Potential Distribution of *Blumea Balsamifera* in China Using MaxEnt and The Ex-Situ Conservation Based on its Effective Components and Fresh Leaf Yield

Lingliang Guan  
Chinese Academy of Tropical Agricultural Sciences

YuXia Yang  
sichuan academy of traditional Chinese medicine science

Pan Jiang  
Southwest University of Science and Technology

Qiuyu Mou  
Mianyang Normal University: Mianyang Teachers' College

Yunsha Gou  
Mianyang Normal University: Mianyang Teachers' College

Xueyan Zhu  
Mianyang Normal University: Mianyang Teachers' College

Yingwen Xu  
chengdu labbio biotechnology Co.

Rulin Wang (✉️ wrl_1986_1@163.com)  
CUIT: Chengdu University of Information Technology

Research Article

**Keywords:** Blumea balsamifera, MaxEnt, suitable habitat, climate change, ex-situ conservation, effective components

**Posted Date:** December 9th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-1076517/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License.  
[Read Full License](https://creativecommons.org/licenses/by/4.0/)
Abstract

*Blumea balsamifera* is a famous Chinese Minority Medicine, which has a long history in Miao, Li, Zhuang and other minority areas. In recent years, due to the influence of natural and human factors, the distribution area of *B. balsamifera* resources has a decreasing trend. Therefore, it is very important to analyze the suitability of *B. balsamifera* in China. Following three climate change scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5) under 2050s and 2070s, geographic information technology (GIS) and maximum entropy model (MaxEnt) were used to simulate the ecological suitability of *B. balsamifera*. The contents of L-borneol and total flavonoids of *B. balsamifera* in different populations were determined by gas chromatography (GC) and ultraviolet spectrophotometry (UV). The results showed that the key environmental variables affecting the distribution of *B. balsamifera* were mean temperature of coldest quarter (6.18-26.57 °C), precipitation of driest quarter (22.46-169.7 mm), annual precipitation (518.36-1845.29 mm) and temperature seasonality (291.31-878.87). Under current climate situation, the highly suitable habitat was mainly located western Guangxi, southern Yunnan, most of Hainan, southwestern Guizhou, southwestern Guangdong, southeastern Fujian and western Taiwan, with a total area of 24.1×10^4 km^2. The areas of the moderately and poorly suitable habitats were 27.57×10^4 km^2 and 42.43×10^4 km^2, respectively. Under the future climate change scenarios, the areas of the highly, moderately, and poorly suitable habitats of *B. balsamifera* showed a significant increasing trend, the geometric center of the total suitable habitats of *B. balsamifera* would move to the northeast. In recent years, the planting area of *B. balsamifera* has been reduced on a large scale in Guizhou, and its ex situ protection is imperative. By comparison, the content of L-borneol, total flavonoids and fresh leaf yield had no significant difference between Guizhou and Hainan (P > 0.05), which indicated that Hainan one of the best choice for ex-situ protection of *B. balsamifera*.

Introduction

According to the fifth IPCC Assessment Report (IPCC AR5), the global average land surface temperature has increased by 0.85 °C from 1880 to 2012, and the average temperature from 2003 to 2012 has increased by 0.78 °C compared with that from 1850 to 1900, and it is expected that it will continue to increase by 0.3 °C to 0.7 °C in 2035 (Zou et al., 2015). With the rising temperature, the extreme weather increases, the cryosphere begins to degenerate, and the ecological environment continues to deteriorate, which leads to significant changes in species migration patterns, seasonal activities, phenology, and geographical distribution, and has a profound impact on the natural ecosystem and the sustainable development of human society (Fu et al., 2005; Abrahms et al., 2017; Williams et al., 2020). Climate, topography, soil and other environmental factors have a significant impact on the growth and geographical distribution of species. In the future, under the background of rising temperature and changing precipitation pattern, the living environment of species will also change, and some of them will migrate to high latitude areas (Wu et al., 2011; Läderach et al., 2016; Guo et al., 2017; Yang et al., 2020; Zhang et al., 2020). Climate change may accelerate species extinction, reduce species diversity, and make regional ecosystems more vulnerable, while some species will form new physiological characteristics to
adapt to climate change (Bowling et al., 2020; Wang et al., 2020; He et al., 2021). In order to understand the change of species adaptability and geographical distribution under the future climate change, and how to take targeted measures to protect rare species and maintain species diversity, many scholars have carried out the simulation and prediction of species geographical distribution under different climate scenarios (Wróblewska and Mirski, 2018; Donatti et al., 2020; Momblanch et al., 2020; Wu et al., 2021).

Niche is the sum of all the abiotic conditions necessary for the survival of species, which can effectively reflect the physiological and ecological needs of species (Godsoe et al., 2017; Citores et al., 2020). In recent years, niche models have been widely used to study the effects of global climate change on species distribution. Common models include classification and regression tree (CART) (Cao et al., 2005; Zhang et al., 2014), artificial neural network (ANN) (Wang et al., 2012; Su et al., 2018), genetic algorithm for rule set prediction (GARP) (Yu et al., 2009; Padalia et al., 2014), biological prediction system (Bioclim) (Booth et al., 2013; Venette, 2017), ecological niche factor analysis (ENFA) (Farashi and Naderi, 2017; Bashir et al., 2018) and maximum entropy model (MaxEnt) (Phillips et al., 2006; Kumar and Stohlgren, 2019), among which MaxEnt is widely used by researchers due to its advantages such as reasonable construction scheme, simple operation, graphical parameter configuration interface, and high combination of input data and GIS (Elith et al., 2010; Petitpierre et al., 2012). MaxEnt is a niche model based on the known distribution information of species and related environmental variables, which is mainly used to judge the ecological needs of species and predict potential suitable habitats based on the actual distribution of species (Warren and Seifert, 2011; Elith et al., 2015). In recent years, scholars at home and abroad have tried to use MaxEnt to study the habitat suitability of medicinal plants, such as Fritillaria cirrhosa D. Don (Zhao et al., 2018), Phellodendron amurense Rupr (Wan et al., 2014), Houttuynia cordata Thunb (Liu et al., 2021), Daphne mucronata Royle (Abolmaali et al., 2018), Brucea mollis Wall (Borthakur et al., 2018), etc., and achieved good results.

In recent years, with the rapid development of traditional Chinese medicine industry, the reserve of traditional Chinese medicine resources has decreased sharply, and the protection is imminent. At present, the protection methods of biological resources mainly include in-situ protection and ex-situ protection. In-situ conservation refers to maintaining and restoring the survival of species in their natural environment by protecting local ecosystems and natural habitats. Ex-situ conservation refers to the migration of species to areas outside their natural habitat for protection. Compared with local protection, ex-situ protection can reduce the impact of the external environment through human intervention and reduce the constraints of time and space. Therefore, ex-situ protection plays an irreplaceable role in the first aid of rare and endangered species, resource protection and development, and is an important way to protect the resources of traditional Chinese medicine (Que et al., 2016).

Blumea balsamifera (L.) DC. (Asteraceae: Blumea), is a perennial herb that likes warm climates and grows in tropical areas at an altitude of 400-800 m. In the world, B. balsamifera is mainly distributed in China, Thailand, Myanmar, Indonesia, Philippines, Indochina Peninsula, India and Pakistan, while in China, it is mainly distributed in Yunnan, Guizhou, Hainan, Guangxi, Guangdong, Fujian and Taiwan provinces (Xie et al., 2017). Blumea balsamifera is a pioneer vegetation for soil and water conservation
because of its strong adaptability. It is the only raw material for the extraction of L-borneolum, which has the effects of analgesia, sweating, dispelling wind and dampness, eliminating phlegm and relieving cough (Yuan et al., 2011). *Blumea balsamifera* is a famous Chinese Minority Medicine, which has a long history in Miao, Li, Zhuang and other minority areas (Guan et al., 2012). With the development of national medicine industry, *B. balsamifera* has been used in medicine, cosmetics, daily necessities and other industries, resulting in great economic and social benefits (Wang et al., 2014). According to our field investigation in Guizhou and Hainan, it is difficult to find the population distribution of *B. balsamifera* in some suitable habitat areas recorded in historical literature and specimen information. People's weak awareness of the protection of wild resources and unreasonable adjustment of agricultural industrialization structure are the direct reasons for the endangered wild resources of *B. Balsamifera* (Xie et al., 2017). In addition, habitat change caused by climate warming may also be one of the potential factors. Therefore, the study on the influence of climate change on the suitable habitat distribution of *B. balsamifera* will be helpful to the selection of introduction and domestication sites, the protection of germplasm resources, and the sustainable reproduction of this medicinal plant resources.

