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Original Research

Simulation of Potential Suitable Distribution of Endangered Medicinal of *Paeonia rockii* under Climate Change Scenarios

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Abstract

Paeonia rockii has been a traditional medicinal material from time immemorial. It is an important plant resource of ethnic medicine and chinese herbal medicine. It has unique effects on heat and cool blood, promoting blood circulation and dispersing blood stasis, analgesia and promoting menstruational flow. It is also a first-class protected plant. With the increasing demand for the bark and roots of *P. rockii* in China's medicinal market, the continuous high-intensity and disorderly excavation has led to a sharp decline in wild resources. *P. rockii* is in imminent danger and needs to be saved and protected urgently. In this study, the distribution records of *P. rockii* in China, combined with environmental factors, are used to simulate the current potential distribution area of *P. rockii* through MaxEnt model. The environmental factors affecting the distribution of *P. rockii* are obtained by using the contribution rate of environmental factors and a jackknife test analysis, and the appropriate value of environmental factors is determined by using the response curve. The results show that the AUC value of test set data is 0.985 and that of training set data is 0.987. The prediction accuracy of the Maxent model is extremely high and the simulation effect is very good. At present, the high suitable areas of *P. rockii* are mainly distributed in the shape of cake in Southern Ningxia, southern Gansu and southern Shanxi, accounting for 15.58% of the total suitable areas. The most important environmental factor affecting the geographical distribution of *P. rockii* is the altitude; Under the future climate change scenario, the total suitable area of *P. rockii* shows a decreasing trend, among which the area of high suitable area shows

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an obvious decreasing trend, the mass center of high suitable area of *P. rockii* generally tends to migrate to the northwest, and the migration range is large under the scenario of high concentration emission. The research results can provide scientific data support for *P. rockii* to to cope with the changes in suitable areas caused by climate change and the establishment of effective protection, clarify the change and heterogeneity of *P. rockii* in different regions of China in the future, and clarify its ecological needs, which has certain practical significance.

Keywords: climate change, suitable distribution, *Paeonia rockii*, Maxent

Introduction

The global warming trend is becoming more pronounced, and climate change in China is mainly converging with global change [1]. China's National Climate Center (NCC) has shown that the frequency and intensity of extreme heat and heavy precipitation have increased significantly. Statistics from the National Climate Center (NCC) show that the frequency and intensity of extremely high temperatures have increased significantly. In contrast, the frequency of extremely heavy precipitation and the days of heavy rainfall have increased. Precipitation variability varies significantly between regions, with the average annual precipitation in northern regions and the Qinghai-Tibet Plateau, where precipitation is low, rising significantly in recent years, and the number of precipitation-free days increasing and precipitation decreasing in southwest China, where precipitation is abundant [2]. Environmental factors (e.g., temperature, water, soil, and surface moisture) and human activities significantly impact species distribution. Agriculture, forestry, livestock, and other industries are severely affected by a significant increase in extreme weather frequency and intensity [3]. As an exceptional plant resource, the cultivation and growth of medicinal plants are affected by climate change, and researchers have been looking at the interaction between plants and the environment and human activities and their impact on the growth of medicinal plants for decades [4-5]. Research has shown that environmental factors and human activities not only influence the distribution of medicinal plants but also play a critical role in forming their active ingredients [6]. Climate heavily influences the growth and reproduction of plants and is, therefore, the primary variable determining the geographical distribution of plant species [7]. The lack of adequate protection of medicinal plant resources due to global warming and the threat of human activity has led to a rapid decline and reduction in the geographical distribution of many medicinal plant species, with some at risk of extinction [8-9]. Some studies have used scientific modeling to predict the distribution of medicinal plant habitats [10-11]. Therefore, ecological models need to be used to predict the distribution of suitable habitats, suitable cultivation areas, and the environmental factors that determine the distribution of medicinal plant habitats and the formation of enhanced active ingredients.

Entropy is an essential concept in physics, representing the magnitude of the disorder of things. The theory of maximum entropy (MaxEnt) originated in information science and is a mathematical method of inferring unknown probability distributions from known partial information. In 2004, Phillips et al. [12]. developed MaxEnt, a species distribution modelling software based on maximum entropy theory, which uses the non-random relationship between the latitude and longitude information of the target species and the corresponding environmental variables to project the ecological requirements of the species, calculate the optimal state of species distribution at maximum entropy, project the results of the operation to different time and space, and then reveal the relationship between environmental variables and the spatial distribution pattern of the species. The results are projected to different times and spaces, the relationships between environmental variables and species spatial distribution patterns are revealed accordingly, and species' fitness in the predicted area is probabilist [13]. The MaxEnt model has been widely used in predicting the geographical distribution of plants and evaluating the climatic suitability of habitats, predicting and analyzing the habitat suitability of endangered species, and the impact of climate change on the geographical distribution of species [14]. Since its introduction in 2004, the MaxEnt model has been widely used by scholars at home and abroad, and its prediction effect has been highly evaluated in the industry. Therefore, it has been widely used in the prediction of potential distribution areas of many tree species, such as *Magnolia wilsonii* [15], *Dipteronia sinensis* [16], *Blumea balsamifera* [17], *Isoetes* [18], etc.

Although there are more than 10 commonly used species distribution models, their simulation and prediction performance varies considerably due to the different theoretical bases of the models. The software is freely available, the interface is simple, and there is no need for complex format conversion of species distribution data and environmental data. (2) ROC (Receiver Operating Characteristic) curves, response curves, and knife cut test plots can be automatically output during simulation without exporting data for secondary calculation and mapping. (3) Only a small sample of species 'presence' data is required for the simulation, and the simulation has excellent results. (4) The theoretical basis is closely linked to ecology and facilitates understanding species suitability [19]. This is why the MaxEnt model has been widely used since its inception. Petltpierre et al. [20], Shitara et al. [21] and Jiang Yi Fan [22] research shows that the MaxEnt model is more effective than other species distribution models, and the prediction accuracy of other models has been compared and validated accordingly. The MaxEnt model has the highest prediction accuracy among all models. Therefore, MaxEnt was selected as the simulation software to predict the potential distribution of target species and to analyze the effects of climatic variables on species distribution in this study.

Paeonia rockii is a deciduous shrub with short, thick branches and stems up to 2m high. It is a woody plant of the peony group, and an endemic plant of China, which is also listed as a first-class protected plant in the State Forestry and Grassland Administration and the Ministry of Agriculture and Rural Development Announcement (No. 15, 2021); its flowers are large and beautiful (Fig. 1), and it has many excellent characteristics such as disease resistance, infertile and drought resistance, and cold resistance. The flowers of *P. rockii* are huge and colorful, which are not only of great ornamental value, but also represent the temperament of a country and the character of the people, and also express people's love for the motherland and profound national feelings [23]. *Paeonia rockii* has many excellent characteristics and is a critical germplasm resource. According to the Chinese Dictionary of Ethnomedicines and the Chinese Pharmacopoeia and related literature, *P. rockii* has unique effects in clearing heat and cooling the blood, activating blood circulation, dispersing blood stasis, relieving pain, and promoting menstruation, and has a solid response to climate change, making it a critical plant resource [24]. *Paeonia rockii* is widely used as a national medicinal material and Chinese herbal medicine. However, because the market demand for the cortex and root of *P. rockii* is particularly large, its wild resources themselves are far from meeting the needs of the market. Driven by economic interests, continuous high-intensity and disorderly excavation has led to a sharp decline in wild resources. According to Hong Deyuan and other researchers, the field survey shows that *Paeonia rockii* is endangered, so it is urgent to save and protect [25-26]. *Paeonia rockii* needs to be saved and protected. As a medicinal plant, *P. rockii* is also a fantastic plant resource, and its cultivation and growth are affected by climate change. Climate change has a significant impact on the distribution of medicinal plants and the quality, clinical benefits, and safety of medicinal herbs [27]. While studies have shown that non-climatic factors dominate short-term biological changes in plants, climate change has an irreversible effect on plant life systems [28-29]. Brooks et al. [30]. and Alkmake et al. [31]. showed that climate and topography are important environmental factors limiting the distribution of species at large scales. Due to global climate change and the lack of effective conservation of medicinal plant resources, the geographical distribution of many medicinal plant species has dramatically decreased or even disappeared [32]. The geographical distribution of many medicinal plant species has been drastically reduced or even disappeared due to global climate change and the lack of effective conservation of medicinal plant resources. Traditional surveys of medicinal plant resources rely mainly on field surveys and manual records, which are heavy, time-consuming, and have limited evaluation capabilities. This method does not adequately reflect

