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Spatial–Temporal Distribution Pattern of *Ormosia hosiei* in Sichuan under Different Climate Scenarios

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Abstract: *Ormosia hosiei* is an endemic plant in China listed as a national grade II key protected wild plant with important scientific, economic, and cultural values. This study was designed to predict the potential suitable distribution areas for *O. hosiei* under current and future climate change and to provide a reference to enhance the species' conservation and utilization. Based on the actual geographical locations of *O. hosiei* in Sichuan, we applied two species distribution models (BIOCLIM and DOMAIN) to predict its current and future potential suitable areas and future change patterns. We also analyzed the major climatic variables limiting its geographical distribution with principal component analysis. The results indicated that *O. hosiei* was mainly distributed in the eastern region of Sichuan and concentrated in the middle subtropical climate zone at relatively low elevations. The principal component analysis identified two critical factors representing temperature and moisture. The temperature was the most critical factor limiting *O. hosiei* distribution in Sichuan, especially the effect of extreme low temperatures. Both models' simulation results of potential suitable areas under the current climate scenario showed that the excellent suitable habitat was consistent with the current actual distribution, remaining in the eastern region of Sichuan. Under the future climate scenario with doubled CO_2 concentration (2100), both models predicted a sharp decrease in the areas of excellent and very high suitable habitats. The findings can inform strategies and guidelines for *O. hosiei* research, conservation, nursery production, and cultivation in Sichuan.

Keywords: bioclimate; suitable area; *Ormosia hosiei*; species distribution model; BIOCLIM; DOMAIN

Citation: Xie, C.; Chen, L.; Li, M.; Liu, D.; Jim, C.-Y. Spatial–Temporal Distribution Pattern of *Ormosia hosiei* in Sichuan under Different Climate Scenarios. *Forests* **2023**, *14*, 1261. https://doi.org/10.3390/f14061261

Academic Editor: Juan A. Blanco

Received: 24 May 2023
Revised: 15 June 2023
Accepted: 15 June 2023
Published: 19 June 2023

1. Introduction

The Quaternary glaciation and interglacial periods provide evidence of the influence of climate change on the geographical distribution patterns of plants. They indicate climate as the primary and crucial factor of species distribution [1]. Analyzing the current species distribution patterns can identify the key climatic factors restricting their distribution [2]. Meanwhile, species' current endangered status, diversity, specialization, historical evolutionary patterns, and future potential distribution can be explored through their geographical distribution [3].

Global warming poses a severe threat to human beings and biodiversity [4], especially to rare and endangered species, exacerbating the risk of extinction [5]. The continuous increase in CO_2 emissions and irreversible climate warming necessitate predicting species' responses to current and future climatic scenarios. Such studies can reveal changes in their suitable habitats, providing the basis to formulate species conservation strategies.

The profound impact of global climate warming on species' geographical distribution is regarded as indisputable [6]. The spatial research questions can be assessed with GIS technology combined with ecological models to predict climate change impacts on species distribution. Species distribution models (SDMs) are one of the most effective ways to predict current and future species distribution changes [7]. Common models include MaxEnt, BIOMOD, DOMAIN, BIOCLIM, and CLIMEX [8]. They are widely applied in many fields, such as delineating conservation areas of rare and endangered species, managing diversity of forest species, predicting invasive plant distribution, identifying introduction and cultivation areas of economic and medicinal plants, and evaluating climate warming impacts on regional biodiversity [1,9].

BIOCLIM is the pioneering species distribution model [10], which paved the way for developing other SDMs [11]. For example, the model was applied to predict the distribution of *Euryale ferox* under future climate change scenarios in 2050 and 2070 in India. In response to rising temperatures, the species' range is expected to contract completely in some regions [12]. BIOCLIM was employed to predict the suitable distribution area of *Jacaranda mimosifolia* D. Don in China. The low temperature is the key factor limiting the species from spreading north [13].

