ASSESSING THE IMPACT OF CLIMATE CHANGE ON THE HABITAT DYNAMICS OF *MAGNOLIA BIONDII* IN CHINA: A MAXENT MODELLING APPROACH

WU, X. P.[1#] – SONG, L. H.[2#] – YANG, Q.[4] – YANG, Y.[3*] – HU, M. L.[1*]

[1]*School of Pharmacy, Hubei University of Science and Technology, Xianning 437100, China*

[2]*Faculty of Agriculture, Forest and Food Engineering, Yibin University, Yibin 644000, China*

[3]*School of Pharmaceutical Sciences, Hunan University of Medicine, Huaihua 418000, China*

[4]*Wenshan Academy of Agricultural Sciences, Yunnan 663099, China*

**Corresponding author*
e-mail: humingli0930@163.com; ORCID: 0000-0001-7900-4714

[#]*These authors contributed equally to this work*

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Abstract. *Magnolia biondii* Pampan., a traditional Chinese medicinal plant, holds significant ornamental and medicinal value. We used the MaxEnt model and ArcGIS software to study the potential habitats of *M. biondii* in China. The results showed that the model exhibited outstanding accuracy, boasting an average area under the receiver–operator curve (AUC) of 0.955. The distribution of *M. biondii* was primarily influenced by three key environmental factors: min temperature of coldest month (Bio06), precipitation of warmest quarter (Bio18), and precipitation of coldest quarter (Bio19). Currently, *M. biondii* habitats are concentrated in East, Central, and Southwest China, covering 107.95×10^4 km^2. Notably, Hubei, Henan, and Shandong host the majority of highly suitable areas. Future global warming will have a positive impact on the potential distribution area of *M. biondii*, and its distribution center has a tendency to migrate to higher latitudes. These findings contribute to the theoretical understanding of plant resources and provide insights into the habitat conservation of *M. biondii*.
Keywords: *traditional Chinese medicine, environmental variables, maximum entropy, ROC, Jackknife*

Introduction

Global biodiversity change is driven by various factors, with climate recognized as the foremost environmental determinant of species distribution in the world's vegetation (Bellard et al., 2012; Graham et al., 2019). Temperature factors regulate species by affecting photosynthesis and respiration of plants. And plant growth and development are also restricted by precipitation conditions (Abeli et al., 2020). Environmental conditions play a crucial role in the accumulation of secondary metabolites in plants (Wang et al., 2020; Zhan et al., 2022). Global climate change affects the migration and size of plant habitats, leading to alterations in the chemical composition of plants (Applequist et al., 2020).

Scientific forecasting of the distribution area and suitability levels of endangered and rare species, along with the establishment of wild nature reserves in suitable habitats, is one of the most effective methods for safeguarding endangered animal and plant resources (Xiao et al., 2011). Several studies focused on appropriate habitats for rare and endangered species have used climatic data to develop models for species distribution (Yi et al., 2016; Zhang et al., 2019; Rana et al., 2020). The MaxEnt model,

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employing probability distribution of maximum entropy, is widely used for constructing and forecasting species distribution due to its high accuracy and superior application performance compared to other models (Yang et al., 2023; Tsoar et al., 2007; Tarroso et al., 2012).

Magnolia biondii Pamp., belonging to the Magnoliaceae family, is primarily found in Henan, Sichuan, Hubei, Gansu, and other regions (Hu et al., 2018). Its medicinal parts, the dried flower buds, grow annually from May to March. Commonly used as “Xin-yi” in traditional Chinese medicine (Wang et al., 2010), it effectively promotes nasal orifice and heals wind-cold, treating symptoms such as runny nose, nasal congestion, and wind-cold headache (China Pharmacopoeia Commission, 2020). The demand for Xin-yi has surged in recent years (Song and Liu, 2019). However, excessive artificial harvesting has adversely affected *M. biondii*’s natural regeneration (Jiang and Sheng, 1997), resulting in its listing as vulnerable in the Red List of Chinese Species (Rivers et al., 2016).

Limited research has focused on potential habitat areas for *M. biondii*, with most studies centering on cultivars (Wang et al., 2010), chemical composition analysis (Hu et al., 2018), and pharmaceutical properties (Velozo et al., 2013; Nie et al., 2020; Gil et al., 2022). We gathered and arranged existing distribution data, considering topography, soil, and climate with 74 effective *M. biondii* distribution points and 33 environmental factors to understand its response to environmental factors and potential habitat changes. Using the MaxEnt model and ArcGIS software, we studied the potential habitats of *M. biondii* in China in the past (LGM, MH), present (1970–2000), and future (2050s, 2090s). Understanding the environmental factors influencing *M. biondii*’s geographic distribution and anticipating its response, which is essential for sustainable resource use and ecological equilibrium. In conserving magnolia resources, it is crucial to consider geographic distribution and implement appropriate conservation strategies. Strategies should focus on strengthening in situ conservation in highly suitable areas, considering relocation options, and sensibly introducing cultivation and breeding programs.