Research on *B. balsamifera* has mainly focused on its resource distribution and investigation (Yuan et al., 2011; Zheng et al., 2017), chemical composition analysis (Wang and Zhang, 2020; Hanh et al., 2021), breeding and cultivation techniques (He et al., 2005; Gu et al., 2016), pharmacological action (Agdamag et al., 2020; Ginting et al., 2020; He et al., 2020), basic genetic research (Guan et al., 2016; Zhang et al., 2016), and germplasm resources identification (Liu et al., 2016; Xiao et al., 2021); however, only a few scholars to date have examined its potential distribution. In 1999, Hu et al. (1999) analyzed the plant resources of *B. balsamifera* in Guizhou Province, and divided the most suitable growing area, suitable growing area and general distribution area. In 2010, Jiang et al. (Jiang et al., 2010) conducted a detailed survey of *B. balsamifera* resources in Red River region, Guizhou Province, and classified and statistically analyzed its ecological types and habitat characteristics. However, the limited research only focused on the suitable distribution area of *B. balsamifera* in Guizhou, and the climate, environment and suitability of other producing areas have not been reported. Under the background of climate change, it is still unknown whether the suitable distribution area of *B. balsamifera* will change.

Guizhou is the genuine production area of *B. balsamifera*, and the quality of *B. balsamifera* produced in Luodian, Qiandongnan Prefecture is the best. Luodian *B. balsamifera* is a national geographical indication protection product approved by AQSIQ (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China), which is an important production area of *Blumea balsamifera* in China. Unfortunately, the construction of Longtan Hydropower Station in 2008 directly led to the inundation of a large area of *B. balsamifera* planting base, which severely damaged the industry. The destruction of the original area has led to the wild resources of the Annah being plundered and exploited wildly, which further aggravates the depletion of its resources. In this case, it is very important to find a suitable migration area for *B. balsamifera*. Hainan, as the only tropical island in China, is the main wild distribution area of *B. balsamifera*. Recently, researchers have carried out research on taking Hainan as a key candidate area for ex-situ conservation of *B. balsamifera*, which has been strongly supported by Hainan provincial government. However, the key to the success of ex-situ
protection of *B. Balsamifera* is whether the quality and yield of medicinal materials are significantly different from those in the original area.

In this study, we collected geographic location information of *B. balsamifera* by searching databases and the literature, downloaded climate variables from the WorldClim website, and used MaxEnt to simulate the potential suitable distribution of *B. balsamifera* in China. We evaluated the dominant environmental variables restricting the geographical distribution of *B. balsamifera* and the change of suitable distribution area in the future, determined the contents of L-borneol, total flavonoids and fresh leaf yield of *B. balsamifera* in different populations to provided theoretical and technical support for the ex-situ conservation of *B. balsamifera* production area in China.

**Methods**

**Collecting occurrence data of *B. balsamifera***

Firstly, the distribution data of *B. balsamifera* were obtained by searching GBIF (Global Biodiversity Information Facility) and publications (Bai et al., 2020; Bao et al., 2020; He et al., 2020; Wang and Zhang, 2020; Wei et al., 2020; Xiao et al., 2021). Secondly, the longitude and latitude of distribution data were picked up by Google Earth 7.1.3 (Google, USA), and were converted into decimal after removing the repeated distribution points. Thirdly, the spatial analysis function of ArcGIS 10.0 (ESRI, USA) was employed to calculate the distance between the distribution points and the centre of the censored grid to ensure that each censored grid contains only one distribution point closest to the centre, so as to reduce the impact of spatial autocorrelation (Wang et al., 2020). Finally, a total of 228 distribution points were obtained (Fig. 1).

**Environmental variables**

The grid data of 19 bioclimatic variables with WGS84 coordinate system and 2.5 arc-minutes resolution were accessed through the Worldclim database (https://www.worldclim.org/), and the current climate data was obtained by interpolating the detailed meteorological information recorded by meteorological stations all over the world, with a time span of 1970-2000. The future climate data was based on BCC-CSM2-MR climate system model developed by National Climate Center, involving SSP5-8.5, SSP2-4.5 and SSP1-2.6 emission scenarios. The 1:16 million administrative division map of China was downloaded from the website of the Ministry of natural resources of the people's Republic of China (http://bzdt.ch.mnr.gov.cn/index.html).

The selection procedure of environment variables was divided into two steps. Firstly, all the 22 environmental variables (Table S1) were imported into MaxEnt model, and the variables with contribution rate of 0 were deleted after three operations. Secondly, all the environmental factors with percent contribution rate greater than 0 were selected for Spearman correlation analysis. Thirdly, the smaller
contribution rate of paired variables with correlation coefficient $\geq 0.8$ was eliminated, and finally 11 environmental variables were selected for MaxEnt. (Table 1).

| Environmental variables | Description                              |
|--------------------------|------------------------------------------|
| Bio3                     | Isothermality                             |
| Bio4                     | Standard deviation of temperature seasonality |
| Bio5                     | Max temperature of warmest month          |
| Bio8                     | Mean temperature of wettest quarter       |
| Bio11                    | Mean temperature of coldest quarter       |
| Bio12                    | Annual precipitation                      |
| Bio15                    | Coefficient of variation of precipitation seasonality |
| Bio17                    | Precipitation of wettest quarter          |
| Altitude                 | Altitude                                 |
| Slope                    | Slope                                    |
| Aspect                   | Aspect                                   |

### Parameter setting of MaxEnt model

Based on the selected distribution data and environmental variables, the model was established and repeated 10 times. The proportion of test data was set as ‘Random seed’, the replicated run type was set as ‘Crossvalidate’, the maximum iterations was set to 500, the importance of climatic variables was measured by ‘Jackknife test’, the impact of variables on the distribution of *B. balsamifera* was analyzed by creating response curves, the output format was logistic, and other settings were set as the default values of the software (Narouei-Khandan et al., 2016).

Verification of model accuracy. The Receiver operating characteristic (ROC) curve output by MaxEnt was one of the effective methods to evaluate the accuracy of niche model. AUC (Areas under Roc curve) $\leq 0.8$ indicated poor performance, $0.8 < \text{AUC} \leq 0.9$ indicated moderate performance, $0.9 < \text{AUC} \leq 0.95$ indicated good performance, and $0.95 < \text{AUC} \leq 1$ indicated excellent performance (Ortega-Huerta and Peterson, 2008; López-Collado et al., 2013).

Division of suitable grade. In the output file, the maximum value of 10 repetitions was selected as the prediction result of the present study. ArcGIS was used to convert the ASC file output by MaxEnt into raster format file. According to IPCC’s explanation of the probability ($P$) of species’ presence and combined with previous research results, the suitability grades were divided into four categories and
indicated by different colors, i.e., highly suitable habitat \((P \geq 0.66, \text{red})\), moderately suitable habitat \((0.33 \leq P < 0.66, \text{orange})\), poorly suitable habitat \((0.05 \leq P < 0.33, \text{yellow})\), and unsuitable habitat \((P < 0.05, \text{white})\) (Remya et al., 2015; Zou et al., 2015; Wang et al., 2018).

**Determination of main effective components and fresh leaf yield of B. balsamifera**

Determination of the weight of fresh leaves. After 6 months of transplanting, 15 plants with the same field performance were selected from each population. All leaves were picked and bagged in the laboratory and weighed with electronic balance. SPSS17.0 was used for data analysis.

