Predicting the Potential Distribution of Two Varieties of *Litsea coreana* (Leopard-Skin Camphor) in China under Climate Change

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Abstract: Climate change considerably affects vegetation growth and may lead to changes in vegetation distribution. Leopard-skin camphor is an endangered species, and the main raw material for hawk tea, and has various pharmacodynamic functions. Studying the potential distribution of two leopard-skin camphor varieties under climate change should assist in the effective protection of these species. We collected the distribution point data for 130 and 89 *Litsea coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa*, respectively, and data for 22 environmental variables. We also predicted the potential distribution of the two varieties in China using the maximum entropy (MaxEnt) model and analyzed the key environmental factors affecting their distribution. Results showed that the two varieties are mainly located in the subtropical area south of the Qinling Mountains–Huai River line in the current and future climate scenarios, and the potentially suitable area for *L. coreana* Levl. var. *lanuginosa* is larger than that of *L. coreana* Levl. var. *sinensis*. Compared with current climatic conditions, the potentially suitable areas of the two leopard-skin camphor varieties will move to high-latitude and high-altitude areas and the total suitable area will increase slightly, while moderately and highly suitable areas will be significantly reduced under future climatic scenarios. For example, under a 2070-RCP8.5 (representative of a high greenhouse gas emission scenario in the 2070s) climatic scenario, the highly suitable areas of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* are 6900 and 300 km², and account for only 10.27% and 0.21% of the current area, respectively. Temperature is the key environmental factor affecting the potential distribution of the two varieties, especially the mean daily diurnal range (Bio2) and the min temperature of the coldest month (Bio6). The results can provide a reference for relevant departments in taking protective measures to prevent the decrease or extinction of the species under climate change.

Keywords: *Litsea coreana* Levl. var. *sinensis*; *Litsea coreana* Levl. var. *lanuginosa*; climate change; potentially suitable area; MaxEnt model

1. Introduction

Ecologists have focused on the relationship between species distribution and environment for a long time, specifically, they have recognized that climatic factors play a key role in species distribution [1]. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) showed that the gradual increase in CO₂ and other greenhouse gases is causing global warming. The global temperature increased by 0.85 °C from 1880 to 2012, and it is expected to continue to rise by 0.3 °C–4.8 °C by the end of the 21st century [2]. Meanwhile, The Third National Climate Change
Assessment Report of China presented that the average temperature of China’s land area increased by 0.9 °C–1.5 °C from 1909 to 2011, and the temperature will rise by 1.3 °C–5.0 °C by the end of the 21st century [3]. Climate warming is expected to change the frequency and intensity of extreme climate events such as high temperatures, heatwaves, drought, wildfires, storms, and floods will increase, while low temperatures, cold waves, and frost will decrease [4]. Observational data show that climate change importantly impacts the structure and function of the ecosystem, the composition and distribution range of biological communities, and biological phenology; thus, it accelerates species extinction [5–7]. Many biological groups migrate to a climatic environment suitable for their growth as a coping mechanism, and this phenomenon may change species distribution [8,9]. Chen et al. [10] and Pauli et al. [11] showed that many plants and animals gradually migrate to high-latitude or altitude areas with global warming. Thus, predicting the potential distribution pattern of species under future climate change is important to effectively monitor species and protect biodiversity.

Understanding the distribution of species and their adaptation to the climatic environment is crucial in the development of effective management and conservation strategies. The development of Internet and geographic information system science has made the application of niche models to study the impact of climate change on species distribution pattern a major topic in ecology and biogeography. Species distribution modeling (SDM, also known as ecological niche modeling (ENM)) relates species distributions to environmental conditions and allows a selected algorithm to predict the future suitable range of the species [1]. At present, commonly used models to predict the potentially suitable range of species are maximum entropy (MaxEnt) [12], ecological niche factor analysis (ENFA) [13], bioclimatic modeling (BIOCLIM) [1], genetic algorithm for rule-set prediction (GARP), and domain environmental envelope (DOMAIN) [14,15]. Among them, MaxEnt is considered to be one of the best prediction methods [15]. It is based on the relationship between the actual distribution of species and environmental variables and is used to simulate the distribution of species in the target area [16]. The MaxEnt model has a simple mathematical basis, easy interpretation of prediction results, and high accuracy; it can also predict species distribution even when the sample size is small. Therefore, it is widely used to study the potential distribution of species under future climate change scenarios [12,17].

