PROJECTING THE POTENTIAL DISTRIBUTION OF *DYSOSMA VERSIPELLIS* (*BERBERIDACEAE*) IN CHINA UNDER PRESENT AND FUTURE CLIMATE CHANGE SCENARIOS

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Abstract. *Dysosma versipellis* is an ethnobotanical plant that has been classified as a Class II protected endangered plant in China due to habitat destruction in recent years. Studying the impact of climate change on the distribution of wild plant resources is of great significance for the sustainable utilization of *D. versipellis* resources. In this study, distribution information of 104 *D. versipellis* samples, 19 climate variables, and two periods under two future climate scenarios were collected. By combining the maximum entropy model (MaxEnt) and Geographic Information System (GIS) technology, the potential distribution of *D. versipellis* under present and future climates, as well as the important climate variables affecting its distribution, were predicted. The results showed that the Maxent model had good predictive performance (AUC > 0.9) with high accuracy and reliability. The key climate variables for *D. versipellis* included annual precipitation (1054.8~1820.9 mm), mean diurnal range (6.2~8.2℃), precipitation of the wettest quarter (486.2~1071.5 mm), mean temperature of the driest quarter (4.4~14.7; 15.1~16.1℃), and temperature seasonality (511.6~578.6; 683.7~828.5). The highly suitable areas for *D. versipellis* were mainly distributed in Guizhou, western and southern Hunan, western Hubei, northeastern and southeastern Chongqing, northeastern and southeastern Sichuan, northern and southwestern Guangxi, northeastern and southeastern Yunnan, northwestern and eastern Jiangxi, southern Zhejiang, northern Fujian, and southern Taiwan. Under future climate change, the suitable areas for *D. versipellis* are projected to gradually shift towards Henan, Anhui, and Jiangsu.
Keywords: *ethnobotanical plant, endangered plant, MaxEnt, ArcGIS, climate variables*

Introduction

Dysosma versipellis, also known as Shanheye, Jinkuilian, Hanbajiao, Heyelian, and Dujiulian, is a perennial herbaceous plant belonging to the family of *Berberidaceae*. *D. versipellis* is a rare and endemic plant in China, mainly distributed in provinces such as Sichuan, Hunan, Hubei, Jiangxi, and Anhui (Li and Wang, 2006). It mainly grows in shady and humid areas of mountain slopes, shrubs, streamsides, bamboo forests, or in evergreen limestone forests at altitudes ranging from 300 to 2400 m (Ying et al., 1993). *D. versipellis* is also an important ethnomedicinal plant used in Chinese folklore for the treatment of traumatic injuries, venomous snake bites, rheumatic pains, epidemic encephalitis B and mumps (Liu et al., 2020; Feng et al., 2022; Palaniyandi and Jun, 2020). Modern pharmacological studies have also confirmed the significant pharmacological effects of *D. versipellis* in anti-tumor, antiviral, and antibacterial activities (Juan et al., 2015; Zhang et al., 2017; Tan et al., 2018; Kumaran et al., 2010).

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Due to its important medicinal value, in recent years, uncontrolled and exploitative harvesting of *D. versipellis* has led to severe damage to its wild resources and habitats. The resources in its original distribution areas are nearing depletion, and the distribution of wild resources nationwide is shrinking. Currently, *D. versipellis* has been listed as a Class II protected endangered plant in China. At the same time, climate change is exacerbating the continuous deterioration of the global ecological environment, causing *D. versipellis* to lose suitable habitats, leading to a continuous reduction in its wild resources and nearing depletion (Zhang et al., 2012). Therefore, studying the impact of climate change on the distribution of wild plant resources and strengthening research on ecological environment protection are of great significance for the sustainable utilization of *D. versipellis* resources.

Species distribution modeling (SDM) is a scientific method employed to estimate the spatial distribution of species by utilizing their observed distribution in geographic space. It serves as a prevalent approach for predicting the correlation between species distribution and the surrounding environment (Miller, 2010). Prominent models utilized in SDM include the maximum entropy model (MaxEnt), bioclimate analysis and prediction system (BIOCLIM), ecological niche factor analysis (ENFA), and genetic algorithm for rule-set production (GARP) (Qiao et al., 2019; Pokhriyal et al., 2022). Notably, the MaxEnt model, initially proposed by Phillips (Phillips et al., 2006; Phillips and Dudík, 2008), has gained significant popularity and has been extensively utilized in recent years, particularly in the investigation of potential habitat distribution of medicinal plants (Soilhi et al., 2022; Guo et al., 2023; Guan et al., 2022).

This study aimed to analyze the distribution of *D. versipellis* by collecting distribution data and utilizing ArcGIS and Maxent models to simulate its ecological suitability based on climate variables. Additionally, the study predicted the future distribution of *D. versipellis* under the climate change scenarios SSP 126 and SSP 585. The main objectives of the study were: (1) to analyze the climate variables that significantly impact the distribution of *D. versipellis*; (2) to predict the current suitable distribution areas of *D. versipellis* in China; and (3) to predict changes in the suitable range of *D. versipellis* under the influence of future climate change. The findings of this study can serve as a theoretical foundation for the transplantation and sustainable utilization of wild resources of *D. versipellis*.