Determination of L-borneol by GC(Agilent 7890A, Agilent Technologies, Inc). 1) Setting of chromatographic conditions. HP-5 quartz capillary \((0.32 \text{ mm} \times 30 \text{ m}, 0.25 \mu\text{m})\) was used as the chromatographic column. The initial temperature was set at 80 °C and kept for 2 min, then the temperature was raised to 100 °C at a rate of 5 °C/min and then raised to 200 °C at a rate of 20 °C/min. The temperature of injector and FID detector were set at 220 °C and 240 °C respectively, and the injection volume was 0.6 µL without diverting. 2) Preparation of internal and external standard solution. L-borneol \((100\text{mg})\) was added into a 100 ml volumetric flask, and ethyl acetate was used to fix its volume to obtain the L-borneol reference solution with a mass concentration of 1.000 mg/ml. Methyl salicylate \((250\text{mg})\) was added into a 250 ml volumetric flask, and the volume was fixed with ethyl acetate and shaken up to obtain an internal standard solution with a mass concentration of 1.000 mg/ml. 3) Preparation of test products. Leaves of *B. balsamifera* were put into a mortar and ground into powder with liquid nitrogen. 2 g of ground powder was accurately weighed and extracted for 30 min in a centrifuge tube containing 25 ml ethyl acetate under 40 kHz ultrasound. 1 ml of filtrate and 1 ml of internal standard solution were added into a 10 ml volumetric flask and diluted with ethyl acetate. After shaking, the filtrate was filtered with a 0.22µm microporous membrane. The filtrate obtained was the test sample. 4) Drawing of standard curve. 100 mg of L-borneol standard was placed in a 100 mL volumetric flask and ethyl acetate was added to determine the volume. The standard solution was obtained after shaking well. Measure 0.1, 0.2, 0.5, 1.0, 2.0 mL of standard solution into 10 mL volumetric flask, add 1 mL of internal standard solution at the same time, and measure volume to scale with ethyl acetate. The determination was carried out according to the above chromatographic conditions. Taking the mass concentration of L-borneol \((\text{mg} \cdot \text{ml}^{-1})\) as the abaxial axis \((X)\) and the peak area ratio of L-borneol to the internal standard as the vertical axis \((Y)\), the standard curve was plotted and the linear regression equation was obtained \(Y = 15.641X + 0.0158, R^2 = 0.9999\). The results showed that there was a good linear relationship between the mass concentration \((10.429–210.448 \mu\text{g} \cdot \text{ml}^{-1})\) and peak area.

Determination of total flavonoids by UV. 1) Preparation of chromogenic agent. NaNO2 \((25g)\), Al(NO3)3·9H2O \((88g)\) and NaOH \((20g)\) were dissolved in H2O and diluted to 500ml respectively to prepare 5% NaNO2 solution, 10% Al(NO3)3 solution and 4% NaOH solution. 2) Preparation of rutin reference solution. The rutin reference substance \((12.06 \text{mg})\) dried to constant weight at 105 °C and ethanol \((75\% \text{ volume fraction})\) in 50 ml volumetric flask were slightly dissolved in water bath. Then, 75% ethanol was
added to the cooled solution for constant volume and shaking to obtain rutin reference solution with mass concentration of \( \text{mg·mL}^{-1} \).

3) Preparation of test solution. *Blumea balsamifera* powder (0.5 g) and 75% ethanol solution (25 ml) were extracted by ultrasound at 400 W power and 40 kHz frequency for 40 min and then cooled. Then, 75% ethanol was used to make up the lost mass, and the test solution was obtained after shaking and filtering. 4) Drawing of standard curve. First, 75% ethanol was added into five 25 ml volumetric flasks containing rutin reference solution (1.00, 2.00, 4.00, 6.00, 8.00 ml) respectively, and the volume was adjusted to 10 ml. Then, 1 ml of 5% NaNO\(_2\) solution was added and shaken well. After 5 min, 1 ml of 10% Al(NO\(_3\))\(_3\) solution was added and shaken well. After 5 min, 10 ml of 4% NaOH solution was added. After shaking well, the volume was fixed to the scale with 75% ethanol, and shaken well for 15 min. The absorbance was detected at 509 nm with the corresponding reagent solution as blank. The absorbance of rutin reference solution was detected, and the standard curve was drawn with the mass concentration of reference as abscissa \( X \) and the absorbance as ordinate \( Y \). The linear regression equation \( Y = 22.03X - 0.01015 \) \( (R^2 = 0.9992) \) were obtained, which showed that the linear relationship was good in the range of 0.00482—0.03859 \( \text{mg·mL}^{-1} \).

**Results**

**Model performance**

The AUC values of training data and test data were 0.965 and 0.938 (Fig. 2), respectively, indicating the performance level of the model was “excellent”.

**Analysis of the importance of environmental variables**

The results showed that mean temperature of coldest quarter (42.8%) was the most important variable determining the distribution of *B. balsamifera*. Precipitation of driest quarter and annual precipitation explained 17.1% and 16.5% of the contribution. Altitude (0.9%), mean temperature of wettest quarter (0.7%), and aspect (0.6%) were the three variables with least impacts on *B. balsamifera* distribution (Table 2).
Table 2
Percent contribution of each variable to the potential distribution of *B. balsamifera* defined by MaxEnt.

| Variables                             | Percent contribution / % |
|---------------------------------------|--------------------------|
| Mean temperature of coldest quarter   | 42.8                     |
| Precipitation of driest quarter       | 17.1                     |
| Annual precipitation                   | 16.5                     |
| Temperature seasonality               | 9.3                      |
| Isothermality                          | 6.2                      |
| Precipitation seasonality             | 3                        |
| Slope                                 | 1.5                      |
| Max temperature of warmest month      | 1.5                      |
| Altitude                              | 0.9                      |
| Mean temperature of wettest quarter   | 0.7                      |
| Aspect                                | 0.6                      |

By comparing the regularized training gain with only variable (Fig. 3), it was found that mean temperature of coldest quarter (bio11) had the highest score (1.81), which was the most important climate variable affecting the distribution of *B. balsamifera*. The regularized training gain of precipitation of driest quarter (bio17), Annual precipitation (bio12) and temperature seasonality (bio4) were 1.48, 1.47 and 1.45, respectively, which were important for its distribution. The regularized training gain of the above four were significantly higher than other variables, which indicated that they contained unique information affecting the distribution of *B. balsamifera*.

**Relationship between environmental variables and probability of presence**

In order to clarify the relationship between key environmental variables and the probability of presence of *B. balsamifera*, we used MaxEnt to draw the response curve using only a single environmental variable (Fig. 4). The results showed that the suitable ranges of mean temperature of coldest quarter (bio11), precipitation of driest quarter (bio17), annual precipitation (bio12) and temperature seasonality (bio4) were 6.18-26.57 °C (Fig. 4-A), 22.46-169.7 mm (Fig. 4-B), 518.36-1845.29 mm (Fig. 4-C), and 291.31-878.87 (Fig. 4-D) respectively.

**Potential distribution of B. balsamifera in China under current climate condition**
Figure 5 showed the geographical distribution of *B. balsamifera* in China under current climate conditions predicted by MaxEnt. The results showed that the highly suitable habitats were mainly located in western Guangxi, southern Yunnan, most of Hainan, southwestern Guizhou, southwestern Guangdong, southeastern Fujian and western Taiwan, with a total area of $24.1 \times 10^4$ km$^2$, accounting for 2.51% of China's land area. Among them, Guangxi had large areas, reaching $7.75 \times 10^4$ km$^2$. The moderately suitable habitats were mainly located in central and southern Yunnan, central and eastern Guangxi, central and eastern Guangdong, southeastern Sichuan, southern Guizhou, western Chongqing and southeastern Fujian., with a total area of $27.57 \times 10^4$ km$^2$, accounting for 2.87% of China's land area. Among them, Yunnan, Guangxi and Guangdong had larger areas, which were $8.12 \times 10^4$ km$^2$, $7.56 \times 10^4$ km$^2$ and $7.21 \times 10^4$ km$^2$, respectively. The poorly suitable habitats were located in most of Yunnan, central and northern Guizhou, eastern Sichuan, most of Guangdong, northern Guangxi, eastern Chongqing, central and northern Fujian, western Hunan, western Hubei, southern Jiangxi and southeastern Tibet, with a total area of $42.43 \times 10^4$ km$^2$, accounting for 4.42% of China's land area. Among them, the area of Yunnan was the largest, reaching $14.14 \times 10^4$ km$^2$.

