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Potential Geographical Distribution of Medicinal Plant *Ephedra sinica* Stapf under Climate Change

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Abstract: *Ephedra sinica* Stapf is an important traditional medicinal plant. However, in recent years, due to climate change and human activities, its habitat area and distribution area have been decreasing sharply. In order to provide better protection for *E. sinica*, it is necessary to study the historical and future potential zoning of *E. sinica*. The maximum entropy model (MaxEnt) was used to simulate the potential geographical distribution patterns of *E. sinica* under historical and future climatic conditions simulated using two Shared Socio-economic Pathways. The main results were also analyzed using the jackknife method and ArcGIS. The results showed that: (1) the potential suitable distribution area of *E. sinica* in China is about 29.18 $\times$ 10^5 km^2—high-suitable areas, medium-suitable areas, and low-suitable areas cover 6.38 $\times$ 10^5 km^2, 8.62 $\times$ 10^5 km^2, 14.18 $\times$ 10^5 km^2, respectively—and *E. sinica* is mainly distributed in Inner Mongolia; (2) precipitation and temperature contribute more to the distribution of *E. sinica*; (3) under two kinds of SSPs, the total suitable area of *E. sinica* increased significantly, but the differences between 2021–2040, 2041–2060, 2061–2080, and 2081–2100 are not obvious; (4) the barycentre of *E. sinica* moves from the historical position to its southwest. The results show that *E. sinica* can easily adapt to future climates well, and its ecological value will become more important. This study provides scientific guidance for the protection, management, renewal and maintenance of *E. sinica*.

Keywords: dryland plant; shared socio-economic pathways; MaxEnt; spatial distribution pattern; barycentre migration

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1. Introduction

Ephedra sinica Stapf is a herbaceous shrub species of the *Ephedra* genus in the *Ephedraceae* family. It grows on hillsides, plains, dry wastelands, riverbeds, and grasslands. It has no strict requirements on soil and is strongly resistant to drought and cold. *E. sinica* is mainly distributed in Liaoning, Jilin, Inner Mongolia, Hebei, Shanxi, Gansu, Henan, and Shaanxi provinces of China. It often forms large simple communities in the distribution areas, with important ecological value in desert community maintenance and stability [1]. *Ephedra* is a traditional herb [2] that is rich in ephedrine [3]. According to the *Pharmacopoeia of the People's Republic of China* [4], the original medical plants of the *Ephedra* genus include *E. sinica*, *Ephedra intermediate* Schrenk et C.A.Mey., *Ephedra equisetina* Bge. *Ephedra* is a traditional drug proven to treat wind-cold syndrome and is anti-inflammatory and anti-arthritic [5]. Experiments have shown that *Ephedra* can effectively reduce body temperature and improve metabolism and the immune level, and *E. sinica* has the best effect among the three kinds of *Ephedra* medicinal plants [6–8]. However, due to climate change and human activities, the total suitable habitat of wild *Ephedra* is decreasing sharply [9]. Therefore, it is vital to study the impact of climate change on the distribution prediction of wild medicinal plant resources and the impact of future climate change on species distribution for the protection of wild medicinal plant resources.

Many studies have shown that global climate change has an increasing impact on plant growth and distribution and also affects the pattern and function of ecosystems and biota by changing water and heat distribution [10,11]. Some scholars, e.g., Yan et al., found that the *Hydrangea macrophylla* distribution range is mainly affected by precipitation and temperature [10]. Under a future scenario of increased greenhouse gas emissions, the area of suitable habitats would increase, and the barycentre would have the longest migration distance [10]. For two genetic lineages of *Mikania micrantha* Kunth, the range will expand for one and decrease for another because of future climate change [12]. The extinction risk of species is related to their limited plasticity and ability to adapt to rapid changes in environmental factors (e.g., temperature or precipitation [13]. However, when involving more species, scholars have found varied changes in distribution in response to climate change or human activities [14–17]. Therefore, under global climate change, it is a topic worth discussing whether the distribution range and area of species will become larger or smaller.

According to Kim et al.'s [18] research, *E. sinica* was used to treat symptoms caused by external stressors, and its extract significantly reduces body temperature rise and improves weight loss. Park et al. [19] and Lv et al. [20] studied *E. sinica* extract, proving that the extract had a preventive effect on ulcerative colitis and had a role in the treatment of adipocyte browning and obesity, respectively. At present, the main focus is on pharmacology, although the potential distribution and distribution pattern changes under historical and future climate scenarios are rare.

For some species, detailed presence/absence occurrence data are available, allowing the use of a variety of standard statistical techniques. However, absence data are not available for most species [21]. The maximum entropy (MaxEnt) model has been widely used to predict the potential geographical distribution based on limited species distribution and bioclimate data under the climate change scenario; the bioclimate data are from the World Climate Database (WorldClim), which contains different time periods and SSPs; as the website is updated, the new database can be better used for climate change analysis [22–34]. He et al. [9] analyzed the important environmental variables affecting the distribution of three *Ephedra* species using the MaxEnt model, establishing a linear relationship between environmental variables and chemical components and determining which habitats can be used as priority conservation areas, providing a theoretical basis for the restoration, protection and cultivation of *Ephedra*. However, these papers did not analyze how *Ephedra* would respond to future climate change. Therefore, under different SSPs, the maximum and minimum potential distribution areas and regional changes of *Ephedra* need to be clarified.

In recent years, due to climate change and human activities, its habitat area and distribution area have been decreasing sharply. Therefore, it is of great significance to study the suitable habitat of *E. sinica* under historical and future climate change for its protection, development, and utilization. The MaxEnt model and bioclimatic data in WorldClim were used to analyze the potential suitable distribution and spatio-temporal evolution of *E. sinica* under two extreme climate scenarios (SSP126, sustainable path and SSP585, unsustainable path) in four different time periods (2021–2040, 2041–2060, 2061–2080, and 2081–2100), indicate the limit range of the distribution of *E. sinica* under the different climate scenarios, and analyze its main influencing factors. This study provides a scientific basis for the protection, development and utilization of wild medicinal plant resources.