Materials and methods

Species distribution information and processing

The distribution information of *D. versipellis* was obtained from various sources, including the Chinese Virtual Herbarium (http://www.cvh.ac.cn), the National Specimen Information Infrastructure (http://www.nsii.org.cn/2017/home.php), and the Global Biodiversity Information Facility database (https://www.gbif.org/). Duplicate information was eliminated, resulting in a total of 104 unique sample distribution records (*Fig. 1*). To comply with the requirements of the Maxent model, all distribution point data, represented by latitude and longitude in decimal format, were stored in .csv format.

Climate variable

The climate data for this study were sourced from the Worldclim website (https://www.worldclim.org/data/index.html). A total of 19 climate factors were

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downloaded, and *Table 1* provides specific information on these factors. To meet the requirements of the Maxent model, these 19 climate factors were stored in .asc format. The future climate data for this study were selected from a global climate model (BCC-CSM2-MR, Beijing Climate Center Climate System Model) within the CMIP6 dataset. The BCC-CSM2-MR model is frequently used by researchers in China to assess species distribution (Wu et al., 2019). For this study, two shared socioeconomic pathways (SSP126 and SSP585) and two time periods (2041-2060 and 2081-2100) were chosen (Zhang et al., 2022; Yang et al., 2023).

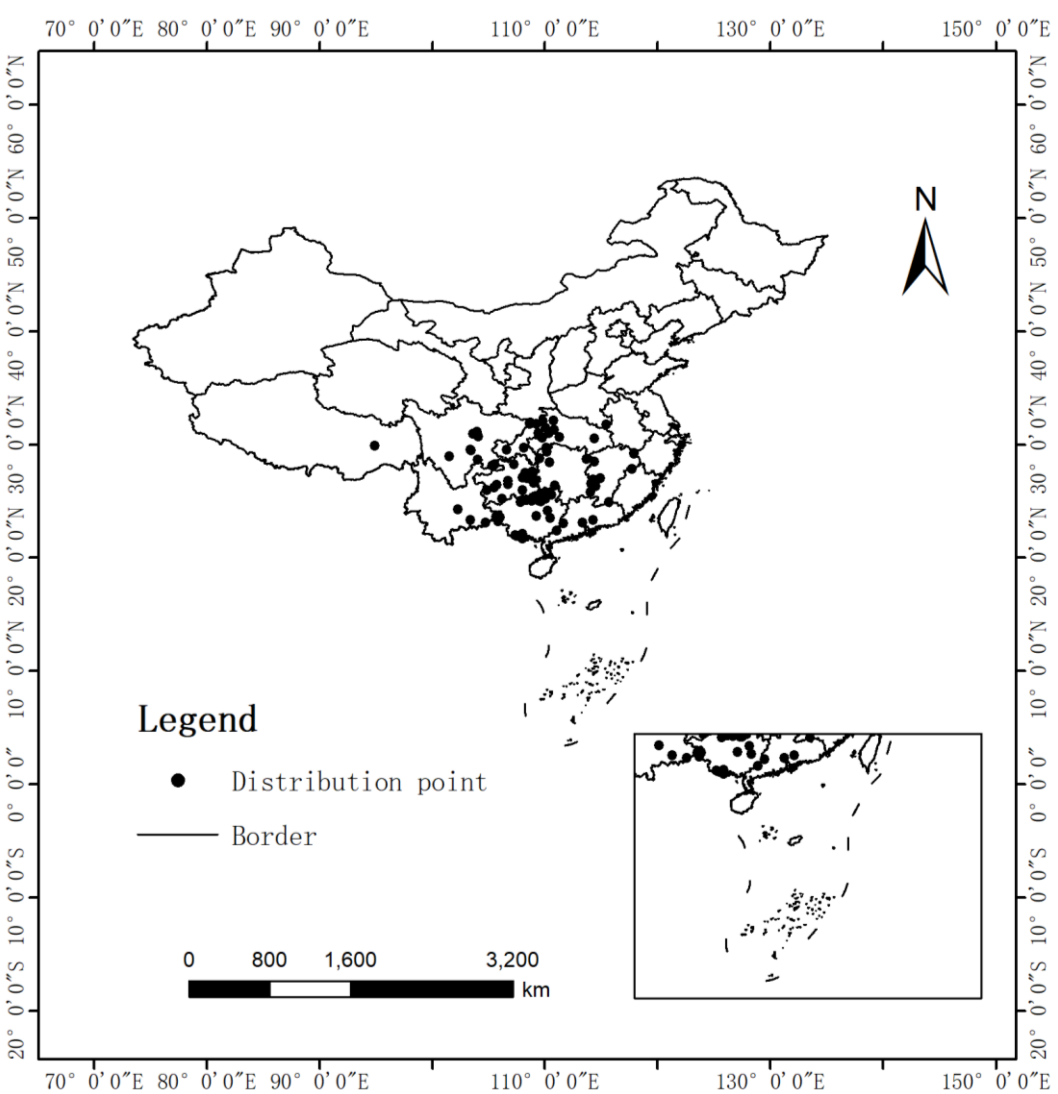

Figure 1. *Distribution information of Dysosma versipellis*

Maximum entropy model

The coordinate data and climate variable data of *D. versipellis* were imported into the Maxent 3.3.3. A random selection of 25% of the distribution points was used as the test dataset, while the remaining 75% served as the training dataset. The maximum number of iterations was set to 500, and the model operation was repeated 10 times. Additionally, response curve, receiver-operating characteristic curve (ROC), and the

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Jackknife were employed. The Jackknife was utilized to assess the influence of each climate variable on the suitable growth conditions for *D. versipellis,* while the other parameters were set to their default values.

