Pol. J. Environ. Stud. Vol. 31, No. 4 (2022), 3597-3609
DOI: *10.15244/pjoes/146936* ONLINE PUBLICATION DATE: 2022-05-05

Original Research

Prediction of Potential Geographic Distribution of Endangered Relict Tree Species *Dipteronia sinensis* in China Based on MaxEnt and GIS

Yi Huang[1], Yan Zeng[2], Pan Jiang[3] , Hao Chen[1], Jingtian Yang[1]*

[1]Ecological Security and Protection Key Laboratory of Sichuan Province, Mianyang Normal University, Mianyang 621000, Sichuan, China
[2]Sichuan Academy of Environmental policy and planning, Chengdu 610093, Sichuan, China
[3]School of Economics and Management, Southwest University of Science and Technology, Mianyang 621010, Sichuan, China

Received: 2 November 2021
Accepted: 24 February 2022

Abstract

Dipteronia sinensis is an endangered relict tree species in the endemic north temperate flora of China, which has important reference values for studying paleoclimate and species variation as well as geographic zonation changes. Based on 96 occurrence points of *D. sinensis* and 9 environmental factors, the potential geographic distribution of *D. sinensis* in China under climate change was predicted using MaxEnt model and ArcGIS software, the Jackknife test was used to assess the important factors governing its potential geographic distribution. In addition, response curves were selected to determine the suitable values of environmental factors and further quantitatively predicted the potential geographic distribution of *D. sinensis* under the climate changet. The results showed that: (1) the prediction accuracy of the MaxEnt model was extremely high, with an area under receiver operating characteristic curve (AUC training value) of 0.959. The potential suitable habitat area of *D. sinensis* under current climate condition was 103.9×10^4 km^2, mainly located in the central and northwestern regions of China; (2) the main environmental factors affecting the potential geographic distribution of *D. sinensis* were the temperature factor (min temperature of coldest month) and the precipitation factor (annual precipitation); (3) the area of low, high and total suitable habitats showed a decreasing trend under SSP1-2.6 and SSP5-8.5 scenarios in 2070s, and the area of moderately suitable habitats showed an increasing trend under the three scenarios in 2050s and 2070s, and the center of gravity of the potential suitable habitats of *D. sinensis* would shift to the northwest. Our results can provide a theoretical basis for the scientific management and resource conservation of *D. sinensis.*

Keywords: *Dipteronia sinensis*, climate change, potential geographic distribution, MaxEnt model

*e-mail: yjtdc83@163.com

Introduction

Among the top ten global environmental issues, climate change has been ranked as the top one and has received increasing attention [1, 2]. The responses and feedbacks generated by terrestrial ecosystems in the context of global climate change have become one of the core research areas and priority issues [3, 4]. Global climate change has already had a significant impact on the ecological characteristics and geographic distribution patterns of species, which will increase in the coming period [5], including global biodiversity, spatial structure of species distribution, intraspecific and interspecific relationships, etc. [6, 7]. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that the current global average temperature has increased by 1ºC compared to pre-industrial periods, and it is likely to increase by 0.3-0.7ºC in 2020-2040 compared to current [8]. Related studies suggest that as the concentration of greenhouse gas emissions increases, it may lead to a sustained increase in precipitation [9, 10]. Changes in the spatial and temporal patterns of climate may lead to changes in the geographic distribution patterns of rare and endangered species, making their original habitats threatened [11, 12]. Systematically exploring the geographic distribution patterns of rare and endangered species in the context of climate change can effectively protect the habitats and ecosystems of rare and endangered species in their originality.

Species distribution models (SDMs) have been widely used in individual ecological studies and to study the effects of climate change on the potential geographic distribution of species. SDMs are increasingly playing an important role in inferring the potential geographic distribution of species using changes in environmental factors, and have been widely used to simulate the potential geographic distribution of rare and endangered species [13, 14] in recent years [15, 16]. MaxEnt, also known as the maximum entropy model, is an ecological niche model based on the theory of maximum entropy constructed by Phillips et al [17]. MaxEnt model is less influenced by the number of species distribution points and the correlation of environmental factors, and still has strong prediction ability even if the species distribution data is incomplete [18, 19]. However, MaxEnt only considers the effect of abiotic factors without biological factors, and its simulation shows only the greatest possibility distribution of species [20, 21]. In recent years, MaxEnt has been expanded to include not only ecological degradation processes such as invasive species and Ecological damage [22-25], but also the prediction of potential risk areas for pests, diseases and epidemics [24, 26, 27], and the study of potential suitable habitats for rare and endangered species has gradually become a hot spot [28, 29]. In the study of rare and endangered species, researchers can identify sites with high ecological stability based on the prediction results, infer the potential geographic distribution, and clarify their potential suitable habitats of different classes. MaxEnt is widely used to predict the impact of climate change on rare and endangered species in a simple and effective way, thus enabling scientists and policy makers to propose corresponding strategies and establish effective conservation mechanisms.

Dipteronia sinensis belongs to *Dipteronia Aceraceae*, which is a rare and endangered plant in China, and is one of the relict tree species in the endemic genera of China and the north temperate flora [30]. It is of great importance to study the origin and evolution of certain taxa in the context of climate change, and to study the flora and geographical distribution [31]. Most studies on *D. sinensis* have focused on morphological development [32], phylogeographic classification [33] and genetic diversity [34]. There are few reports on the distribution pattern and potential suitable habitats of *D. sinensis*. In this study, we used the MaxEnt model and the spatial analysis technique of ArcGIS software to simulate the potential geographic distribution of *D. sinensis* under current climate condition and to study the relationship between *D. sinensis* and climate, to predict the changes of potential geographic distribution under future climate change scenarios, and clarify its ecological needs in different regions of China, so as to provide a theoretical basis for its conservation, and also to provide a reference for the conservation and restoration of rare and endangered plants in China.

Materials and Methods

Species Data Sources

In this study, by visiting the National Plant Specimen Resource center (NPSRC, http://www.cvh.ac.cn/) and other related websites, the geographic coordinates of *D. sinensis* were screened and confirmed. Records with insufficiently specific descriptions and repeated distributions were removed. A buffer zone of 5 km radius was established around each distribution point according to the resolution of environmental variables using the buffer zone tool in ArcGIS 10.2, and only one point was retained. Finally, 96 distribution points of *D. sinensis* were collected (Fig. 1). All records were imported into Microsoft Excel and saved as “CSV” format.

Environmental Factors Data

By accessing the Worldclim Database (http://www.world-clim.org//), 19 bioclimatic factors with the coordinate system WGS84 and raster size of 2.5′ were obtained. The database collects detailed meteorological information recorded by meteorological stations around the world from 1970 to 2000. BCC- CSM2-MR climate system model which involved three emission scenarios (SSP5-8.5, SSP2-4.5 and SSP1-2.6) was obtained as the future climate data.

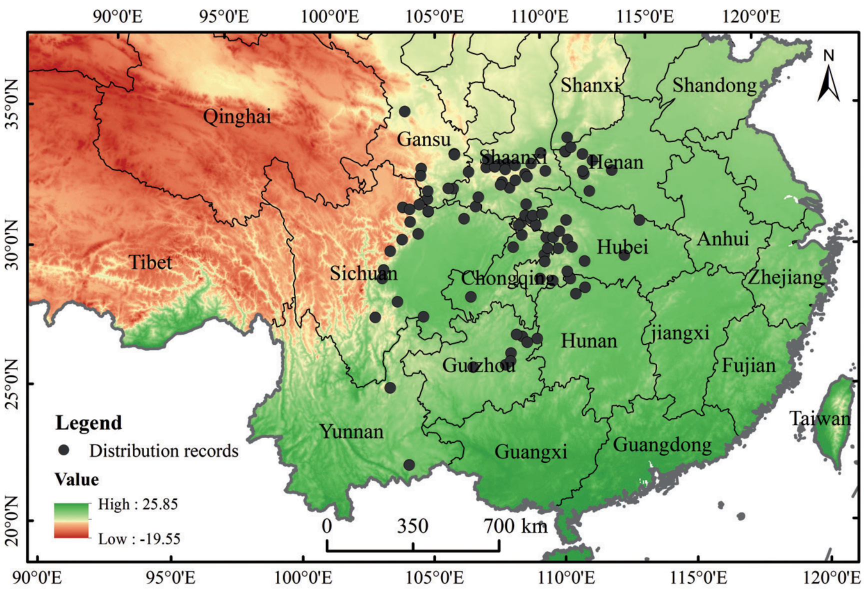

Fig. 1. Spatial Distribution of the sample sites of *D. sinensis* in China.