The DOMAIN is also a widely used SDM, which calculates potential species distribution based on range standardization and a point-to-point similarity algorithm. It provides a simple, robust method to simulate a species potential distribution [14]. The principle of continuous similarity function offers a heuristic tool with considerable flexibility. This model can investigate endangered species and the selection of protected areas [15]. Comparing the potential suitable areas of *Pseudolarix amabilis* (J. Nelson) Rehder predicted by different niche models, DOMAIN yielded results similar to GARP and MaxEnt. The AUC value exceeded 0.9, indicating good results in predicting species suitable habitats [16]. The BIOCLIM and DOMAIN models have been embedded in the DIVA-GIS [17] to facilitate SDM studies and boost their adoption by researchers.

Ormosia hosiei Hemsl. et Wils., a member of the Leguminosae family, is listed as a second-class national protected plant in China [18]. The tree is sporadically distributed in eastern, central, and southwestern China, including Zhejiang, Jiangsu, Jiangxi, Hunan, Hubei, Guizhou, and Sichuan provinces [19]. The species is the northernmost and the most cold-resistant tree species in the genus *Ormosia* [18]. *O. hosiei* has high ornamental, medicinal, and timber value [20]. Inherent reproductive limitations and external disturbances have sharply reduced its natural population, calling for urgent protection efforts [21]. Most studies of *O. hosiei* focus on genetic diversity [19,22], phytochemical composition [23,24], seedling cultivation [25,26], and ecology [27], furnishing a rich empirical and theoretical basis for species protection. However, phytogeography studies are lacking [28].

In contemporary urban forestry practice, using native plants is widely supported [29]. *O. hosiei* was first found and studied in Chengdu [30]. Therefore, it has special value for the city of Sichuan regarding biodiversity conservation. This study aims to apply the BIOCLIM and DOMAIN models to achieve the following objectives: (1) To identify and evaluate the crucial climatic factors shaping the present distribution of *O. hosiei*, (2) to forecast the optimal areas for the future growth of *O. hosiei* based on its current distribution data, and (3) to predict and determine the most suitable areas for *O. hosiei* growth under different climate-change scenarios. This study is envisaged to provide a reference for studies on selecting and breeding tree species for urban greening in Sichuan and other places.

2. Materials and Methods

2.1. Study Area

Sichuan is located in southwest China (26°03′–34°19′ N, 97°21′–108°12′ E) (Figure 1) with an area of 486,000 km^2. The large province is marked by complex topography, including mountains, hills, plains, basins, and plateaus, and the origin and passage of major rivers. Its unique climate types include the humid subtropical of central Asia, the semi-humid subtropical of southwestern and northwestern Sichuan, and the high-altitude and cold climate of the plateau.