Leopard-skin camphor is an evergreen shrub or small tree of the family Lauraceae, and is widely distributed in Guizhou, Hubei, Anhui, Sichuan, Chongqing, and Zhejiang in China [18,19]. It mainly includes Litsea coreana Levl. var. sinensis and L. coreana Levl. var. lanuginosa, which are varieties of L. coreana. The main difference is that the leaves of L. coreana Levl. var. lanuginosa have dense trichomes, and is suitable for living in the altitude range of 300–2300 m; in contrast, L. coreana Levl. var. sinensis is suitable for growing below 900 m [20,21]. Given that its bark peels off and leaves a mark similar to deerskin on the trunk, it is called the leopard-skin camphor in China [19,20]. Leopard-skin camphor is the main raw material plant of hawk tea, which has been consumed as a drink for hundreds of years in China. Its leaves are rich in flavonoids, organic acids, coumarin, and other compounds, which exert detoxifying, detumescence, liver protection, anti-inflammatory, and anti-oxidant properties [18,22]. However, the excessive tea collection and unreasonable management of the local people have seriously affected the growth of the trees, which are in an endangered state; thus, monitoring and protection measures are urgently needed [20]. Previous studies have reported the chemical components [19,22], pharmacology [18,23], artificial propagation [21,24], and stress resistance [25] of L. coreana Levl. var. lanuginosa. However, relatively few studies have focused on the potential distribution of L. coreana Levl. var. sinensis under climate change. The current study uses the MaxEnt model to predict the potential distribution range of the two leopard-skin camphor varieties in China by collecting existing distribution and environmental variable data. This study may serve as a reference for the effective protection and management of the species by the ecological and environmental protection departments.
2. Materials and Methods

2.1. Species Distribution

The distribution data of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* in China were obtained from the plant specimens stored in the laboratory, the Chinese Virtual Herbarium (http://www.cvh.ac.cn/), the Global Biodiversity Information Facility (https://www.gbif.org/), and the CNKI Chinese database (http://www.cnki.net/). The geographical coordinates were not recorded in detail in some of the distribution points. Thus, we used Google Earth 7.1 (Google Inc., Mountain View, CA, USA) to obtain the geographical coordinates of the point. In this study, 130 and 89 distribution data of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* were obtained, respectively (Figure 1). The redundant screening was performed on original data by using the Trim Duplicate Occurrences function in ENMTools 1.4 to avoid the spatial autocorrelation caused by geographic aggregation. In the end, we obtained 124 and 86 effective distribution points to build the model.

![Figure 1. Distribution records of two leopard-skin camphor varieties in China.](image)

2.2. Environmental Variables

In this study, 22 environmental variables included 19 BIOCLIM variables and elevation (Ele), annual mean ultraviolet-B radiation (UVB), and annual mean vapor pressure (VAP) (Table 1). Current (1970–2000), future (2050s (2041–2060), and 2070s (2061–2080)) BIOCLIM variable data were downloaded from the WorldClim v2.0 (http://www.worldclim.org/) [26]. Each period included six sets of climate simulation data: two general circulation models, namely, the Community Climate System Model version 4 (CCSM4) and Model for Interdisciplinary Research on Climate, Earth System Model (MIROC-ESM); and three representative concentration pathways (RCP), namely, RCP2.6 (low), RCP4.5 (middle), and RCP8.5 (high) [27]. Elevation (Ele), annual mean ultraviolet-B radiation (UVB), and annual mean vapor pressure (VAP) were also obtained from WorldClim v2.0 (http://www.worldclim.org/). These parameters were unchanged to analyze the distribution of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* in future climatic scenarios [28]. The spatial resolution of the abovementioned data was 2.5 arc-minutes.
Table 1. Environmental variables and percentage contribution rate (%) to two leopard-skin camphor varieties.