SSPs scenarios are more scientifically descriptive of future climate change projections than the scenarios used in previous studies [35, 36]. In order to avoid correlation between environmental variables, a correlation analysis is required. First, all environmental factors were imported into the MaxEnt model for 3 operations, and the factors with contribution rate of 0 were deleted. Second, the retained environmental factors were selected for Spearman correlation analysis, and when the correlation coefficient of 2 factors was ≥0.8, the one with higher contribution rate was retained [37]. Finally, 9 environmental factors were retained (Table 1).

The 1:16 million China administrative division map was obtained from the Ministry of Natural Resources of the People's Republic of China (http://bzdt.ch.mnr.gov.cn/index.html). MaxEnt V3.4.1 was downloaded from the website (http://biodiversityinformatics.amnh.org/open source/MaxEnt/). The version of ArcGIS software used in this paper was 10.2.

Table 1. Environmental variables in MaxEnt model.

Index	Description
Bio3	Isothermality (Bio2/Bio7×100)
Bio4	Standard deviation of temperature seasonality
Bio6	Min temperature of coldest month
Bio8	Mean temperature of wettest quarter
Bio12	Annual precipitation
Bio15	Coefficient of variation of precipitation seasonality
Altitude	Altitude
Aspect	Aspect
Slope	Slope

MaxEnt Model Parameters

The distribution points of *D. sinensis* and 9 environmental factors data were imported into the MaxEnt for modeling operations. 25% of the distribution points was selected for the test set and 75% for the training set. Receiver operating characteristic curve (ROC) was selected to evaluate model accuracy. MaxEnt model requires the user to specify a set of parameters, i.e., test training (i.e., for model development and the percentage of positions tested for internal testing), the number of background points, the clamp (that is, whether to restrict the prediction to the variability of the input predictor environment factors) and the canonical multiplier (i.e., to avoid overfitting of the response curve) [17, 38]. However, there is no standard set of parameter values in the literature for use in MaxEnt, and best practice suggests performing preliminary sensitivity to the chosen parameters for model performance testing. Area under Receiver operating curve (AUC) values and ROC curves were used to test the accuracy of the applicability results. The ROC curve is an acceptance curve where the horizontal coordinate represents the false positive rate (1-specificity) and the vertical coordinate represents the true positive rate (1-omission rate). Since the AUC value is not influenced by the threshold, its assessment of the model is more objective [39].

In this study, in order to evaluate the performance of the parameter configurations, different parameter configurations were selected for trial runs, which had been used to adjust the optimal parameters of the model. In this study, first, the RM (regularization multiplier) was set to 0.5 to 4 based on the known distribution points of *D. sinensis* and its corresponding environmental factors, respectively. six feature combinations (FC) were used to optimize the model parameters to select the best combination of parameters: L (linear features); LQ (linear features+secondary features), H (hinge features), LQH (linear features + secondary features+hinge features), LQHP (linear features + secondary features+hinge features + product features) and LQHPT (linear features + secondary features + hinge features+product features + threshold features) [40]. Finally, the RM in this study was set to 1, the feature combination was LQHPT, and the Jackknife method was chosen to determine the weight of each variable that affected the variables.

Model Accuracy Validation

The prediction accuracy of the model was evaluated by using the area under the curve (AUC). The closer the AUC value is to 1, the better the prediction effect of the model. The evaluation criteria of model simulation accuracy were classified into four levels: poor (AUC≤0.80), fair (0.8<AUC≤0.90), good (0. 90<AUC≤0. 95) and very good (0.95<AUC≤1.00) [41].

Classification of Suitable Habitats

In the output file, the average of 10 replicates was selected as the simulation result. The results were generated as ASCII raster layers based on the logical value of species presence probability (P), with P values ranging from 0 to 1. Higher P values indicated a higher probability of species presence. The prediction results were converted into raster format using ArcGIS10.2 software to classify and visualize the hierarchy of suitable habitats. Based on the P-value, the natural interruption point method was used to classify the suitable habitat into four classes, namely, high suitable habitat (0.7≤P≤1.0), moderately suitable habitat (0.5≤P<0.7), low suitable habitat (0.2≤P<0.5) and unsuitable habitat (0.0≤P<0.2). The number of grids in each class was counted, and the proportion of suitable habitat area in each class was calculated.

Results and Discussion

Environmental Factors Affecting the Potential Geographic Distribution of *D. sinensis*

The potential geographical distribution of *D. sinensis* in China was simulated and predicted using the MaxEnt model based on 96 distribution records, and the AUC values of training and test data were 0.959 and 0.945, respectively, indicating that the model fitting effect turned out to be relatively good (Fig. 2).

There is disagreement on the determination of the number of dominant factors. Most researchers base their determination on the cumulative contribution rate, where the environmental factor with a cumulative contribution rate above a specific value is considered the dominant environmental factor [42]. This specific value is usually chosen subjectively based on the characteristics of the respective study species and the results of the study, and therefore the criteria vary. In this study, the environmental factor with a contribution greater than 10% was selected as the dominant environmental factor. Of the nine environmental factors used in the Maxent model predictions, those with a contribution greater than 10% were: annual precipitation (Bio12, 35.1%) and min temperature of coldest month (bio6, 35.1%), with a cumulative contribution of 70.2% (Fig. 3); the results of the Jackknife method test (Fig. 4) showed that the two environmental factor variables that have the greatest influence on the gain in formal training when only a single environmental factor variable is used are: annual precipitation (Bio12) and min temperature of coldest month (bio6), suggesting that these

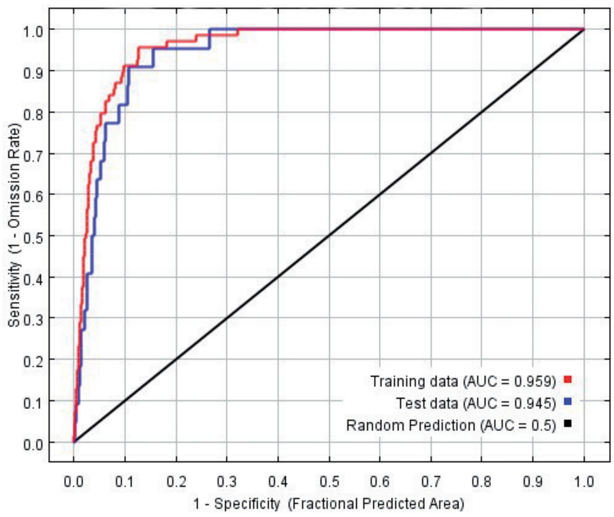

Fig. 2. Receiver operating characteristic curve of *D. sinensis*.

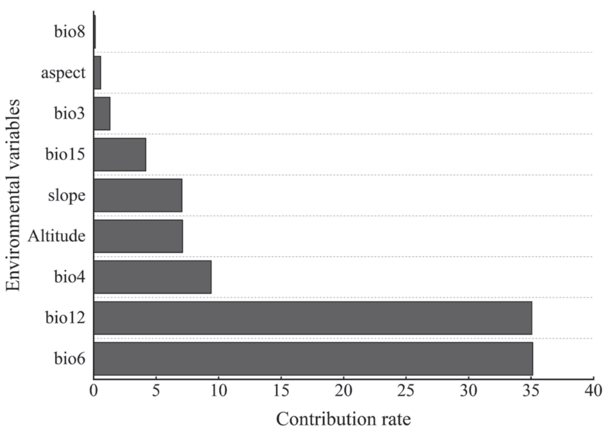

Fig. 3. Contribution rate of environmental factors on the distribution of *D. sinensis*.