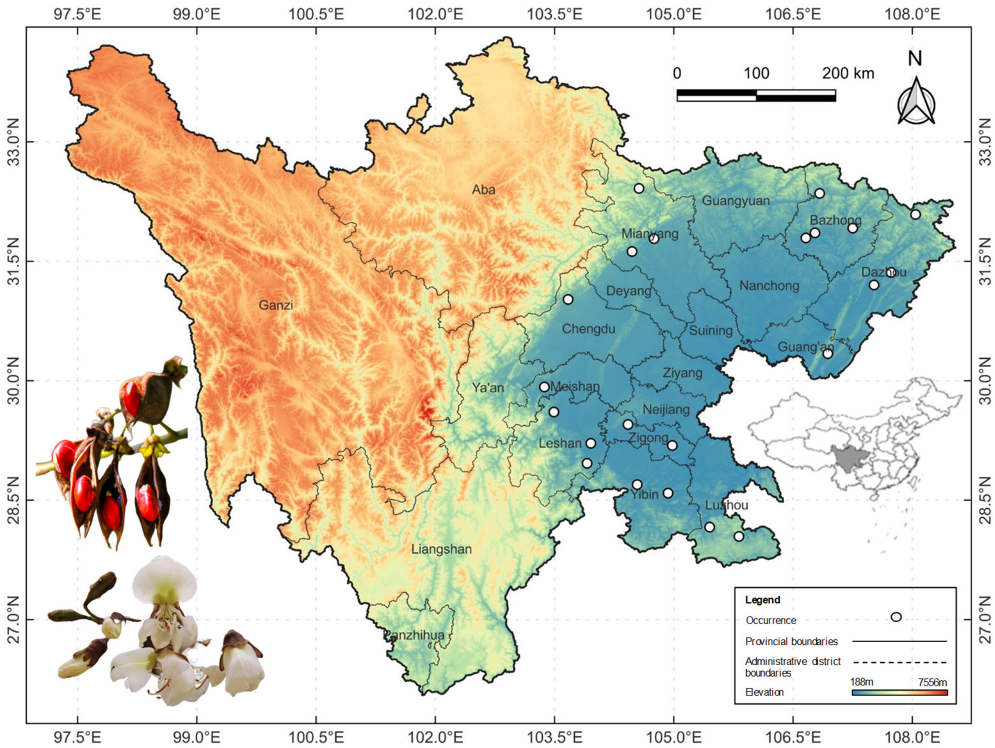

Figure 1. Locations of 22 collected occurrence records (shown by white dots) of *Ormosia hosiei* in Sichuan and images of its flowers and fruits (photographed by Chenghui Nan).

O. hosiei is mainly distributed in eastern Sichuan, which includes the Sichuan Basin and surrounding mountains. The distribution area has a humid subtropical climate with oceanic characteristics. The warm and humid climate offers an average annual temperature of 16–18 °C, 240–280 days with a daily temperature ≥10 °C, an annual accumulated temperature of 4000–6000 °C, a small diurnal temperature range, and a large annual temperature range. The winters are warm, and summers are hot with 230–340 days of frost-free period. The annual precipitation reaches 900–1200 mm.

The complex topography and abundant water and heat resources have nurtured a rich plant diversity in this region. Some rare and endangered plants, such as *Alsophila spinulosa* (Wall. ex Hook.) R. M. Tryon, *Torreya fargesii* Franch., *Phoebe zhennan* S. Lee et F. N. Wei, *Davidia involucrata* Baill., *Acer amplum* subsp. *catalpifolium* (Rehder) Y. S. Chen, *Tetracentron sinense* Oliv., *Magnolia sinensis* (Rehd. et Wils.) Stapf, etc., have been found. The region has the most intensive economic development and human activities in Sichuan, which has exerted impacts on the survival of rare and endangered plants.

2.2. Data Collection

2.2.1. Geographical Data

The distribution data of *O. hosiei* in Sichuan were acquired from literature records, online specimen databases, and field investigations. The online databases mainly included the Chinese National Museum of Natural History (http://www.cfh.ac.cn/, accessed on 3 December 2022), Chinese Virtual Herbarium (http://www.cvh.org.cn/, accessed on 4 December 2022), National Specimen Platform (http://www.nsii.org.cn, accessed on 7 December 2022), and Teaching Specimen Resource Sharing Platform (http://mnh.scu.edu.cn/, accessed on 11 November 2022). The distribution occurrences explicitly indicated at or below the county level were retained, and the others were deleted. Finally, 22 valid county-level distribution points were obtained, and the latitudes and longitudes were obtained from the coordinate acquisition system (http://aqsc.shmh.gov.cn/gis/getpoint.htm, accessed on 12 March 2023).

2.2.2. Bioclimatic Data

Currently, 19 bioclimatic data variables are commonly used for species distribution and related ecological modeling. Our modeling used climate data extracted from the DIVA-GIS 7.5 software (sourced from the WorldClim database, http://www.worldclim.org/, accessed on 20 May 2020) [31]. They included annual mean temperature (bio1), annual precipitation (bio12), extreme high temperature (bio5), extreme low temperature (bio6), precipitation of warmest quarter (bio18), precipitation of coldest quarter (bio19), etc. (the parameters are listed in Table 1) [32]. Derived from monthly temperature and precipitation values, these bioclimatic factors are biologically meaningful, representing annual trends and seasonal and extreme or limiting environmental factors. Future climate data were generated using the CCM3 model of the National Center for Atmospheric Research (NCAR) in the United States. It simulates the 2100 climate scenario after doubling the atmospheric CO_2 concentration [33,34]. The spatial resolution of 2.5 min was used in the current and future climate data.

Table 1. The factor loadings of the first five principal components concerning the 19 bioclimatic variables for *Ormosia hosiei*.