Fig. 1. *Paeonia rockii* photographed from wild habitat.

the intrinsic relationship between plants and environmental factors, especially changes in suitable areas under future climate scenarios [33]. The method does not adequately reflect the intrinsic relationships between plants and environmental factors, especially changes in suitable areas under future climate scenarios. How to effectively respond to future climate change and human interference is a critical issue in medicinal plant conservation planning. This study analyses the relationship between the geographical distribution of the target species and climate and human activities by modeling *P. rockii*'s geographical distribution from the ecological niche theory's perspective and investigates the influence of key environmental variables and human activities on the distribution of *P. rockii*. The study's results can provide scientific data to support the establishment of adequate protection for the peony in response to changes in its habitat due to climate change. The study results can provide scientific data to support the establishment of effective conservation of the peony in response to changes in the habitat of the Yunnan peony due to climate change.

Materials and Methods

Sources of Species Data

Information on the distribution of the *P. rockii*: The distribution was collected through a review of relevant publications and literature [34-36], field surveys, and queries to the China Digital Herbarium (CVH) to collect distribution points of *P. rockii*. Referring to Elith et al. [37]. Using the ArcGIS buffer analysis function, the distance between the center of the grid and the distribution points was calculated, and only one record closest to the center was retained in the same grid. The distribution records were then imported into an Excel sheet, with positive values for north and east latitudes and negative values for south and west latitudes, and recorded and saved in the order of species name, longitude, and latitude. The above procedure resulted in 62 *Paeonia rockii* distribution points (Fig. 2).

Sources and Treatment of Variables

The climate data is derived from the Worldclim database based on global meteorological records and integrated with interpolation to generate global climate raster data, including 19 bioclimatic factors. The above data is spatially resolved at 2.5 arc-minutes, in tiff format raster files, using the administrative map of China as the base map to extract climate variables. All data is available at All data are freely available on the Worldclim website. The Beijing Climate Centre climate system model (BCC-CSM2-MR) with coupled mode 6 (CMIP6) was selected as the future climate model after intercomparison, as the CMIP6 scenario model is closer to the actual situation [38]. The Human Activity Intensity (HAI) grid, also known as the Human Footprint Index (HFI) grid, was developed by the 2009 Human Footprint [39]. We then used Euclidean linear distance analysis in ArcGIS10.5 to derive the distance layer of human disturbance. The spatial resolution

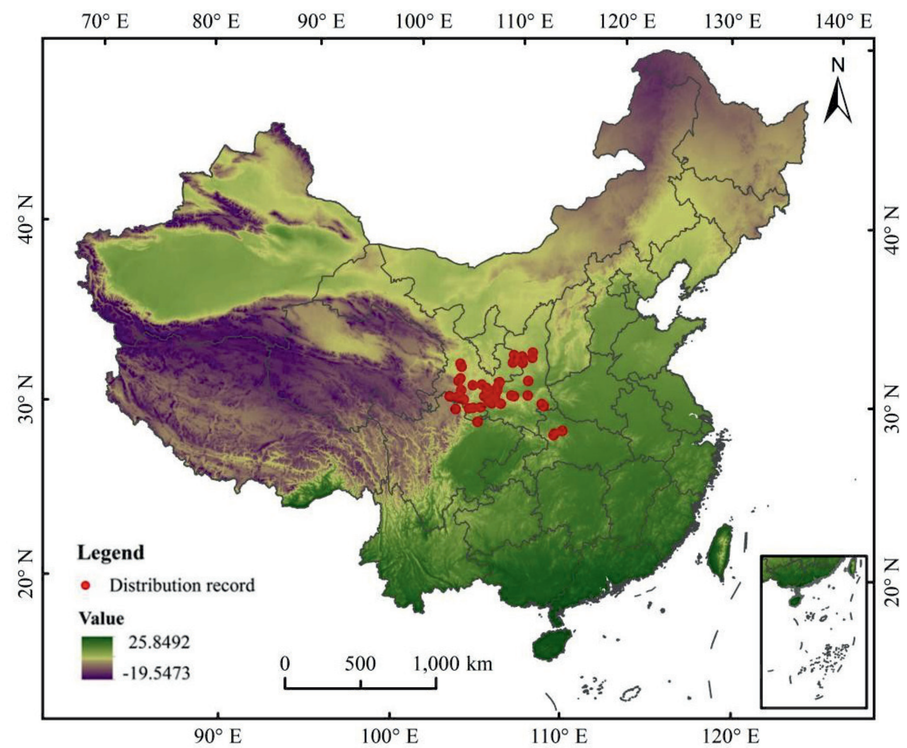

Fig. 2. Species occurrence records of *P. rockii* [trail No.GS (2016)2923].

of the above data was 2.5 arc-minutes. Height data (30 m) was downloaded from the Geospatial Data Cloud (GDC), and its resolution was harmonized with climate variables by kriging (2.5 arc-minutes).

Modelling Variable Screening

In order to evaluate the performance of the parameter configurations, different parameter configurations were selected for trial runs, which have been used to adjust the optimal parameters of the model: in this study, the RM was set to 0.5 to 4, respectively, based on the known *P. rockii* and its corresponding environmental factors. Six feature combinations (FC) were used to optimize the model parameters and select the best combination. Finally, for this study, the RM was set to 1, and the feature combinations to LQHPT. A knife-cut approach was chosen to determine the weights of each variable affecting the variables [40]. Many researchers have introduced Pearson correlation coefficients into the comparison process to screen variables and remove covariates. For example, Wan Ji-Chung explored the uncertainties in the distribution model of invasive alien plants and pointed out that using Pearson's correlation coefficient to analyze the covariance of 19 variables could reduce the influence of this factor on the simulation results [41]; Li Lihe et al. used the knife cut method to determine the importance of variables in the prediction of the spatial distribution of Canada's one-dimensional yellow flowers and conducted Pearson correlation analysis on the variables to avoid over-fitting during the simulation [42]. In this study, the following steps were taken to screen the modeling variables: firstly, the initial variables and species distribution data were imported into MaxEnt, the initial contribution of each variable was calculated, and the variables with meager contribution were removed. Secondly, the attribute values of all remaining variables were extracted using ArcGIS software. Thirdly, the correlation analysis was performed by Spearman. Fourthly, the correlation coefficients between the variables were compared. For variables with correlation coefficients higher than 0.80, they were first screened according to their ecological significance. Then the contribution rates in the initial model were compared if they could not be determined. Finally, eight environmental factors were screened for purple-spotted peonies (Table 1).