| Code | Environment Variables                                      | Unit   | L. Coreana Levl. var. Sinensis | L. Coreana Levl. var. Lanuginosa |
|------|-----------------------------------------------------------|--------|---------------------------------|----------------------------------|
| Bio1 | Annual mean temperature                                  | °C     | 24.0                            | 19.1                             |
| Bio2 | Mean daily diurnal range                                 | °C     |                                  |                                  |
| Bio3 | Isothermality (Bio2/Bio7)                                 | %      | 11.2                            |                                  |
| Bio4 | Temperature seasonality                                   |        | 0.2                             |                                  |
| Bio5 | Max temperature of the warmest month                     | °C     |                                  |                                  |
| Bio6 | Min temperature of the coldest month                     | °C     | 41.7                            | 60.4                             |
| Bio7 | Temperature annual range (Bio5–Bio6)                     | °C     |                                  |                                  |
| Bio8 | Mean temperature of the wettest quarter                  | °C     | 1.0                             |                                  |
| Bio9 | Mean temperature of the driest quarter                   | °C     |                                  |                                  |
| Bio10| Mean temperature of the warmest quarter                  | °C     |                                  |                                  |
| Bio11| Mean temperature of the coldest quarter                  | °C     |                                  |                                  |
| Bio12| Annual precipitation                                     | mm     | 12.9                            | 1.6                              |
| Bio13| Precipitation of the wettest month                       | mm     |                                  |                                  |
| Bio14| Precipitation of the driest month                        | mm     | 8.4                             |                                  |
| Bio15| Precipitation seasonality coefficient of variation       | mm     |                                  |                                  |
| Bio16| Precipitation of the wettest quarter                     | mm     | 0.4                             | 0.5                              |
| Bio17| Precipitation of the driest quarter                      | mm     |                                  |                                  |
| Bio18| Precipitation of the warmest quarter                     | mm     |                                  |                                  |
| Bio19| Precipitation of the coldest quarter                     | mm     |                                  |                                  |
| Ele  | Elevation                                                | m      | 7.8                             | 0.7                              |
| UVB  | Annual mean ultraviolet-B radiation                       | Jm⁻²·day⁻¹ | 1.8                            | 4.8                              |
| VAP  | Annual mean vapor pressure                               | hPa    | 0.1                             | 3.6                              |

The variables in bold are the main variables selected by their contribution rates and the multi-collinearity test. The data under the species column represent the percentage contribution rate of environmental variables to the distribution of this species.

A total of 22 environmental variables were screened to avoid overfitting. The screening steps are as follows: (1) the Correlation function in ENMTools 1.4 was used to calculate the correlation among 20 environmental variables, and the 0.80 threshold was used to determine the significance of the correlation; and (2) the MaxEnt 3.4.1 software (Columbia University, NY, USA) was run using species distribution data and 22 environmental variables to obtain the preliminary percentage contribution and jackknife analysis results of each variable to the model. Then, remove the factors with a correlation coefficient greater than 0.80 and a smaller contribution rate, and determine the final environmental variables for model construction [29,30].

2.3. Model Optimization

Feature Class and Regularization Multiplier were optimized using the R 3.6.2 program (MathSoft Inc., Massachusetts, Cambridge, UK) and kuenm package. According to the criteria for selecting the best model by Cobos et al. [31], statistically significant means that the missing rate was lower than the threshold (0.05) and the delta AICC value was not higher than 2. Therefore, we chose Feature Class as LQ and L (L: Linear features, Q: Quadratic features) and the Regularization Multiplier as 0.2 and 0.1 for the final MaxEnt model of L. coreana Levl. var. sinensis and L. coreana Levl. var. lanuginosa.

2.4. MaxEnt Modeling

The selected species distribution point data and environment variables were imported into MaxEnt 3.4.1 software. Then, the 30% and 70% distribution point data were randomly selected as the test and training sets, respectively. Output format was Logistic, output file type was grd, maximum iterations was set to 5000, threads was set to 10, and repeat number was 10 times. Other parameters were set as default. After MaxEnt modeling was completed, the receiver operating characteristic (ROC) curve was adopted to evaluate the model, and the area under curve (AUC) was used to measure the accuracy of the model [32]. The model was excellent when AUC > 0.9 [12,33].
2.5. Classification of Potentially Suitable Area

In this study, ArcGIS 10.3 software (Esri Inc., Redlands, CA, USA) was used to create a suitable area prediction map of the current (1970–2000), the future (2050s and 2070s), and a low-impact area prediction map and to calculate the suitable area. The production results of MaxEnt were imported into ArcGIS 10.3 and analyzed with the map of China as the bottom layer. Jiménez-Valverde and Lobo [34] compared the effects of four thresholds on large-scale sample size and prevalence. They found the absence of the so-called “optimal threshold division method”. In addition, the threshold selection should be based on the research object and needs. Previous studies have shown that a large threshold should be selected for model prediction when invasive species or potentially harmful species are taken as research subjects; this method enables limited resources to be allocated into areas most needed. However, a small threshold should be chosen to protect the species when endangered species are selected as subjects [35–37]. Therefore, the present study selected a relatively small threshold (fixed cumulative value $1 = 0.0254$) as a criterion for the classification of suitable areas. The suitable growing areas were divided into four grades: unsuitable area ($P < 0.0254$), lowly suitable area ($0.0254 \leq P < 0.3503$), moderately suitable area ($0.3503 \leq P < 0.6751$), and highly suitable area ($P \geq 0.6751$).