Figure 6 showed the suitable habitat of *B. balsamifera* under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios in the future. The results showed that the areas of the highly, moderately, and poorly suitable habitats of *B. balsamifera* showed a significant increasing trend. By 2050s, the areas of the highly suitable habitats would increase to $68.73 \times 10^4$ km$^2$ (SSP1-2.6), $57.25 \times 10^4$ km$^2$ (SSP2-4.5) and $77.04 \times 10^4$ km$^2$ (SSP5-8.5), and the moderately suitable habitats would increase to $49.06 \times 10^4$ km$^2$ (SSP1-2.6), $47.34 \times 10^4$ km$^2$ (SSP2-4.5) and $57.97 \times 10^4$ km$^2$ (SSP5-8.5), and the poorly suitable habitats would increase to $81.19 \times 10^4$ km$^2$ (SSP1-2.6), $93.79 \times 10^4$ km$^2$ (SSP2-4.5) and $74.85 \times 10^4$ km$^2$ (SSP5-8.5) (Figure 6). By 2070s, the areas of the highly suitable habitats would increase to $49.34 \times 10^4$ km$^2$ (SSP1-2.6), $81.42 \times 10^4$ km$^2$ (SSP2-4.5) and $106.08 \times 10^4$ km$^2$ (SSP5-8.5), and the moderately suitable habitats would increase to $40.39 \times 10^4$ km$^2$ (SSP1-2.6), $63.08 \times 10^4$ km$^2$ (SSP2-4.5) and $67.89 \times 10^4$ km$^2$ (SSP5-8.5), and the poorly suitable habitats would increase to $99.23 \times 10^4$ km$^2$ (SSP1-2.6), $70.6 \times 10^4$ km$^2$ (SSP2-4.5) and $62.18 \times 10^4$ km$^2$ (SSP5-8.5) (Figure 6).

Figure 7 showed the changes of the total suitable habitats of *B. balsamifera* under different climate change scenarios. Compared with the current simulation, the newly gained suitable habitats were mainly located in most of Hunan, Jiangxi, most of Zhejiang, Anhui, central and eastern Hubei, central and southern Henan, western Jiangsu, southern Shaanxi and northeast Guangxi. The newly lossed suitable habitats were relatively small.

Under SSP1-2.6, the areas of the gained area would be $80.59 \times 10^4$ km$^2$ (2050s) and $70.48 \times 10^4$ km$^2$ (2070s), accounting for 40.57% (2050s) and 37.38% (2070s) of the total suitable habitat. The areas of the stable area would be $118.07 \times 10^4$ km$^2$ (2050s) and $118.08 \times 10^4$ km$^2$ (2070s), accounting for 59.43% (2050s) and 62.62% (2070s) of the total suitable habitat.
Under SSP2-4.5, the areas of the gained area would be about $80.04 \times 10^4 \text{ km}^2$ (2050s) and $96.71 \times 10^4 \text{ km}^2$ (2070s), accounting for 40.42% (2050s) and 45.03% (2070s) of the total suitable habitat. The areas of the stable area would be $117.97 \times 10^4 \text{ km}^2$ (2050s) and $118.08 \times 10^4 \text{ km}^2$ (2070s), accounting for 59.58% (2050s) and 54.97% (2070s) of the total suitable habitat.

Under SSP5-8.5, the areas of the gained area would be about $91.45 \times 10^4 \text{ km}^2$ (2050s) and $117.92 \times 10^4 \text{ km}^2$ (2070s), accounting for 43.64% (2050s) and 49.97% (2070s) of the total suitable habitat. The areas of the stable area would be $118.1 \times 10^4 \text{ km}^2$ (2050s) and $118.07 \times 10^4 \text{ km}^2$ (2070s), accounting for 56.36% (2050s) and 50.03% (2070s) of the total suitable habitat.

**Variations of the geometric center of the suitable habitats under climate change scenarios**

Under SSP1-2.6, the geometric center of the total suitable habitats of *B. balsamifera* would move 262.23 km from Daxin (Current) to northeast to Rongshui (2050s), then 97.73 km to southwest to Hechi (2070s). By 2070s, the center would generally displaced 194.96 km to the northeast. Under SSP2-4.5, the geometric center of the total suitable habitats of *B. balsamifera* would move 210.69 km from Daxin (Current) to northeast to Huanjiang (2050s), then 50.19 km to northeast to Huanjiang (2070s). By 2070s, the center would generally displaced 260.81 km to the northeast. Under SSP5-8.5, the geometric center of the total suitable habitats of *B. balsamifera* would move 257.43 km from Daxin (Current) to northeast to Luocheng (2050s), then 142.14 km to northeast to Jingzhou (2070s). By 2070s, the center would generally displaced 397.78 km to the northeast (Fig. 8).

**Main effective components and fresh leaf yield of B. balsamifera from Guizhou and Hainan**

In order to clarify the feasibility of the migration of the producing areas of *B. balsamifera*, we measured the main effective components and fresh leaf yield in Luodian, Anlong, Xingyi and Wangmo (national geographical indication protected areas) in Guizhou and Baisha, Qiongzhong, Danzhou and Wuzhishan in Hainan (areas with a large number of wild resources). Results showed that the L-borneol content of *B. balsamifera* from Luodian was the highest (6.58 mg/g), while that from Wangmo was the lowest (3.79 mg/g). In Hainan, the content from Baisha was the highest (6.97 mg/g), while that from Wuzhishan was the lowest (4.23 mg/g). For the yield of fresh leaves, the yield of Luodian (0.64 kg) in Guizhou was slightly higher than that in other regions, while the yield of Qiongzhong (0.63 kg) in Hainan was higher. By comparison, the content of L-borneol and fresh leaf yield had no significant difference among populations (P > 0.05), and there was also no significant difference between Guizhou and Hainan (P > 0.05). The content analysis of total flavonoids showed that the content of total flavonoids in Danzhou was the highest (124.16 mg/g) in Hainan, while in Guizhou, the content of total flavonoids in Luodian was the highest (53.58 mg/g), and there was significant difference among populations (P < 0.05), but there was no significant difference between the average values of Hainan and Guizhou (P > 0.05) (Table 3).
Table 3
Comparison of the content of L-borneol, total flavonoids and fresh leaf yield of *B. balsamifera* in different populations

| Province | Location | L-borneol (mg/g) | Total flavonoids (mg/g) | Fresh leaf yield (kg) |
|----------|----------|------------------|------------------------|----------------------|
| Guizhou  | Luodian  | 6.58 a           | 53.58 b                | 0.64 a               |
|          | Anlong   | 5.57 a           | 28.69 abc              | 0.62 a               |
|          | Xingyi   | 4.36 a           | 25.41 abc              | 0.53 a               |
|          | Wangmo   | 3.79 a           | 13.27 c                | 0.58 a               |
|          | Mean     | 5.08 A           | 30.24 A                | 0.59 A               |
| Hainan   | Baisha   | 6.97 a           | 24.54 abc              | 0.60 a               |
|          | Qiongzhong | 6.78 a       | 40.01 abc              | 0.63 a               |
|          | Danzhou  | 5.66 a           | 124.16 d               | 0.59 a               |
|          | Wuzhishan| 4.23 a           | 27.33 abc              | 0.66 a               |
|          | Mean     | 5.91 A           | 54.01 A                | 0.62 A               |

Discussion

**Key climatic variables affecting the occurrence of** *B. balsamifera*

Climate factors are the key factors limiting the geographical distribution of species, and the study of the interaction between plants and climate is a hot spot in ecology (Ramachandran et al., 2020). As a special agricultural resource, the cultivation, growth, harvesting and distribution of traditional Chinese medicine resources will also be greatly affected by the climate (Xia et al., 2019). Studies have shown that the extreme value and variation range of temperature were closely related to the large-scale landscape geographical distribution of species (Renne et al., 2019). Zheng et al. (2016) considered that temperature was the key meteorological index affecting the cultivation of *B. balsamifera*. Based on five temperature indexes, a regression model was established to determine the planting area of *B. balsamifera* in Guizhou. The results showed that the mean temperature of coldest quarter had the highest percent contribution rate to the simulation (42.8%), which was the most critical variable affecting its distribution. When the mean temperature of coldest quarter was lower than 6.18 °C, the probability of presence of *B. balsamifera* was very low, indicating that it has poor cold resistance and needs to be planted in the area with higher temperature in winter. He et al. (2005) found that in warm winter years, even if the flower
shoots of *B. balsamifera* in December were frozen to death, the smooth overwintering of old stems would not affect the fruiting in the second year. This is in line with our view.

