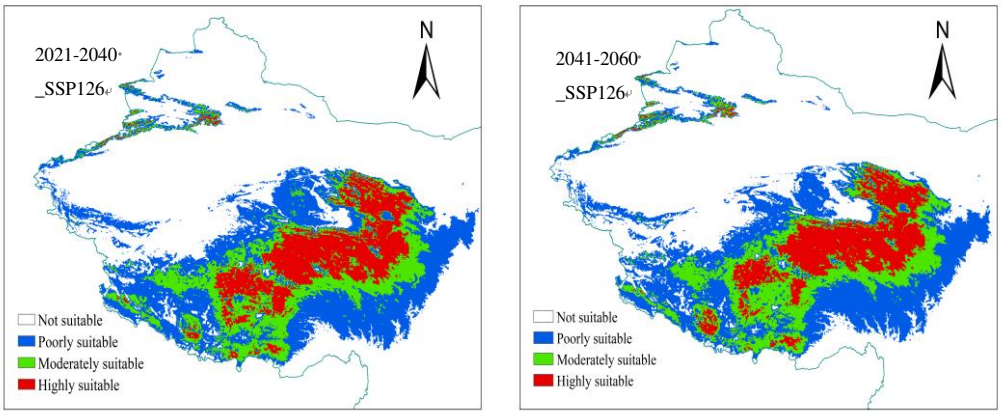


Figure 7 Prediction of the potential distribution of *Kengyilia thoroldiana* under future climate scenarios.

4. Discussion

The geographical distribution of plants is primarily restricted by climatic factors. The MaxEnt model was used to simulate the potential distribution of *Kengyilia thoroldiana* in China. The model prediction results had an AUC > 0.9, and the test accuracy reached an excellent level. By Sort the climate factor contribution rate and the training gain score, the results showed that the climate factors affecting. *Kengyilia thoroldiana* are the mean annual temperature (Bio01), isothermality (Bio3), temperature seasonality (Bio04), max temperature of the warmest month (Bio05), mean temperature of the wettest quarter (Bio08), mean temperature of the warmest quarter (Bio10), mean temperature of the coldest quarter (Bio11), and precipitation of the wettest quarter (Bio16). Among them, the mean temperature of the warmest quarter (Bio10, 50.2%) has the greatest influence, followed by isothermic and seasonal changes in temperature. Therefore, temperature is the dominant climatic factor affecting the distribution of *Kengyilia thoroldiana*.

Under continuous drought stress, because the relative water content of *Kengyilia*

thoroldiana decreased the slowest, it has the least chlorophyll and has the largest increase in malondialdehyde and soluble sugar content, it is more drought-tolerant compared to other grass species, indicating that it does not have high water requirements (Sun et al. 2010). In this study, an influencing factor of *Kengyilia thoroldiana* is the precipitation of the wettest quarter, which contributed only 4%, which also proved that precipitation had little influence on the distribution of *Kengyilia thoroldiana*. It showed that different temperature treatments had significant effects on the germination of *Kengyilia thoroldiana* seeds, and the germination rate of seeds at room temperature (25 ℃) was extremely low (12~18%)(Li et al. 2010b). In this experiment, the highest temperature of the warmest month was 11.1 ～ 16.2 ℃, indicating that *Kengyilia thoroldiana* is suitable for germination at low temperatures. This proves that temperature affects the elongation of *Kengyilia thoroldiana* young spike (Li et al. 2013). From December to early March, the temperature was low, and the elongation of *Kengyilia thoroldiana* ears was very slow. The average temperature in late March gradually increased from 0 ℃, and the growth rate was rapidly accelerated. Therefore, temperature can affect the growth and development of *Kengyilia thoroldiana* by affecting germination and young spike elongation and determining its distribution.

According to the Sample analysis, there are no coordinates for Ningxia; thus, in the low-fitness area, *Kengyilia thoroldiana* does not survive easily. Studies have shown that regions with an existence probability above 0.33 have a high probability of species existence and are easy to grow species (Lin et al. 2023; Wu et al. 2022). This confirms the reliability and necessity of dividing the suitable zones in this study. Therefore, the

core suitable areas of *Kengyilia thoroldiana* are mainly high and moderate areas, and the prediction results show that they are mainly distributed in western, central, southern, and southeastern Qinghai; southwest and southeastern Gansu; central and eastern Tibet; and northwest Sichuan.