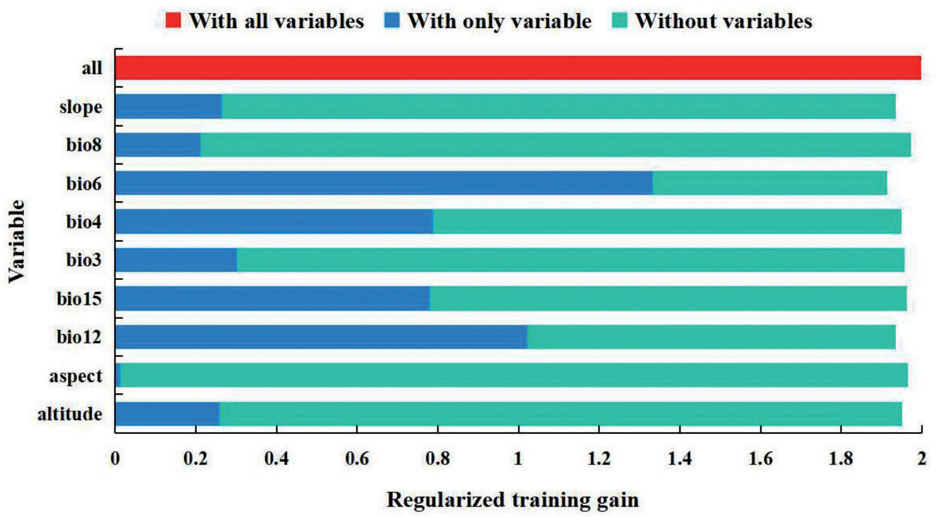

Fig. 4. The Jackknife method test result of environmental factor of *D. sinensis.*

environmental factor variables contain information that other environmental factor variables do not, and further supporting the idea that the dominant environmental factor influencing the potential geographical distribution of *D. sinensis* was the "coldest month". The dominant environmental factors influencing the potential geographic distribution of *D. sinensis* were also further corroborated. In summary, the dominant environmental factors influencing the potential geographic distribution of *D. sinensis* are annual precipitation (Bio12) and min temperature of coldest month (Bio6).

The response curves of species survival probability to environmental factors in the results of MaxEnt model runs are often used to determine the relationship between species presence probability and environmental factors (Fig. 5). In this study, referring to previous studies, when the presence probability of *D. sinensis* was greater than the threshold of high suitable habitat, its corresponding environmental factor interval was a suitable interval for *D. sinensis* survival.

The results of the MaxEnt model runs showed that the probability of survival of *D. sinensis* reached the threshold of high habitat suitability (0.7) when the min temperature of coldest month (bio6) reached –7.8ºC. As the min temperature of coldest month (bio6) increased –4.4ºC, the probability of *D. sinensis* reached a peak (0.78). The probability then began to decrease as the temperature (Bio6) increased. When the min temperature of coldest month to 1.5ºC, the probability 0.7. It is thus clear that the range of the min temperature of coldest month suitable for the survival of *D. sinensis* was –4.4ºC~1.5ºC. When the annual precipitation (bio12) was 490.9 mm, and the probability of survival of *D. sinensis* showed an increasing trend as the annual precipitation increased. The probability of survival of *D. sinensis* reached a peak (0.83) at an annual precipitation (bio12) of 738.8 mm. As annual precipitation (bio12) continued to increase, the probability of survival of *D. sinensis* began to decline to 0.7 at 1204.7 mm The range of annual

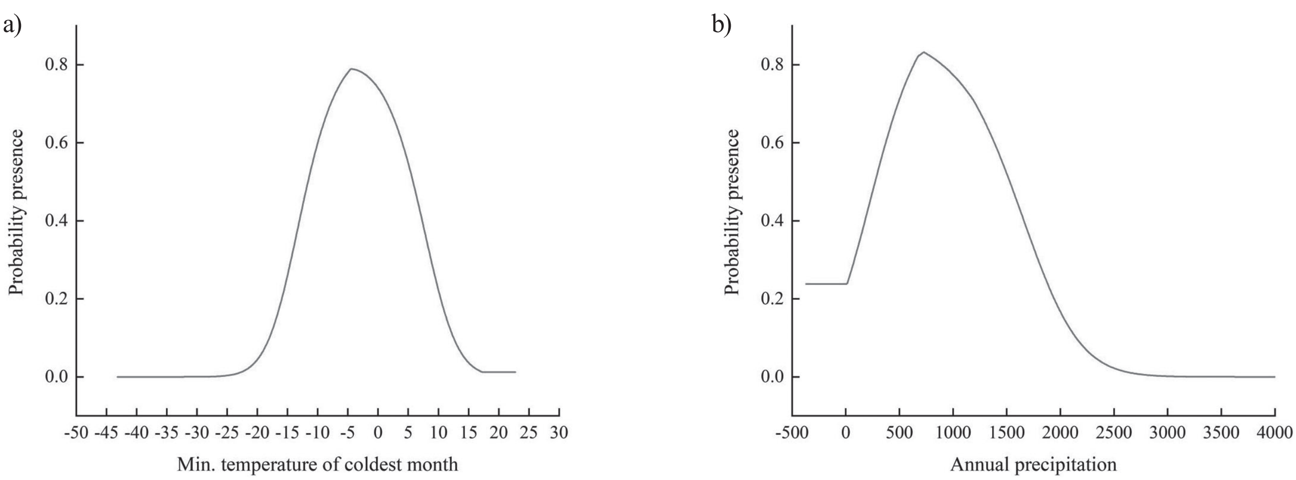

Fig. 5. Response curves of existence probability of *D. sinensis* for environmental variable.

precipitation (bio12) suitable for survival of *D. sinensis* was 490.9 mm to 1204.7 mm.

The MaxEnt model prediction results showed that the important environmental factors limiting the potential geographical distribution of *D. sinensis* were the temperature factor (min temperature of coldest month) and the precipitation factor (annual precipitation). This study showed that as the coldest monthly minimum temperature and annual precipitation increase, the probability of the presence of *D. sinensis* tends to increase and then decrease. Li et al's study showed that *D. sinensis* is mainly distributed in areas with high humidity and minimum temperatures below 0°C and precipitation of 690-1200 mm, while in drought prone area its distribution gradually decreases or even disappears, indicating that it has high requirements for temperature and precipitation [43] This further confirms the accuracy of the results of this study. The fossil record of the genus *D. sinensis* in North America is relatively comprehensive, ranging from the middle of the Eocene to the Miocene, while the fossil record in East Asia is less extensive. But nowadays, *D. sinensis* remains in some mountain systems in China, with small and scattered populations and extremely limited numbers. It is assumed that the climate became colder from the Late Tertiary onwards, and with the onset of the Pleistocene in the Quaternary, the climate became significantly colder, which was responsible for the reduction in the distribution of the genus Phyllostachys, thus suggesting that low temperatures were an important environmental stressor affecting the survival of Phyllostachys.

The fossils of *D. sinensis* were first found in the Tertiary period in East Asia and North America, where the fossil record was more comprehensive, ranging from the middle of the Eocene Epoch to the Miocene Epoch, while the fossil record in East Asia was less extensive. However, *D. sinensis*, nowadays, remains in some mountain systems in China, with small and scattered populations and extremely limited numbers. It is hypothesized that since the Neogene, the climate has entered a cold phase, and with the beginning of the Quaternary Pleistocene, the climate has become significantly colder, which is the reason for the reduction of the distribution area of *D. sinensis*. This indicates the importance of low temperature stress on the existence of *D. sinensis*, and further verifies the accuracy of identifying the min temperature of coldest month as the dominant variable. In this study, the potential geographical distribution of *D. sinensis* in China was predicted, and the climatic factors limiting the potential geographical distribution of *D. sinensis* were identified. The expansion of the study area may have led to changes in the range of environmental factors limiting the growth of *D. sinensis*. Other environmental factors, such as vegetation cover and other data, also have an influence on the potential geographical distribution of *D. sinensis*. As it is not possible to accurately predict the vegetation cover in China in future periods, the prediction of the potential geographical distribution of *D. sinensis* was not included, so the potential geographical distribution area obtained in this study may be partially unsuitable for the survival of *D. sinensis* and must be combined with local hydrogeological conditions when applied in practice. However, the results of this study are the first step in macro planning, which is crucial for the scientific management and conservation of *D. sinensis* and the provision of good habitat and breeding sites for *D. sinensis*.