Water is the main factor to control the vegetation coverage level in most areas, but also the decisive factor to affect the formation and growth of medicinal plants. Our results showed that precipitation of driest quarter (bio17) and annual precipitation (bio12) were important factors affecting the distribution of *B. balsamifera*. Liu et al. (2019) pointed out that the drought resistance of *B. balsamifera* was poor, and the water content should be kept as high as 40% in order to maintain the accumulation and growth of leaf biomass. Therefore, close attention should be paid to the precipitation in the cultivation region during the introduction and artificial cultivation, especially for the area with annual precipitation less than 518.36 mm, water management should be strengthened. Studies have shown that the slowly growth period of *B. balsamifera* is from February to April, and the water demand is not high at this stage. Our results showed that the suitable range of precipitation of driest quarter was 22.46-169.7 mm, which was consistent with its biological characteristics. The precipitation is 15, which is consistent with its biological characteristics (He et al., 2005). However, this does not mean that water management can be ignored at this stage, but it needs to be strengthened, especially for the plants planted in that year. This is mainly due to the weak water absorption capacity caused by the shallower root system of the seedlings, and the artificial intervention can better promote the growth and development of the seedlings.

In addition to climate factors, topography, soil, light, interspecific competition, human disturbance and other factors also affect the geographical distribution of vegetation (Douda et al., 2016; Xu et al., 2019; Meng and Gao, 2020). However, the existing technical conditions are not mature enough, and there is still no model that can integrate all the impact factors into one model to simulate the potential distribution of species. Therefore, our study still has important reference value for the distribution of potential suitable habitats and the introduction and cultivation of *B. balsamifera* under the background of climate change.

**Potential distribution of B. balsamifera in China**

In this study, the simulation results showed that, under current climate condition, the highly suitable habitat of *B. balsamifera* in China was mainly located in western Guangxi, southern Yunnan, most of Hainan, southwestern Guizhou, southwestern Guangdong, southeastern Fujian and western Taiwan. According to field investigation and literature review, *B. balsamifera* mainly grows in Hainan, Guizhou, Guangxi, Guangdong, Fujian, Taiwan and other provinces south of the Yangtze River (Xie et al., 2017). In terms of climate types, the distribution area extends from the Emei mountains in Sichuan to the dry hot valley in Guizhou, and then to the subtropical and tropical regions in Yunnan, Guangxi and Guangdong. It is also widely distributed in Hainan Island, Leizhou Peninsula and Taiwan Island, and sporadically distributed in Fujian, Jiangxi, Zhejiang and Hunan. In contrast, the distribution frequency, abundance and relative coverage of *B. balsamifera* in Guangdong, Guangxi, Hainan and Southern Guizhou were higher (Yuan et al., 2011). All the above areas were located in the suitable habitats predicted in this paper, which showed that the results were reliable.
In 2008, the construction of Longtan Hydropower Station directly led to the inundation of a large area of *B. balsamifera* planting base, which severely damaged the industry (Fig. 9-A, C). Based on the investigation results of its germplasm resources from 2009 to 2011, *B. balsamifera* is distributed in Baisha, Danzhou, Qiongzhong, Wanning, Wuzhishan and other cities and counties in Hainan, covering mountains, hills, Plains, paddy fields, residential areas and other types. In addition, Hainan Island has suitable climatic conditions, rich land resources, sound science and technology service system, and good policy support, so it is considered as the key area for the migration of *B. balsamifera*. The results of this paper also showed that the area of the highly suitable habitat in Hainan was extremely high, accounting for 94.66% of the total area of the whole province (Fig. 9-B). For this, in the early stage, we have collected 82 germplasm resources of *B. balsamifera* from five provinces in China, and systematically compared and analyzed the content of active components after they migrated to Hainan. The results showed that the quality and disease resistance of the resources from Guizhou were significantly better. Moreover, the content of active components of Guizhou materials decreased slightly after they were introduced into Hainan, but the difference was not significant (Huang et al., 2016). At present, our research group has initially established a gap demonstration area in Hainan, and established a Pilot-Plant for its extraction and processing, which has laid a solid foundation for the migration of *B. balsamifera*-growing regions.

In order to further evaluate the feasibility of ex-situ conservation of *B. balsamifera* resources from Guizhou to Hainan, the contents of L-borneol, total flavonoids and fresh leaf yield of *B. balsamifera* in different populations were determined. The results showed that the content of L-borneol in Baisha and Qiongzhong in Hainan was slightly higher than that in Luodian, Guizhou, although the difference was not significant. However, for a long time, in Hainan, *B. balsamifera* has been mostly used by the Li people for daily use, such as postpartum bathing and mosquito repellent, so its planting area is small. With the destruction of the genuine producing area of *B. balsamifera* in Guizhou and the continuous reduction of its suitable planting area, the ex-situ protection and ex-situ planting were imperative. In addition, in Hainan, *B. balsamifera* can be harvested twice a year, that is, the yield can be doubled under the condition of little difference in L-borneol content. Therefore, we believe that so far, Hainan is the best choice for ex-situ protection of *B. balsamifera*.

**Potential distribution of *B. balsamifera* in China in the future**

We quantitatively analyzed the area changes of suitable habitats of *B. balsamifera* in 2050s and 2070s under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios. The results showed that the areas of the suitable habitats would increase. The impact of climate change on the distribution pattern of different species is different. Some species are threatened by climate change and are endangered or even extinct, while some species will benefit from climate change and continue to expand their distribution areas (Ma and Jiang, 2005). According to our results, *B. balsamifera* obviously belongs to the latter case. Many studies have confirmed that the changes of plant geographical distribution caused by global warming are mostly related to the changes of temperature and precipitation in the growing season of this species. (Root et al., 2003; Guo et al., 2014; Zhu and Xu, 2019). In the future, the suitable habitats of *B. balsamifera* would expand significantly in most of Hunan, Jiangxi, most of Zhejiang, Anhui, central and eastern Hubei,
central and southern Henan, western Jiangsu, southern Shaanxi and northeast Guangxi, and the annual precipitation in these areas was expected to show a significant growth trend (Wu et al., 2015; A et al., 2016). Compared with the simulation under current climate situation, the stable area of the total suitable habitat, that was, the area less affected by climate change, accounted for a relatively high proportion (50.03%-62.62%), which could be used as an ideal candidate for large-scale cultivation of *B. balsamifera*.

Studies have shown that there are regional and latitudinal differences in the change of plant phenology under the background of temperature rise. Some studies have shown that under the influence of climate change in the future, the suitable habitats of many medicinal plant would move northward. Peng and Guo (2017) explored potential impacts of climate change on the suitability of *Astragali Radix* by MaxEnt, and the results showed that by the 2050s and 2070s, the suitable habitats would move forward to north. Tan et al. (2020) simulated the ecological suitability of *Gentiana macrophylla* Pall..under current and future scenarios of global climate and found that its distribution center would shifted to the northeastern China. Xiong et al. (2019) analyzed the potential distribution of *Sorbus tianschanica*, an important ethnomedicinal plant, and the results showed that the suitable distribution habitats would move to high latitudes under climate warming in the future. Fan et al. (2021) simulated the potential geographical distribution of *Rosa roxburghii* under future climate scenarios and demonstrated that the suitable region tended to move to high latitude area. Referring to the methods of Yue et al. (2011), we calculated the geometric center of the suitable habitat with the area as the weight, and the results showed that the geometric center of the total suitable habitat would move to the northeast. There may be two reasons for this phenomenon. First, climate warming has a positive impact on the expansion of thermophilic plants (Araujo et al., 2010), which makes the suitable habitat of *B. balsamifera* expand. Secondly, the climate warming may lead to the increase of precipitation intensity in the middle and high latitudes of the northern hemisphere and the drought days in the middle and low latitudes of the northern hemisphere, resulting in its movement to high latitudes, which is consistent with its living habits of warm and humid climate, tolerance to a certain degree of low temperature and weak drought resistance.