Bioclimatic Variable	Factor Loading				
	PC1	**PC2**	**PC3**	**PC4**	**PC5**
bio1 Annual mean temperature	**<u>0.29</u>**	−0.06	−0.11	0.26	0.03
bio2 Mean diurnal range [a]	−0.28	0.04	0.00	0.06	0.54
bio3 Isothermality [b]	−0.17	0.25	−0.31	−0.03	0.63
bio4 Temperature seasonality [c]	−0.19	−0.23	**<u>0.44</u>**	0.14	−0.09
bio5 Max. temperature of warmest month	0.20	−0.29	0.20	0.24	0.27
bio6 Min. temperature of coldest month	**<u>0.30</u>**	−0.02	−0.13	0.03	0.02
bio7 Annual temperature range [d]	−0.24	−0.19	0.32	0.13	0.18
bio8 Mean temperature of wettest quarter	0.25	−0.17	−0.03	0.26	0.24
bio9 Mean temperature of driest quarter	**<u>0.29</u>**	0.01	−0.20	0.16	0.07
bio10 Mean temperature of warmest quarter	0.23	−0.22	0.15	0.38	0.02
bio11 Mean temperature of coldest quarter	**<u>0.29</u>**	0.01	−0.20	0.16	0.07
bio12 Annual precipitation	0.16	0.27	**<u>0.47</u>**	−0.06	0.17
bio13 Precipitation of wettest month	0.10	**<u>0.40</u>**	0.23	0.14	0.00
bio14 Precipitation of driest month	0.27	−0.07	0.08	−0.36	0.08
bio15 Precipitation seasonality [e]	−0.07	**<u>0.37</u>**	−0.19	0.38	−0.28
bio16 Precipitation of wettest quarter	0.10	**<u>0.39</u>**	0.27	0.09	0.02
bio17 Precipitation of driest quarter	0.28	−0.01	0.08	−0.36	0.07
bio18 Precipitation of warmest quarter	0.14	**<u>0.38</u>**	0.19	0.07	0.02
bio19 Precipitation of coldest quarter	0.28	−0.01	0.08	−0.36	0.07
Eigenvalue	10.65	4.86	1.61	1.19	0.54
Variance %	56.05	25.59	8.46	6.25	2.84
Cumulative variance %	56.05	81.64	90.10	96.34	99.18

(1) Bold and underlined values indicate the most influential variables of the first four principal components. (2) [a] Mean diurnal range = mean of monthly (max. temp − min. temp); [b] isothermality = (bio2/bio7) × 100; [c] temperature seasonality = standard deviation × 100; [d] annual temperature range = bio5 − bio6; [e] precipitation seasonality = coefficient of variation.

To avoid collinearity among the 19 bioclimatic variables, those with Spearman rank correlation coefficients less than 0.8 were kept using correlation analysis and variance inflation factors (VIF) [35]. We also considered the result of the principal component analysis, selecting the top four and top two factors with the largest loadings for the first principal component and second principal component, respectively. Ultimately, six bioclimatic variables were kept: bio1, bio6, bio9, bio11, bio13, and bio16. The environmental limiting factors for *O. hosiei* distribution in Sichuan were evaluated with principal component analysis using the PAST 4.09 software [36].

2.3. Models Analysis

The BIOCLIM and DOMAIN models were used to simulate the suitable habitats for *O. hosiei* in Sichuan. The BIOCLIM model uses environmental data from known species distribution points to determine the climate scenario suitable for species occurrence. The percentile distribution of each climate variable in each grid of the species distribution area is used for multivariate analysis. If the range of all climate variables in the grid falls within the range suitable for the species, the location is suitable [10,11].

DOMAIN uses point-to-point similarity measures based on Gower distance, a method for creating a distance matrix from a set of species features. DOMAIN assigns a suitability index classification value to each potential location based on its proximity to the most similar occurrence location in the environmental space. Then, the suitability threshold is selected to determine the distribution boundary of the species' ecological niche [15,37].

Both models were analyzed in the Modeling-Bioclim/Domain module of the DIVA-GIS 7.05 software [17]. The generated simulation maps of the suitable habitats (in .bmp format) were imported into QGIS 3.20 for corresponding raster calculations [38], resulting in the current and future changes in the distribution area of *O. hosiei* under different climate scenarios.