2. Materials and Methods

2.1. Acquisition of Species Distribution Data

This paper selected China as the study area to study the distribution of *E. sinica* in China. The geographic distribution data (longitude and latitude) of E. *sinica* were gathered from the Chinese Virtual Herbarium (CVH, https://www.cvh.ac.cn/, (accessed on 10 September 2022)) and the Global Biodiversity Information Facility (GBIF, https://doi.org/10.15468/dl.rc84eb, (accessed on 16 September 2022)). Then, removing duplicate sample points and sample points without accurate longitude and latitude information. Data autocorrelation was disabled in ArcGIS 10.3 (Esri, Redlands, CA, USA), and the resolution was set at 10 km; finally, 56 reliable distribution points were obtained to execute the MaxEnt model program (Figure 1).

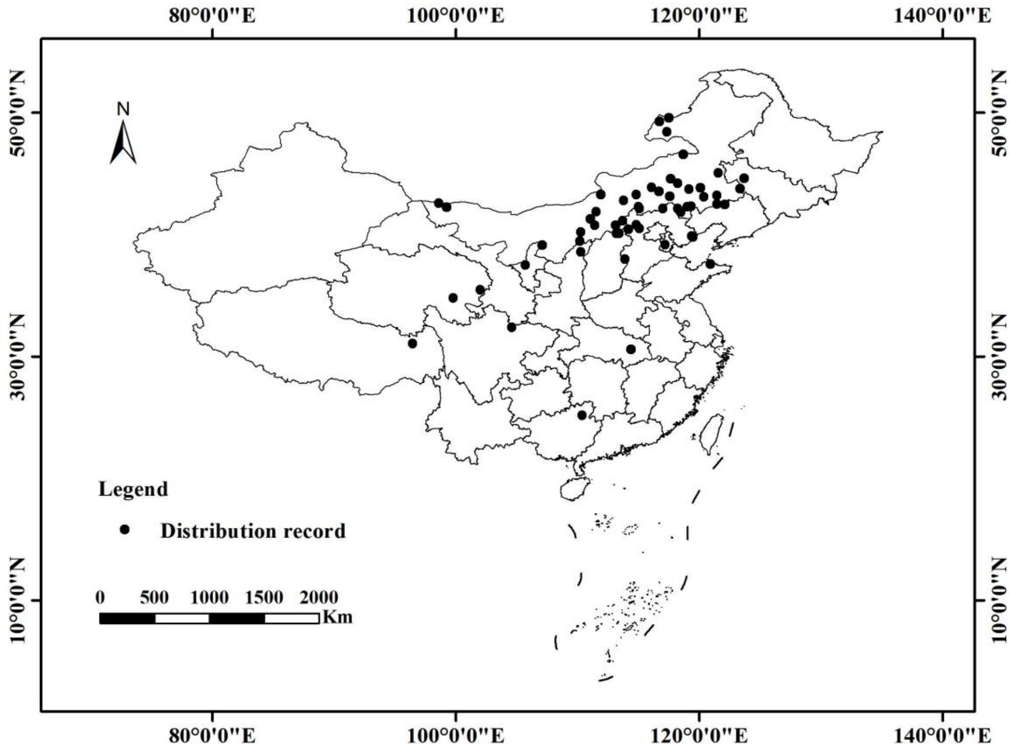


Figure 1. Distribution of *E. sinica* data points. This map was made based on the standard map No. GS (2019) 1822 downloaded from the National Administration of Surveying, Mapping and Geoinformation (NASG) of China. The base map is unchanged, and the geographical coordinate is WGS84. The same is below.

2.2. Acquisition of Environment Variable Data

The climate data in this study were all from the global climate database (https://www.worldclim.org/, (accessed on 6 September 2022)), with a spatial resolution of 30″, about 1 km × 1 km. The historical environmental data were 19 bioclimatic factors from 1970 to 2000. The MIROC6 (Model for Interdisciplinary Research On Climate version 6) model was developed by East Asian scholars and can be used to simulate the climate scenarios in East Asia.

This study downloaded the data of SSP126 (maximum) and SSP585 (minimum) climate scenarios, corresponding to the MIROC6 model in CMIP6 (Coupled Model Intercomparison Project Phase 6) in 4 different time periods of 2021–2040, 2041–2060, 2061–2080, and 2081–2100.

2.3. Build MaxEnt Model

MaxEnt mainly constructs models based on the longitude and latitude data of species' existence points and the data of species' living environment factors and expresses the degree of habitat suitability of species in the form of probability [30]. Under the condition that the sample size of species points is small and the correlation between various climatic and environmental factors is not clear, the prediction results of the MaxEnt model are better than those of other models, and the MaxEnt model could produce robust and accurate distribution maps [35,36]. During the operation of the MaxEnt model, the importance of variables can be measured by jackknife to avoid the influence of correlation among factors, which truly reflects the importance of each factor [37].

MaxEnt (version 3.4.1, Steven Phillips et al., New York, NY, USA) was used for this study (https://biodiversityinformatics.amnh.org/open_source/maxent/, (accessed on 5 July 2022)). When building the model, the geographic location information data of the sample were divided into 2 parts, of which 75% was randomly selected for model simulation, and the remaining 25% was used for model testing. The 10 simulation results of the MaxEnt model were averaged to determine the contribution of various environmental factors [38,39].

The receiver operating characteristic (ROC) curve analysis method was used to test the accuracy of the model. The area under the curve (AUC) can easily explain the accuracy of the model simulation [40]. The AUC value range is [0, 1]. If the AUC value is between 0.5 and 0.7, the prediction accuracy is poor. If the AUC value is between 0.7 and 0.9, the prediction accuracy is medium. If the AUC value is >0.9, the prediction accuracy of the model is very high [41,42].