Materials and methods

Data collection and processing

We collected a comprehensive set of 401 occurrence records nationwide by obtaining distribution point information for *M. biondii* specimens from the Digital Herbarium of China (http://www.cvh.ac.cn/) and the NSII-China National Herbarium Resource Platform (http://www.nsii.org.cn/). After removing redundant and imprecise data, we analyzed sample points with precise geographic locations but due to the lack of latitude and longitude data a Baidu latitude and longitude query was used to determine coordinates. Consequently, we obtained the distribution sample points for *M. biondii*. ArcGIS 10.4 facilitated neighborhood analysis to establish a buffer zone with a 10 km radius. Within a 20 km range, one distribution point was randomly retained, and the others were filtered and eliminated, resulting in 74 valid distribution points (*Fig. 1*). This process aimed to reduce sampling bias-related model overfitting. Subsequently, the species name, latitude, and longitude were recorded in a CSV file for further examination.

The World Climate Database (http://www.worldclim.org) provided nineteen climate factors. We selected historical climate data from the Last Glacial Maximum (LGM) and

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Mid-Holocene (MH) and future projections (2041–2060 and 2081–2100) under various scenarios, with the current (1970–2000) climate data serving as the baseline (Yang et al., 2023). Future climatic data is based on the Shared Socio-Economic Pathways (SSPs) model from the Sixth International Coupled Model Intercomparison Program (CMIP6) (Xin et al., 2019). The two selected scenarios representing optimistic and pessimistic future greenhouse gas (GHG) emissions are SSP126 (low-forcing scenario) and SSP585 (high-forcing scenario), respectively (Zhang et al., 2019; Ünal, 2023). Additionally, we gathered 33 independent environmental parameters for further research, including 11 soil factors and three terrain factors, from the World Soil Database (http://www.fao.org/soils-portal/data-hub/en/) and the WorldClim website (https://www.worldclim.org/) (*Table 1*).

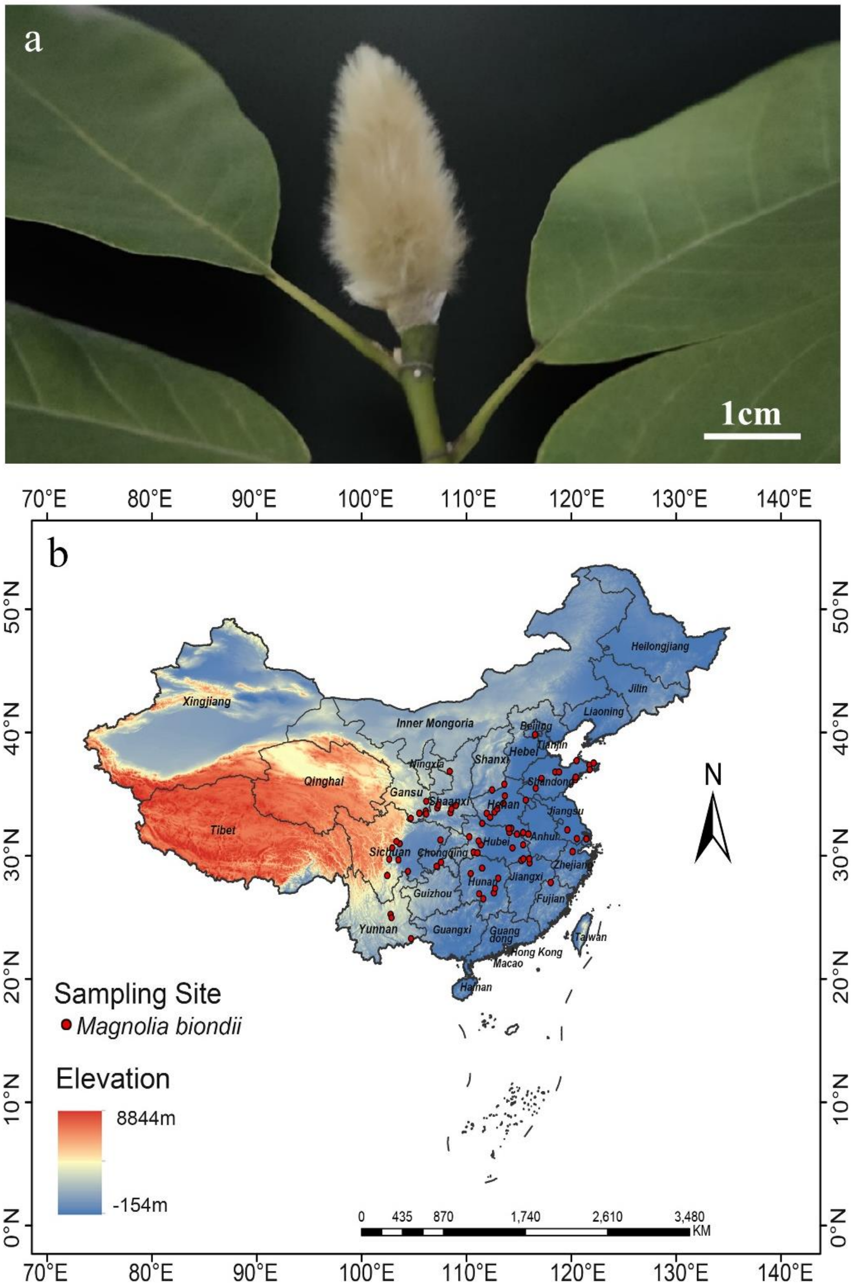

Figure 1. *M. biondii flower buds (a) and distribution of sample sites (b)*

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Table 1. *Description of environmental data*