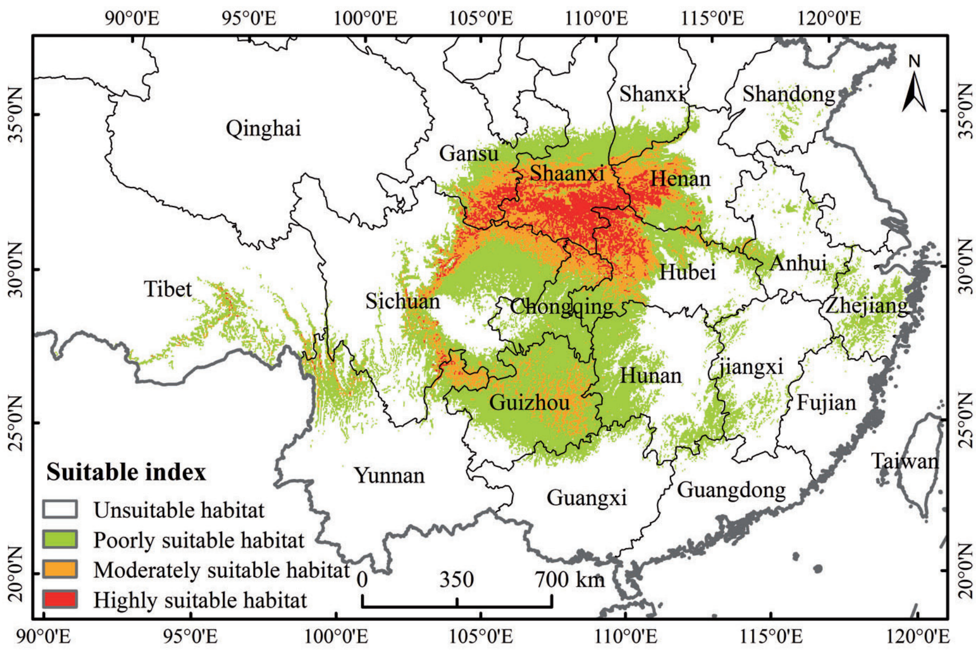

Fig. 6. Potential geographical distribution of *D. sinensis* under current climate conditions.

Table 2. Suitable areas for *D. sinensis* under climate change scenarios ($10^4 km^2$).

Period	High suitable area	Moderately suitable area	Low suitable area	Total suitable area
Present	10.39	22.05	71.46	103.9
2050, SSP1-2.6	11.76	25.36	78.56	115.68
2070, SSP1-2.6	8.30	23.39	66.16	97.85
2050, SSP2-4.5	13.90	22.33	75.32	111.55
2070, SSP2-4.5	13.21	25.56	77.60	116.37
2050, SSP5-8.5	14.42	25.64	76.73	116.79
2070, SSP5-8.5	9.14	25.57	65.99	100.69

Potential Geographical Distribution of *D. sinensis* under Current Climatic Conditions

The potential geographic distribution area of *D. sinensis* under current climatic conditions was simulated using MaxEnt model operations (Fig. 6). Of the 96 logical values for the presence probability of the valid distribution points of *D. sinensis*, the highest logical value was in Xiji Village, Shaanxi Province (0.83) and the lowest logical value was in Wenshan County, Yunnan Province (0.02), with an average logical value of 0.55.

The highly suitable habitats were mainly located in Sanmenxia, Luoyang and Nanyang in Henan Province, Xi'an, Hanzhong, Baoji, Ankang and Shangzhou in Shaanxi Province, Yichang, Xiangyang and Shiyan in Hubei Province, and sporadically in Tianshui and Longnan in Gansu and Mianyang, Guangyuan, Bazhong County, Dazhou, Markang County and Chongqing in Sichuan, with a total area of 10.39×10^4 km^2, accounting for 1.08% of China's land area (Table 2). The area of moderately suitable habitat was 22.05×10^4 km^2, accounting for about 2.30% of the total area of China (Table 2), mainly located in patches around the highly suitable habitat of *D. sinensis*. With medium suitability habitat distributed around its highly suitable habitat and scattered in Zhongdian County, Yunnan Province; Linzhi County, Tibet; Kaili, Guiyang, Zunyi, Tongren and Bijie cities, Guizhou Province; Zhaotong City, Yunnan Province; Ya'an City and Leshan City, Sichuan Province. Overall, the highly and moderately suitability habitats of *D. sinensis* were concentrated distributed in the central and north-western parts of China and scattered in the southwest, which was in good agreement with its actual distribution and indicates that the modelling results of this study are accurate.

Projections of Climate Change Impacts on the Potential Geographic Distribution of *D. sinensis*

MaxEnt model was used to predict the potential geographic distribution of *D. sinensis* in China under three emission scenarios, SSP1-2.6, SSP2-4.5 and SSP5-8.5 in 2050s and 2070s, resulting in the potential geographic distribution areas of *D. sinensis* in China under future climate change scenarios (Fig. 7) and a map of the change in the geometric center of potential suitable habitat for *D. sinensis* (Fig. 8). The areas of the different classes of suitable habitat under the three emission scenarios in 2050s and 2070s change to varying degrees compared to current climate conditions (Table 2).

In the 2050s SSP1-2.6 emission scenario, the area of highly suitable habitat for *D. sinensis* is 11.76×10^4 km^2, accounting for approximately 1.2% of China's total land area, an increase of 0.12% compared to the area of highly suitable habitat for *D. sinensis* under current climate conditions. Under the 2070s SSP1-2.6 emission scenario, the area of highly suitable habitat for *D. sinensis* was 8.30×10^4 km^2, which accounts for about 0.86% of the total area of China's national territory, with a decrease of 0.22% compared to current climate condition. Under the 2050s SSP2-4.5 emission scenario, the area of highly suitable habitat was 13.90×10^4 km^2, which accounts for about 1.45% of the total land area of China, with an increase of 0.37% compared to current climate condition. Under SSP2-4.5 emission scenario in 2070s, the area of highly suitable habitat was 13.21×10^4 km^2, accounting for 1.38% of the total land area of China, with an increase of 0.3% compared to current climate condition. The area of highly suitable habitat under the SSP5-8.5 emission scenario in 2050s was 14.42×10^4 km^2, accounting for 1.5% of China's total land area, 0.42% higher than the current climate conditions. Under the SSP5-8.5 emission scenario in 2070s, the area of highly suitable habitat for *D. sinensis* was 9.14×10^4 km^2, accounting for approximately 0.95% of the total area of China, with a decrease of 0.13% compared with under current climate conditions. The area of highly suitable habitat for *D. sinensis* will decrease under the low and high emissions scenarios in 2070s, increase under the low, medium and high emissions scenarios in 2050s and the medium emissions scenario in 2070s, and decrease proportionally the most under the SSP1-2.6 emissions scenario in 2070s, and SSP5-8.5 emissions scenario in 2050s. The largest proportional increase was observed for the SSP5-8.5 emission scenario in 2050 (Fig. 7, Table 2).