Model Accuracy Validation

Species distribution models often over- or underestimate the distribution of species, i.e., false positives and negatives. False positives are areas where species are actually 'absent' (hostile areas) predicted to be 'present' (positive areas), and false negatives are areas where species are 'present' predicted to be "not present." Therefore, assessing the accuracy of model simulations using valid evaluation metrics is an essential step in determining the accuracy and usability of the model. Commonly used theoretical evaluation metrics for species distribution models include overall accuracy, sensitivity, specificity, AUC values, etc. Indicators have different judging methods and criteria, among which AUC is more widely used. The assessment of the prediction accuracy of the model is based on the area under the operational characteristics curve of the subjects. The AUC value from 0 to 1 is positively correlated with the prediction effectiveness, and the closer it is to 1, the higher the prediction accuracy of the model, and vice versa. The accuracy of the model was also assessed as poor, fair, good and very good, with AUC values in the intervals of ($AUC \leq 0.80$), ($0.80 < AUC \leq 0.90$), ($0.90 < AUC \leq 0.95$) and ($0.95 < AUC \leq 1.00$) respectively [43].

Classification of Habitat Classes

The format conversion function of ArcGIS software was applied to convert the ASCII format files outputted by MaxEnt software to Raster format files. The default suitability class of the MaxEnt model is 10. Based on the IPCC interpretation of species distribution probability (P) and previous research results, and based on the study by Hanley et al. [44], the suitability zones were divided into unsuitable, low, moderate and high suitability zones, which are represented by the

Table 1. List of the environmental variables used to develop the model of *P. rockii.*

Variable	Description	Description
Altitude	Elevation	Reflecting the effects of altitude
Bio12	Annual precipitation	Reflects the amount and seasonal distribution of rainfall
Bio6	Coldest monthly minimum temperature	Reflects the effects of extreme temperatures
HAI	Intensity of human activity	Reflects cumulative human pressures on the environment
Bio15	Coefficient of variation of precipitation	Reflects the amount and seasonal distribution of rainfall
Bio4	Standard deviation of seasonal variation in air temperature	Reflects average temperature and its variability
Bio3	Isothermal	Reflects temperature difference characteristics
Bio10	Warmest quarterly average temperature	Reflects the effects of extreme temperatures

P values were in the ranges of (0.0≤P<0.1), (0.1≤P<0.3), (0.3≤P<0.6) and (0.6≤P), respectively.

Results and Discussion

Model Accuracy Validation

Based on 62 records of the distribution of purple spotted peonies, the MaxEnt model was used to simulate and predict the potential habitat of purple spotted peonies in China, based on the AUC values of 0.985 for the test set and 0.987 for the training set data, respectively. The ROC curves are shown in Fig. 3.

Dominant Influencing Factors Affecting the Potential Habitat of *P. rockii*

Researchers' views on determining the number of dominant factors are inconsistent. Most scholars believe that the dominant factors should be determined according to their contribution rates, and the environmental factors that reach a certain degree should be taken as the dominant factors. However, the choice of degree is subjective, so different criteria emerge. This study selected the top four environmental factors in terms of contribution rate as the dominant environmental factors. After calculation, from the calculation results of the *P. rockii*, among the eight environmental factors, the contribution rates of altitude (altitude), annual precipitation (Bio12), coldest monthly minimum temperature (Bio6), and intensity of human activities (HAI) were 24.20%, 19.60%, 18.10%, and 15.80% respectively. The cumulative value of the four reached 77.70%, ranking the top four as a dominant environmental factor as dominant environmental factor (Table 2).

In this study, the Jackknife test showed that altitude, annual precipitation (Bio12), the minimum temperature in the coldest month (Bio6), and human activity intensity (HAI) were the four environmental factors that had the most significant influence on the gain in formal training of *P. rockii* when a single environmental factor variable was used. These environmental variables indeed dominated the growth of the *P. rockii* (Fig. 4).

Relationship between Presence Probability of *P. rockii* and Dominant Influencing Factors

In determining the values of favorable and unfavorable environmental factors to the growth of Zea mays, the response curves of the environmental factors can be judged (Fig. 5). From this, we can conclude that the dominant environmental factors that are suitable for the growth of purple peonies are altitude, annual precipitation (Bio12), the minimum temperature in the coldest month (Bio6), and intensity of human activity (HAI) (Fig. 5). This is also consistent with the growth habits of the *P. rockii* and further illustrates the accuracy of the predictions.

Current Potential Distribution Areas and Conservation Measures for *P. rockii*

The results of the potential habitat of *P. rockii* under the current climate conditions are shown in Fig. 6.

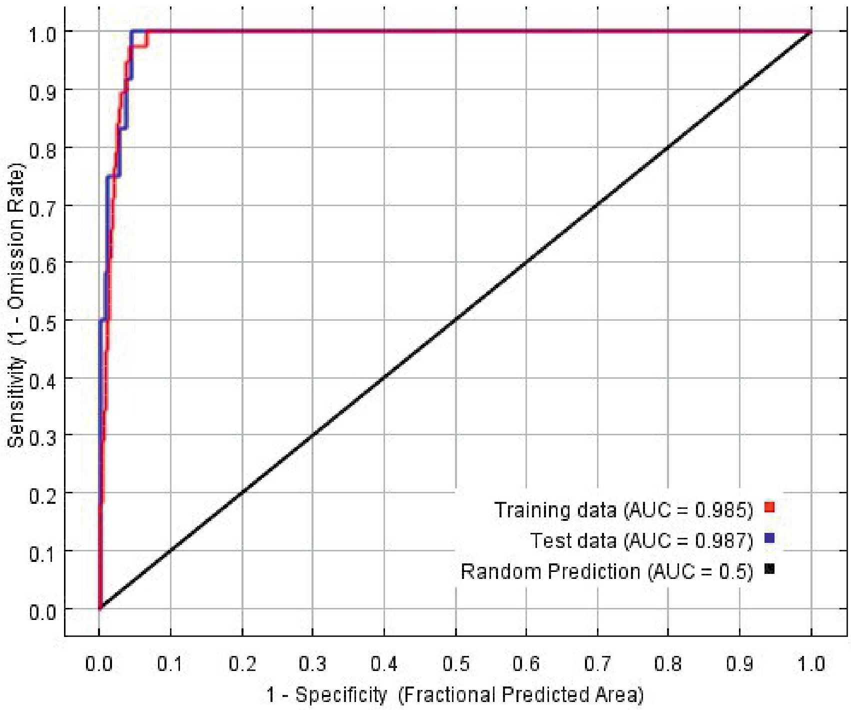

Fig. 3. Receiver operating characteristic curve of *P. rockii* Maxent model.

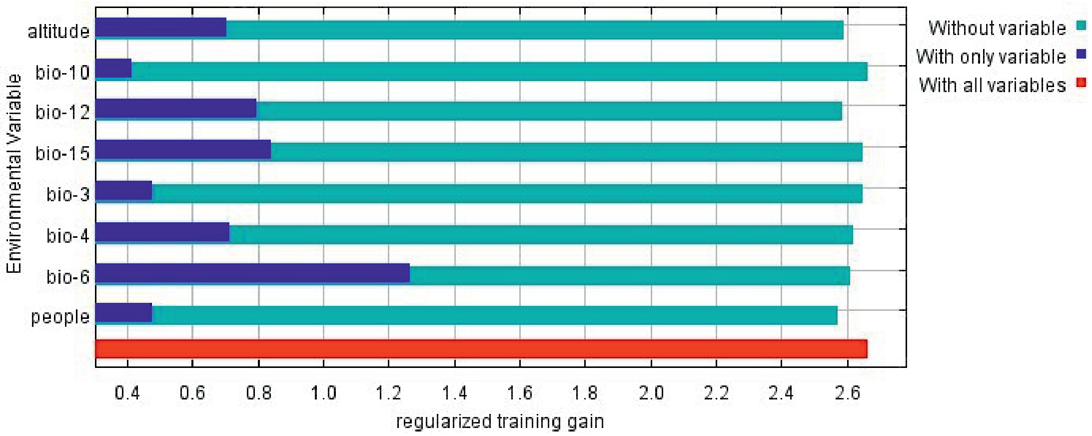

Fig. 4. The jackknife test result of environmental factor for *P. rockii*.