Table 1. *Climate variables*

Climatic variables	Name	Unit
BIO1	Annual Mean Temperature	℃
BIO2	Mean Diurnal Range (Mean of monthly (max temp-min temp))	℃
BIO3	Isothermality (BIO2/BIO7) (×100)	1
BIO4	Temperature Seasonality (standard deviation ×100)	1
BIO5	Max Temperature of Warmest Month	℃
BIO6	Min Temperature of Coldest Month	℃
BIO7	Temperature Annual Range (BIO5-BIO6)	℃
BIO8	Mean Temperature of Wettest Quarter	℃
BIO9	Mean Temperature of Driest Quarter	℃
BIO10	Mean Temperature of Warmest Quarter	℃
BIO11	Mean Temperature of Coldest Quarter	℃
BIO12	Annual Precipitation	mm
BIO13	Precipitation of Wettest Month	mm
BIO14	Precipitation of Driest Month	mm
BIO15	Precipitation Seasonality (Coefficient of Variation)	1
BIO16	Precipitation of Wettest Quarter	mm
BIO17	Precipitation of Driest Quarter	mm
BIO18	Precipitation of Warmest Quarter	mm
BIO19	Precipitation of Coldest Quarter	mm

Analysis of key climate variables

Following each iteration of the Maxent model, climate factors with a contribution rate of 0 are eliminated until the remaining climate factors exhibit a contribution rate. Through a comprehensive analysis of the contribution rate and the results of the Jackknife test, we have identified the key climatic factors that influence the suitability of *D. versipellis*.

Model accuracy analysis

ROC analysis is a widely used method in species prediction modeling to assess the strengths and weaknesses of such models. This analysis involves calculating a range of sensitivities and specificities by varying the critical values for continuous variables. The Area Under the Curve (AUC) is a metric derived from the ROC curve, which quantifies the model’s ability to accurately predict species distribution. The AUC value ranges from 0 to 1, with higher values indicating greater reliability in the prediction results. An AUC of 1 signifies a perfect match between the model’s predictions and the actual distribution. The AUC is commonly evaluated using the following criteria: 0.5 to 0.6 indicates prediction failure, 0.6 to 0.7 denotes poor performance, 0.7 to 0.8 suggests fair performance, 0.8 to 0.9 indicates good performance, and 0.9 to 1.0 signifies very good performance (Ren et al., 2020).

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Suitable habitat

MaxEnt 3.3.3 software was utilized to generate the response curve for the key climatic factors and to analyze their characteristics that influence the potential distribution of *D. versipellis*. By setting the screening condition of presence probability ≥ 0.5, the optimal range value for the key climate factor was determined. The peak value of the presence probability was identified as the most suitable value for the key climate factor (Zhang et al., 2022).

Climate suitability zones

The predictions of the MaxEnt model were imported into the ArcGIS10.8 software. Subsequently, the Reclassify function in the raster calculator of the Spatial Analyst Tools was employed to combine the predictions. The resulting suitability index was then categorized into four distinct classes using Jenks' natural breaks method. These classes were defined as follows: non-suitable habitat (0-0.1), low suitable habitat (0.1-0.3), moderately suitable habitat (0.3-0.5), and highly suitable habitat (0.5-1) (Brismar, 1991).

Results

Maxent model accuracy evaluation

The AUC value is a measure that quantifies the effectiveness of a model's judgment ability. In the case of the MaxEnt model, the AUC value obtained from the ROC curve analysis is 0.927. This value is greater than 0.9 and approaches 1, indicating that the MaxEnt model accurately predicts outcomes and exhibits a high level of reliability. The graphical representation of these results can be observed in *Figure 2*.