3. Results

3.1. Potential Distribution of Two Leopard-Skin Camphor Varieties under Current Climate and Model Accuracy

The potential distributions of *L. coreana* Levl. var. *sinensis*, and *L. coreana* Levl. var. *lanuginosa* were evaluated by the ROC curve, and the mean AUC values were 0.970 and 0.960, respectively (Figure 2). These values indicate the excellent accuracy of the prediction results. The prediction results of our MaxEnt model were considerably larger than the real geographical distribution of two leopard-skin camphor varieties under current climatic conditions (Figures 1 and 3). Figure 3 shows that the moderately and highly suitable areas are mainly located in the subtropical area south of the Qinling Mountains–Huaihe River line such as Anhui, Zhejiang, Fujian, Jiangxi, Hunan, Hubei, Guizhou, Sichuan, Chongqing, and Yunnan. The highly suitable area was mainly distributed in the Xuefeng and Heng Mountains of Hunan Province, Wu Mountain in the border of Chongqing, Guizhou, Hunan, and Hubei Provinces, and south central Zhejiang Province. However, the highly suitable area of *L. coreana* Levl. var. *lanuginosa* was larger and more concentrated. Compared with the lowly suitable area of *L. coreana* Levl. var. *sinensis*, that of *L. coreana* Levl. var. *lanuginosa* was more to the south such as Yunnan and Hainan. However, the lowly suitable area of *L. coreana* Levl. var. *sinensis* was northward to Shanxi, Hebei, and Liaoning (Figure 3).

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Prediction validation with receiver operator characteristic (ROC) curves using the MaxEnt model. AUC: the area under curve. (A) AUC value when simulating the distribution of *L. coreana* Levl. var. *sinensis*; (B) AUC value when simulating the distribution of *L. coreana* Levl. var. *lanuginosa*. 
Curves using the MaxEnt model. AUC value when simulating the distribution of L. coreana Levl. var. sinensis, respectively (Table 2). Among them, the highly and moderately suitable areas of L. coreana Levl. var. lanuginosa were 6.48 × 10^4 km^2 (nearly two times) and 17.11 × 10^4 km^2 higher than those of L. coreana Levl. var. sinensis, respectively; meanwhile, the lowly suitable area was 9.71 × 10^4 km^2 lower than that of L. coreana Levl. var. sinensis (Table 2).

Table 2. Prediction of suitable area of two leopard-skin camphor varieties under different climatic scenarios.

| Species                      | Climatic Scenarios | Total Suitable Area | Lowly Suitable Area | Moderately Suitable Area | Highly Suitable Area |
|------------------------------|--------------------|---------------------|---------------------|--------------------------|----------------------|
|                              | (10^4 km^2)        | (10^4 km^2)         | (10^4 km^2)         | (10^4 km^2)              | (10^4 km^2)          |
|                              | Ratio (%)          | Ratio (%)           | Ratio (%)           | Ratio (%)                | Ratio (%)            |
| L. coreana Levl. var. sinensis | 1970–2000          | 234.78              | 141.18              | 86.87                    | 6.73                 |
|                              | 2050-RCP2.6        | 236.08              | 100.55              | 177.87                   | 125.99               | 56.99                | 65.60               | 1.21                | 18.04               |
|                              | 2050-RCP4.5        | 241.90              | 103.03              | 177.41                   | 125.67               | 62.58                | 71.80               | 2.11                | 31.27               |
|                              | 2050-RCP8.5        | 245.45              | 104.54              | 189.52                   | 134.24               | 54.55                | 62.79               | 1.38                | 20.43               |
|                              | 2070-RCP2.6        | 239.26              | 101.90              | 170.91                   | 121.06               | 66.02                | 75.99               | 2.34                | 34.69               |
|                              | 2070-RCP4.5        | 237.39              | 101.11              | 177.58                   | 125.79               | 57.16                | 65.80               | 2.64                | 39.24               |
|                              | 2070-RCP8.5        | 253.47              | 107.96              | 223.29                   | 158.16               | 29.48                | 33.94               | 0.69                | 10.27               |
| L. coreana Levl. var. lanuginosa | 1970–2000          | 248.65              | 131.47              | 103.98                   | 13.21                | —                   | —                   | —                   | —                   |
|                              | 2050-RCP2.6        | 252.98              | 101.74              | 150.85                   | 114.74               | 90.94                | 87.46               | 11.19               | 84.74               |
|                              | 2050-RCP4.5        | 257.33              | 103.49              | 171.34                   | 130.33               | 79.94                | 76.88               | 6.06                | 45.87               |
|                              | 2050-RCP8.5        | 264.31              | 106.30              | 189.66                   | 144.27               | 73.47                | 70.66               | 1.18                | 8.96                |
|                              | 2070-RCP2.6        | 256.14              | 103.01              | 163.11                   | 124.07               | 85.10                | 81.85               | 7.92                | 60.00               |
|                              | 2070-RCP4.5        | 260.71              | 104.85              | 188.29                   | 143.22               | 71.78                | 69.04               | 0.63                | 4.79                |
|                              | 2070-RCP8.5        | 267.96              | 107.77              | 219.56                   | 167.00               | 48.38                | 46.53               | 0.03                | 0.21                |