Variable	Description	Variable	Description
Bio01	Annual mean temperature	Bio18	Precipitation of warmest quarter
Bio02	Mean diurnal range (mean of monthly (max temp-min temp))	Bio19	Precipitation of coldest quarter
Bio03	Isothermality ((Bio02/Bio07) * 100)	awc_class	Soil available water content
Bio04	Temperature seasonality (standard deviation *100)	s_caco3	Topsoil calcium Carbonate
Bio05	Max temperature of warmest month	s_clay	Substrate-soil clay content
Bio06	Min temperature of coldest month	s_oc	Substrate-soil organic carbon
Bio07	Temperature annual range (Bi05-Bi06)	s_ph_h2o	Substrate-soil pH
Bio08	Mean temperature of driest quarter	s_sand	Sediment content in the subsoil
Bio09	Mean temperature of warmest quarter	t_caco3	Topsoil carbonate or lime content
Bio10	Mean temperature of coldest quarter	t_clay	Clay content in the upper soil
Bio11	Annual precipitation	t_oc	Topsoil organic carbon
Bio12	Precipitation of wettest month	t_ph_h2o	Topsoil pH
Bio13	Precipitation of driest month	t_sand	Sand content
Bio14	Precipitation seasonality (coefficient of variation)	aspect	Aspect
Bio15	Precipitation of wettest quarter	elev	Elevation
Bio16	Precipitation of driest quarter	slope	Slope
Bio17	Driest quarterly precipitation		

Statistical analysis and model selection

The accuracy of predictions may be impacted by changing multicollinearity (Azeem et al., 2021; Karakaya and Yücel, 2021). We performed Spearman correlation analysis for all environmental factors using SPSS 26.0 software to test for multicollinearity among different variables (Ranjitkar et al., 2014). Based on the order of importance of the environmental variables (*Table 2*), we excluded environmental variables with correlation coefficients $|r| > 0.8$ (Li et al., 2024; Yang et al., 2013). Maintaining forecast accuracy and reducing model overfitting, 15 environmental factors were retained for building the *M. biondii* prediction model. These factors included three topographic factors (aspect, elev, and slope), six soil factors (awc_class, t_caco3, t_oc, s_oc, s_clay, and s_sand), and six climate factors (Bio18, Bio04, Bio06, Bio15, Bio19, and Bio03).

Habitat prediction modeling and evaluation

The MaxEnt (V3.4.3) software was used to predict probable habitat areas for *M. biondii* based on data from sample points and relevant environmental parameters. The model underwent ten runs, with 106 iterations for each training partition (Huang et al., 2023). Model settings included a logistic output format, the bootstrap method for sampling, and a random selection of 75% of distribution points as the training set, whereas the remaining 25% served as the test set (Hosni et al., 2022). Model prediction accuracy was assessed using the area under the receiver’s operating characteristic curve (ROC AUC) (Chen et al., 2022). The Jackknife approach was employed to assess the influence of environmental factors. The prospective suitable area for *M. biondii* was delineated using the maximum test sensitivity plus specificity logistic threshold (MTSPS) (Liu et al., 2016; Ramos et al., 2019) and was divided into 4 categories: unsuitable habitats (0 - MTSPS), low-suitable habitats (MTSPS - 0.3), medium-suitable habitats (0.3 - 0.5), and high-suitable habitats (0.5 - 1). Subsequently, the area of each class was calculated.

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Results and analysis

Modelling M. biondii distribution with MaxEnt

The MaxEnt software was used to simulate the distribution area of *M. biondii*. After ten cycles, the average ROC curves from ten computations were obtained. AUC values, ranging between 0 and 1, indicate model accuracy, with values closer to 1 signifying more precise predictions (Porfirio et al., 2014). Notably, models are considered highly accurate when AUC > 0.9 (Ren et al., 2020). The average training value of the ROC curve for this study was 0.955 (*Fig. 2*), indicating a remarkably accurate model. This high accuracy level positions the model as a reliable tool for exploring the potential habitability zones of *M. biondii*.