ArcGIS 10.3 (Esri, Redlands, CA, USA) was used to visualize the simulation results and divide the habitat suitability into 4 levels (Jenks' natural breaks) [27] and reclassify the simulation results into 4 categories: unsuitable areas, low-suitable areas, medium-suitable areas, and high-suitable areas.

3. Results

Firstly, the distribution of *E. sinica* in China was analyzed. Then, the MaxEnt model was used to analyze the importance of 19 bioclimatic factors on *E. sinica.* Then, ArcGIS was used to analyze the past potential geographical distribution, adaptability degree, future distribution area, and migration of the distribution center of *E. sinica*.

3.1. Geographical Distribution

E. sinica is mainly distributed in the Inner Mongolia Autonomous Region, Hebei Province, Shanxi Province, Shaanxi Province, Beijing City, Gansu Province, and other provinces, with a total of 56 record points; and its distribution scope is concentrated in the semi-humid and semi-arid areas near the Hu Huanyong Line (Figure 1). *E. sinica* was usually distributed on hillsides, plains, arid wastelands, river beds and grasslands. It has no strict requirements on soil and has strong drought resistance and cold resistance. The provinces where the species distribution points are located meet the main conditions.

3.2. MaxEnt Model Accuracy Test

In this study, the ROC curve analysis method was used to test the accuracy of the MaxEnt model. The average AUC value of the model training set was 0.926 ± 0.022, and the AUC value of 10 simulation training sets was high (Figure 2, Table 1), indicating that the predictive accuracy of the model was good.

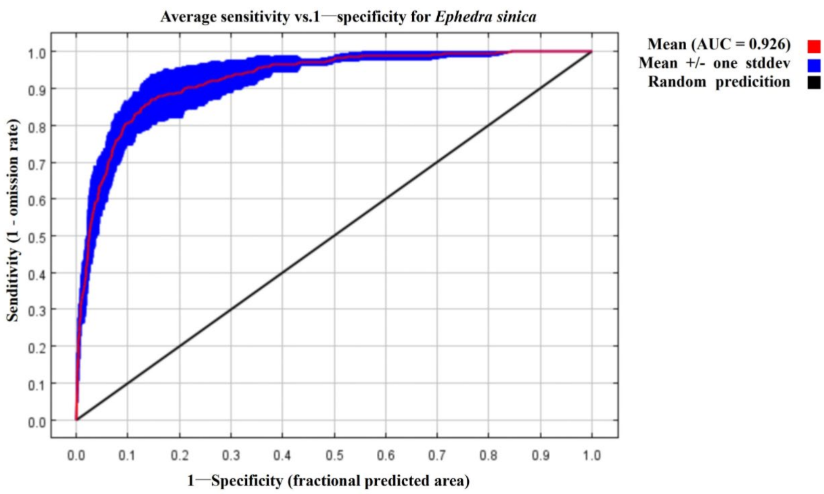


Figure 2. AUC training values for *Ephedra sinica* Stapf.

Table 1. AUC value of ten simulations.

No.	AUC Value of Ten Simulations Training	Test
1	0.94	0.94
2	0.95	0.88
3	0.89	0.91
4	0.95	0.91
5	0.89	0.91
6	0.90	0.94
7	0.94	0.91
8	0.93	0.88
9	0.94	0.82
10	0.94	0.94

3.3. Contribution Percentage of Environment Variables

During the operation of the MaxEnt model, the importance of variables can be measured by jackknife to avoid the influence of correlation among various factors, which truly reflects their importance. The average value according to 10 simulation results of the MaxEnt model was taken to determine the contribution degree and ranking importance of each environmental factor (Table 2).

Table 2. Relative contributions of environmental variables to the Maxent model for *E. sinica*.

Bioclimate Variable		Contribution (%)	Permutation Importance
BIO15	Precipitation Seasonality (Coefficient of Variation)	23.30	14.50
BIO4	Temperature Seasonality (standard deviation × 100)	21.00	0.70
BIO13	Precipitation of Wettest Month	19.30	26.70
BIO6	Min Temperature of Coldest Month	8.60	1.30
BIO5	Max Temperature of Warmest Month	5.30	0.40
BIO19	Precipitation of Coldest Quarter	4.80	0.50
BIO12	Annual Precipitation	3.00	4.40
BIO16	Precipitation of Wettest Quarter	2.70	17.60
BIO3	Isothermality (BIO2/BIO7) (×100)	2.50	1.00
BIO2	Mean Diurnal Range (Mean of monthly (max temp—min temp))	2.00	2.60
BIO18	Precipitation of Warmest Quarter	1.80	12.70
BIO8	Mean Temperature of Wettest Quarter	1.70	9.10
BIO14	Precipitation of Driest Month	1.30	0.60
BIO17	Precipitation of Driest Quarter	1.10	4.00
BIO10	Mean Temperature of Warmest Quarter	0.70	0.70
BIO7	Temperature Annual Range (BIO5–BIO6)	0.40	1.10
BIO9	Mean Temperature of Driest Quarter	0.40	1.70
BIO1	Annual Mean Temperature	0.00	0.10
BIO11	Mean Temperature of Coldest Quarter	0.00	0.20

It can be seen from Table 2 that, among the contribution rates of various climate factors obtained by running the MaxEnt model, the top factors are precipitation seasonality (BIO15, 23.3%), temperature seasonality (BIO4, 21.0), the precipitation of the wettest quarter (BIO13, 19.3%), the minimum temperature of the coldest quarter (BIO6, 8.6%), the maximum temperature of the hottest quarter (BIO5, 5.3%), and the precipitation of the coldest quarter (BIO19, 4.8%), with a cumulative contribution rate of 82.3%; thus, the prediction of *E. sinica* can yield rich information.