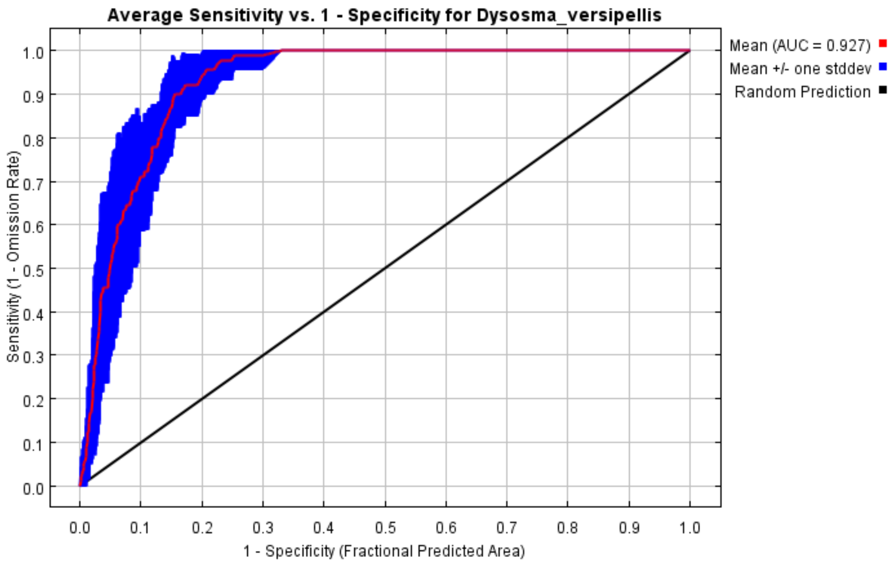

Figure 2. *ROC curve of MaxEnt model*

Key climate variables

After three calculations, the MaxEnt model retained 12 climate variables with a contribution rate greater than 0. The MaxEnt model then uses 12 climate variables for

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10 iterations and takes the average as the final result. From the results, we selected 6 climate variables with a contribution rate > 1.5% for further analysis. The total contribution rate of the 6 climate factors bio16, bio2, bio12, bio4, bio9, and bio3 was 95.4% (*Table 2*). Based on the Jackknife analysis (*Fig. 3*), the variables satisfying higher gains are sorted as follows: bio12, bio2, bio16, bio6, bio17, bio11, bio14, bio19, bio9, bio4. We intersect the climatic factors with high contribution rates and with higher gain in the Jackknife experiment (*Fig. 4*), and finally screen the key climatic factors, which are the annual precipitation (bio12), mean diurnal range (bio2), precipitation of wettest quarter (bio16), mean temperature of driest quarter (bio9), temperature seasonality (bio4). The total contribution rate of the above 5 climatic factors reached 93.7%, suggesting that they are the most important climatic variables affecting the distribution of *D. versipellis*.

Table 2. *Six high-contributing climate factors*

Climatic variables	Name	Percent contribution (%)
bio16	Precipitation of wettest quarter	38.7
bio2	Mean diurnal range	20.5
bio12	Annual precipitation	16.6
bio4	Temperature seasonality	15.4
bio9	Mean temperature of driest quarter	2.5
bio3	Isothermality	1.7

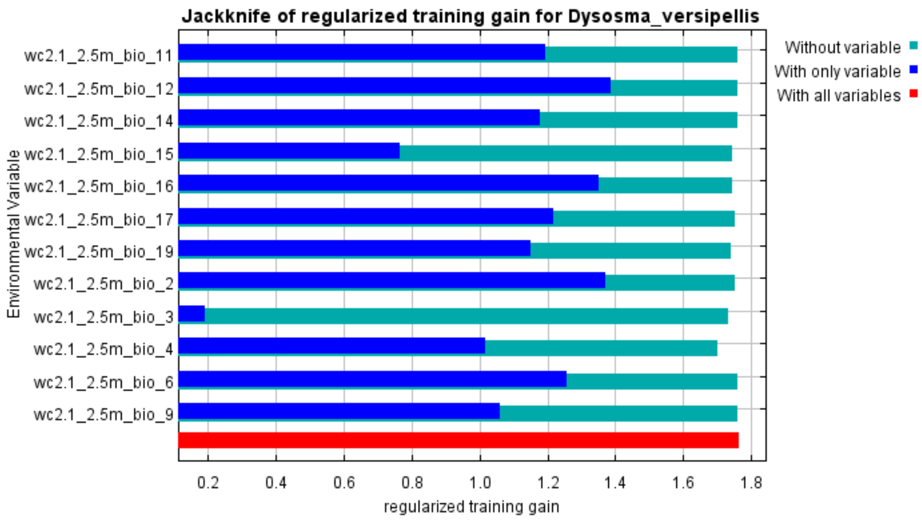

Figure 3. *Gain of each variable in jackknife test*

Suitable habitat range

The climate variable response curve enables the assessment of the correlation between the likelihood of occurrence and climate variables. In this study, we employed the MaxEnt model to examine the optimal range of climate factors for the distribution of *D. versipellis* and determine its adaptive threshold. The findings are presented in *Figure 5* and *Table 3*, providing comprehensive details.

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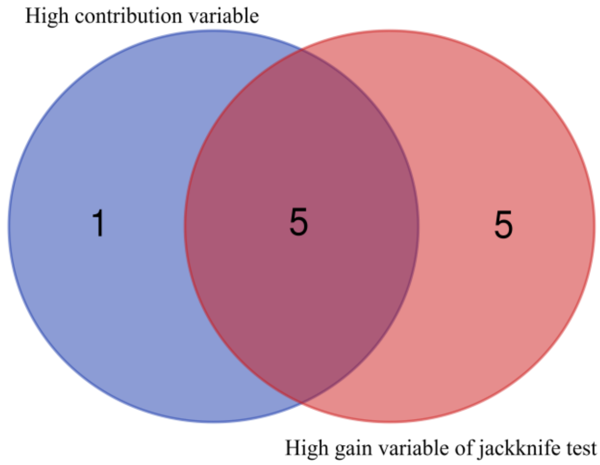