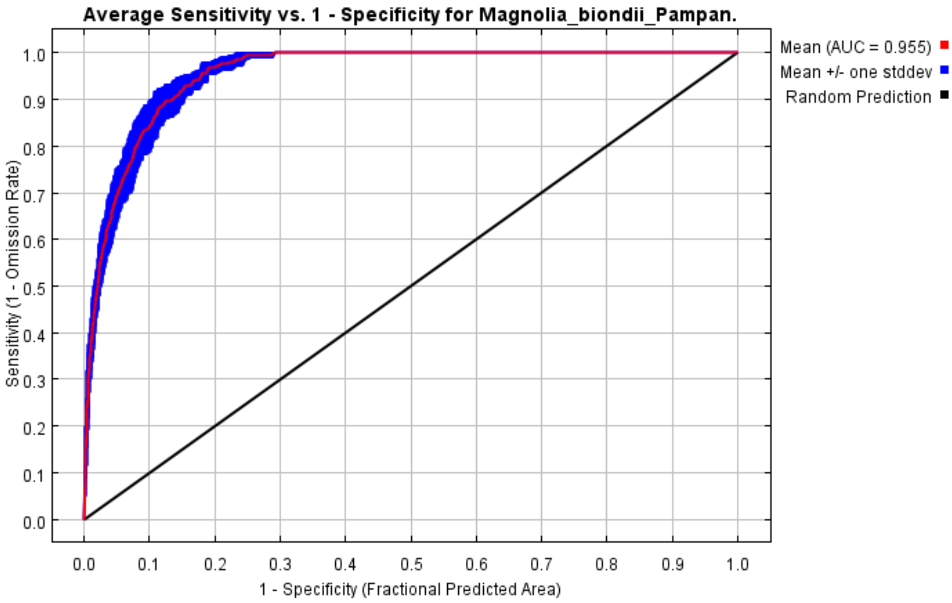

Figure 2. *ROC curve of Maxent model for M. biondii*

Contribution of environmental factors in the MaxEnt model

We employed the MaxEnt model to assess the contribution rate of each of the 15 environmental elements, elucidating their impact on constructing the prediction model. Min temperature of coldest month (Bio06) exerted the most substantial influence at 44.9%, followed Precipitation of warmest quarter (Bio18), contributing 19.4% (*Table 2*). Additionally, precipitation of coldest quarter (Bio19), temperature seasonality (standard deviation *100) (Bio04), Sediment content in the subsoil (s_sand), slope (Slope), aspect (Aspect), and Substrate-soil clay content (s_clay) accounted for 6.8%, 6.2%, 4.6%, 4%, 3.7%, and 2.0%, respectively. Other environmental factors did not surpass the 2% threshold. These findings indicate that Bio06 and Bio18 are the primary drivers influencing the potential habitat for *M. biondii*. Furthermore, Bio06 is the most critical factor determining the distribution of *M. biondii*.

We used the folding-knife method to assess the impact of major environmental factors on the distribution of *M. biondii* in specific regions of China, aiming to determine the significance of each factor (*Fig. 3*). Our findings demonstrated that three environmental factors—Bio06, Bio18, and Bio19—had the most pronounced effects on

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M. biondii distribution. This finding suggests a higher data reliability for these factors than the others. The combination of Bio06, Bio18, and Bio19 emerged as the primary environmental variables influencing *M. biondii* distribution. Consequently, temperature and precipitation are the key factors influencing *M. biondii* distribution.

Table 2. *Importance of dominant environmental factors in the MaxEnt model*

Variable	Description	Percent contribution (%)	Permutation importance (%)
Bio06	Min temperature of coldest month	44.9	69.2
Bio18	Precipitation of warmest quarter	19.4	4.6
Bio19	Precipitation of coldest quarter	6.8	1.4
Bio04	Temperature seasonality (standard deviation *100)	6.2	2.6
s_sand	Sediment content in the subsoil	4.6	4.6
slope	Slope	4	3
aspect	Aspect	3.7	2.2
s_clay	Substrate-soil clay content	2	1.2
t_oc	Topsoil organic carbon	1.9	2.6
elev	Elevation	1.7	3.1
awc_class	Soil available water content	1.2	0.5
Bio15	Precipitation seasonality (coefficient of variation)	1.2	0.8
Bio03	Isothermality ((Bio02/Bio07) * 100)	1.1	2.8
t_caco3	Topsoil carbonate or lime content	0.8	0.9
s_oc	Substrate-soil organic carbon	0.4	0.6