The habitat areas of *P. rockii* are located in the southeastern part of Northwest China, the southwestern part of North China, the northwestern part of Central China in a pie-shaped distribution and the eastern part of Southwest China in a strip-shaped distribution, with a total habitat area of 69.60×10^4 km^2 . The high habitat area accounts for 15.58% of the total habitat area, with an area of 10.84×10^4 km^2 , and is distributed in a pie-shaped distribution in the southwestern part of Gannan, Ningnan and Shaanxi. The other part is scattered in northeastern Sichuan, western Henan and southern Jinan. The middle-suitable area accounts for 30.01% of the total suitable area, with an area of 20.89×10^4 km^2 , mainly surrounded by the periphery of the high-suitable area in a pie-shaped distribution, concentrated in the periphery of the high-suitable area in the south of Gan, south of Ning, south of central Shaanxi, south of Jin and west of Xiang, and sporadically distributed in the east of Qing, east of Chuan, central of Chuan, northeast of Yunnan, northeast of Yu and northwest of E. The other part is scattered in the eastern part of Qinghai, the eastern part of Sichuan, the central part of Sichuan, the northeast of Yunnan, the northeast of Chongqing and the northwest of E. The area of the low fitness zone accounts for 54.41% of the total fitness zone, with an area of 37.87×10^4 km^2 , mainly surrounded by the periphery of the middle fitness zone and filled within the middle fitness zone in a pie-shaped distribution, concentrated in the central and southern Gansu, northern Qian, western E, western Henan, central Jin, southwest Jin and central Jin, and partly in a strip or scattered distribution in the central Sichuan and northwest Yunnan regions. More than half of the total habitat area. In general, the high fitness zone and the middle fitness zone of *P. rockii* were distributed in thin strips in Gannan, Ningnan and southwestern

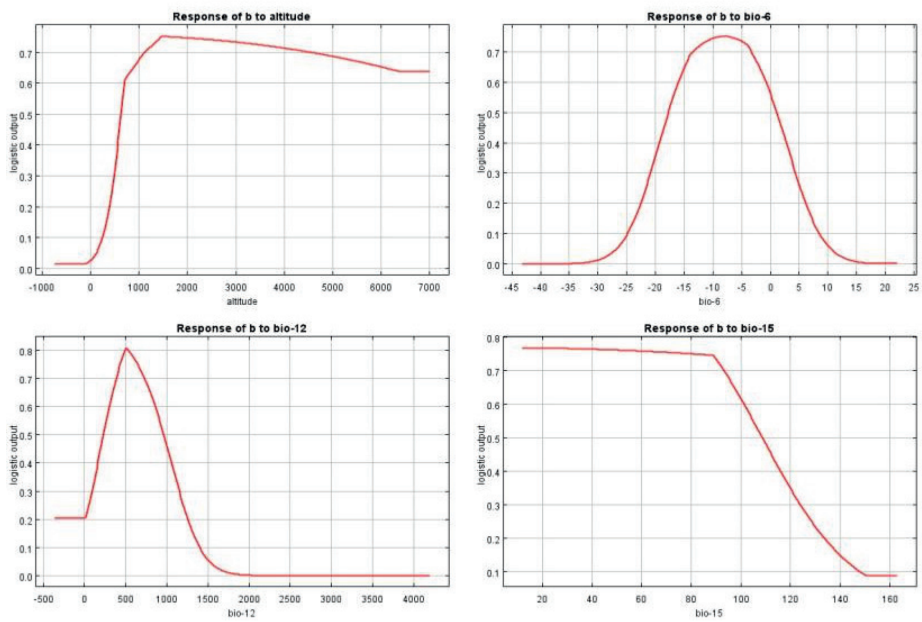

Fig. 5. Response curves of existence probality of *P. rockii*.

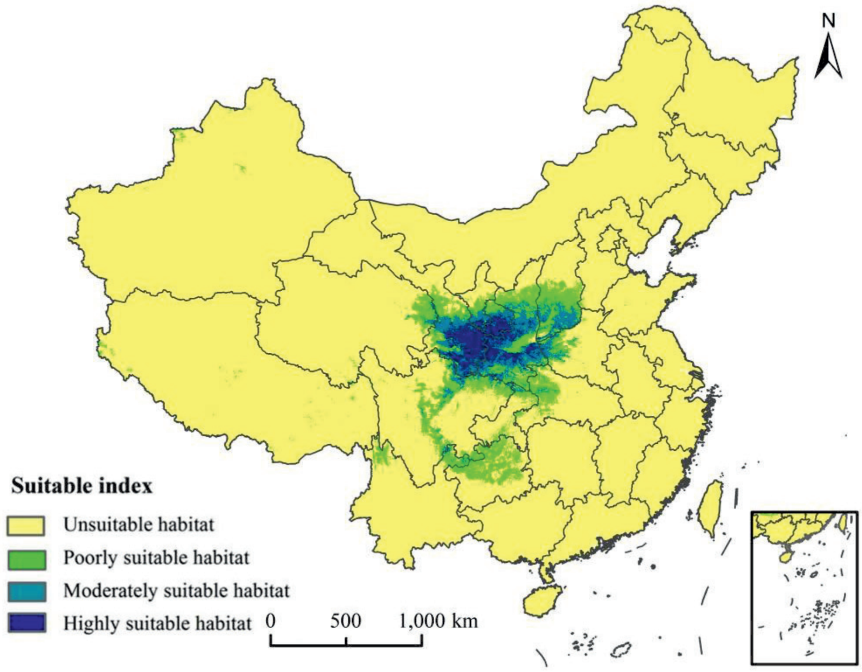

Fig. 6. Potential geographical distribution of *P. rockii* under modern climate conditions [trail No.GS (2016)2923].

Shaanxi regions, which were in good agreement with their actual distribution, further indicating the high accuracy of the simulation effect of this study. The results of the potential habitat of purple-spotted peonies under the current climate conditions are shown in Fig. 6. The habitat areas of *P. rockii* are located in the southeastern part of Northwest China, the southwestern part of North China, the northwestern part of Central China in a pie-shaped distribution, and the eastern part of Southwest China in a strip-shaped distribution, with a total habitat area of 69.60×10^4 km^2. The high habitat area accounts for 15.58% of the total habitat area, with an area of 10.84×10^4 km^2, and is distributed in a pie-shaped distribution in the southwestern part of Gannan, Ningnan, and Shaanxi. The other part is scattered in northeastern Sichuan, western Henan, and southern Jinan. The middle-suitable area accounts for 30.01% of the total suitable area, with an area of 20.89×10^4 km^2, mainly surrounded by the periphery of the high-suitable area in a pie-shaped distribution, concentrated in the periphery of the high-suitable area in the south of Gan, south of Ning, south of central Shaanxi, south of Jin and west of Xiang, and sporadically distributed in the east of Qing, east of Chuan, central of Chuan, northeast of Yunnan, northeast of Yu and northwest of E. The other part is scattered in the eastern part of Qinghai, the eastern part of Sichuan, the central part of Sichuan, the northeast of Yunnan, the northeast of Chongqing, and the northwest of E. The area of the low fitness zone accounts for 54.41% of the total fitness zone, with an area of 37.87×10^4 km^2, mainly surrounded by the periphery of the middle fitness zone and filled within the middle fitness zone in a pie-shaped distribution, concentrated in the central and southern Gansu, northern Qian, western E, western Henan, central Jin, southwest Jin and central Jin, and partly in a strip or scattered distribution in the central Sichuan and northwest Yunnan regions. More than half of the total habitat area. In general, the high and middle fitness zones of purple-spotted peonies were distributed in thin strips in Gannan, Ningnan, and southwestern Shaanxi regions, which were in good agreement with their actual distribution, further indicating the high accuracy of the simulation effect of this study.