The suitable habitats were classified into excellent, very high, high, medium, low, and unsuitable and differentiated by color in DIVA-GIS 7.05 [17]. The two models differ notably in defining the suitable habitats' class thresholds. BIOCLIM defines unsuitable to excellent as "Unsuitable", 0%–2.5%, 2.5%–5.0%, 5.0%–10.0%, 10.0%–20.0%, and 20.0%–46.0%. DOMAIN uses the evaluation index to define the unsuitable to excellent classes as −210–50, 51–90, 91–95, 96–97, 98–99, and 100 based on [39].

We assigned 75% of the distribution points to the training set and the remaining 25% to the test set. Model accuracy was evaluated using the area under the receiver operating characteristic curve (AUC). An AUC value close to 1 signifies a higher prediction accuracy. The values 0.5–0.6, 0.6–0.7, 0.7–0.8, and >0.9 represent the fair, good, very good, and excellent prediction results, respectively. AUC < 0.5 means failed prediction [40].

3. Results

3.1. Geographic Distribution Pattern

Based on field investigations, online specimen data, and the literature, *O. hosiei* was mainly distributed in Sichuan's eastern region, which can be divided into northeastern and southeastern Sichuan. In southeastern Sichuan, the distribution included Gulian, Xuyong, Yibin, Changning, and other places. In northeastern Sichuan, the main occurrences were Tongjiang, Nanjiang, Dazhou, Jiange, and Cangxi. The high-altitude areas, such as Garze, Aba, and Liangshan prefectures in western Sichuan and the cities of Panzhihua, Neijiang, and Nanchong, had no *O. hosiei* record. In addition, *O. hosiei* was mostly distributed in middle and low-altitude areas, concentrated in the 200–900 m range. The communities accommodating *O. hosiei* were mainly secondary forests disturbed by some factors located mainly in sunny areas, such as valleys, mountain slopes, and stream banks.

3.2. Restrictive Climatic Factors

The bioclimatic data of *O. hosiei* in different distribution areas in Sichuan were evaluated using principal component analysis (Table 1). The first four axes with eigenvalues >1 were the main principal components (PCs). The contributions of the first three principal components (PC1 to PC3) were 56.05%, 25.59%, and 8.46%, respectively, reaching a cumulative value of 90.10% (>75%). Therefore, the climatic profile affecting the geographic distribution of *O. hosiei* could largely be reflected by the first three PCs. In PC1, bio6 (0.30), bio1 (0.29), bio9 (0.29), and bio11 (0.29) ranked in the top four. Therefore, the dominant distribution factor was temperature, and extreme low temperature was the most crucial factor. In PC2, bio13 (0.40), bio16 (0.39), bio18 (0.38), and bio15 (0.37) ranked in the top four. Therefore, PC2 reflected the impact of precipitation on distribution with the average precipitation of the wettest month as the most important factor. PC3 had a relatively limited influence on distribution compared with PC1 and PC2. The two most important factors were bio12 (0.47) and bio4 (0.44). The contributions of the remaining PCs were <10%, indicating a weak impact on distribution.

Descriptive statistical analysis was performed on the major bioclimatic factors selected with principal component analysis (Table 2). The average annual temperature was approximately 17 °C, fluctuating in the 16.36–17.40 °C range, which falls within the annual average temperature range (16 °C to 20 °C) observed in China's subtropical region. Therefore, *O. hosiei* can be considered a subtropical species based solely on annual average temperature. The average precipitation during the wettest month was 617.27 mm, fluctuating in a 547.04–687.50 mm range. However, the annual average precipitation in the region is approximately 1000 mm, mainly concentrated in the summer months (June to September), indicating uneven temporal spread. The coefficients of variation (CV) of these five key climatic factors were 14.51% (bio1), 1.58% (bio6), 5.05% (bio11), 3.26% (bio13), and 3.90% (bio16). Generally, for a climatic factor, a smaller CV signifies a greater limiting effect on species distribution [2]. Therefore, extreme low temperature (bio6) is the most critical factor of *O. hosiei* distribution in Sichuan, consistent with the results of principal component analysis (with the highest loading on PC1). In addition, the range of precipitation during the wettest month (bio13) and wettest quarter (bio16) was 202.35–266.10 mm and 547.04–687.50 mm, respectively, indicating the impact of summer precipitation on *O. hosiei* growth.