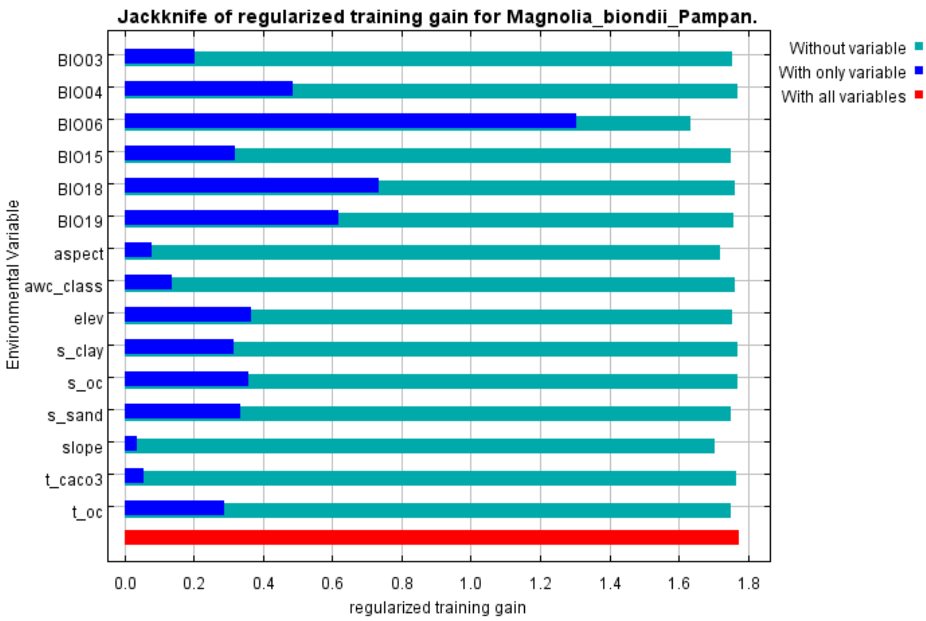

Figure 3. *The jackknife test of variable contribution in modelling*

Current distribution of M. biondii in China

M. biondii is typically found in mountainous woodlands at elevations ranging from 600 and 2100 m in Gansu, Henan, Hubei, and Sichuan, China, as documented by the Flora of China (Editorial Committee of Flora of China, 2007). The Digital Herbarium of

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China's distribution records reveal a concentration in Henan (129 distribution points), followed by Shaanxi (29 distribution points), Hunan (24 distribution points), Jiangxi (20 distribution points), Shandong (15 distribution points), Hubei (14 distribution points), and sporadic occurrences in other provinces.

The simulated distribution pattern of *M. biondii* under the current climate scenario is shown in *Figure 4*. The white area denotes unsuitable zones, yellow denotes low suitability, orange represents moderate suitability, and red represents high suitability. The primary distribution range of *M. biondii* spans 25°N–40°N and 100°E–120°E, encompassing moderately and highly suitable habitats. The total area of aptitude zones was 107.95×10^4 km^2, constituting 11.24% of China's total land area. Highly suitable areas occupy only 28.02% of the total suitable area.

The current distribution of the total suitable area is concentrated mainly in central and east China, along with the east of southwest China. Fragmented suitable areas are observed in south China, consistent with the natural distribution recorded in the Flora of China. Among them, highly suitable areas are primarily found in Hubei, Henan, and Shandong provinces, exhibiting extensive and continuous distribution. The medium-suitability areas is distributed along the high-suitability areas in an encircling pattern, mainly covering Chongqing, Hunan, Jiangxi, and areas in southern Shaanxi, southern Gansu, eastern Sichuan, central Zhejiang, and northern Guizhou. The low-suitability area encompasses 70.89×10^4 km^2, constituting 7.38% of China's land surface. The unsuitable areas are mostly located in the north of China, and there are also large areas in Guangxi, Guangdong, Fujian and southern Yunnan.

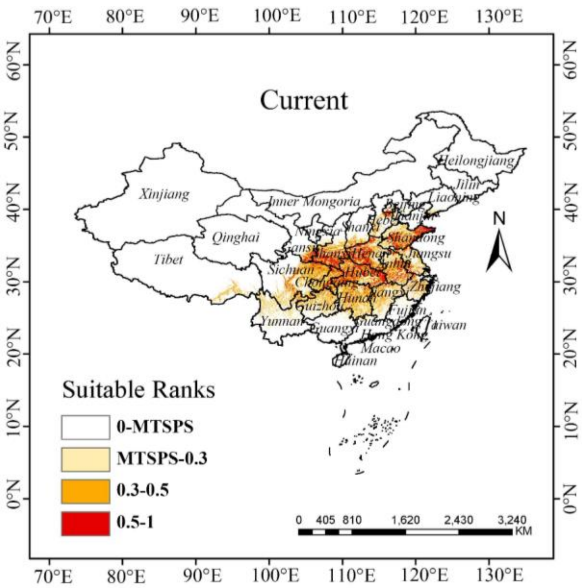

Figure 4. *Distribution of suitable habitats for M. biondii in China under current climate scenarios*

Predicting future distribution of M. biondii in China

To predict the potential distribution of *M. biondii* in China, this study considered six periods. Using predictions from the MaxEnt model, maps were generated illustrating potential habitats for *M. biondii* under two different scenarios (SSP126 and SSP585) in the 2050s and 2090s.

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From LGM to MH, *M. biondii* exhibited significant southwestward migration. A few new total suitable areas appeared, predominantly in Guizhou, Hunan, Jiangxi, and Zhejiang (*Fig. 5a, b*). The total suitable area during LGM was 19.40×10^4 km^2, whereas that in MH was 40.30×10^4 km^2, signifying an increase of 20.90×10^4 km^2, and the same trend was observed in the low, medium and high-suitability areas.