Under the SSP1-2.6 emission scenario in 2050, the area of moderately suitable habitat for *D. sinensis* is 25.36×10^4 km^2, accounting for about 2.64% of the total land area of China, an increase of 0.34% compared to the area of moderately suitable habitat for *D. sinensis* under current climate conditions; under the SSP1-2.6 emission scenario in 2070, the area of moderately suitable habitat for *D. sinensis* is 23.39×10^4 km^2 in 2070, accounting for 2.44% of China's total land area, an increase of 0.14% compared to the area of moderately suitable habitat for *D. sinensis* under current climate conditions; 22.33×10^4 km^2 in 2050 under the SSP2-4.5 emission scenario, accounting for 2.33% of China's total land area, an increase of Under the SSP2-4.5 emission scenario in 2070, the area of moderately suitable habitat for *D. sinensis* is 25.56×10^4 km^2, which is about 2.66% of China's total land area, an increase of 0.36% compared to the area of moderately suitable habitat for *D. sinensis* under current climate conditions; under the SSP5-8.5 emission scenario in 2050, the area of moderately suitable habitat for *D. sinensis* is 25.64×10^4 km^2, which is about 2.66% of China's total

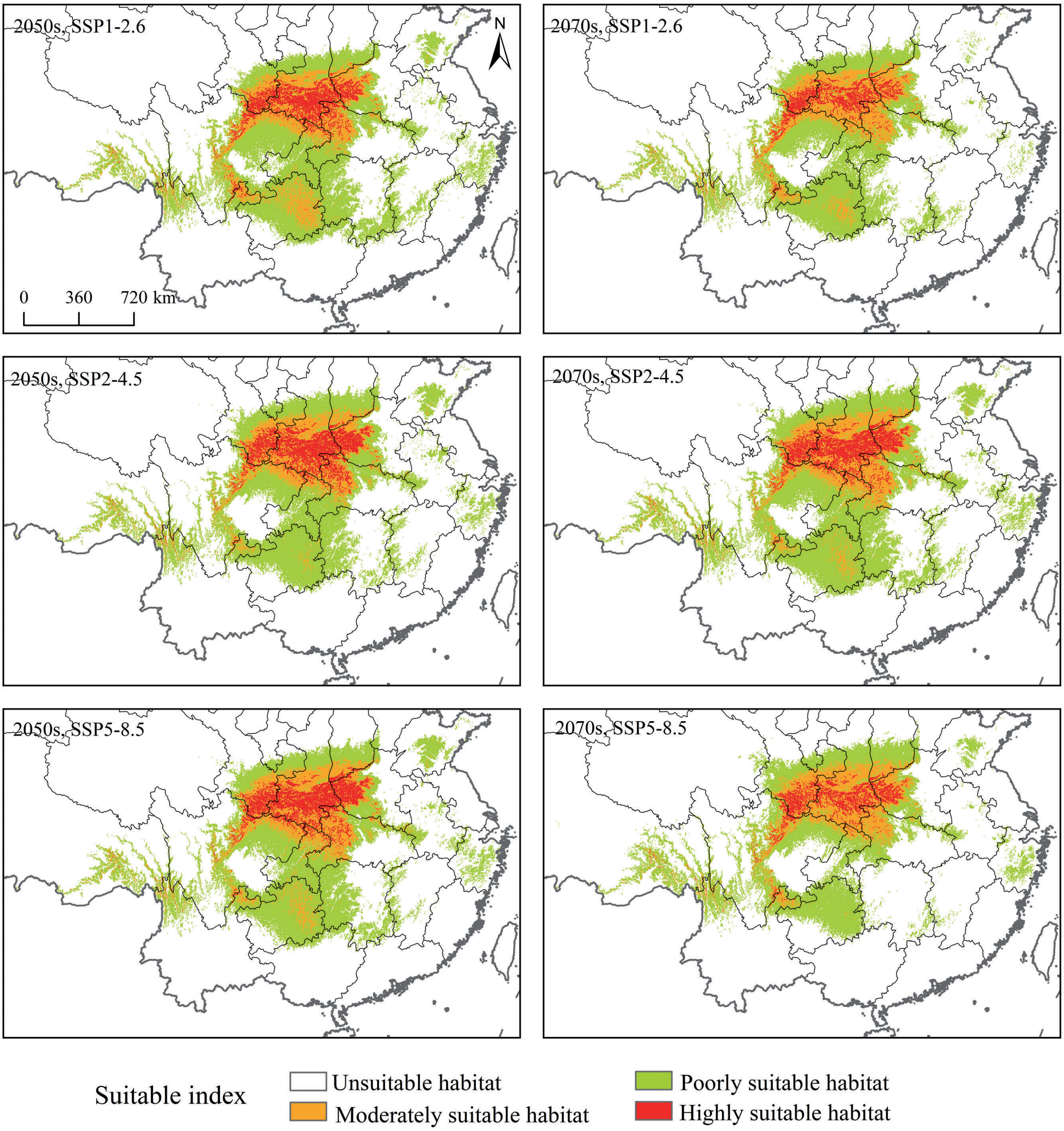

Fig. 7. Potential geographical distribution of *D. sinensis* under future climate change scenarios.

land area. This is the largest increase of 0.37% over the area of moderately suitable habitat for *D. sinensis* under current climate conditions, and the area of moderately suitable habitat for *D. sinensis* under the SSP5-8.5 emission scenario in 2070 is 25.57×10^4 km^2, accounting for 2.66% of the total area of China, which is a 0.37% increase over the area of moderately suitable habitat for *D. sinensis* under current climate conditions. This is an increase of 0.36% compared to the area of suitable habitat for *D. sinensis* under current climate conditions. The area of intermediate suitable habitat for *D. sinensis* under future climate change scenarios tended to increase under all three emission scenarios in 2050s and 2070s, with the largest proportional increase under the 2050s SSP5-8.5 emission scenario (Fig. 7, Table 2).

In summary, the trends in the area of low suitable habitat and total suitable habitat for *D. sinensis* under future climate change scenarios are consistent with the trends in its high suitable habitat, with an overall increasing trend in its potential suitable habitat and a decreasing trend in its low, high and total suitable habitat only under the low and high emission scenarios in 2070, and an increasing trend in the area of moderately suitable habitat under all three emission scenarios in 2050s and 2070s.

The trajectory and trends of potentially suitable habitat for *D. sinensis* were revealed based on the center of gravity of its highly suitable habitat (potential survival probability ≥0.2) under current climate conditions and future climate change scenarios. Under all three emission scenarios in 2050s and 2070s, the center of gravity of potentially suitable habitat for *D. sinensis* tends to shift to the northwest and to higher latitudes, with the most pronounced shift in the center of gravity of potentially suitable habitat for *D. sinensis* under the 2070s SSP5-8.5 emission scenario (Fig. 8) and the largest area of habitat loss. Under the low and high emission scenarios in 2070s, the loss of potentially suitable habitat for *D. sinensis* occurs to varying degrees, mainly in the form of a shift from high to medium and low suitable habitat and a partial conversion of low suitable habitat to unsuitable habitat (Fig. 7). In summary, under future climate change scenarios, potentially suitable habitat for *D. sinensis* tends to shift to the northwest and higher latitudes, and the area of potentially suitable habitat tends to decrease under the low and high emissions scenarios in 2070.

Based on three emission scenarios in 2050s and 2070s combined with current climate conditions, the MaxEnt model was used to predict the potential geographical distribution of *D. sinensis* in China under future climate change scenarios (Fig. 7), and the results were spatially overlaid in ArcGIS to obtain changes in the potential distribution of *D. sinensis* under future climate change scenarios (Fig. 9). The predicted results showed that the potential geographic distribution of *D. sinensis* under the three emission scenarios in 2050s and 2070s showed an overall increasing trend. Under the low and high concentration emission scenarios in 2070s, its low and high suitable habitat and total suitable habitat area showed a decreasing trend (Fig. 7). The results of this study indicated that with increasing temperature and this may be due to the fact that the temperature and precipitation in the low and high emission scenarios