In terms of the importance of the arrangement, the precipitation of the wettest month (BIO13, 26.7%), the precipitation of the wettest quarter (BIO16, 17.6%), the precipitation of the hottest quarter (BIO18, 12.7%), the precipitation seasonality (BIO15, 14.5%), and the average temperature of the wettest quarter (BIO8, 9.1%) add up to 80.6%, which also reflects the importance of precipitation and temperature on the distribution of *E. sinica*.

Furthermore, based on the training gains of different climate factors analyzed by the jackknife method (Figure 3), the average value of the 10 simulation results shows that the environment variable with the highest gain when simulated alone is BIO12; thus, it itself has the most useful information. BIO15 will reduce the benefit to the greatest extent when omitted; therefore, it has the most information that does not exist in other variables.

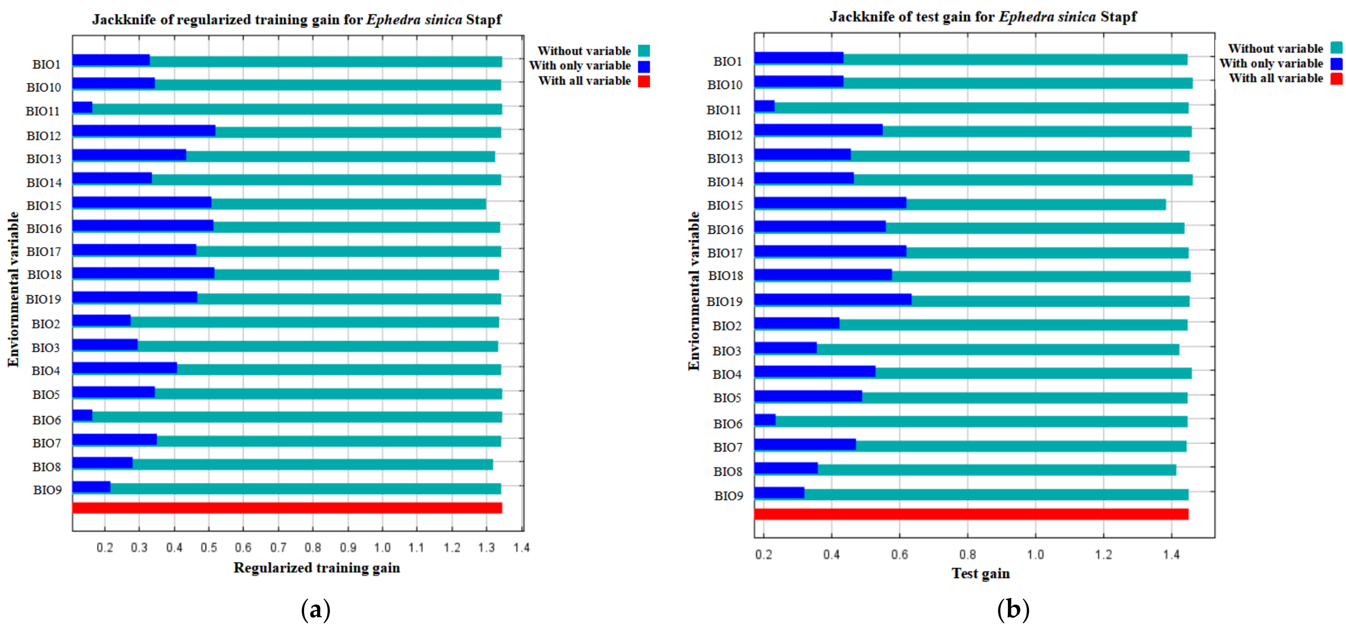


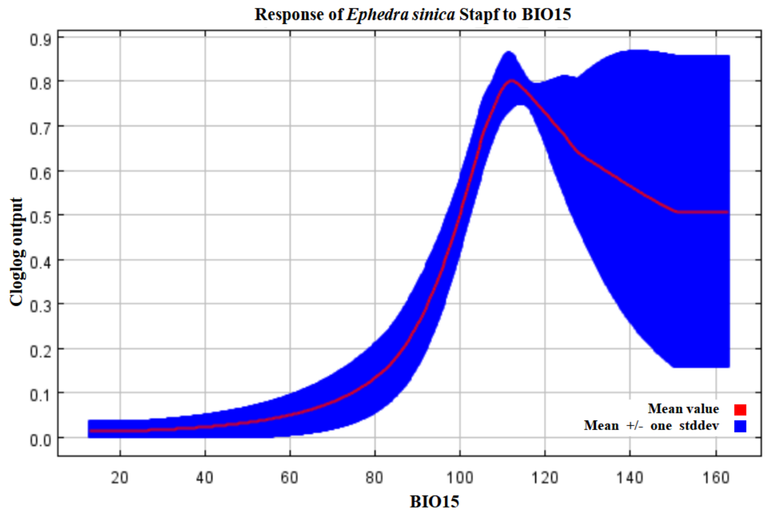
Figure 3. The Jackknife test with (**a**) training gain and (**b**) test gain for variable importance. The blue bar (left part of each variable row) indicates model gain with a single variable, and the cyan bar (right part of each variable row) indicates model gain with the other remaining variables. The red bar (base, all variables) represents the total gain with all variables in the final model.