Figure 4. *The Venn diagram of the high contribution variable and high gain variable of the jackknife test*

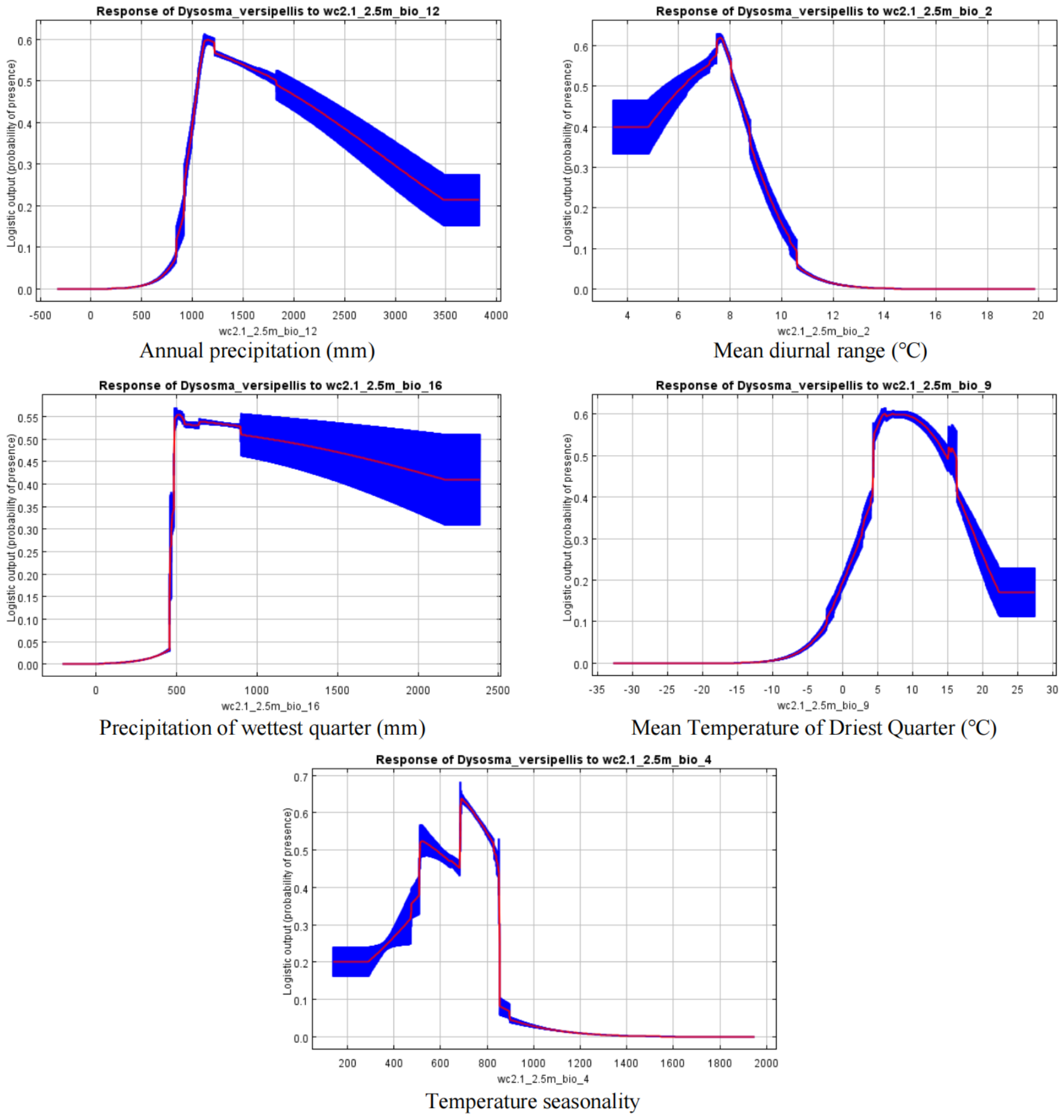

Figure 5. *The response curve of key climatic variables*

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Table 3. *The suitable value range for the key variables*

Climatic variables	Suitable range	Adaptive threshold
bio16	486.2~1071.5 mm	501.8 mm
bio2	6.2~8.2℃	7.6℃
bio12	1054.8~1820.9 mm	1154.7 mm
bio4	511.6~578.6; 683.7~828.5	689.1
bio9	4.4~14.7; 15.1~16.1℃	7.3℃

Potential distribution under present climate

The results of the MaxEnt model were utilized in ArcGIS10.8 to generate predictions for the potential distribution area of *D. versipellis* in China. *Figure 6* displays the outcome of this analysis. The map exhibits different color-coded regions: blue represents unsuitable areas, green represents generally suitable areas, yellow represents moderately suitable areas, and red represents highly suitable areas. The distribution map clearly indicates that the region most conducive to the growth of *D. versipellis* are primarily located south of the Yangtze River. Notably, highly suitable areas encompass Guizhou, western and southern Hunan, western Hubei, northeastern and southeastern Chongqing, northeastern and southeastern Sichuan, northern and southwestern Guangxi, northeastern and southeastern Yunnan, northwestern and eastern Jiangxi, southern Zhejiang, northern Fujian, and southern Taiwan (*Table 4*).