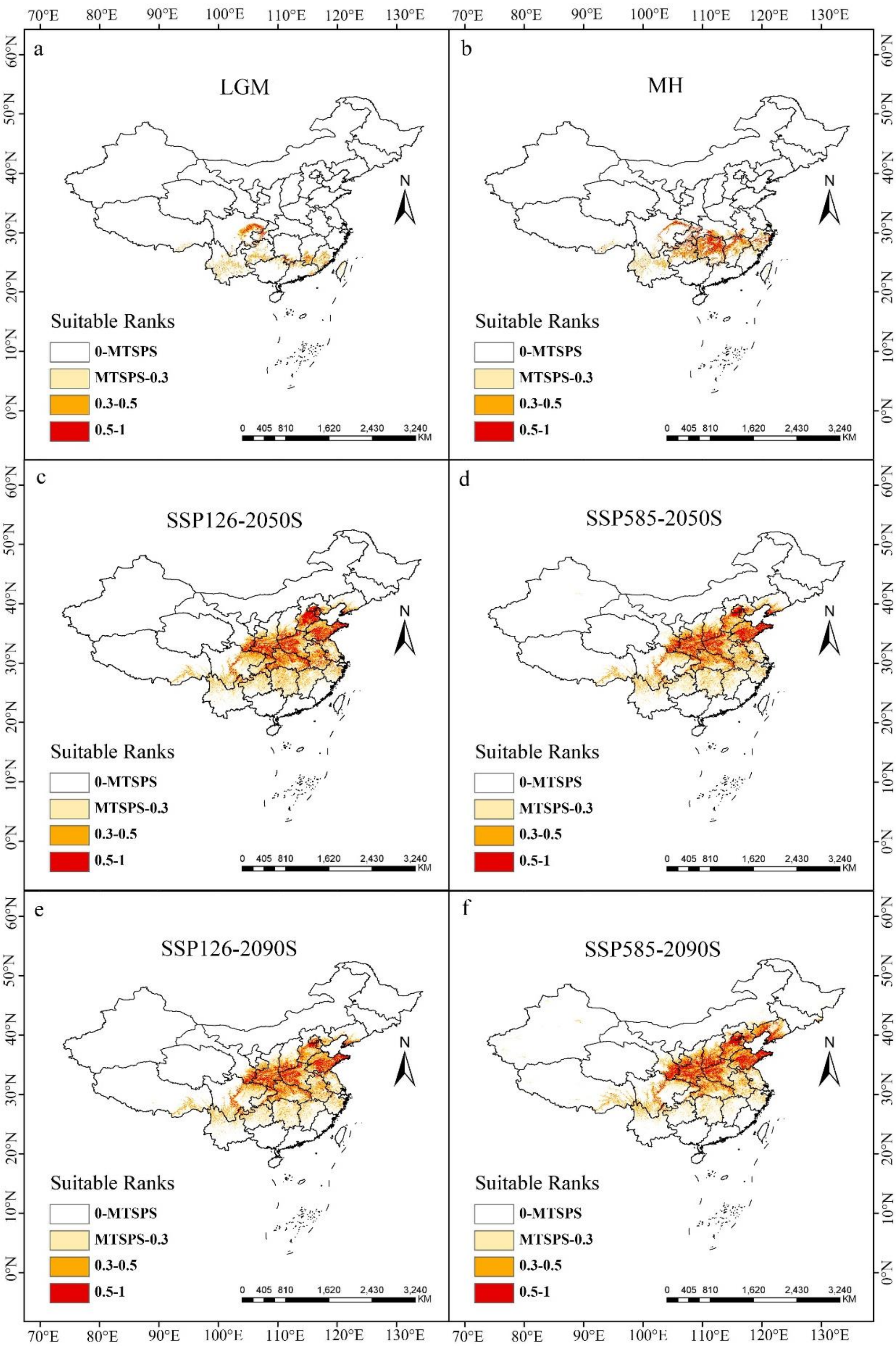

Figure 5. *Suitable habitats for M. biondii under different climate scenarios. (a) Last glacial maximum (LGM); (b) Middle Holocene (MH); (c) Average for 2041-2060 (2050 S), SSP126; (d) Average for 2041-2060 (2050 S), SSP585; (e) Average for 2081-2100 (2090 S), SSP126; (f) Average for 2081-2100 (2090 S), SSP585*

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From MH to the present, the total suitable area expanded notably into neighboring provinces, indicating a gradual increase in area. The current total suitable area is 107.95×10^4 km^2, with the high-suitability area covering 30.29×10^4 km^2, accounting for only 3.15% of the country's land surface, indicating severe limitations of the high-suitability areas of *M. biondii* during LGM and MH periods, likely associated with the cold climate during the LGM period (Huang and Zhang, 2000).

Stability and future changes in M. biondii distribution

The distribution pattern of *M. biondii* has changed to varying degrees from the present to the future (*Fig. 5c–f*). *Table 3* and *Figure 6* show the future shrinkage and expansion of suitable habitat for *M. biondii*.