3.4. Threshold Analysis of Important Environmental Variables

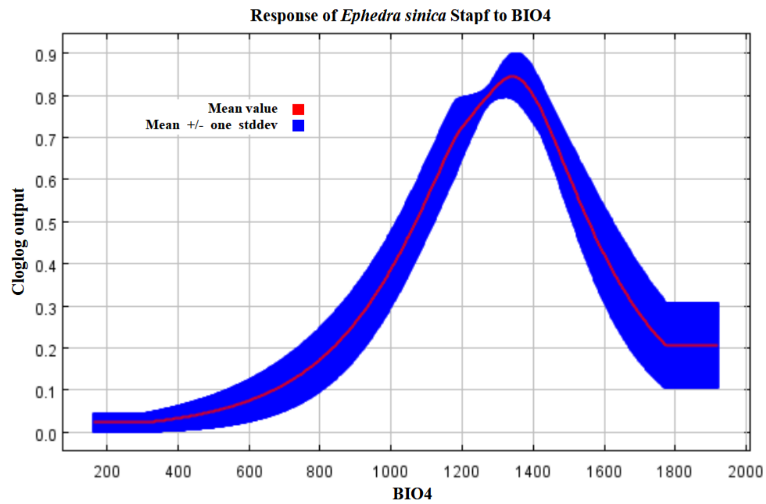
It can be seen from the response curve analysis that the climate characteristics of *E. sinica* in China's distribution area are precipitation seasonality (BIO15; 25.4–150.6), temperature seasonality (BIO4; 308.1%–1773.9%), the precipitation of the wettest month (BIO13; 3.0–768.0 mm), the minimum temperature of the coldest month (BIO6; 37.2–16.6 °C), the maximum temperature of the hottest month (BIO5; 1.8–42.1 °C), and the precipitation of the coldest month (BIO19; 0–461.0 mm). Six bioclimatic factors mainly determine the living range of *E. sinica* and also show the species' basic niches formed in the process of adapting to the environment. This shows that the growth of *E. sinica* is mainly affected by "extreme" precipitation and "extreme" temperature. It has a wide range of temperature tolerance, can withstand a certain degree of low temperature, and is suitable for growing in arid and semi-arid deserts, grassland, sandy land, river beaches, etc. (Figure 4).

3.5. Evaluation of Potential Geographical Distribution and Suitable Areas

The total distribution area of *E. sinica* in China is about 29.18 $\times$ 10^5 km^2, accounting for 30.33% of the land area. High-suitable areas are mainly located in the middle of the Inner Mongolia Autonomous Region, northern Shaanxi Province, northern and central Shanxi Province, central and southern Hebei Province, western Liaoning Province, western Jilin Province, southwestern Heilongjiang Province, northwestern Beijing, Gansu Province, and the Ningxia Hui Autonomous Region of Qinghai Province (Figure 5). The optimal area based on model simulation is about 6.38 $\times$ 10^5 km^2.



(**a**)



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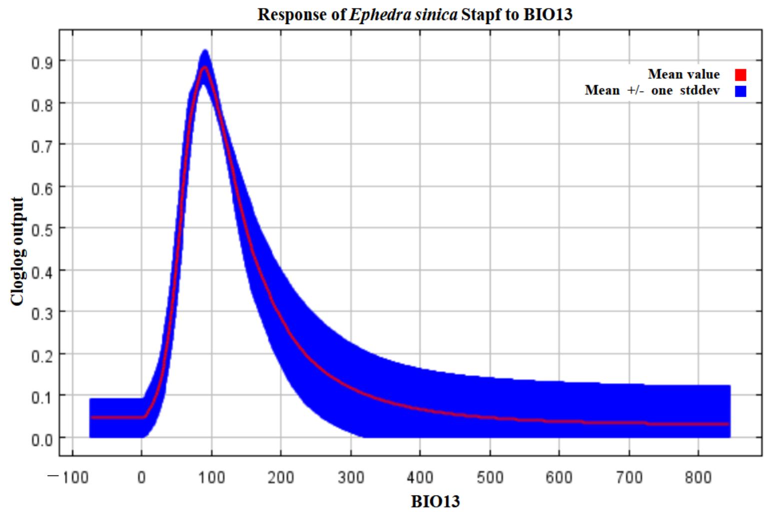
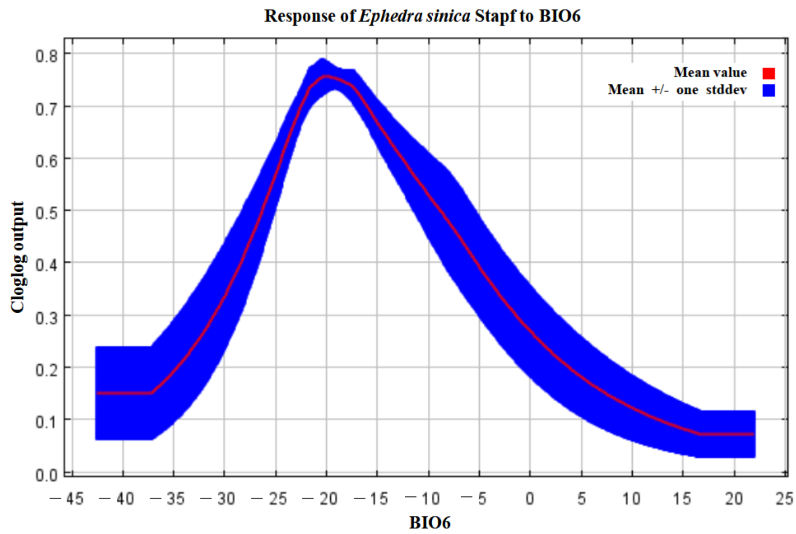


(**c**)

Figure 4. *Cont*.