**Conclusions**

Based on the MaxEnt model and species distribution data, it was concluded that the highly suitable habitats of *B. balsamifera* were mainly located in western Guangxi, southern Yunnan, most of Hainan, southwestern Guizhou, southwestern Guangdong, southeastern Fujian and western Taiwan. The key environmental variables affecting the potential distribution of *B. balsamifera* were mean temperature of coldest quarter (6.18-26.57 °C), precipitation of driest quarter (22.46-169.7 mm), annual precipitation (518.36-1845.29 mm) and temperature seasonality (291.31-878.87). Under the three climate change scenarios, the areas of the highly, moderately, and poorly suitable habitats of *B. balsamifera* showed a significant increasing trend, the geometric center of the total suitable habitats of *B. balsamifera* would move to the northeast. Our results can provide theoretical and technical support for the migration of *B. balsamifera* production area. As a medicinal plant, the quality of medicinal materials must be valued, but this study only investigated the suitability of climate factors for the growth of *B. balsamifera*. Therefore,
in the next work, we need to further study the effects of different climatic factors on the active components of *B. balsamifera* and the quality differences in different regions.

**Declarations**

**Author contribution**

Lingliang Guan and Yuxia Yang provided relevant data of *Blumea balsamifera* and required funds for the experiment. Yingwen Xu and Rulin Wang planned and supervised the project. Pan Jiang, Qiuyu Mou, Yunsha Gou and Xueyan Zhu analyzed the data and performed simulations.

**Funding**

This work was funded by the Hainan Natural Science Foundation (No. 2019RC316), National Natural Science Fundation of China (No. 31870317), the National key R & D Program (No.2017YFC1701802 and 2017YFC1700700), Pilot Project of Collaborative Extension Program of Major Agricultural Technologies of Ministry of Agriculture and Rural Affairs in 2020 (Agricultural Office Branch [2018] No. 16), the Technological Development of Meteorological Administration/Heavy Rain and Drought-Flood Disasters in Plateau and Basin Key Laboratory of Sichuan Province (Key Laboratory of Sichuan Province-2018-Key-05-06).

**Data availability**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

**References**

1. A, D., Xiong, K., Zhao, W.J., Gong, Z.N., Jing, R., Zhang, L., 2016. Temporal trend of climate change and mutation analysis of North China Plain during 1960 to 2013. Scientia. Geographica Sinica 36, 1555-1564.

2. Abolmaali, S.M.R., Tarkesh, M., Bashari, H., 2018. MaxEnt modeling for predicting suitable habitats and identifying the effects of climate change on a threatened species, *Daphne mucronata*, in central Iran. Ecological Informatics 43, 116-123.
3. Abrahms, B., Dipietro, D., Graffis, A., Hollander, A., 2017. Managing biodiversity under climate change: challenges, frameworks, and tools for adaptation. Biodiversity and Conservation 26, 2277-2293.

4. Agdamag, A., Aggabao, L., Agudo, M., Alcachupas, F., Rosa, T., 2020. Anti-urolithiatic Activity of Sambong (*Blumea balsamifera*) Extract in Ethylene Glycol-induced Urolithiatic Wistar Rats (*Rattus norvegicus*). Acta medica Philippina 54, 31-35.

5. Araujo, M.B., Pearson, R.G., Thuiller, W., Erhard, M., 2010. Validation of species–climate impact models under climate change. Global Change Biology 11, 1504-1513.

6. Bai, L., Guan, L.L., Zha, Y., Yu, F.L., Wang, K., Xie, X.L., Pang, Y.X., Chen, S.B., 2020. Bioinformatics analysis of dehydrogenase genes family from the *Blumea balsamifera* (L.) DC. Chinese Journal of Tropical Crops 41, 1145-1153.

7. Bao, Y.R., Feng, Y.D., Zheng, W.Z., Ye, W.C., Feng, H.L., 2020. Research progress of chemical constituents and pharmacological activities of essential oil of *Blumea balsamifera* DC. Renshen Yanjiu 32, 59-64.

8. Bashir, T., Bhattacharya, T., Poudyal, K., Qureshi, Q., Sathyakumar, S., 2018. Understanding patterns of distribution and space-use by Ursus thibetanus in Khangchendzonga, India: Initiative towards conservation. Mammalian Biology 92, 11-20.

9. Booth, T.H., Nix, H.A., Busby, J.R., Hutchinson, M.F., Franklin, J., 2013. bioclim: the first species distribution modelling package, its early applications and relevance to most current MaxEnt studies. Diversity & Distributions 20, 1-9.

10. Borthakur, S.K., Baruah, P.S., Deka, K., Das, P., Sarma, B., Adhikari, D., Tanti, B., 2018. Habitat distribution modelling for improving conservation status of *Brucea mollis* Wall. ex Kurz.– An endangered potential medicinal plant of Northeast India. Journal for Nature Conservation 43, 104-110.

11. Bowling, L.C., Cherkauer, K.A., Lee, C.I., Beckerman, J.L., Volenec, J.J., 2020. Agricultural impacts of climate change in Indiana and potential adaptations. Climatic Change 163, 2005-2027.

12. Cao, M.C., Zhou, G.S., Wong, E.S., 2005. Application and comparison of generalized models and classification and regression tree in simulating tree species distribution. Acta Ecologica Sinica 25, 2031-2040.

13. Citores, L., Ibaibarriaga, L., Lee, D.J., Brewer, M.J., Chust, G., 2020. Modelling species presence–absence in the ecological niche theory framework using shape-constrained generalized additive models. Ecological Modelling 418, 108926.

14. Donatti, C.I., Harvey, C.A., Hole, D., Panfil, S.N., Schurman, H., 2020. Indicators to measure the climate change adaptation outcomes of ecosystem-based adaptation. Climatic Change 158, 413-433.

15. Douda, J., Boublk, K., Slezk, M., Biurrun, I., Nociar, J., Havrdov, A., Doudov, J., Ačić, S., Brisse, H., Brunet, J., Chytr, M., Claessens, H., Csiky, J., Didukh, Y., Dimopoulos, P., Dullinger, S., FitzPatrick, N., Guisan, A., Horchler, P.J., Hrvinč, R., 2016. Vegetation classification and biogeography of European floodplain forests and alder carrs. Applied Vegetation Science 19, 147-163.
16. Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huerlimann, F., Leathwick, J.R., Lehmann, A., 2010. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29, 129-151.

17. Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E., Yates, C.J., 2015. A statistical explanation of MaxEnt for ecologists. Diversity & Distributions 17, 43-57.

18. Fan, X., Pan, J.W., He, S.T., 2021. Prediction of the potential distribution of *Rosa roxburghii* under the background of climate change based on MaxEnt model. Acta Botanica Boreali-Occidentalia Sinica 41, 159-167.

19. Farashi, A., Naderi, M., 2017. Predicting invasion risk of raccoon Procyon lotor in Iran using environmental niche models. Landscape and Ecological Engineering 13, 229-236.

20. Fu, B.J., Niu, D., Zhao, S.D., 2005. Study on global change and terrestrial ecosystems: history and prospect. Advances in Earth Science 20, 556-560.

21. Ginting, B., Maulana, I., Kamila, I., 2020. Biosynthesis Copper Nanoparticles using Blumea balsamifera Leaf Extracts: Characterization of its Antioxidant and Cytotoxicity Activities - ScienceDirect. Surfaces and Interfaces 21, 100799.

22. Godsoe, W., Jankowski, J., Holt, R.D., Gravel, D., 2017. Integrating Biogeography with Contemporary Niche Theory. Trends in Ecology & Evolution 32, 488-499.

23. Gu, C., Wang, H.L., Zhao, Z., Liu, H.C., Luo, C.L., Li, J.L., Luo, F.L., 2016. Effect of plant density and harvest on yield and quality in *Blumea balsamifera*. Journal of Chinese Medicinal Materials 39, 235-239.

24. Guan, L.L., Pang, Y.X., Wang, D., Zhang, Y.B., Kong, W.Y., 2012. Research progress on Chinese Minority Medicine of *Blumea balsamifera* L. DC. Journal of Plant Genetic Resources 13, 695-698.

25. Guan, L.L., Xian, Q.F., Shi, X.B., Lan, H.P., Chen, Z.X., Zhao, Z., Pang, Y.X., 2016. Cloning and analysis of Geranyl Pyrophosphate Synthase (GPPS) sequence of *Blumea balsamifera* L.DC on transcriptome information. Chinese Journal of Tropical Crops 37, 901-909.