1. SSP126 scenario (2041–2060):
    - Total suitable area: 110.74×10^4 km^2, a 2.58% decrease from the current scenario.
    - Highly suitable areas increased by 25.75%, while low and moderately suitable areas decreased by 0.82% and 6.44%, respectively.
    - Total suitable area is the biggest (110.74×10^4 km^2), new suitable areas have been added, mainly located in Beijing, Tianjin and southern Hebei.
2. SSP126 scenario (2081–2100):
    - Total suitable area: 98.58 × 104 km2, a 8.68% decrease from the current scenario.
    - Highly suitable areas increased by 1.98%, while low and moderately suitable areas decreased by 1.95% and 12.84%, respectively.
3. SSP585 scenario (2041–2060):
    - Total suitable area: 105.62 × 104 km2, a 2.16% decrease from the current scenario.
    - Highly suitable areas increased by 19.54%, while low and moderately suitable areas decreased by 3.71% and 10.62%, respectively.
4. SSP585 scenario (2081–2100):
    - Total suitable area: 114.63 × 104 km2, a 6.19% increase from the current scenario.
    - Highly suitable areas increased significantly, concentrated in Beijing and at the border between Hebei and Liaoning, with a 43.03% increase, whereas the low and moderately suitable areas decreased by 8.46% and 8.20%, respectively.

Table 3. *Area statistics of M. biondii suitable areas with different time expectation*

Period		Unsuitable habitats		Low-suitable habitats		Medium-suitable habitats		High-suitable habitats	
		Area (*10^4 km^2)	Percent (%)	Area (*10^4 km^2)	Percent (%)	Area (*10^4 km^2)	Percent (%)	Area (*10^4 km^2)	Percent (%)
LGM		929.64	96.84	10.97	1.14	16.00	1.67	3.39	0.35
MH		904.54	94.22	15.16	1.58	26.57	2.77	13.73	1.43
Current		781.17	81.37	70.89	7.38	77.66	8.09	30.29	3.15
2050s	SSP126	778.95	81.14	70.31	7.32	72.66	7.57	38.09	3.97
	SSP585	786.13	81.89	68.26	7.11	69.41	7.23	36.21	3.77
2090s	SSP126	791.91	82.49	69.51	7.24	67.69	7.05	30.89	3.22
	SSP585	780.48	81.30	64.89	6.76	71.29	7.43	43.34	4.51

Percentage of area is the ratio of the land surface area of China (960×10^4 km^2) occupied by each suitable area in each period

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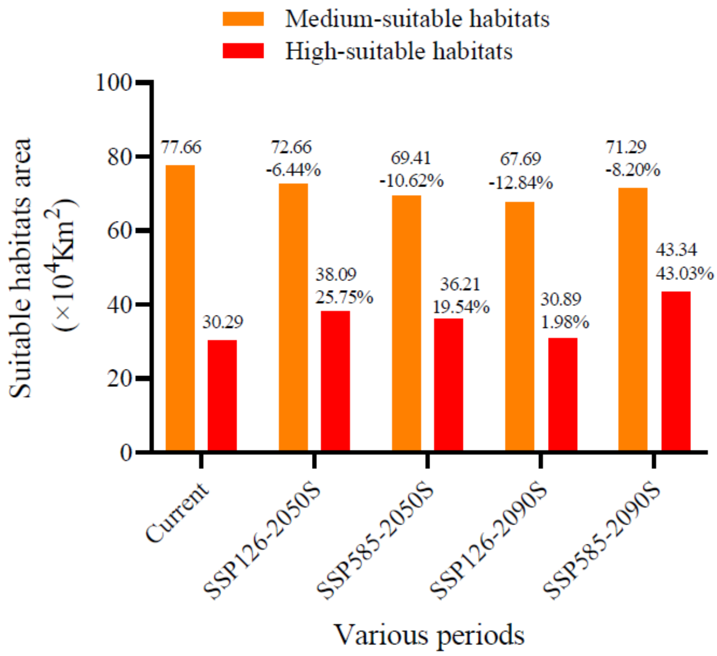

Figure 6. *Percentage change in the area of the suitable area of Ficus religiosa under the future climate compared with the current climate. The numbers on the top of the bar graph indicate the potential distribution area of the resource fir in different time periods; the numbers on the bottom indicate the change in the distribution area compared with the current climate, and "-" is the percentage decrease in the potential distribution area*

Discussion

The MaxEnt model, recognized for its accuracy and versatility, is the most widely used species distribution model (Tsoar et al., 2007; Tarroso et al., 2012). Greater data availability on species distribution points enhances the model's predictive accuracy (Guo et al., 2020). To mitigate prediction bias resulting from sample problems, we collected extensive data on *M. biondii* specimens while maintaining a linear distance of 10 km to reduce geographical bias in spot selection. In addition, correlation coefficients exceeding an absolute value of 0.8 were excluded to prevent model overfitting, resulting in more accurate simulation results. While Song and Liu (2019) emphasized elevation, temperature, and rainfall as the crucial factors for *M. biondii* distribution, our study expanded on this by incorporating soil as an additional environmental factor, enhancing predictive accuracy. Despite these improvements, the prediction results may differ significantly from the actual situation due to incomplete consideration of plant growth characteristics and the effects of anthropogenic and natural variables. Future research could optimize MaxEnt model parameters and integrate additional related factors for more accurate prediction results. The outcomes of this study were validated by the ROC curve, with the MaxEnt model achieving a high AUC of 0.955. This indicates the model's effectiveness and accuracy, providing valuable insights into the macroscopic protection strategy of *M. biondii*.