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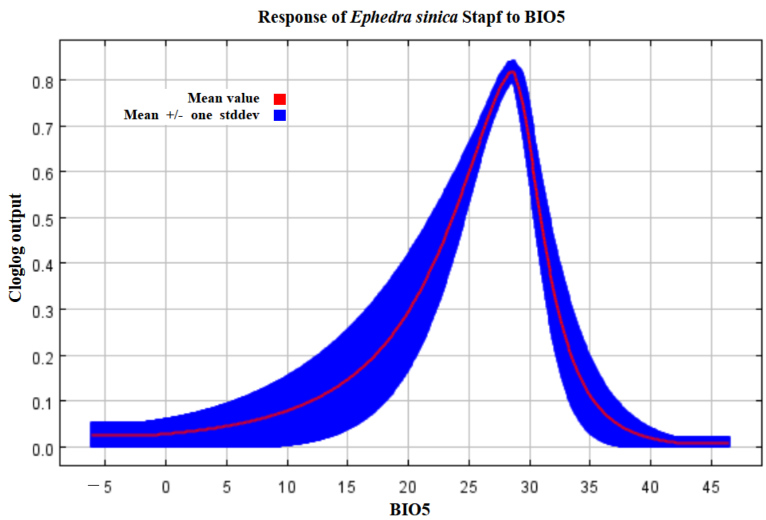
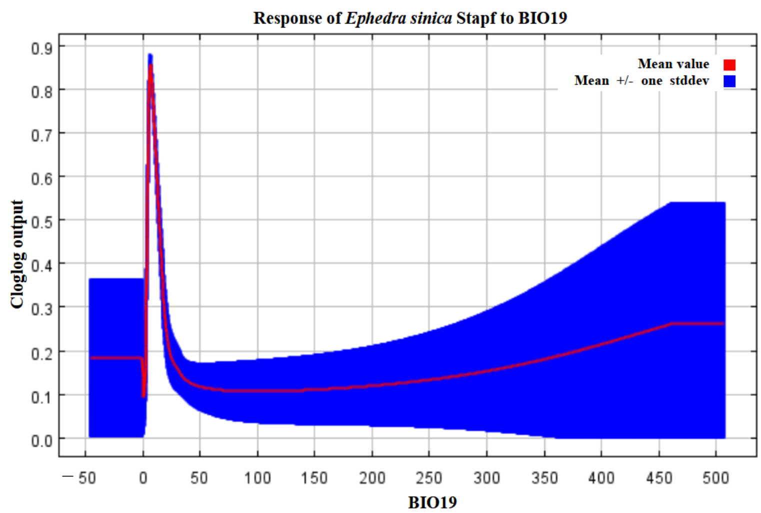


(**e**)



(**f**)

Figure 4. The response curve of dominant environment variables. (**a**–**f**) represent the response curves of ephedra under the influence of BIO15, BIO4, BIO13, BIO6, BIO5 and BIO19 respectively.

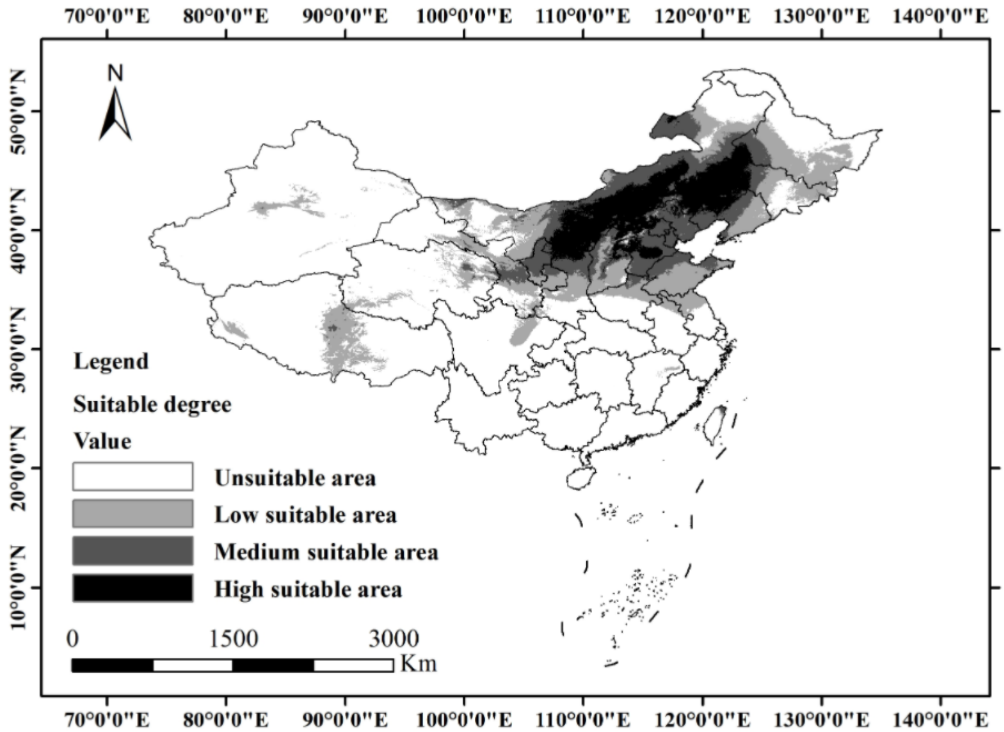


Figure 5. Distribution of suitable areas for *E. sinica*. The map source is the same as in Figure 1.

The medium-suitable areas are located around the most suitable regions. There are also some suitable regions in the center of the Tibet Autonomous Region, the center of the Xinjiang Uygur Autonomous Region, Gansu Province, Taiwan and Qinghai Province. The distribution of the medium-suitable area covers about 8.62×10^5 km^2 (Figure 5).

The distribution of low-suitability area covers about 14.18×10^5 km^2, mainly concentrated in the east and west of the Inner Mongolia Autonomous Region, the east and center of Xinjiang, the west and center of Tibet, the east and west of Qinghai Province, the center and east of Gansu Province, the south of the Ningxia Hui Autonomous Region, the center of Shaanxi Province, the south and center of Shanxi Province, the north and center of Henan Province, the north of Anhui Province, the north of Jiangsu Province, most of Shandong Province, the east of Liaoning Province, and northeast and center of Jilin Province. There are also a few in Hebei Province, Jiangxi Province and Taiwan Province in the east-central part of Heilongjiang Province (Figure 5).