The frequency and intensity of extreme weather are increasing significantly, with severe impacts on agriculture, forestry, livestock, and other industries [45]. The importance of global climate and environmental change research in scientific research is increasingly appreciated [46]. The importance of global climate and environmental change research in scientific research is increasing. For example, in the internationally renowned journal Science, resource stocks have been studied in recent years [47-48]. Ecologists have realized the enormous damage caused by the loss of biodiversity and have adopted ecological conservation as a hot topic of research in the environmental field. As an exceptional plant resource, the cultivation and growth of medicinal plants are affected by climate change. In addition to the enormous impact on the distribution of medicinal plants, climate change also has a potential impact on the quality, clinical benefits, and safety of medicinal herbs [27]. Only the best varieties of herbs with significant therapeutic effects can be called quality herbs. However, the origin of quality herbs is not fixed and can expand, contract, or migrate under the influence of

Table 2. Environmental variables and their contributions of *P. rockii.*

Variable	Percent contribution
Altitude	24.20%
Bio12	19.60%
Bio6	18.10%
HAI	15.80%
Bio15	9.30%
Bio4	8.90%
Bio3	3.90%
Bio10	0.20%

climate change. For example, Shen et al. [49]. predicted that future increases in mean annual temperatures will cause the main distribution area of saffron gentian to expand to higher altitudes.

This study analyzed the distribution of the potential habitat of P. purpurea in China. According to the study (Fig. 6), the total area of the habitat of *P. rockii* is 69.60×10^4 km^2, with most of it located in the southeastern part of Northwest China, southwestern part of North China, and northwestern part of Central China in a pie-shaped distribution, and a small part of it is located in the eastern part of Southwest China in a strip-shaped distribution, of which the high habitat area is 10.84×10^4 km^2, distributed in a pie-shaped distribution in the southern part of Gansu, the southern part of Ning and southern part of Shaanxi, and another part. The other part is scattered in northeast Sichuan, west Henan, and south Jinan. According to the data from field surveys, literature, and botanical specimen database, *P. rockii* is distributed in northeast Sichuan and southern Gannan. The areas mentioned above are within the suitable areas predicted in this study. According to Zhang Chenglin et al. [50]. The distribution of purple-spotted peonies in the western part of the country is also within the suitable area predicted by the study, according to Cui Zhijia et al. [34]. and Li Longtao et al. [35]. The accuracy of the prediction results is further illustrated by the fact that the *P. rockii* is found in the Gannan region, according to Cui Zhijia et al.

Impacts of Future Climate Change on the Geographical Distribution of *P. rockii*

Under the three SSPs (SSP1-2.6, SSP2-4.5 and SSP5-8.5), the area of each fitness zone of *P. rockii* decreased to different degrees in the 2050s and 2070s, but the Highly suitable habitat of *P. rockii* decreased greatly in the 2050s and 2070s, and the largest decrease was in the S2070s with SSP5-8.5. Under the SSP5-8.5 scenario, the Highly suitable habitat decreased by 57.75%, which is more than half of the current Highly suitable habitat of *P. rockii*, indicating that climate change has a significant impact on the high fitness zone of *P. rockii* (Fig. 7, Table 3). The total habitat area of *P. rockii* decreased to some extent in the 2050s and 2070s, indicating that a large part of the habitat area disappeared and few new habitat areas were added (Table 3). Compared to the current distribution, the total area of suitable areas will decrease by 12.84%, 7.79% and 12.33% under the three SSPs (SSP1-2.6, SSP2-4.5 and SSP5-8.5) in the 2050s, respectively, while the area of highly suitable areas will decrease by 23.62%, 15.87% and 42.16%, respectively, and the area of medium suitable areas will decrease by 11.49% and 6.03%, respectively. 11.49%, 6.03% and 14.07% respectively, and 10.51%, 6.44% and 2.83% respectively in the low fitness zone (Table 3). Compared to the current distribution, in the 2070s the total suitable area would be reduced by 12.41%, 16.51% and 20.69% under the three SSPs (SSP1-2.6, SSP2-4.5 and SSP5-8.5), respectively, the high suitable area would be reduced by 27.40%, 39.67% and 57.75%, respectively, and the medium suitable area would be reduced by 6.85%, 14.22% and 19.91%, and 11.14%, 11.14% and 10.51% in the low fitness zone (Table 3).

In summary, under future climate change scenarios, the area of all suitable zones for *P. rockii* shows a general trend of reduction, with the area of high suitable zones showing a clear trend of reduction, especially in the 2070s, when the area of high suitable zones is reduced by half under SSP5-8.5 scenario.

Climate factors are key factors in limiting the potential distribution of species at macroscopic scales, and the study of plant-climate interactions is an essential direction in ecology. The MaxEnt model predicts (Fig. 5) that altitude, annual precipitation (Bio12), coldest monthly minimum temperature (Bio6), and human activity intensity (HAI) are the dominant environmental factors limiting the potential geographic distribution of P. purpura. The results of this study show that elevation is the dominant environmental factor limiting the probability of purple-spotted peonies. To a certain extent, the probability of the presence of purple-spotted peonies increases with increasing elevation. As the annual precipitation rises, the probability of the presence of purple-spotted peonies gradually increases. However, as the annual precipitation continues to rise, the probability of the presence of purple-spotted peonies gradually decreases. Altitude also influences precipitation, indicating that altitude significantly influences the potential geographical distribution of purple-spotted peonies. The distribution of the *P. rockii* is also governed to a greater extent by the minimum temperature of the coldest month, with the probability of the presence of the *P. rockii* increasing as the minimum temperature of the coldest month increases but decreasing as the minimum temperature of the coldest month continues to increase. This indicates that temperature and precipitation also have a significant influence on the distribution of the *P. rockii*. The study by Zhang Li [51]