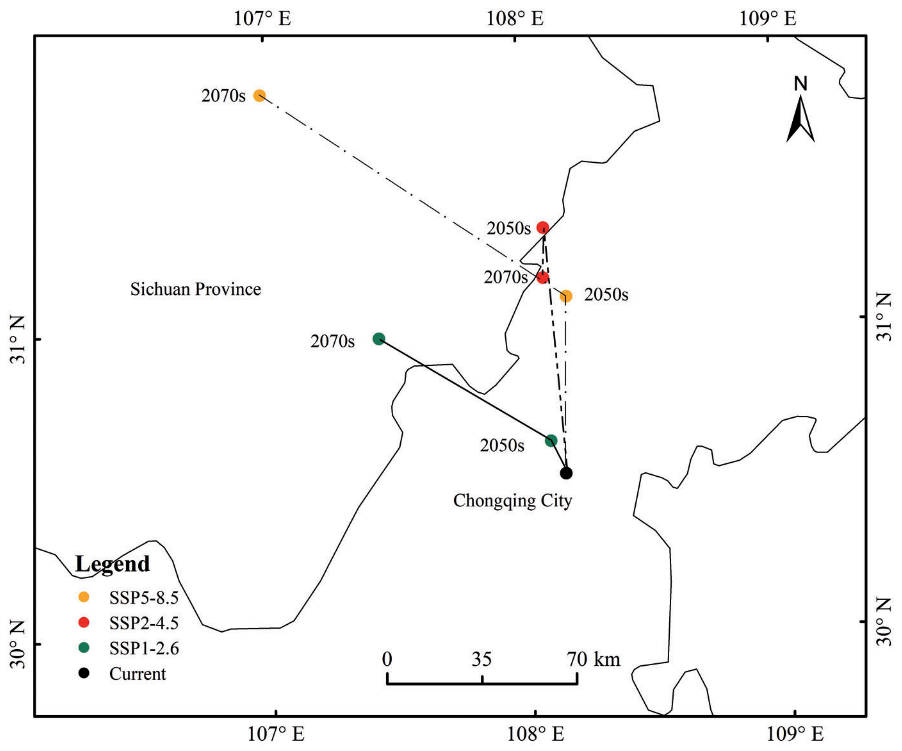

Fig. 8. Changes in gravity center of the potential suitable habitat areas and its moving tendency under future climate change scenarios.

in 2070 exceed the threshold of suitable habitat for *D. sinensis*, making it less likely to survive in some areas, while in the other emission scenarios, the temperature and precipitation were within the range of suitable habitat for *D. sinensis*, making its potential suitable habitat increase. A shift in the center of gravity of potentially suitable habitat towards the northwest and higher latitudes (Fig. 8) may mean that some areas become unsuitable for *D. sinensis* under future climate change scenarios and that areas suitable for *D. sinensis* will emerge. Emission concentration scenarios indicated that 15-37% of species will be at risk of extinction in 2050s, while other species will be at low risk of extinction. With some species benefiting from warming, suggesting that the effects of warming on the potential geographic distribution of species are two-sided and that not all species are at risk of extinction or benefit equally under climate change [44]. In this study, under the three emission scenarios for 2050s and 2070s, suitable habitat for *D. sinensis* was lost to varying degrees in central and southern China, and increased to varying degrees in high latitude and high altitude areas of northern and northwestern China (Fig. 9).

In the 2050s SSP1-2.6 emission scenario, the loss of suitable habitat for *D. sinensis* was the smallest, with an area of 2.69×10^4 km^2; in the 2070 SSP5-8.5 emission

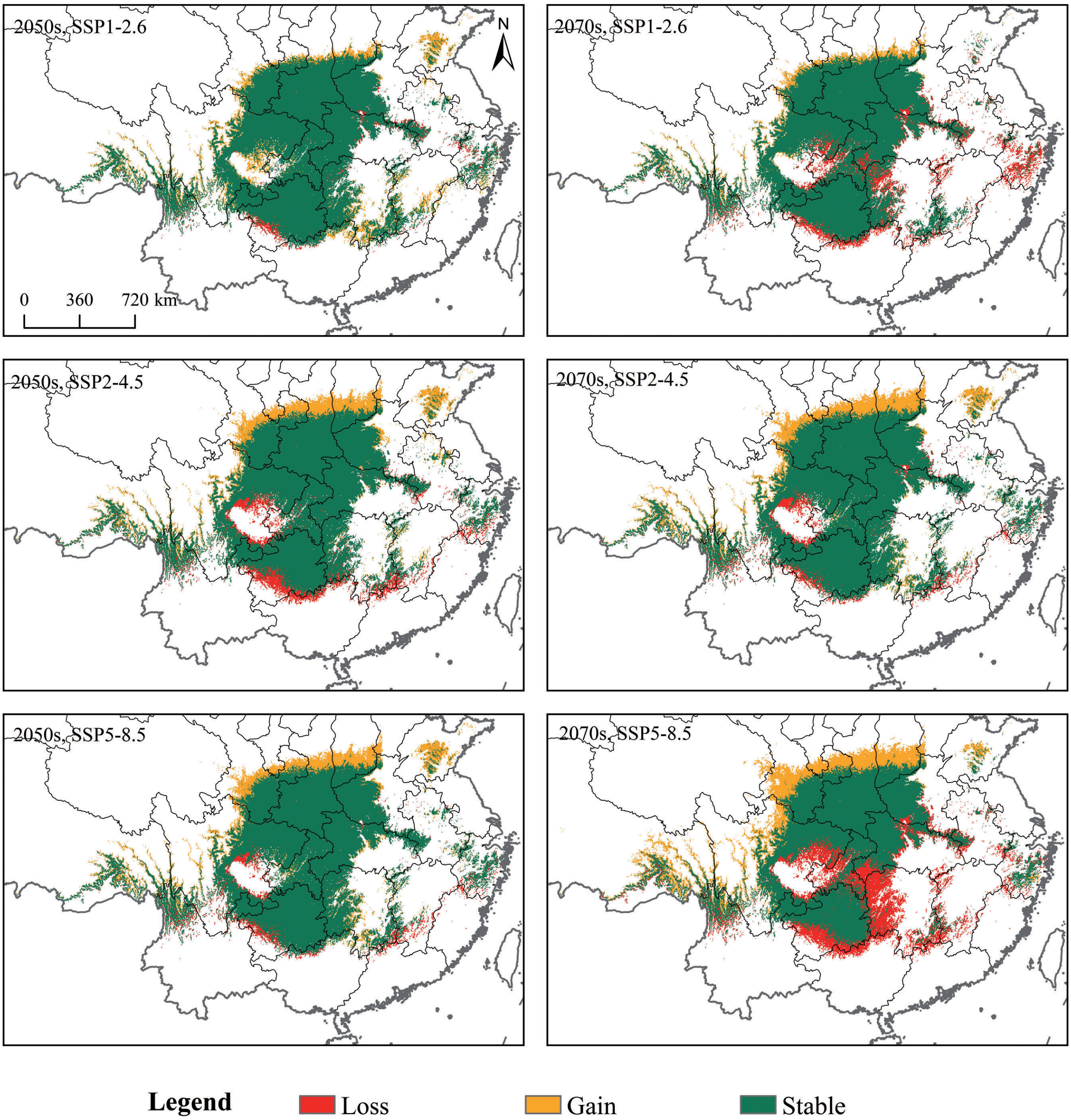

Fig. 9. Changes of potential geographical distribution of *D. sinensis* under climate change scenarios in the future.

Table 3. Changes of *D. sinensis* in suitable habitat area in the future ($10^4 km^2$).

Period	Loss	Gain	Stable
2050, SSP1-2.6	2.69	13.56	101.87
2070, SSP1-2.6	12.67	7.08	91.20
2050, SSP2-4.5	9.74	17.21	94.45
2070, SSP2-4.5	6.53	18.79	97.64
2050, SSP5-8.5	5.33	17.85	98.97
2070, SSP5-8.5	25.90	22.88	78.08

scenario, the loss of suitable habitat for *D. sinensis* was the largest, with an area of 25.90×10^4 km^2, (Table 3), and the loss of suitable habitat for *D. sinensis* was mainly located in Hubei Province, Hunan Province, Henan Province. Under the 2070s SSP1-2.6 emission scenario, the increase area of suitable habitat for *D. sinensis* was the smallest, with an area of 22.88×10^4 km^2; under the 2070 SSP5-8.5 emission scenario, the increase area of suitable habitat for *D. sinensis* was the largest, with an area of 22.88×10^4 km^2 (Table 3), and the increase area for *D. sinensis* was mainly located in the southern part of the Qinling Mountains in Shaanxi Province, Shanxi Province and the Ningxia Hui Autonomous Region, among other areas (Fig. 9). The Qinling and Bashan Mountain regions of China are at the northern edge of the subtropical zone, where the subtropical and warm temperate climates meet [31].