3.6. Future Trends in the Barycentre of Suitable Habitat

Through simulation, it was found that, under future climate scenarios, the distribution area of *E. sinica* will become larger, and the distribution range will continue to increase (Table 3). The results infer that the ecological value of *E. sinica* will become more and more important. Using ArcGIS to analyze the center of gravity transfer trajectories of *E. sinica* at different suitability levels, it was found that the center of gravity coordinates of high-suitable, medium-suitable, and low-suitable areas were 115.7090° E, 42.0735° N; 115.0260° E, 41.2850° N; and 110.7560° E, and 38.8274° N, respectively, under historical climate conditions. Under SSP126, the distribution barycentre of the three types of suitable areas will shift from northeast to southwest, compared with historical climate conditions. Under SSP585, the gravity center of different suitable areas will also move to the southwest. It shows that climate change will cause the barycentre of the *E. sinica* distribution area to migrate (Figure 6).

Table 3. Potential distribution area changes in different periods.

Shared Socio-Economic Pathways	Time Periods	Area ($\times 10^4$ km^2)
Historical	1970–2000	291.76
SSP126	2021–2040	611.40
	2041–2060	617.67
	2061–2080	624.19
	2081–2100	644.53
SSP585	2021–2040	630.14
	2041–2060	648.23
	2061–2080	621.06
	2081–2100	644.25

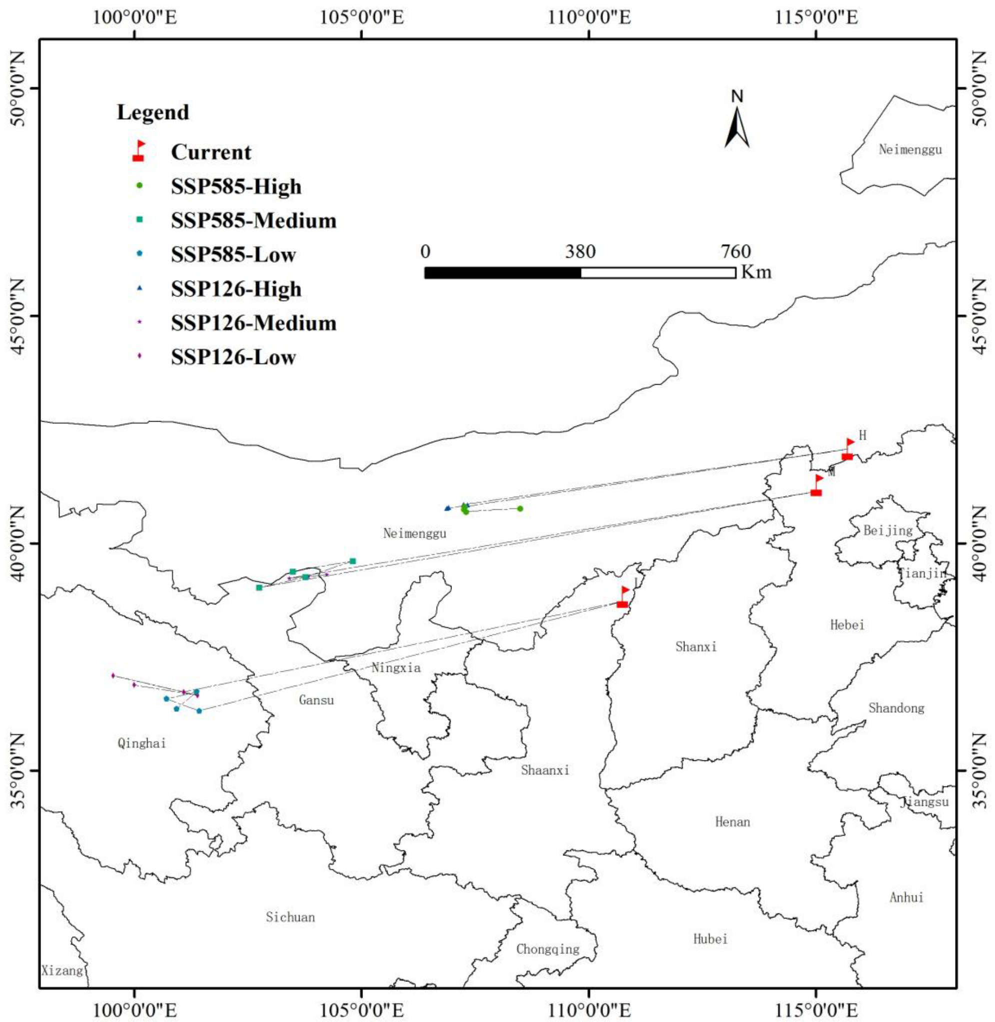


Figure 6. The change trends in the gravity points of the suitable areas for *E. sinica* under different climatic conditions. The map source is the same as in Figure 1.

4. Discussion

In this study, the MaxEnt model was selected to simulate the historical potential distribution and future potential distribution of *E. sinica*; it was found that the simulation accuracy was very good. Some scholars also found that the prediction accuracy indicators of the MaxEnt model are all greater than 0.90 [41,43], which is consistent with these results. Therefore, this model can be used as a powerful tool to study the potential distribution of species and plant distribution under future climate change scenarios [44–46]. Of course, some scholars (e.g., Cotto et al.) believed that the high fitting degree of MaxEnt fitting results does not mean that the simulation results can accurately reflect the actual distribution and potential distribution of species [47]. In this regard, we should be more careful in interpreting the results.

The main bioclimatic factors affecting the distribution of *E. sinica* are precipitation seasonality, temperature seasonality, the precipitation of the wettest month, the minimum temperature of the coldest month, the maximum temperature of the hottest month, and the precipitation of the coldest quarter. The order of importance was as follows, the precipitation of the wettest month, the precipitation of the wettest quarter, the precipitation of the hottest quarter, precipitation seasonality, and the average temperature of the wettest quarter are more important. It can be seen from this that the distribution of *E. sinica* in China is limited by water and temperature, indicating that *E. sinica* has a wide range of temperature ecology, can withstand a certain degree of drought, and can grow in arid and semi-arid deserts, grasslands, sandy lands, river beaches, etc.