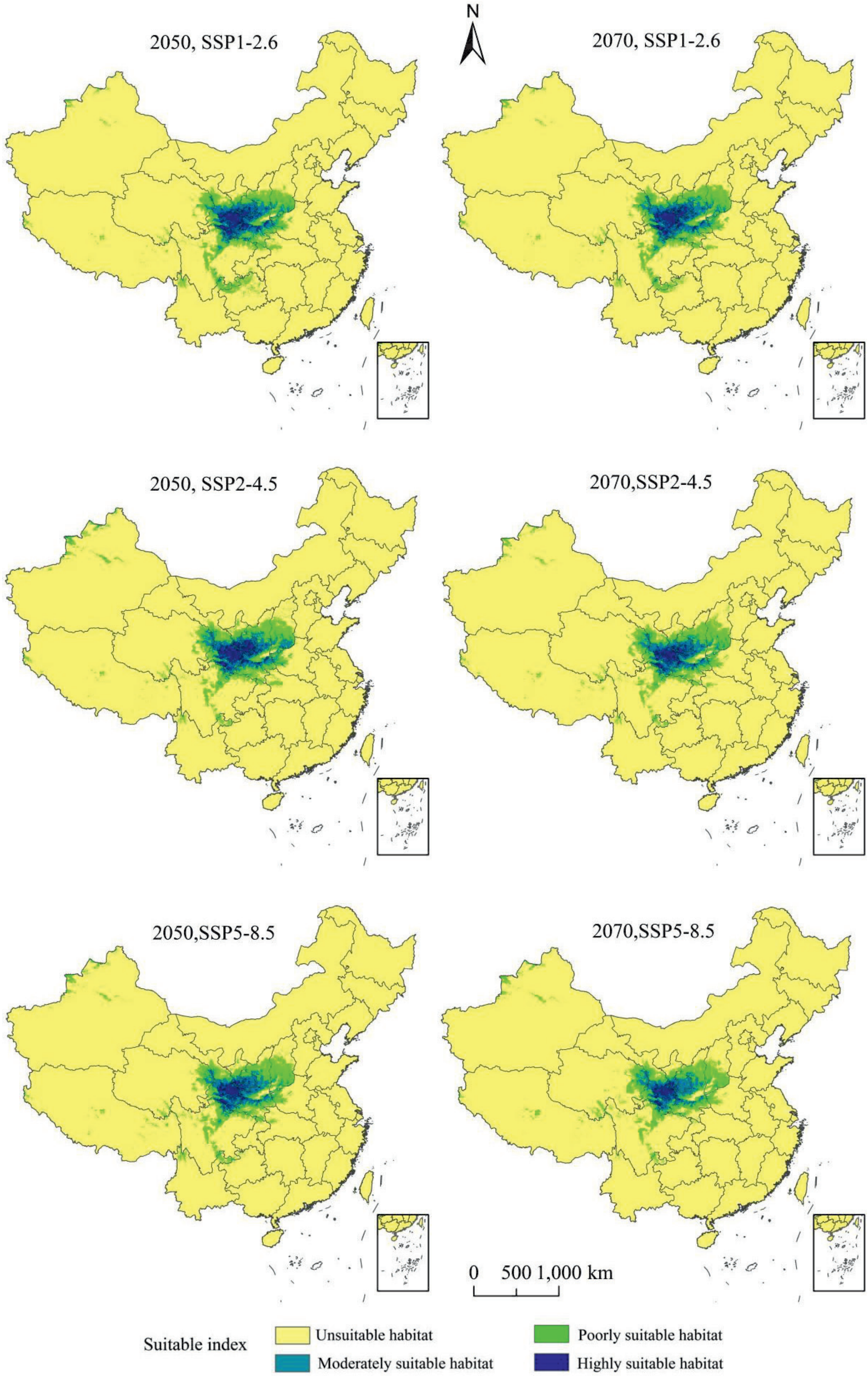

Fig. 7. Potential geographical distribution of *P. rockii* under future climate change scenarios [trail No.GS (2016)2923].

Table 3. Suitable areas for *P. rockii* under different climate change scenarios (10^4 km^2).

Periods	Highly suitable habitat	Moderately suitable habitat	Poorly suitable habitat	Total suitable habitat
Present	10.84	20.89	37.87	60.66
2050 SSP1-2.6	8.28	18.49	33.89	64.18
2050 SSP2-4.5	9.12	19.63	35.43	61.02
2050 SSP5-8.5	6.27	17.95	36.80	60.96
2070 SSP1-2.6	7.87	19.46	33.63	58.11
2070 SSP2-4.5	6.54	17.92	33.65	55.2
2070 SSP5-8.5	4.58	16.73	33.89	60.66

also shows that temperature and humidity significantly influence the growth and survival of the peony, which may also be related to the peony's light-loving and semi-shade tolerant habit. Wenliang Cui [52] simulated the response of three medicinal plants to climate change through the MaxEnt model, showing that the area and elevation of the plant's distribution area will change with the increase of temperature and precipitation, generating new distribution areas. However, some distribution areas will disappear again when the plant's suitable threshold is exceeded, indicating that temperature and precipitation have a more critical influence on the plant's fitness zone. Wu Jianguo [53] a study on seven species of protected plants in response to climate change by applying the CART model showed that the fitness zones of plants would change with the increase of temperature to produce new areas; also, with the increase of precipitation, the fitness zones of plants would start to expand, but when the threshold of suitability for the survival of the species was reached, some of the fitness zones would disappear again, indicating that temperature and precipitation have more acute effects on the fitness zones of *P. rockii*. Jiang Yifan [22] used five models to simulate the response of Horsetail pine in the context of climate change and analyze its suitable planting sites. The simulation results of various models show that precipitation and temperature are the dominant environmental factors governing the distribution of Horsetail pine. The area, elevation, and boundary of the plant distribution area will increase with the increase in temperature and precipitation. However, with the continuous increase of temperature and precipitation, after exceeding the threshold of plant suitability, This also indicates that temperature and precipitation have a more critical influence on the habitat of the *P. rockii*. The study shows that an increase in the intensity of human activity reduces the potential probability of the *P. rockii* and fragments its distribution area, which means that the *P. rockii* is very sensitive to human disturbance. Although the market for the plant can be partially met by cultivation, wild harvesting is still the most important source for the drug market. Therefore, human activities, especially commercial harvesting, continue to pose a severe threat to the survival of wild species.

Trajectory of the Centre of Mass in the High Fitness Zone of *P. rockii* under Future Climate Cange

The trajectory of the high fitness zone center of mass was calculated for the different periods. Their climate change scenarios (Fig. 8). From the baseline climate to the 2050 time period and then to the 2070 time period, the center of mass of the high fitness zone of *P. purpurea* generally tends to move towards higher latitudes and north-west under the three emission scenarios (Fig. 9). From the baseline climate to the 2070 time period, the cores of the Zea mays high fitness zone migrated towards lower latitudes and south-west under the low concentration scenario, and towards higher latitudes and north-west under the medium and high concentration scenarios, with more incredible migration under the high concentration scenario and less migration under the medium and low concentration scenarios. From period 2050 to 2070, the core of mass in the high fitness zone of *P. rockii* migrated towards lower latitudes and south-west in the medium concentration emission scenario and higher latitudes and north-west in the low and high concentration emission scenarios, with more incredible migration in the high concentration emission scenario and less migration in the medium and low concentration scenarios. In general, the migration was more significant in the high-emission scenario and less in the medium and low-emission scenarios. Hence, the reduction in the area of the high-fitness zone was also most significant in the high-emission scenario.