26. Guo, Y.L., Li, X., Zhao, Z.F., Wei, H.Y., Gao, B., 2017. Prediction of the potential geographic distribution of the ectomycorrhizal mushroom Tricholoma matsutake under multiple climate change scenarios. Scientific Reports 7, 46221.

27. Guo, Y.L., Wei, H.Y., Lu, C.Y., Zhang, H.L., Gu, W., 2014. Predictions of potential geographical distribution of *Sinopodophyllum hexandrum* under climate change. Chinese Journal of Plant Ecology 38, 249-261.

28. Hanh, T., Le, T., Giang, V.H., Trung, N.Q., Cuong, N.X., 2021. Chemical constituents of *Blumea balsamifera*. Phytochemistry Letters 43, 35-39.

29. He, C.L., Yang, P.Y., Wang, L., Jiang, X.L., Zhang, W., Liang, X.X., Yin, L.Z., Yin, Z.Q., Geng, Y., Zhong, Z.J., Song, X., Zou, Y.F., Li, L.X., Lv, C., 2020. Antibacterial effect of *Blumea balsamifera* (L.) DC. essential oil against Staphylococcus aureus. Archives of Microbiology 202, 2499-2508.

30. He, Y.N., Ding, Y., Xian, F.R., Pan, J.F., Zou, C.L., 2005. The preliminary observation on growth characteristics of *Blumea balsamifera*. Guizhou Agricultural Sciences 33, 19-23.
31. He, Y.N., Ding, Y., Zeng, L.X., Xian, F.R., Pan, J.F., Zou, C.L., Zhang, L., 2005. Analysis on factors affecting survival rate of transplant of *Blumea balsamifera* and its technical countermeasure. Guizhou Agricultural Sciences 33, 40-43.

32. He, Y.Z., Huang, W.D., Zhao, X., Lv, P., Wang, H.J., 2021. Review on the impact of climate change on plant diversity. Journal of Desert Research 41, 59-66.

33. Hu, Q., Zhou, J.W., 1999. A preliminary study on the current situation of *Blumea balsamifera* plant resources and its suitable area division in Guizhou Province. Guizhou Forestry Science and Technology 27, 44-48.

34. Huang, M., Yu, F.L., Pang, Y.X., Chen, C., Liu, L.W., Chen, Z.X., Guan, L.L., 2016. Distribution of I-borneol and total flavone in different tissues of *Blumea balsamifera*. Guizhou Agricultural Sciences 44, 30-32.

35. Jiang, W.K., Zhou, T., He, P., Li, L., He, Y.N., Lou, R.Y., 2010. Resources and protection strategy of *Blumea balsamifera* in Red River region of Guizhou province. Guizhou Agricultural Sciences 38, 1-4.

36. Kumar, S., Stohlgren, T.J., 2019. Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. African Journal of Ecology and Ecosystems 6, 1-5.

37. Läderach, P., Villegas, J.R., Navarro-Racines, C., Zelaya, C., Jarvis, A., 2016. Climate change adaptation of coffee production in space and time. Climatic Change 141, 47-62.

38. Liu, J.M., Deng, M.M., Li, L.X., Chi, X., Li, J., Xiong, X., 2019. Response on the biomass and leaf structure of *Blumea balsamifera* L. DC. seedling to water stress. Journal of Yunnan Agricultural University (Natural Science) 34, 138-144.

39. Liu, L., Guan, L.L., Zhao, H.X., Huang, Y., Mou, Q.Y., Liu, K., Chen, T.T., Wang, X.Y., Zhang, Y., Wei, B., Hu, J., 2021. Modeling habitat suitability of *Houttuynia cordata* Thunb (Ceercao) using MaxEnt under climate change in China. Ecological Informatics 63, 101324.

40. Liu, L.W., Chen, X.L., Pang, Y.X., Yang, Q., Yu, F.L., Chen, Z.X., Wang, D., 2016. Leaf microstructure of *Blumea balsamifera* germplasm from Guizhou and Hainan. Guizhou Agricultural Sciences 44, 120-122.

41. López-Collado, J., López-Arroyo, J.I., Robles-García, P., 2013. Geographic distribution of habitat, development, and population growth rates of the Asian citrus psyllid, *Diaphorina citri*, in Mexico. Journal of Insect Science 13, 114.

42. Ma, R.J., Jiang, Z.G., 2005. Impact of global climate change on wildlife. Acta Ecology Sinica 25, 3061-3066.

43. Meng, X.Y., Gao, X., 2020. Spatial and Temporal Characteristics of Vegetation NDVI Changes and the Driving Forces in Mongolia during 1982–2015. Remote Sensing 12, 603.

44. Momblanch, A., Beevers, L., Srinivasalu, P., Kulkarni, A., Holman, I.P., 2020. Enhancing production and flow of freshwater ecosystem services in a managed Himalayan river system under uncertain future climate. Climatic Change 162, 343-361.
45. Narouei-Khandan, H.A., Halbert, S.E., Worner, S.P., 2016. Global climate suitability of citrus huanglongbing and its vector, the Asian citrus psyllid, using two correlative species distribution modeling approaches, with emphasis on the USA. European Journal of Plant Pathology 144, 655-670.

46. Ortega-Huerta, M.A., Peterson, A.T., 2008. Modeling ecological niches and predicting geographic distributions: a test of six presence-only methods. Revista Mexicana De Biodiversidad 79, 205-216.

47. Padalia, H., Srivastava, V., Kushwaha, S.P.S., 2014. Modeling potential invasion range of alien invasive species, *Hyptis suaveolens* (L.) Poit. in India: Comparison of MaxEnt and GARP. Ecological Informatics 22, 34-43.

48. Peng, L.X., Guo, Y.L., 2017. Geographical distribution of *Astragali radix* and prediction of its suitable area in China. Journal of Sichuan Agricultural University 35, 60-68.

49. Petitpierre, B., Kuffer, C., Broennimann, O., Randin, C., 2012. Climatic niche shifts are rare among terrestrial plant invaders. Science 335, 1344-1348.

50. Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190, 231-259.

51. Que, L., Yang, G., Miao, J.H., Wang, H.Y., Chen, M., Zang, C.X., 2016. Current status and prospects of traditional Chinese medicine resource ex-situ conservation. China Journal of Chinese Materia Medica 41, 3703-3708.

52. Ramachandran, R.M., Roy, P.S., Vishnubhotla, C., Joshi, P.K., Sanjay, J., 2020. Land use and climate change impacts on distribution of plant species of conservation value in Eastern Ghats, India: a simulation study. Environmental Monitoring and Assessment 192, 86.

53. Remya, K., Ramachandran, A., Jayakumar, S., 2015. Predicting the current and future suitable habitat distribution of *Myristica dactyloides* Gaertn. using MaxEnt model in the Eastern Ghats, India. Ecological Engineering 82, 184-188.

54. Renne, R.R., Schlaepfer, D.R., Palmquist, K.A., Bradford, J.B., Burke, I.C., Lauenroth, W.K., 2019. Soil and stand structure explain shrub mortality patterns following global change–type drought and extreme precipitation. Ecology 100, e2889.

55. Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C., Pounds, J.A., 2003. Fingerprints of global warming on wild animals and plants. Nature 421, 57-60.

56. Su, J.H., Piao, Y.C., Luo, Z., Yan, B.P., 2018. Mapping potential distribution of wild bird using convolutional neural network. Computer Systems & Applications 27, 248-254.

57. Tan, Y.H., Zhang, X.J., Yun, S.S., Yu, J.H., 2020. Prediction of the ecological suitability of *Gentiana macrophylla* Pall. under scenarios of global climate change. Chinese Journal of Ecology 39, 3766-3773.

58. Venette, R.C., 2017. Climate Analyses to Assess Risks from Invasive Forest Insects: Simple Matching to Advanced Models. Current Forestry Reports 3, 255-268.

59. Wan, J.Z., Wang, C.J., Yu, J.H., Nie, S.M., Han, S.J., Zu, Y.G., Chen, C.M., Yuan, S.S., Wang, Q.G., 2014. Model-based conservation planning of the genetic diversity of *Phellodendron amurense* Rupr due to
climate change. Ecology and Evolution 4, 2884-2900.