Table 2. Descriptive statistics of the main bioclimatic parameters in the distribution areas of *Ormosia hosiei* in Sichuan.

Bioclimatic Variable	Minimum	Maximum	Mean ± SD	Coefficient of Variation	95% Confidence Interval
bio1 Annual mean temperature	13.84	18.53	16.88 ± 1.16	14.51	16.36~17.40
bio6 Min. temperature of coldest month	−1.00	5.80	3.06 ± 1.93	1.58	2.20~3.92
bio9 Mean temperature of driest quarter	3.91	9.72	7.41 ± 1.57	6.15	6.22~7.81
bio11 Mean temperature of coldest quarter	3.93	9.42	7.36 ± 1.46	5.05	6.72~8.01
bio13 Precipitation of wettest month	165.00	447.00	234.23 ± 71.89	3.26	202.35~266.10
bio16 Precipitation of wettest quarter	481.00	1099.00	617.27 ± 158.39	3.90	547.04~687.50

3.3. Current Potential Distribution

The potential distribution of *O. hosiei* in Sichuan under the current climate scenario simulated by the BIOCLIM and DOMAIN models is shown in Figure 1. Overall, the two models' simulation results share a similar structure with a concentrated distribution in the eastern region of Sichuan spreading in a "C" shape, consistent with the actual *O. hosiei* distribution. However, BIOCLIM yielded a more concentrated pattern for high to excellent suitable habitats, while DOMAIN was more scattered. Secondly, the two models were largely consistent in predicting the unsuitable habitat. The western plateau areas of Aba, Ganzi, and Liangshan in Sichuan had extensive gray or dark green areas, indicating that high-altitude and cold areas were unsuitable. BIOCLIM demarcated the areas of high, very high, and excellent suitable habitats to be 28,717 km^2, 50,832 km^2, and 42,218 km^2, totaling 121,767 km^2. DOMAIN's results were 51,569 km^2, 30,304 km^2, and 738 km^2, totaling 82,611 km^2. The two models generated considerable differences in the excellent suitable habitat. This divergence could be attributed to the different algorithms and definitions used by the models to define suitable habitats. DOMAIN requires a stringent value of 100 for the excellent class. However, both models predicted that the eastern region of Sichuan contains the most suitable habitats for *O. hosiei* growth under the current climate scenario.

The potential suitability areas of *O. hosiei* in Sichuan under the current climate scenario obtained by the BIOCLIM and DOMAIN models are shown in Figure 2. For BIOCLIM, the top three areas with the highest proportion of excellent suitable habitat were Suining (64.14%), Deyang (63.66%), and Ziyang (59.81%) followed closely by Nanchong (49.56%), Neijiang (42.81%), Mianyang (38.86%), and Chengdu (38.48%). The proportion of excellent habitat in other regions was <30%. For DOMAIN, the top three areas with the highest proportion of excellent habitat were Zigong (3.36%), Mianyang (0.72%), and Bazhong (0.59%). The excellent suitable habitat in Yibin (0.57%), Dazhou (0.55%), Luzhou (0.46%), and Leshan (0.44%) ranked fourth to seventh. The proportion of excellent suitable habitat in other areas was <0.3%. Despite some differences in the proportion of excellent suitable habitat obtained by the two models, several areas, such as Deyang, Nanchong, and Mianyang, had a consistently high proportion. Therefore, these areas have a great potential for protection, cultivation, and introduction of *O. hosiei* in the future.