In terms of latitudinal changes, there is an overall trend of migration to the northwest of high latitudes, which is related to the light-loving, drought-resistant, and semi-shade-tolerant growth habit of *P. rockii*. Yuan Junhui's [54] study shows that rainfall and temperature of purple-spotted peonies are the main environmental factors affecting the growth differentiation of purple-spotted peonies. Wang Rulin et al. [55]. investigated the potential distribution of the tasty kiwifruit in China and its response to climate change, and Lai Wenfeng et al. [56]. investigated the potential habitat of the Tibetan

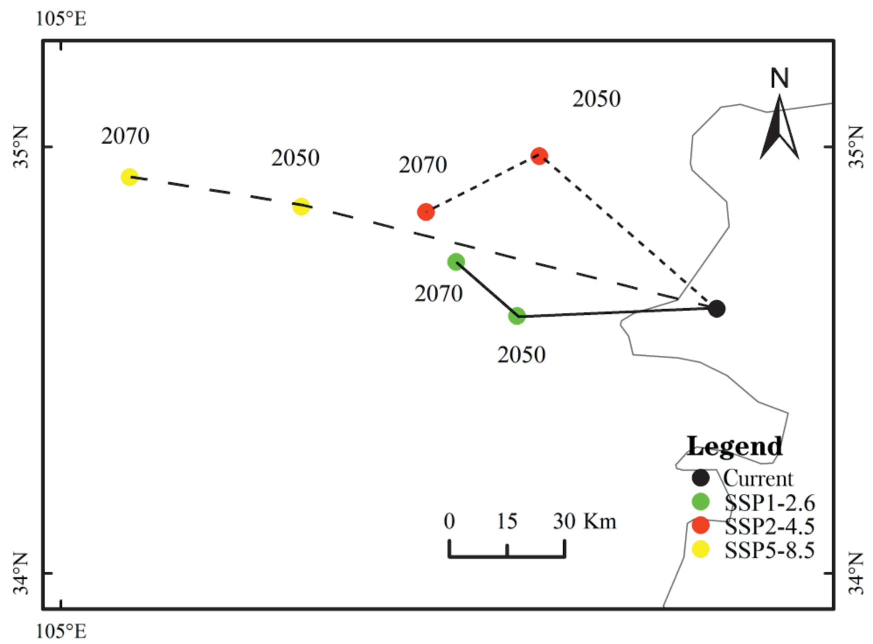

Fig. 8. Variations of the centroids of highly suitable areas of *P. rockii* under climate change scenarios.

medicine Taoyiqi, showing that the suitable distribution areas of the plant are strongly influenced by climatic facilitation such as temperature and precipitation and will change with changes in these variables, with some habitat areas disappearing and some new habitat areas emerging. Zhang Hua et al. [57], showed in their study of the potential geographic distribution of the relict plant Cyathea in China that species will migrate to different latitudes as the climate warms. Like other species in this study, the potential geographic range of the *P. rockii* is expected to increase and disappear under the influence of warming. The potential geographic distribution will also shift.

Changes in the Potential Geographical Distribution of *P. rockii* under Future Climate Change Scenarios

In this paper, the potential geographical distribution of *P. rockii* under three future emission scenarios with different concentrations (SSP1-2.6, SSP2-4.5, and SSP5-8.5) was predicted by the MaxEnt model using environmental factors combined with current climatic conditions. The two were spatially superimposed to derive the potential distribution of purple spotted peonies under three future emission scenarios with different concentrations (Fig. 9). The changes in the potential distribution of purple spotted peonies under three emission scenarios (Fig. 9).

The predicted results show that the potential geographic distribution of P. purpura in the subsequent two time periods shows different degrees of reduction in the three suitable areas under any concentration emission scenario, especially under the high concentration emission scenario, the area of the highly suitable area of P. purpura is significantly reduced, with 42.16% and 57.75% in the 2050s and 2070s respectively (Fig. 9, Table 3). The study by Zhang Yu et al. [58]. showed that temperature and soil water content had a great influence on the growth and yield of *P. rockii*. When the temperature and soil water content were too high, the death probability of *P. rockii* would increase and the growth status would deteriorate. The centroid of the high suitable area of P.rockii generally migrated to high latitudes and northwest under the three concentration emission scenarios. The migration range of P.rockii was larger under the high concentration emission scenario, and the migration range was smaller under the medium concentration and low concentration emission scenarios. Therefore, the area of high suitable area changed most significantly under the background of high concentration emission (Fig. 8). Thomas et al. [59], showed that under the background of climate warming, some species will be extinct, but a large part of the growth and distribution of species will be subject to different degrees of development during this period, which shows that the climate warming is a double-edged sword for the growth and distribution of species. Obviously, the growth and distribution of *P. rockii* under climate warming has been seriously affected. From the prediction results, it can be seen that in the future, there will be many areas that are no longer suitable for the growth of *P. rockii*. Although there will be some new areas suitable for the growth of *P. rockii*, the lost areas are far more than the new areas, so climate warming is very unfavorable for *P. rockii*. Therefore, in the protection of *P. rockii*, enough attention must be paid to it, and it is necessary

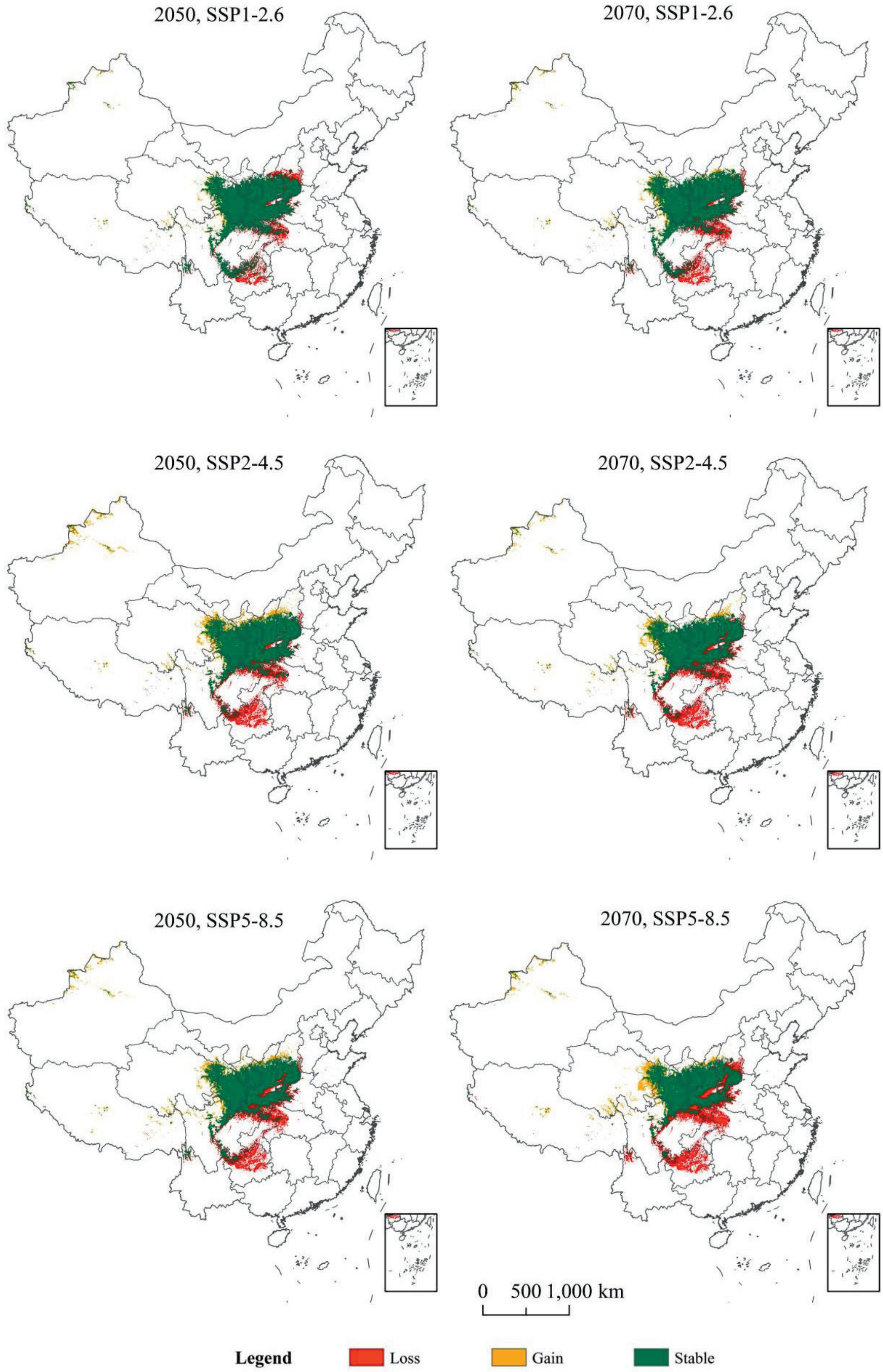

Fig. 9. Changes in the potential geographical distribution of *P. rockii* under climate change scenarios [trail No.GS (2016)2923].

to strengthen its protection in policy guidance, agricultural production and other aspects.