60. Wang, Q., Fan, B.G., Zhang, G.H., 2020. Prediction of potential distribution area of Corylus mandshurica in China under climate change. Chinese Journal of Ecology 39, 3774-3784.

61. Wang, R.L., Li, Q., He, S.S., Liu, Y., Jiang, G., 2018. Modeling and mapping the current and future distribution of Pseudomonas syringae pv. actinidiae under climate change in China. Plos One 13, e192153.

62. Wang, R.L., Yang, H., Wang, M.T., Zhang, Z., Li, Q., 2020. Predictions of potential geographical distribution of Diaphorina citri (Kuwayama) in China under climate change scenarios. Scientific Reports 10, 1-9.

63. Wang, S., Zhao, Y.H., Zhou, Y.S., Li, F.F., 2014. Research progress of Blumea balsamifera L. D C. and dosage form development value discuss. Modern Chinese Medicine 16, 953-956.

64. Wang, X., Xu, X.H., Lv, J.K., Wei, C.F., Xie, D.T., 2012. GIS-fuzzy neural network-based evaluation of tobacco ecological suitability in southwest mountains of China. Chinese Journal of Eco-Agriculture 20, 1366-1374.

65. Wang, Y.H., Zhang, Y.R., 2020. Variations in compositions and antioxidant activities of essential oils from leaves of Luodian Blumea balsamifera from different harvest times in China. Plos One 15, e234661.

66. Warren, D.L., Seifert, S.N., 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications 21, 335-342.

67. Wei, N.N., Niu, X.L., Zhang, Q.F., Shao, M., 2020. Identification of Blumea blasamifera and adulterants based on ITS2 sequence. Molecular Plant Breeding 18, 7500-7505.

68. Williams, J.J., Newbold, T., Di Minin, E., 2020. Local climatic changes affect biodiversity responses to land use: A review. Diversity and Distributions 26, 76-92.

69. Wróblewska, A., Mirski, P., 2018. From past to future: impact of climate change on range shifts and genetic diversity patterns of circumboreal plants. Regional Environmental Change 18, 409-424.

70. Wu, J., Xu, H.G., Chen, L., 2011. A review of impacts of climate change on species. Journal of Ecology and Rural Environment 27, 1-6.

71. Wu, J., Zhou, B.T., Xu, Y., 2015. Response of precipitation and its extremes over China to warming: CMIP5 simulation and projection. Chinese Journal of Geophysics 58, 3048-3060.

72. Wu, S.H., Yan, J.Z., Yang, L., Cheng, X., Wu, Y., 2021. Farmers and herders reclaim cropland to adapt to climate change in the eastern Tibetan Plateau: a case study in Zamtang County, China. Climatic Change 165, 1-23.

73. Xia, M.M., Zhong, W.L., Zhang, Z.L., Qin, M.Y., 2019. Coping strategies and effects of climate change on traditional Chinese medicine resources. China Journal of Traditional Chinese Medicine and Pharmacy 34, 677-680.

74. Xiao, Y.F., Huang, M., Yu, F.L., Chen, Z.X., Liao, L., Pang, Y.X., 2021. Genetic diversity on phenotypes of Blumea balsamifera germplasms. Fujian Journal of Agricultural 36, 157-167.
75. Xie, X.L., Chen, Z.X., Pang, Y.X., Guan, L.L., Guo, K.J., 2017. Research progress on resources of *Blumea balsamifera*. World Science and Technology-Modernization of Traditional Chinese Medicine 19, 2024-2029.

76. Xiong, Z.R., Zhang, X.C., Zou, X., Zhao, Y., Chen, X., 2019. Prediction of the suitable distribution and responses to climate change of *Sorbus tianschanica* in China. Ecological Science 38, 44-51.

77. Xu, D.P., Zhuo, Z.H., Wang, R.L., Ye, M., Pu, B., 2019. Modeling the distribution of *Zanthoxylum armatum* in China with MaxEnt modeling. Global Ecology and Conservation 19, e691.

78. Yang, T., Wang, S.T., Wei, X.Z., Jiang, M.X., 2020. Modelling potential distribution of an endangered genus (*Sinojackia*) endemic to China. Plant Science Journal 38, 627-635.

79. Yu, Y., Chen, L.L., HE, X.J., 2009. Potential distributions of *Solidago canadensis* (Asteraceae) in China as predicted by GARP. Plant Diversity 31, 57-62.

80. Yuan, Y., Pang, Y.X., Wang, W.Q., Zhang, Y.B., Yu, J.B., 2011. Investigation on the plants resources of *Blumea* DC. in China. Journal of Tropical Organisms 2, 78-82.

81. Yuan, Y., Pang, Y.X., Wang, W.Q., Zhang, Y.B., Yu, J.B., Zhu, M., 2011. Medical ethnobotany of the genus of *Blumea* in China. Chinese Journal of Tropical Agriculture 31, 21-27.

82. Yue, T.X., Fan, Z.M., Sun, X.F., Li, B.L., 2011. Surface modelling of global terrestrial ecosystems under three climate change scenarios. Ecological Modelling 22, 2342-2361.

83. Zhang, H., Zhao, H.X., Wang, H., 2020. Potential geographical distribution of *Populus euphratica* in China under future climate change scenarios based on Maxent model. Acta Ecology Sinica 40, 6536-6552.

84. Zhang, L., Wang, L.L., Zhang, X.D., Liu, S.R., Sun, P.S., Wang, T.L., 2014. The basic principle of random forest and its applications in ecology: a case study of *Pinus yunnanensis*. Acta Ecologica Sinica 34, 650-659.

85. Zhang, Y.B., Yuan, Y., Pang, Y.X., Wang, D., Hu, X., 2016. Comparative analysis of SRAP and AFLP markers for genetic diversity of *Blumea balsamifera* D C. Journal of Southern Agriculture 47, 1261-1267.

86. Zhao, Q., Li, R., Gao, Y.Y., Yao, Q., Guo, X.Q., Wang, W.G., 2018. Modeling impacts of climate change on the geographic distribution of medicinal plant *Fritillaria cirrhosa* D. Don. Plant Biosystems 152, 349-355.

87. Zheng, K.Y., Wang, Q., Hou, F.J., You, H.L., Zheng, Y.G., Zhang, D., 2016. Climatic division of *Blumea balsamifera* in Guizhou province based on topographical conditions. Chinese Journal of Chinese Materia Medica 41, 3164-3168.

88. Zheng, K.Y., Zhang, D., Hou, F.J., You, H.L., Zheng, Y.G., Wang, Q., 2017. Study on the distribution of suitability type for *Blumea Balsamifera* planting in southwest of Guizhou province based on climate and land use information. Chinese Journal of Agricultural Resources and Regional Planning 38, 153-158.

89. Zhu, Y.Y., Xu, X.T., 2019. Effects of climate change on the distribution of wild population of *Metasequoia glyptostroboides*, an endangered and endemic species in China. Chinese Journal of
Ecology 38, 1629-1636.

90. Zou, J., Teng, F., Fu, S., 2015. The Latest Progress in Socioeconomic Assessment of the Mitigation of Climate Change-Review of the IPCC Fifth Assessment WGIII Report. Progressus Inquisitiones De Mutatione Climatis 10, 313-322.

**Figures**

**Figure 1**
Distribution data of B. balsamifera.

**Figure 2**
ROC curve and AUC values for the model.

**Figure 3**
Importance of environmental variables to B. balsamifera by jackknife analysis.

**Figure 4**
Response curves of presence probability of B. balsamifera to mean temperature of coldest quarter (A), annual precipitation (B), precipitation of wettest quarter (C) and temperature seasonality (D).

**Figure 5**
Potential distribution of B. balsamifera in China under current climate condition.

**Figure 6**
Potential distribution of B. balsamifera in China under climate change scenarios.

**Figure 7**
Changes of the total suitable habitats of B. balsamifera under different climate change scenarios.
Figure 8

Variations of the centroids of the total suitable habitats of B. balsamifera under climate change scenarios in the future.

Figure 9

Potential distribution of B. balsamifera in Guizhou (A) and Hainan (B).