Ratio (%): the ratio of the predicted area of future climatic conditions to the area of current climatic conditions.
3.2. Potential Distribution of Two Leopard-Skin Camphor Varieties under Future Climatic Scenario

We predicted the potential distribution of two leopard-skin camphor varieties in China in the future two periods (2050s and 2070s) and three greenhouse gas scenarios (RCP2.6, RCP4.5, and RCP8.5) using the MaxEnt model (Figures 4 and 5). Compared with the current climatic scenario (1970–2000), their total suitable area will increase in the future under several climatic scenarios. However, moderately and highly suitable areas will decrease, and the suitable area will be small when the concentration of greenhouse gases is high (Table 2 and Figures 4 and 5). Compared with the current climatic scenario, the moderately and highly suitable areas of *L. coreana* Levl. var. *sinensis* will be reduced by 37.21% and 79.57%, respectively, under the 2050-RCP8.5 scenario. Those of *L. coreana* Levl. var. *lanuginosa* will be reduced by 29.34% and 91.04%, respectively. The moderately and highly suitable areas of two varieties will be the smallest under the 2070-RCP8.5 scenario. Among them, the highly suitable areas were only 6,900 and 300 km² and accounted for only 10.27% and 0.21% of the current suitable area, respectively (Table 2).

![Figure 4](image-url)

**Figure 4.** Prediction of the potential distribution of *Litsea coreana* Levl. var. *sinensis* in China under future climatic scenarios. (A1–A4), the 2050s; (B1–B4), the 2070s; (1) future climate scenario RCP 2.6; (2) future climate scenario RCP 4.5; (3) future climate scenario RCP 8.5.

The potentially suitable areas of two leopard-skin camphor varieties will move to high-latitude and -altitude areas with global warming. Compared with the current climate, the lowly suitable areas of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* will appear in the Junggar Basin of Xinjiang and southern Liaoning, respectively, under the future climate scenario (Figures 4 and 5). The moderate suitable area of *L. coreana* Levl. var. *sinensis* will increase in Shaanxi, but will decrease in Guizhou, Guangxi, Jiangxi, and Fujian (Figure 4). The highly suitable areas of the two varieties in
Zhejiang will be greatly reduced and will be mainly distributed in the higher altitude around the Wu and Xuefeng Mountains (Figures 4 and 5).

Figure 4. Prediction of the potential distribution of Litsea coreana Levl. var. sinensis in China under future climatic scenarios. Scenarios (A1–A4): the 2050s; (B1–B4): the 2070s; (1) future climate scenario RCP 2.6; (2) future climate scenario RCP 4.5; (3) future climate scenario RCP 8.5.

Figure 5. Prediction of potential distribution of Litsea coreana Levl. var. lanuginosa in China under future climatic scenarios. Scenarios (A1–A4): the 2050s; (B1–B4): the 2070s; (1) future climate scenario RCP 2.6; (2) future climate scenario RCP 4.5; (3) future climate scenario RCP 8.5.

3.3. Relationship between Environmental Variables and Distribution of Two Leopard-Skin Camphor Varieties

The variable contribution rate of the MaxEnt model showed that temperature is the main environmental variable affecting two leopard-skin camphor varieties (Table 1). Among them, the cumulative contribution rates of the mean daily diurnal range (Bio2, 24.0%) and the min temperature of the coldest month (Bio6, 41.7%) for L. coreana Levl. var. sinensis reached 65.7%. Moreover, the cumulative contribution rates of Bio2 (19.1%) and Bio6 (60.4%) for L. coreana Levl. var. lanuginosa reach 79.5%, which was much higher than the contribution rates of precipitation, elevation, ultraviolet-B radiation, and vapor pressure factors. This finding indicates that Bio2 and Bio6 are the key affecting factors of the distribution of two leopard-skin camphor varieties.

MaxEnt’s jackknife test was used to evaluate the importance of environmental factors to the potential distribution of two leopard-skin camphor varieties. Figure 6 shows that the variables with the highest gain in isolation were the mean daily diurnal range (Bio2), the min temperature of the coldest month (Bio6), the precipitation of the driest month (Bio14), and the annual mean vapor pressure (VAP). Therefore, they had the most useful information. Elevation (Ele) and the annual mean ultraviolet-B radiation (UVB) were the variables that mostly decreased the gain for L. coreana Levl. var. sinensis and L. coreana Levl. var. lanuginosa, respectively, when they were omitted. Thus, these variables had the
most unique information not found in other variables. Accordingly, bio14, VAP, Ele, and UVB also play an important role in the distribution of two leopard-skin camphor varieties.