The shared socio-economic pathway scenarios presented in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change indicated that the extent of warming and the increase in temperature were more pronounced due to the important influence of temperature on the growth of *D. sinensis*, and the increase in temperature with higher emission concentrations in the 2070s SSP5-8.5 emissions scenario may result in the loss of suitable habitat for *D. sinensis* [8]. This may also account for the largest loss of habitat under this scenario. In terms of changes in the center of gravity, Leng et al. analysed the effects of climate change on the potential geographic distribution of three *Larix gmelinii* species in northeastern China using an RF model and showed that the potential geographic distribution of three *Larix gmelinii* species (Larix spp.) shifts significantly towards higher latitudes under future climate change scenarios [45]. Bellard et al. modelled the potential geographic distribution of 100 of the world's most aggressive non-native species and showed a general trend towards a northward expansion of the potential geographic distribution of these species [4]. Thuiller found that in the context of a warming climate, most species would migrate northwards, with the exception of those species that are themselves distributed in the north [46]. Garah found that the Aurès region of suitable areas for Aleppo pine would migrate to the north [12]. The trends in suitable habitat for *D. sinensis* in the coming period were generally consistent with this. The effects of climate warming on the potential geographic distribution of species are mainly in the form of shifts to higher latitudes or higher altitudes and the expansion and contraction of the potential geographic range of species. The trend in this study for the potential suitable habitat of *D. sinensis* to shift to higher latitudes and northwestern regions under future climate change scenarios is consistent with this feature.

Climate change has indirectly affected the population and distribution characteristics of *D. sinensis* through direct impacts on ecosystems. In addition to the important influence of climate change on the potential geographic distribution of the *D. sinensis*, irrational human activities (e.g. agricultural development, the rise of tourism, hydropower development and other industrial practices) have led to a dramatic decline in wild populations of the *D. sinensis*. As wild populations of *D. sinensis* continue to decline, not only do they need to be relocated and conserved with reference to the distribution of potentially suitable habitats for *D. sinensis*, but they also need to be systematically conserved with reference to detailed information on topographic features, climate change, ecosystem development, population genetic structure, anthropogenic factors and phylogeography, which was a greater challenge for the conservation of *D. sinensis* populations in the 21st century. In this study, environmental factor variables were used for only two time periods, 2050s and 2070s, so that in future studies of the response of the species' potential geographic distribution to climate change, multiple study periods can be selected to derive overall trends in the potential geographic distribution of the study population.

Conclusions

Dipteronia sinensis is an endangered relict woody plant species with ecological and economic value in China [47]. Due to the poor natural regeneration ability, the continuous deterioration of ecological environment and large-scale deforestation, the distribution range and population size of *D. sinensis* have been constantly decreasing [48], so artificial intervention should be taken to save the natural ecosystem. Therefore, this study has a certain theoretical and practical significance. From the perspective of species and habitat restoration, it is very important to understand their climatic characteristics and suitable habitat. The dominant environmental factors affecting the potential geographic distribution of *D. sinensis* under current climate condition were temperature factor (min temperature of coldest month) and precipitation factor (annual precipitation). The potential geographic distribution of *D. sinensis* under current climate condition was mainly located in the central and northwestern regions of China. The low, high and total suitable habitat tends to decrease under the SSP1-2.6 and SSP5-8.5 scenarios in 2070s, the area of moderately suitable habitat tends to increase under three scenarios in 2050s and 2070s, and the potentially suitable habitat tends to shift to higher latitudes.

Author Contributions

Y.H. planned and supervised the project. Y.Z. performed the experiments, analyzed the data, contributed reagents/materials/analysis tools., P.J and H.C. contributed to data collection and evaluation. J.-T.Y.. revised the manuscript.

Funding

This work was funded by the Innovation and entrepreneurship training program for college students in Sichuan Province (S202010639170), the Open Project from the Ecological Security and Protection Key Laboratory of Sichuan Province (ESP1801),the Scientific research initiation project of Mian yang normal university (QD2019A13)

Conflict of Interest

The authors declare no conflict of interest.

References

1. HE J.K. Global low-carbon transition and China's response strategies. Advances in Climate Change Research. **7** (4), 204, **2016**.
2. RAJKHOWA S., SARMA J. Climate change and flood risk, global climate change. global climate change. 321, **2021**.
3. TERMAAT T., VAN STRIEN A.J., VAN GRUNSVEN R.H.A., DE KNIJF G., BJELKE U., BURBACH K., CONZE K.J., GOFFART P., HEPPER D., KALKMAN V.J. *et al*. Distribution trends of European dragonflies under climate change. Divers. Distrib. **25** (6), 936, **2019**.
4. BELLARD C.,BERTELSMEIER C., LEADLEY P., THUILLER W., COURCHAMP F. Impacts of climate change on the future of biodiversity. Ecol. Lett. **15** (4), 365, **2012**.
5. PIMM S.L., JENKINS C.N., ABELL R., BROOKS T.M., GITTLEMAN J.L., JOPPA L.N., RAVEN P.H., ROBERTS C.M.,SEXTON J.O. The biodiversity of species and their rates of extinction, distribution, and protection. Science. **344** (6187), 1246752, **2014**.
6. RUSHING C.S., RUBENSTEIN M., LYONS J.E, RUNGE M.C. Using value of information to prioritize research needs for migratory bird management under climate change: a case study using federal land acquisition in the United States. Biological Reviews. **95** (4), 1109, **2020**.
7. GARCIA K., LASCO R., INES A., LYON B., PULHIN F. Predicting geographic distribution and habitat suitability due to climate change of selected threatened forest tree species in the. Philippines. Applied Geography. **44** (2013), 12, **2013**.
8. GROUP I. IPCC Sixth Assessment Report (AR6): Climate Change 2021-The Physical Science Basis, IPCC. **2021**. Retrieved from https://policycommons.net/artifacts/1804180/ipcc_ar6_wgi_full_report/2535824/on 15 Aug 2021. CID: 20.500.12592/4v6p2k.
9. MONERIE P.A., WAINWRIGHT C.M., SIDIBE M., AKINSANOLA A.A. Correction to: Model uncertainties in climate change impacts on Sahel precipitation in ensembles of CMIP5 and CMIP6 simulations. Climate Dynamics. **55** (7), 2309, **2020**.
10. ZHU Y.Y., YANG S.N. Evaluation of CMIP6 for historical temperature and precipitation over the Tibetan Plateau and its comparison with CMIP5. Advances in Climate Change Research. **11** (3), 239, **2020** [In Chinese].
11. INAGUE G.M., ZWIENER V.P., MARQUES M.C.M. Climate change threatens the woody plant taxonomic and functional diversities of the *Restinga* vegetation in Brazil. Perspectives in Ecology and Conservation. **19** (1), 53, **2021**.
12. GARAH K., BENTOUATI A. Using the MaxEnt model for assessing the impact of climate change on the Aurasian Aleppo pine distribution in Algeria. Afr. J. Ecol. **57** (4), 500, **2019**.
13. ELITH J., LEATHWICK J.R. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. Annual Review of Ecology, Evolution and Systematics. **40** (1), 677, **2009**.
14. STOCKWELL D.R.B., PETERSON A.T. Effects of sample size on accuracy of species distribution models. Ecol. Model. **148** (1), 1, **2002**.
15. BITTNER R.E., ROESLER E.L., BARNES M.A. Using species distribution models to guide seagrass management. Estuarine Coastal and Shelf Science. **240**, 106790, **2020**.
16. MOTLOUNG R., ROBERTSON M., ROUGET M.,WILSON J. Forestry trial data can be used to evaluate climate-based species distribution models in predicting tree invasions. Neobiota. **20**, 31, **2020**.
17. PHILLIPS S.J., ANDERSON R.P., SCHAPIRE R.E. Maximum entropy modeling of species geographic distributions. Ecol. Model. **190** (3-4), 231, **2006**.
18. ELITH J., PHILLIPS S.J., HASTIE T., DUDíK M., CHEE Y.E.,YATES C.J. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions. **17** (1), 43, **2015**.
19. WANG G., WANG C., GUO Z., DAI L.J., WU Y.Q., LIU H.Y., LI Y.F., CHEN H.,ZHANG Y.N., ZHAO Y.X., CHENG H., MA T.W., XUE F. Integrating Maxent model and landscape ecology theory for studying spatiotemporal dynamics of habitat: Suggestions for conservation of endangered Red-crowned crane. Ecol. Indicators. **116**, 106472, **2020**.
20. CAI J.Y., ZHANG M.M., SU H.J., ZHANG H.B. Application of Ecological Niche Models for Selection of Species Habitat. Journal of Economic Animal. **18** (1), 47, **2014** [In Chinese].
21. WANG R.L., LI Q., FENG C.H., SHI C.P. Predicting potential ecological distribution of *locusta migratoria tibetensis* in China using maxent ecological niche modeling. Acta Ecologica Sinica. **37** (24), 8556, **2017** [In Chinese].
22. ATWATER D.Z. BARNEY J.N. Climatic niche shifts in 815 introduced plant species affect their predicted distributions. Global Ecol. Biogeogr. **30** (8), 1671, **2021**.
23. SRIVASTAVA V., ROE A.D., KEENA M.A., HAMELIN R.C., GRIESS V.C. Oh the places they'll go: improving