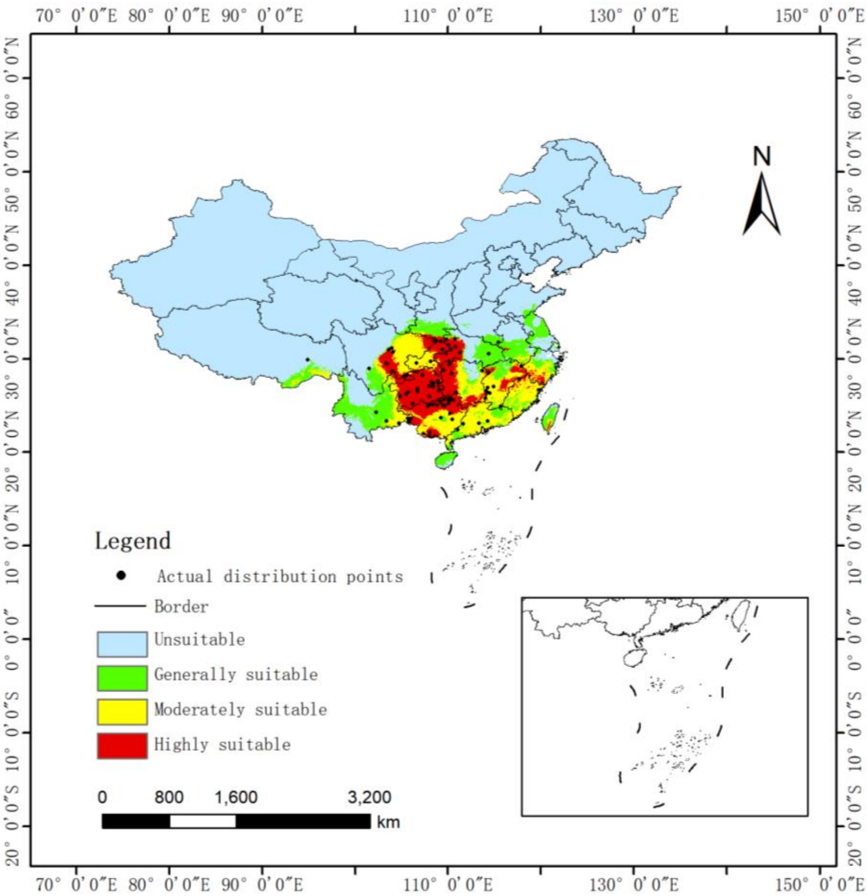

Figure 6. *Potential distribution of Dysosma versipellis under present climate*

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Table 4. *Highly suitable areas of Dysosma versipellis under present climate*

Name	Main suitability distribution location
Guizhou	Guiyang, Zunyi, Tongren, Qiandongnan, Qiannan, Anshun, Qiuxinan, Liupanshui, Bijie
Hunan	Changde, Zhangjiajie, Jishou, Huaihua, Shaoyang, Yongzhou, Chenzhou, Zhuzhou
Hubei	Enshi, Yichang, Shennongjia, Shiyan, Xiangyang
Chongqing	Wushan, Fengjie, Wuxi, Chengkou, Kaixian, Yunyang, Wanzhou, Shizhu, Qianjiang, Pengshui, Youyang, Xiushan, Nanchuan, Qijiang
Sichuan	Bazhong, Dazhou, Yibin, Luzhou, Leshan, Meishan, Ya'an
Guangxi	Qinzhou, Fangchenggang, Chongzuo, Baise, Hechi, Liuzhou, Guilin, Hezhou, Wuzhou
Yunnan	Wenshan, Zhaotong
Jiangxi	Jiujiang, Yichun, Jingdezhen, Shangrao, Fuzhou
Zhejiang	Quzhou, Lishui, Wenzhou
Taiwan	Pingtung, Taitung, Kaohsiung
Fujian	Ningde, Nanping, Sanming

Potential distribution under future climate

In the SSP126 scenario, during the period of 2041-2060, the area of highly suitable regions is 43.41×10^4 km^2, the area of moderately suitable regions is 64.94×10^4 km^2, and the total area of suitable regions is 211.97×10^4 km^2. In the period of 2081-2100, the area of highly suitable regions is 55.10×10^4 km^2, the area of moderately suitable regions is 71.76×10^4 km^2, and the total area of suitable regions is 209.25×10^4 km^2. In the SSP585 scenario, during the period of 2041-2060, the area of highly suitable regions is 52.09×10^4 km^2, the area of moderately suitable regions is 70.34×10^4 km^2, and the total area of suitable regions is 217.98×10^4 km^2. In the period of 2081-2100, the area of highly suitable regions is 49.49×10^4 km^2, the area of moderately suitable regions is 66.10×10^4 km^2, and the total area of suitable regions is 213.21×10^4 km^2 (*Fig. 7*). Although the area of highly suitable and moderately suitable regions in different periods of the SSP126 and SSP585 scenarios is reduced compared to the present climate, the total area of suitable regions under future climate conditions shows a general increasing trend.