![Figure 6](image)

**Figure 6.** Jackknife test for evaluating the relative importance of major environmental variables for *Lithsea coreana* Levl. var. *sinensis* (A) and *L. coreana* Levl. var. *lanuginosa* (B) in China. Table 1 provides the full definitions of each variable and the percentage contribution rate of the major variables.

Figures 7 and 8 show the response curves of six environmental variables to the potential distribution of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa*, respectively. The occurrence probability of *L. coreana* Levl. var. *sinensis* was the highest when Bio2 was 5.0 °C, Bio6 was 0 °C, Bio14 was 50 mm, VAP was 0.6 hPa, elevation was 660 m, and UVB was 9224 Jm⁻²·day⁻¹. The occurrence probability of *L. coreana* Levl. var. *lanuginosa* was the highest when Bio2 was 6.1 °C, Bio6 was 7.1 °C, Bio14 was 41 mm, VAP was 0.7 hPa, and UVB was 9454 Jm⁻²·day⁻¹. As the elevation increased, the occurrence probability of *L. coreana* Levl. var. *lanuginosa* decreased, but the probability was higher than that of *L. coreana* Levl. var. *sinensis* when the elevation was above 1000 m.
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**Figure 7.** Response curves between the occurrence probability of *Litsea coreana* Levl. var. *sinensis* and environmental variables. (A), the response curve for the mean daily diurnal range (Bio2); (B), the response curve for the min temperature of the coldest month (Bio6); (C), the response curve for the precipitation of the driest month (Bio14); (D), the response curve for the annual mean vapor pressure (VAP); (E), the response curve for the elevation (Ele); (F), the response curve for the annual mean ultraviolet-B radiation (UVB).
were mainly located in the subtropical area south of the Qinling Mountains–Huai River line in the
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suitable climatic conditions for leopard-skin camphor are annual mean temperature higher than
800 mm of precipitation in July [38], and the temperature in January is below 0
° C [40]. In general,
the suitable climatic conditions for leopard-skin camphor are annual mean temperature higher than
13 °C, annual mean precipitation greater than 1000 mm, and air humidity greater than 80% [21].

Figure 8. Response curves between the occurrence probability of Litsea coreana Levl. var. lanuginosa
and environmental variables. (A), the response curve for the mean daily diurnal range (Bio2); (B), the response curve for the min temperature of the coldest month (Bio6); (C), the response curve for the precipitation of the driest month (Bio14); (D), the response curve for the annual mean vapor pressure (VAP); (E), the response curve for the elevation (Ele); (F), the response curve for the annual mean ultraviolet-B radiation (UVB).

4. Discussion

Our research found that the potentially suitable areas of the two leopard-skin camphor varieties
were mainly located in the subtropical area south of the Qinling Mountains–Huai River line in the
current or future climate scenarios (Figures 3–5). The Qinling Mountains–Huai River line is an
important geographical and ecological boundary in China such as between subtropical and warm
temperate zones, humid and semi-humid areas, and temperate monsoon and subtropical monsoon
climates. The area is also 0 °C isotherm and 800 mm isohyet and is thus important to the geographical
distribution of China [38,39]. As a result, climate conditions such as the temperature, humidity,
and precipitation in the north and south of the Qinling Mountains–Huaihe River line are quite
different. For example, the climate characteristic of the area north of the boundary is usually less than
800 mm of precipitation in July [38], and the temperature in January is below 0 °C [40]. In general,
the suitable climatic conditions for leopard-skin camphor are annual mean temperature higher than
13 °C, annual mean precipitation greater than 1000 mm, and air humidity greater than 80% [21].
Therefore, this finding may be the reason for its limited distribution in the area south of the Qinling Mountains–Huai River line.