species distribution modelling for invasive forest pests in an uncertain world. Biol. Invasions. 1, **2021**.
24. ZHANG H., SONG J.Y., ZHAO H.X., LI M., HAN W.H. Predicting the Distribution of the Invasive Species *Leptocybe invasa*: Combining MaxEnt and Geodetector Models. Insects. **12** (2), 92, **2021**.
25. TORUN P., ALTUNEL A.O., Effects of environmental factors and forest management on landscape-scale forest storm damage in Turkey. Annals of Forest Science. **77** (2), 39, **2020**.
26. LÓPEZ-MARTÍNEZ V., SÁNCHEZ-MARTÍNEZ G., JIMÉNEZ-GARCÍA D., PÉREZ-DE LA O.N.B., COLEMAN T.W. Environmental suitability for *Agrilus auroguttatus* (Coleoptera: Buprestidae) in Mexico using MaxEnt and database records of four *Quercus* (Fagaceae) species. Agricultural and Forest Entomology, **18** (4), 409, **2016**.
27. LV W.C., LI Z.H., WU X.X., NI W.L., QV W.W. Maximum Entropy Niche-Based Modeling (Maxent) of Potential Geographical Distributions of *Lobesia Botrana* (Lepidoptera: Tortricidae) in China. International Conference on Computer and Computing Technologies in AgricultureV. CCTA **2011**. IFIP Advances in Information and Communication Technology, vol 370. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-27275-2_26.
28. ZHAO H.X., ZHANG H., XU C.G. Study on *Taiwania cryptomerioides* under climate change: MaxEnt modeling for predicting the potential geographical distribution. Global Ecology and Conservation. **24**, e01313, **2020**.
29. LIU L., GUAN L.L., ZHAO H.X., HUANG Y., MOU Q.Y., LIU K., CHEN T.T., WANG X.Y., ZHANG Y., WEI B., HU J.Y. Modeling habitat suitability of *Houttuynia cordata* Thunb (Ceercao) using MaxEnt under climate change in China. Ecological Informatics. **63**(4), 101324, **2021**.
30. CLENNETT C. Dipteronia sinensis: Sapindaceae. Curtiss Botanical Magazine. **30** (3), 208, **2013**.
31. SHAHZAD K., LIU M.L., ZHAO Y.H., ZHANG T.T., LIU J.N. Evolutionary history of endangered and relict tree species *Dipteronia sinensis* in response to geological and climatic events in the Qinling Mountains and adjacent areas. Ecology and Evolution. **10** (24), 14052, **2020**.
32. YANG J., WANG X.M., LI S., ZHAO G.F. What is the phylogenetic placement of *Dipteronia dyerana* Henry? An example of plant species placement based on nucleotide sequences. Giornale Botanico Italiano. **144** (3), 634, **2010**.
33. HARRIS A.J., FRAWLEY E.,WEN J. The Utility of Single-Copy Nuclear Genes for Phylogenetic Resolution of *Acer* and *Dipteronia* (Acereae, Sapindaceae). Ann. Bot. Fenn. **54** (4-6), 209, **2017**.
34. ZHOU T., LI Z.H., BAI G.Q., FENG L., CHEN C., WEI Y., CHANG Y.X., ZHAO G.F. Transcriptome Sequencing and Development of Genic SSR Markers of an Endangered Chinese Endemic Genus *Dipteronia* Oliver (*Aceraceae*). Molecules. **21** (3), 166, **2016**.
35. RUIJVEN B.J., LEVY M.A., AGRAWAL A., BIERMANN F., BIRKMANN J., CARTER T.R., EBI K.L., GARSCHAGEN M., JONES B.,JONES R. *et al*. Enhancing the relevance of Shared Socioeconomic Pathways for climate change impacts, adaptation and vulnerability research. Clim. Change. **122** (3), 481. **2014**.
36. YANG S.H.,CUI X.F. Building Regional Sustainable Development Scenarios with the SSP Framework. Sustainability. **11** (20), 5712, **2019**.
37. YANG X.Q., KUSHWAHA S.P.S., SARAN S., XU J.C., ROY P.S. Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol. Eng. **51**, 83, **2013**.
38. FIELDING A.H., BELL J.F. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ Conser. **24** (1), 38, **1997**.
39. VANAGAS G. Receiver operating characteristic curves and comparison of cardiac surgery risk stratification systems. Interact Cardiovasc Thorac Surg. **3** (2), 319, **2004**.
40. COBOS M.E., PETERSON A.T., BARVE N.,OSORIO-OLVERA L. kuenm: an R package for detailed development of ecological niche models using Maxent. PeerJ. **7**, e6281, **2019**.
41. SIMUNDIĆ A.M. Measures of diagnostic accuracy: basic definitions. Ejifcc. **19** (4), 203, **2009**.
42. LI J.J., FAN G.,HE Y. Predicting the current and future distribution of three *Coptis* herbs in China under climate change conditions, using the MaxEnt model and chemical analysis. The Science of the Total Environment. **698** (Jan.1), 134141, **2020**.
43. LI S., QIAN Z.Q., CAI Y.L.,ZHAO G.F. A comparative study on the genetic diversity of *Dipteronia sinensis* and *Dipteronia dyeriana*. Chinese Journal of Plant Ecology. **29** (5), 785, **2005** [In Chinese].
44. THOMAS C.D., CAMERON A., GREEN R.E., BAKKENES M., BEAUMONT L.J., COLLINGHAM Y.C., ERASMUS B.F., SIQUEIRA M.D., GRAINGER A.,HANNAH L. *et al*. Extinction risk from climate change. Nature. **427** (6970), 145, **2004**.
45. LENG W.F., HE H.S., BU R.C., DAI L.M., HU Y.M.,WANG X.G. Predicting the distributions of suitable habitat for three larch species under climate warming in Northeastern China. Forest Ecology and Management. **254** (3), 420, **2008**.
46. THUILLER W. BIOMOD-optimizing predictions of species distributions and projecting potential future shifts under global change. Global Change Biol. **9** (10), 1353, **2003**.
47. ACEVEDO-RODRÍGUEZ P., VAN WELZEN P.C., ADEMA F., VAN DER HAM R.W.J.M. Flowering Plants. Eudicots: Sapindales, Cucurbitales, Myrtaceae. The Families and Genera of Vascular Plants. Springer, Berlin, 357, **2011**.
48. ZHAN Y.X., HU Z.R., ZHOU S.X., ZHANG L., ZHAN X.H.,PENG Y.S. Quantitative dynamics of Dipteronia sinensis populations in Saiwudang Nature Reserve, Hubei province. Ecological Science. **39** (1), 41, **2020** [In Chinese].