In the domain of metabolic pathways encompassing signaling, self-defense, and physiological regulation, water and temperature play significant roles in influencing plant growth (Ashrafi et al., 2018; Pant et al., 2021). This study highlights that Bio06 (44.9%), Bio18 (19.4%), and Bio19 (6.8%) predominantly influenced the potential

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distribution of *M. biondii*. Temperature emerged as the primary factor influencing *M. biondii*'s suitable area, followed by precipitation. Among these factors, Bio06 was the most critical climatic determinant for *M. biondii* distribution. This finding aligns with similar findings for *Gentiana macrophylla* Pall. and *Toona ciliata* var. *pubescens* (Tan et al., 2020; Huang et al., 2018), emphasizing the paramount influence of low temperatures on plant growth. Studies on *Agaricus bisporus* reveal a semi-lethal temperature of approximately –25°C, with no reported frost damage in its northeastern cultivation (Ren, 2006). Additional research has revealed a degree of cold tolerance (Liang et al., 2010). Shi's research underscores the significance of low temperatures in influencing *M. wufengensis*, *M. denudata*, *M. biondii*, and *M. liliiflora*, where precipitation is also a key factor affecting the distribution of *M. wufengensis* (Shi, 2023), aligning with *M. biondii*'s preference for a warm, cool, and humid climate alongside cold resistance (Editorial Committee of Flora of China, 2007).

Many species will experience habitat fragmentation and reduced appropriate range areas due to global warming (Thomas et al., 2004). Climate change exerts different effects on potential distribution locations (Chang et al., 2020). In response to environmental shifts, plants are expected to migrate to higher latitudes and altitudes in search of hospitable environments (Zhang et al., 2022). Understanding the effects of climate change on species and formulating effective conservation strategies necessitates insights into the species' distribution under changing climatic conditions (Deb et al., 2017). In addition, due consideration should be given to the genetic diversity of species (Cires et al., 2013). Modelling of potential habitat areas of *M. biondii* for different periods of time in the past, present and future shows that climate change is having a significant impact on this species. The study revealed a significant expansion in the overall suitable area for *M. biondii* from the MH to the current period, this indicates that the current climatic conditions are favorable for the growth of the species.

Compared with the current period, future high-temperature environments caused by carbon emissions result in the expansion of the range of the springbok magnolia towards northern China. Under both the SSP126 and SSP585 scenarios, the fluctuations in the increase or decrease in the area of suitable areas over the next 20 years are small, while on a longer time scale, the expansion of the total area of suitable areas under the SSP126 scenario with low emission concentrations is much smaller than the area of the lost area, thus reducing the total area of suitable areas, which is located in the border between the central and southern parts of Hebei and Beijing, as well as in most parts of Tianjin. Under the high emission concentration SSP585 scenario, *M. biondii* expanded further into the high-latitude northeastern part of the country, and the total habitable area increased by 6.68×10^4 km^2, with the additional area located in the southern part of Liaoning, and on the border between Hebei and Liaoning. Thomas et al. (2004) showed that a proportion of the species will become extinct in the context of a warming climate, but that a large proportion of the species' growth and distribution are subject to different degrees of development. The above results show that climate warming has two sides to the growth and distribution of species. It is clear that the growth and distribution of *M. biondii* have developed to a certain extent in the context of climate warming. The expansion and contraction in suitable habitat are located to the north-east and north of suitable habitat in the current period, which is a sensitive area for the species to respond to future climate change (Diamond et al., 2011), and the above areas should be protected and relevant measures should be taken.

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First, for areas classified as highly suitable or with distribution records, it is important to precisely define plant geographic location and growth characteristics. Regular assessments of the habitats around the plant and its growth conditions should be conducted to strengthen in situ protection tailored to local conditions, strictly prohibiting artificial harvesting and destruction. Second, in less populated areas identified for relocation protection, corresponding measures such as seed introduction, cultivation, and breeding can be implemented. Medicinal economic gardens for magnolias can be established, and scientifically sound harvesting principles should be developed to fully exploit the ecological, medicinal, and garden values of magnolias.

Conclusion

Using the MaxEnt model, this study predicted the potential habitat of *M. biondii* in China for four future periods, the current period, and two previous periods. The study's key findings are outlined below:

1. The primary environmental factors influencing *M. biondii* distribution in China are min temperature of coldest month (Bio06) (44.9%), precipitation of warmest quarter (Bio18) (19.4%), and precipitation of coldest quarter (Bio19) (6.8%). This underscores that the suitable area of *M. biondii* was particularly affected by temperature, followed by precipitation.
2. Currently, the total suitable area of *M. biondii* is concentrated in East China, Central China, and the eastern part of Southwest China, totaling 107.95×10^4 km^2. The highly suitable area is predominantly found in Hubei, Henan, and Shandong.
3. Future global warming will have a positive impact on the potential distribution area of *M. biondii*, and its distribution center has a tendency to migrate to higher latitudes.

In the long run, field resource surveys should be established, priority should be given to the protection of sensitive areas that will respond to future climate change, and work should be carried out on the introduction of cultivation and breeding, so as to give full play to their ecological and economic benefits.

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