Discussion

Multiple studies have shown that the MaxEnt model is one of the better ecological niche models, with good predictive ability and accurate results. The MaxEnt model has higher accuracy in predicting results compared to other ecological niche models under the same conditions (Zhuo et al., 2020). In this study, the MaxEnt model was used to predict the potential suitable habitat for the endangered plant species *D. versipellis* in China. The predicted results showed an AUC value greater than 0.9, indicating the accuracy and high reliability of the predictions (Zhao et al., 2021). Based on the model results, temperature (mean diurnal range, mean temperature of driest quarter, temperature seasonality) and precipitation (annual precipitation, precipitation of wettest quarter) were identified as the main climatic factors influencing the distribution of *D. versipellis*. Surveys have shown that in the Dawaoling Nature Reserve in Guangxi, China, the monthly average temperature ranges from 8.7°C in January to 24.2°C in July, with an annual precipitation of 1300~1400 mm (Farm et al., 2003). *D. versipellis* has been found in abundance in such habitats, which is consistent with our predicted results for annual precipitation (1054.8~1820.9 mm) and mean temperature of driest quarter

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(4.4~14.7; 15.1~16.1℃). The study also found that *D. versipellis* thrives in low temperature environments (4~6℃), and the biomass, chlorophyll, carotenoid, and toxin content grown under low temperature conditions are higher than those grown in greenhouse conditions at 25~30℃ (Palaniyandi and Jun, 2020). This further confirms the importance of temperature for the growth of *D. versipellis*. The predicted highly suitable areas under present climate are mainly concentrated in central China, including Guizhou, Hunan, Hubei, Sichuan, Chongqing, Jiangxi, and other regions. These areas are characterized by mountains, forests, and bamboo forests, and belong to typical subtropical monsoon climates with abundant precipitation and suitable temperatures, which align with the suitable habitat of *D. versipellis* (Zeng, 2001).