*L. coreana* Levl. var. *lanuginosa* had a larger highly suitable area (nearly two times larger than that of *L. coreana* Levl. var. *sinensis*) and more concentrated distribution in the Wu, Xuefeng, and Heng Mountains and south central Zhejiang Province (Figure 3). The main reason is that *L. coreana* Levl. var. *sinensis* is suitable to grow at an altitude below 900 m, whereas *L. coreana* Levl. var. *lanuginosa* is suitable for growing in a large altitude range of 300–2300 m. Meanwhile, plant surface characteristics exert protective effects on some biological and abiotic stress factors to increase their adaptability [41]. Previous studies have shown that plant leaf surface trichomes can prevent insect feeding and the attack of pathogenic fungi [42,43], help control leaf temperature, reduce water evaporation [44,45], and avoid excessive ultraviolet radiation [46]. In our study, the leaf of *L. coreana* Levl. var. *lanuginosa* had dense trichomes, which could have enhanced its ability to resist a harsh environment. Thus, it had a larger suitable habitat. In the global warming scenario, plant leaf surface trichomes can weaken the transpiration of leaf and ultraviolet radiation [45,46], which may also be the reason why the lowly suitable area of *L. coreana* Levl. var. *lanuginosa* could be distributed in low-latitude tropical areas (Yunnan and Hainan Provinces) and the southeast Tibetan Plateau (Figures 3 and 5).

Booth [47] published a review on assessing species climatic requirements beyond the realized niche. He suggested that increasing the planting data beyond the natural distribution in the study of climate change would be extremely useful in predicting how natural forests should cope with climate change. A study by Richardson and McMahon [48] found that Eucalyptus nitens (Deane and Maiden) grows in successful plantations in southern Africa “under much warmer and drier conditions than any that exist within the natural range of E. nitens” in Australia. Introduction experiments can provide important information for tree growth conditions, but few have provided information on successful reproduction [47]. At present, no reports on the successful cultivation or introduction of leopard-skin camphor outside its natural distribution are available. Therefore, transplant experiments should be conducted in the future, especially in the moderately suitable area, to further understand the response of leopard-skin camphor to climate change. In addition, the highly suitable area can be used as a breeding base for high-quality germplasm resources. Some nature reserves should also be established to protect them effectively. The lowly suitable area should be focused on the investigation of germplasm resources, consider introduction experiments, and strengthen the research on drought, cold, and insect pest resistance.

Compared with the current climatic scenario (1970–2000), the total suitable area of two leopard-skin camphor varieties will increase slightly in the future under several climatic scenarios mainly due to the increase in the lowly suitable region (Table 2). This finding is consistent with the previous research results [28,49,50]. The possible explanation is that the leopard-skin camphor is a thermophilic tree species and loves to grow in a warm climate with an annual average temperature over 13 °C; as a result, global warming may promote its geographical expansion [51]. However, moderately and highly suitable areas will be significantly reduced, and the suitable area will be small when the concentration of greenhouse gases is high (Table 2). This condition indicates that the negative effects of global warming on leopard-skin camphor will exceed the positive impact even though it is a thermophilic tree species. For example, the highly suitable area of *L. coreana* Levl. var. *sinensis* and *L. coreana* Levl. var. *lanuginosa* are only 6900 and 300 km² under the 2070-RCP8.5 climatic scenario and account for only 10.27% and 0.21% of the current scenario, respectively (Table 2). RCP8.5 is an extreme greenhouse gas emission scenario, and the temperature rise is much higher than those in the other two scenarios [30]. By the end of the 21st century, the average surface temperature of the globe and China will continue to rise [2,3]. However, the increase in temperature will be accompanied by a decrease in precipitation and an increase in drought days, in addition to a significant increase in the frequency of high-temperature events; this condition will lead to a reduction in the potentially suitable growth area for the species [52]. Consequently, urgent tasks in the highly suitable area of the leopard-skin camphor are to establish nature reserves, strengthen monitoring and protection, and reduce human
disturbance. In general, species distributions move toward high-altitude and high-latitude areas because of future climate warming [11]. This situation explains why the highly suitable areas of two leopard-skin camphor varieties in Zhejiang Province will be greatly reduced, and will be mainly distributed in the higher altitude around the Wu and Xuefeng Mountains, respectively, under the future climate scenario. In addition, the lowly suitable areas will appear in the higher latitude Junggar Basin of Xinjiang and southern Liaoning (Figures 4 and 5).