Using ArcGIS 10.8, we counted the different suitable areas for *Kengyilia thoroldiana*. This shows that the suitable areas for plants will increase in the future. Under the SSP126 scenario, the high and moderate areas from 2021 to 2040 could increase by 4.72 and 3.60%, respectively, compared with the current climate scenario. From 2041 to 2060, the high and moderate-risk areas increased by 12.71 and 7.66%, respectively. In the context of global warming, plants can cope with climate change by changing their suitable areas (Cuena Lombraña et al. 2018). Overall, climate warming promoted the expansion of suitable areas for *Kengyilia thoroldiana*. The fitness area of *Kengyilia thoroldiana* simulated in the present study was significantly larger than the known total area. The possible reasons are as follows: (1) the suitable area of *Kengyilia thoroldiana* counted in this study did not consider the soil, altitude, and other factors that may affect its distribution; (2) The MaxEnt model simulates based on climate similarity and does not take into account other factors that are affected by the actual distribution of species, such as species growth characteristics, natural renewal capabilities, and interactions between organisms (Chao et al. 2019; Zhang et al. 2011); and (3) influenced by urban development and human factors, these suitable areas may not be available. Nevertheless, the distribution area of *Kengyilia thoroldiana* obtained using the MaxEnt model has similar climatic

characteristics, which can provide a reference value for the ecological restoration and introduction of the above areas. In terms of protecting species diversity, the Tibetan Plateau is one of the most important biodiversity reserves in China and the world. Although it is predicted that the suitable area of *Kengyilia thoroldiana* will increase under climate change, its highly suitable and actual areas will decrease, and overgrazing and reclamation on the Tibetan Plateau will also lead to grassland degradation. As the dominant species of sandy loam on the Qinghai-Tibet Plateau, *Kengyilia thoroldiana* is an indispensable part of biodiversity. We should reduce grazing, restore the degraded habitats of *Kengyilia thoroldiana*, establish species breeding bases, expand the population number of species, and enhance the ability of species to adapt to climate change in their original distribution areas, including the construction and expansion of nature reserves. Shi Jianjun et al. studied and summarized the technical regulations for the cultivation of *Kengyilia thoroldiana*, and Li Changhui et al. carried out the research on the breeding and cultivation and utilization of new varieties of *Kengyilia thoroldiana* in alpine grassland, and the experimental results showed that the grass yield was 691 g/m^2 and the coverage was 95%, and the grass yield was 691 g/m^2, and the coverage was 95%, and the effect was good. The average seed yield of seed field was 15.7 kg/mu, and the seed production was suitable for the area of 3200~3600m. In 2015, it was used for mine vegetation restoration in the Muli coalfield in Tianjun County. It is suitable for alpine grassland vegetation restoration at an altitude of 3600 m to 4200 m. However, at present, no forage varieties have been selected for the ecological restoration of alpine

grassland, and there is still no seed available, and the development and sustainable utilization of *Kengyilia thoroldiana* are of great significance to the ecological restoration and management of alpine grassland and the development of seed industry.

5. Conclusion

(1) In this study, the MaxEnt analysis showed that the dominant factor affecting the change in the fitness zone of *Kengyilia thoroldiana* was temperature.

(2) The dominant climate factors affecting the suitable area of *Kengyilia thoroldiana* were the mean annual temperature (Bio01) -5.8 ～ -1.2 ℃, mean temperature of the warmest quarter (Bio10) 4.5～9.4 ℃, and mean temperature of the coldest quarter (Bio11) -16.4～-11.9℃.

(3) *Kengyilia thoroldiana* is mainly distributed in the west, south, and southeast of Qinghai, southwest of Gansu, and eastern Tibet. Under future climatic conditions, each suitable area for *Kengyilia thoroldiana* will increase slightly.

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