The distribution center of *E. sinica* is Inner Mongolia Autonomous Region-Ningxia Hui Autonomous Region–Qinghai Province. *Flora of China* [1] records that the flowering period of *E. sinica* is concentrated from May to June, and the seed maturity is concentrated from August to September; there, it can be inferred that *E. sinica* completes its life cycle in a relatively short time (2–3 months), which is consistent with the hydrothermal conditions in the growing season of *E. sinica*. The environment in these areas is mainly semi-humid and semi-arid desert and sandy land, with four distinct seasons and harsh conditions. In the assessment area, the very serious and very serious interference areas are mainly distributed in the south and east of Inner Mongolia, and the middle interference areas are concentrated in Gansu and Inner Mongolia [10]. Due to the dry climate, cold waves and frequent wind and sand dust disasters, plants in some areas are difficult to survive, which can be proved by these results and the results of the MaxEnt model.

Withstanding extinction while facing rapid climate change depends on a species' ability to track its ecological niche or to evolve a new one [47]. The adaptation of plants to arid environments can be reflected by their functional traits [48]. However, when it is difficult to obtain functional traits, the distribution area and distribution area of plants can reflect the adaptation of plants to the environment. This paper has chosen two extreme pathways of social and economic sharing. Under SSP126 and SSP585, the distribution range and area of *E. sinica* increased significantly, but the two different SSP pathways had no significant impact on the distribution of *E. sinica*. In the future, due to the impact of human socio-economic activities, the potential distribution of *E. sinica* will change significantly, *E. sinica* can adapt well both in the sustainable development pathways and the unsustainable development way, and its distribution area could rapidly expand and be maintained, indicating that the survival prospects of *E. sinica* are improving under climate change. This may be related to future climate warming and the redistribution of hydrothermal conditions in the temperate zone where *E. sinica* grows. This is consistent with Wang et al.'s research on the increase in the suitable habitat of *Tricholoma matsutake* in the western Sichuan Plateau under the future climate scenario [49].

The barycenters of different suitability levels of *E. sinica* in the future climate were extracted using ArcGIS, and their transfer tracks were analyzed. It was found that the range of *E. sinica* will move to the southwest in the future. When Xu et al. [26] studied the future distribution of the traditional medicinal plant *Rheum nanum* Siev. ex Pall., they also found that its distribution center will shift to the south. Similarly, the southwest movement of *E. sinica* may be due to the redistribution of temperature and precipitation caused by global warming; thus, it moves to the southwest to expand new distribution areas.

The rapid economic growth, overexploitation of natural resources, habitat degradation, pollution and pressure related to global climate change are all serious challenges to plant protection in the new millennium. At the same time, management problems (such as lack of protection awareness of government officials and local people, imperfect legal system) and insufficient basic research on endangered species are also obstacles to success [50]. The protection and sustainable use of biodiversity is an important task of nature conservation.

Mankind's predatory development and utilization of *E. sinica* may reduce its numbers to a certain extent [9]; for the protection, development, and utilization of *E. sinica*, therefore, we should not only pay attention to climate change but also consider the impact of human beings.

This paper analyzes the potential distribution of *E. sinica*, the bioclimatic factors affecting its distribution, and the future distribution changes, obtains some good results, and puts forward some useful suggestions. Whether the simulation results of the MaxEnt model and other niche models are consistent? If not, what is the reason and how to improve? How about the impact of human beings on the distribution of *E. sinica*, and how to measure the impact of human beings? Are more species consistent with climate change? How can biodiversity be maintained? How does the higher classification unit "genus" adapt to climate change? These all need to be further studied.

5. Conclusions

The MaxEnt model can be used to simulate the potential distribution of species, but attention should be paid to the interpretation of the model results, and excessive inference is not allowed. According to the data collection points and simulated niches of *E. sinica*, the conditions of temperature and water, namely the combination of water and heat, limit the changes in the actual distribution and future distribution of *E. sinica*. Therefore, regional moisture and heat conditions should be considered when protecting *E. sinica*. The existing distribution area of *E. sinica* is greatly disturbed by human activities, so it is necessary to protect *E. sinica* pertinently, such as setting up natural reserves, carrying out publicity and education, raising people's awareness of *E. sinica* and enhancing the awareness of ecological environment protection.

This study provides a research model for the evolution of the distribution pattern of *E. sinica*, an important traditional medicinal plant in ethnic minority areas, and also provides a theoretical basis for the protection and management of *E. sinica*, a single community in desert areas, which is conducive to maintaining regional ecological balance and sustainable development. Of course, in view of the small sample size of research species, it is not enough to study only one kind of plant as an indicator of environmental change and a guide for government decision-making.

In the future, authors will continue to pay attention to plants in arid areas and deduce the response of plants to climate change through experiments and simulation calculations so as to provide better guidance for regional ecological balance and government decision-making. For example, these topics should continue to be studied in depth; the response of more plant species' geographical distribution patterns to climate change, the analysis of biodiversity maintenance mechanisms, and the adaptive changes in plant evolution should be analyzed from the higher taxon "genus", etc.

E. sinica, as an important wild medicinal plant resource, should take on-site protection measures for large populations as soon as possible, such as delimiting natural population protection areas and ecological protection areas of *E. sinica* in Inner Mongolia, which can not only protect the local ecological environment, but also protect the wild resources of *E. sinica*, and reserve natural germplasm resources for domestication, cultivation and resource development. In addition, *E. sinica* cultivation should be actively promoted in other potentially suitable areas as the main repair service for ecological restoration of sandy land, and the local people should be guided to cultivate so as to ensure species protection, desert control and economic development into a coordinated and sustainable state.

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