The variable contribution rate of the MaxEnt model showed that the temperature, especially the mean daily diurnal range (Bio2) and the min temperature of the coldest month (Bio6), was the main environmental variable affecting two leopard-skin camphor varieties (Table 1 and Figure 6). The single-factor response curve of Bio6 showed that the occurrence probabilities of L. coreana Lev. var. sinensis and L. coreana Lev. var. lanuginosa were the highest when Bio6 was 0 °C and 7.1 °C, respectively (Figures 7 and 8). This result further indicates that the two leopard-skin camphor varieties were mainly located in the subtropical area south of the Qinling Mountains–Huai River line. At the same time, L. coreana Lev. var. sinensis may have stronger cold resistance than L. coreana Lev. var. lanuginosa and may be suitable to grow in some areas of Hebei, Liaoning, and Xinjiang in the future climate condition. In general, the plant is mainly photosynthetic in the daytime, and high temperature can promote the formation of photosynthetic, while respiration is mainly at night, and low temperature can promote dry matter accumulation [53,54]. Diurnal temperature difference also affects plant growth rate [55], flower bud differentiation [56], crop yield, and quality [57]. The single-factor response curve of Bio2 showed that the occurrence probabilities of L. coreana Lev. var. sinensis and L. coreana Lev. var. lanuginosa were the highest when Bio2 was 5.0 °C and 6.1 °C, respectively (Figures 7 and 8). At present, the mechanism of the influence of diurnal temperature on the leopard-skin camphor is unclear. Therefore, research in this field should be strengthened in the future.

The precipitation of the driest month (Bio14), the annual mean vapor pressure (VAP), elevation (Ele), and the annual mean ultraviolet-B radiation (UVB) are also important environmental variables affecting the distribution of two leopard-skin camphor varieties (Figure 6). The response curve of Bio14 showed that the occurrence probabilities of L. coreana Lev. var. sinensis and L. coreana Lev. var. lanuginosa were the highest when Bio14 was only 50 mm and 41 mm, respectively (Figures 7 and 8). Therefore, they could tolerate a certain degree of drought. This finding is consistent with the results of Tang et al. [21], that is, the leopard-skin camphor tree has strong stress resistance and wide adaptability, and can grow on the hillside with poor soil. At the same time, L. coreana Lev. var. lanuginosa may have stronger drought resistance than L. coreana Lev. var. sinensis. The reason is that the leaf of L. coreana Lev. var. lanuginosa has dense trichomes, which helps to control leaf temperature, reduce water evaporation, and avoid excessive ultraviolet radiation [44–46]. Qin and Jing [58] showed that the larger sap flow of the camphor tree exhibited strong transpiration when the water vapor pressure and solar radiation increased. Thus, water vapor pressure (Vap) and ultraviolet-B radiation (UVB) affect tree transpiration, which may lead to changes in the geographical distribution of this species. Furthermore, an increase in elevation can change many environmental factors such as temperature, water, light, and soil fertility [59–61]. Thus, elevation is also an important environmental affecting factor of the potentially suitable area of the leopard-skin camphor varieties. The single-factor response curve of elevation showed that the occurrence probability of L. coreana Lev. var. sinensis was the highest when the elevation (Ele) was 660 m. The occurrence probability of L. coreana Lev. var. lanuginosa decreased as elevation increased, but the probability was higher than that of L. coreana Lev. var. sinensis when the elevation was above 1000 m. This result indicates that L. coreana Lev. var. lanuginosa can adapt to higher elevation, which may be related to the dense trichomes in its leaves and branches. In addition to climate change, the dispersal capacity of a species, interspecific competition, and human disturbance affect species and lead to changes in distribution [32,62]. In particular, habitat fragmentation driven by human activities has made the landscape increasingly impassable [63] and impeded seed dispersal and gene flow among populations [64]. For example, Zhang et al. [65] showed that the forest recovery at low elevations following the cessation of deforestation and found that L. coreana, Celtis sinensis,
Quercus variabilis, Q. glauca, and Q. chenii showed downslope shifts. However, all types of affecting factors of the distribution of species cannot be integrated into the model due to the current limited technical conditions. Therefore, further research is necessary to more accurately predict the suitable habitat of species in future climatic conditions.

5. Conclusions

Our study showed that the potentially suitable areas of two leopard-skin camphor varieties are mainly located in the subtropical area south of the Qinling Mountains–Huai River line under current and future climatic scenarios. These varieties are mainly limited by temperature, especially the mean daily diurnal range and the min temperature of the coldest month. Moreover, the precipitation of the driest month, the annual mean vapor pressure, elevation, and the annual mean ultraviolet-B radiation also play an important role in the distribution of two leopard-skin camphor varieties. Compared with the current climatic conditions (1970–2000), the potentially suitable areas of the two leopard-skin camphor varieties will move to high-latitude and -altitude areas and the total suitable area will increase slightly, while moderately and highly suitable areas will be significantly reduced in the future under several climatic scenarios. We suggest that the highly suitable area of the leopard-skin camphor can be used as a breeding base for high-quality germplasm resources and should establish some nature reserves. The moderately suitable area can be a large area of artificial cultivation. Meanwhile, the investigation of germplasm resources, introduction experiments, and studies on drought, cold, and insect pest resistance should be strengthened in the lowly suitable area to further understand the response of leopard-skin camphor to climate change.

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