The projections show that in the 2050s, the most significant loss of suitable area is 16.82 x 10^4 km^2 under the high emissions scenario. The most significant increase in suitable area is 10.59 x 10^4 km^2 under the medium emissions scenario. In the 2050s, the most significant loss and increase

Table 4. Future changes in suitable habitat area of *P. rockii* under climate change scenarios (10^4 km^2).

Periods	Loss	Gain	Stable
2050 SSP1-2.6	11.07	3.30	57.73
2050 SSP2-4.5	15.25	10.59	53.74
2050 SSP5-8.5	16.82	8.82	52.26
2070 SSP1-2.6	12.82	4.96	56.17
2070 SSP2-4.5	18.41	7.52	50.65
2070 SSP5-8.5	23.46	9.63	45.64

in the suitable area are 23.46 x 10^4 km^2 and 9.63 x 10 under the high emissions scenario, respectively – (Fig. 9, Table 4). Under the future climate scenario, the trend of reduction in the habitat of the *P. rockii* is observed at all levels, so we must strengthen the protection of the *P. rockii*. Under the low emission scenario, in the 2050s, the loss of habitat areas for *P. rockii* was mainly in the eastern part of Qian, the western part of E, the central part of Jin, and the northeastern part of Sichuan, while the new habitat areas were mainly scattered in the three regions of Sichuan, Qing, and Tibet; in the 2070s, compared with the 2050s, the loss of habitat areas in the central part of Jin was reduced, the other loss of habitat areas was more or less the same, and the loss of habitat areas tended to increase In the 2070s, the loss of fitness zones in the Jinzhong region decreased compared to the 2050s, while the other loss of fitness zones were more or less the same, with an increasing trend in the extent of the loss of fitness zones. In the mid-intensity emission scenario, in the 2050s, the loss of suitable areas for *P. rockii* was mainly in most of Qian, west of E, central Shaanxi, west of Henan, north of Yunnan and northeast of Sichuan, while the newly suitable areas were mainly in the north of Jin, east of Qing, central of Gansu, central of Ning and central of Shaanxi. In the 2070s, compared with the 2050s, the loss of suitable areas was more or less the same, and the loss of suitable areas showed a decreasing trend. Their newly suitable areas were also more or less similar, and the new suitable areas also showed a decreasing trend. Under the high emission scenario, the loss of suitable areas for purple-spotted peonies in the 2050s was mainly in the western part of Henan, most of Qian, central Shaanxi, western E, northern Yunnan, and northeastern Sichuan, while the newly suitable areas were mainly in central Gan, northern Jin, central Ning, eastern Qing, and central Shaanxi regions; in the 2070s, compared with the 2050s, the loss of suitable areas was more or less the same, and the loss of In the 2070s, the loss of suitable areas was more or less the same, and the loss of suitable areas tended to increase, as did the addition of suitable areas (Fig. 9).

As one of the most critical environmental issues, global climate change is already significantly impacting the ecological characteristics and geographical distribution of plants. This impact will increase in the coming period [48]. The impact will increase in the coming period. Climate change is already threatening global biodiversity, with a more significant impact on rare and endangered medicinal plants, varying degrees of impact on the spatial structure and suitable distribution of plants, and intra- and inter-species relationships [49-50]. This has had varying degrees of impact on the spatial structure and suitable distribution of plants and intra- and interspecific relationships. Studies have shown that changes in the spatial and temporal patterns of climate may lead to changes in the geographic distribution of plants, putting their original habitats at risk [60-61]. In order to mitigate the impact of climate change on the ecosystem, we modeled the distribution of the species to effectively determine the conservation strategy to identify the areas where sensitive species exist or are likely to exist [62-63], and systematically explored the geographical distribution pattern of the *P. rockii* in the context of climate change, which provides a scientific basis for the introduction of cultivation, scientific and rational zoning, and the formulation of relevant conservation policies. In this paper, we refer to Yue et al. [45]. In this paper, we used the calculation method of Yue et al. to calculate the changes in the area of the aptitude zone under three scenarios, the location of the center of mass of the high altitude zone and the displacement trend of the center of the aptitude zone over time, showing the response of the peony to climate change. The results show that the fitness area of P. purpurea in China increased and decreased at different rates up to the 2070s, indicating a certain degree of uncertainty in the impact of climate change on the potential distribution of P. purpurea under different emission scenarios. The choice of climate variables and the amount of data available on the species' distribution points had a significant impact on the accuracy of the MaxEnt model simulations. Climate change itself is highly uncertain. The uncertainty in the impact of climate change on the adaptive distribution of *P. rockii* will increase if other conditions suitable for the growth of *P. rockii* are taken into account. As the wild population of the *P. rockii* continues to decline, not only does it need to be relocated and protected concerning the distribution of its potential habitat, but it also needs to be systematically protected concerning detailed information on topographic features, climate change, ecosystem development, population genetic structure, and phylogeography, which is a more significant challenge for the conservation of *P. rockii* populations in the 21st century. In this study, environmental factor variables were used for two time periods, 2050 and 2070, in response to the potential geographic distribution of P. purpurea in response to climate change. Subsequent studies can examine the overall trends in the potential geographic distribution of the species in response to climate change by using environmental factor variables from multiple study periods.

Conclusion

The elevation is the most critical environmental variable influencing the geographical distribution of purple peonies, and the dominant combination of environmental factors are altitude, annual precipitation, the minimum temperature in the coldest month, and intensity of human activities; the habitat area of *P. rockii* is located in the provinces of southeastern Northwest China, southwestern North China, and northwestern Central China, and its high habitat area is mainly distributed in a pie shape in areas such as Ningnan, Gannan and southern Shaanxi, accounting for 15.58% of the total habitat area Under the future climate change scenario, the total area of Zoysia peony's fitness zone generally shows a decreasing trend, among which the area of the high fitness zone is decreasing. The mass center of the high fitness zone of Zoysia peony generally tends to migrate towards the northwest, and its migration is more prominent under the high concentration emission scenario; the analysis of the current potential distribution area of Zoysia peony shows that this Zoysia peony distribution area is generally small, with isolated populations and The analysis of the current potential distribution area of the *P. rockii* shows that the distribution area is generally small, the population is isolated, and the population is small. In this regard, the ecological problems the peony faces need to be addressed with appropriate conservation measures. Based on the biological characteristics of the species in this study, the correlation coefficients between variables were compared, and the initial contribution rates were compared to screen the modeling variables, effectively removing the influence of covariance between variables on the species distribution model and providing a scientific basis for the conservation and macro layout of the *P. rockii*.

Author Contributions

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

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Competing Interests

The authors declare no competing interests.

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