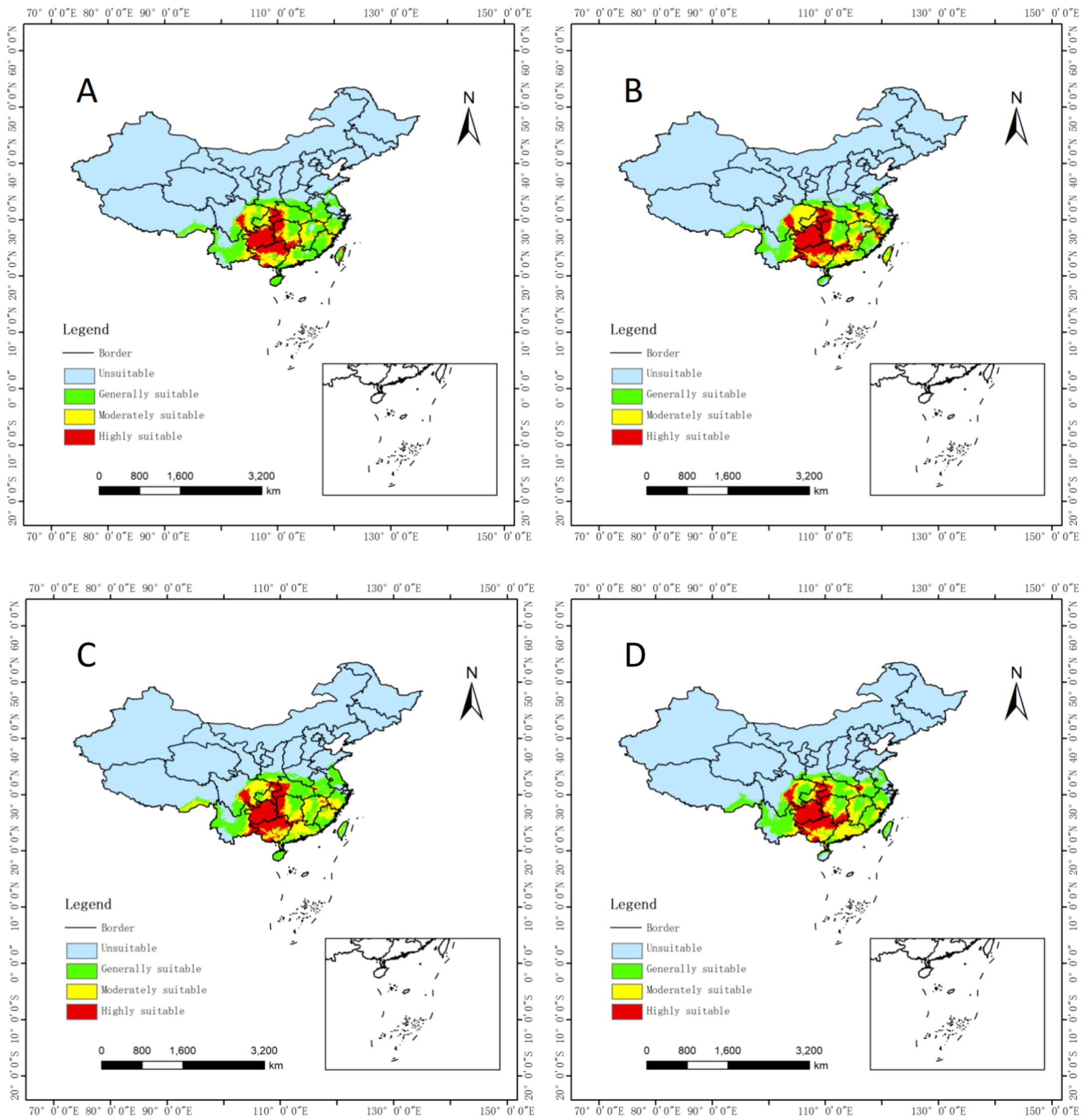

Figure 7. *Potential distribution of Dysosma versipellis under future climate: 2041-2060, SSP 126 (A); 2081-2100, SSP 126 (B); 2041-2060, SSP 585 (C); 2081-2100, SSP 585 (D)*

In previous studies, different Shared Socioeconomic Pathways (SSP) were simulated to explain varying levels of future climate change (Lehtonen et al., 2021; Ahn et al.,

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2023). SSP126 represents the most optimistic scenario for future greenhouse gas emissions (limiting global warming to below 2°C), while SSP585 represents the worst-case scenario for greenhouse gas emissions by 2100 (Zhang et al., 2022). This study selected the SSP126 and SSP585 scenarios, as well as the time periods of 2041-2060 and 2081-2100, to predict the future distribution of *D. versipellis*. The results of the predictions showed that under the SSP126 scenario, by 2060, the highly suitable area decreased by 24.44%, the moderately suitable area decreased by 10.81%, and the total suitable area increased by 6.95%. By 2100, the highly suitable area decreased by 4.09%, the moderately suitable area decreased by 1.44%, and the total suitable area increased by 5.58%. These results indicate that by the end of this century, with climate change, the suitable habitat for *D. versipellis* has improved to some extent, especially in the moderately and highly suitable areas, which have experienced significant warming. Non-suitable areas have also gradually transitioned into suitable areas. Under the SSP585 scenario, by 2060, the highly suitable area decreased by 9.31%, the moderately suitable area decreased by 3.39%, and the total suitable area increased by 9.98%. By 2100, the highly suitable area decreased by 13.86%, the moderately suitable area decreased by 9.22%, and the total suitable area increased by 7.58%. In the worst-case scenario for greenhouse gas emissions, the changes in the moderately and highly suitable areas align with natural patterns, and the outcome is not too dire, as non-suitable areas also gradually transition into suitable areas, indicating a growth trend in the suitable habitat for *D. versipellis*. Based on *Figures 6* and *7*, we can observe that the suitable habitat range of *D. versipellis* has expanded to some extent in two different periods under the SSP126 and SSP585 scenarios. This expansion is gradually moving towards the northeast, particularly in areas such as Henan, Anhui, and Jiangsu, where a certain area of suitable habitat has emerged. This suggests that future introduction experiments of *D. versipellis* in these regions may become feasible.

D. versipellis, an important medicinal plant in China, has been listed as an endangered plant in the China Species Red List and the China Plant Red Data Book (Fu, 1991; Wang and Xie, 2004). This study predicts the potential distribution and suitable habitats of *D. versipellis* under present and future climates, providing suggestions for the conservation of endangered medicinal plants from ecological and environmental perspectives. However, medicinal plants are special in that they require specific environments to synthesize or accumulate medicinal active ingredients, and their medicinal efficacy decreases or disappears when they are removed from their native habitats. Therefore, in future research, we can consider reintroducing artificially cultivated seedlings back into suitable wild environments to increase the population of *D. versipellis* in the wild, expand the distribution range of wild resources, rebuild more complete ecosystems, and enhance ecosystem biodiversity and community stability. In addition, local governments and relevant national departments should strengthen supervision of the suitable areas for *D. versipellis*, consolidate existing achievements, and ultimately achieve sustainable utilization of *D. versipellis* resources.

Conclusions

Based on the results and discussions above, the following conclusions were drawn in this study:

(1) A correlation analysis of 19 climate variables was conducted using the MaxEnt model, and 5 key climate factors were ultimately identified, namely annual precipitation

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(1054.8~1820.9 mm), mean diurnal range (6.2~8.2℃), precipitation of wettest quarter (486.2~1071.5 mm), mean temperature of driest quarter (4.4~14.7; 15.1~16.1℃), and temperature seasonality (511.6~578.6; 683.7~828.5) along with their optimal ranges.

(2) In China, the highly suitable area for *D. versipellis* is mainly distributed in the southern region of the Yangtze River, including Guizhou, western and southern Hunan, western Hubei, northeastern and southeastern Chongqing, northeastern and southeastern Sichuan, northern and southwestern Guangxi, northeastern and southeastern Yunnan, northwestern and eastern Jiangxi, southern Zhejiang, northern Fujian, and southern Taiwan. Under future climate change, the suitable area for *D. versipellis* is gradually expanding towards the northeast, with a certain range of suitable habitats appearing in Henan, Anhui, and Jiangsu.

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