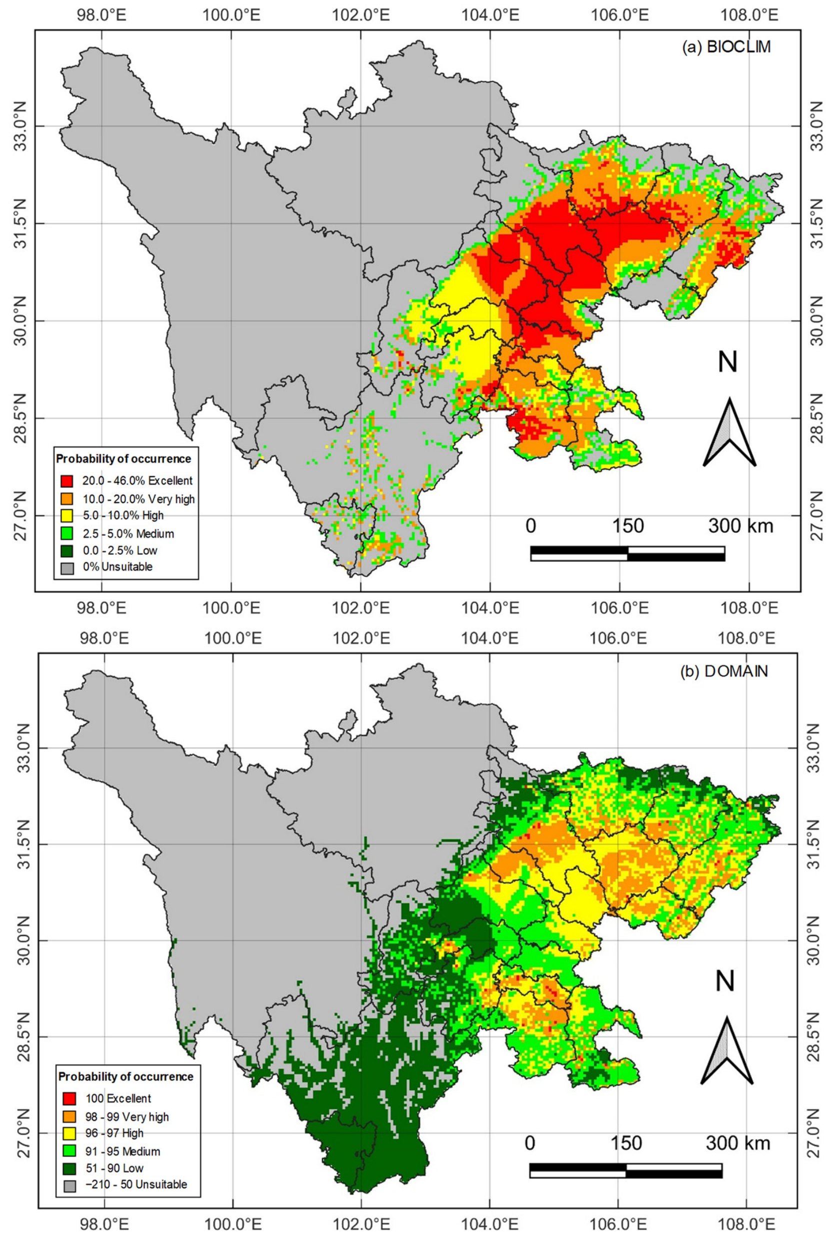

Figure 2. Potential suitability areas of *Ormosia hosiei* under the current climate scenario (1970–2000) generated by the (**a**) BIOCLIM model and (**b**) DOMAIN model. They are divided into six categories based on the calculated habitat suitability index, as explained in the legend.

Under the current climatic scenario, the models found some differences in the environmental factors limiting *O. hosiei* distribution in Sichuan (Figure 3). BIOCLIM demarcated large white areas representing unsuitable and excluded them from assessing the limiting factors. The most significant factor of *O. hosiei* growth in Chengdu, Meishan, Leshan, and Nanchong was rainfall during the wettest season, highlighting the impact of summer rain.

Extreme low temperatures greatly impacted Luzhou, Yibin, and Guangyuan. DOMAIN found the influence of the annual average precipitation covering a larger part of Sichuan followed by the wettest season precipitation, which generated more scattered distribution in Luzhou, Neijiang, Chengdu, and Nanchong. In addition, the limiting effect of extreme low temperatures was more prominent in Garze, Aba, Liangshan, Panzhihua, and the Chengdu Plain. Overall, the environmental limiting factors in eastern Sichuan were more complex than in western Sichuan.

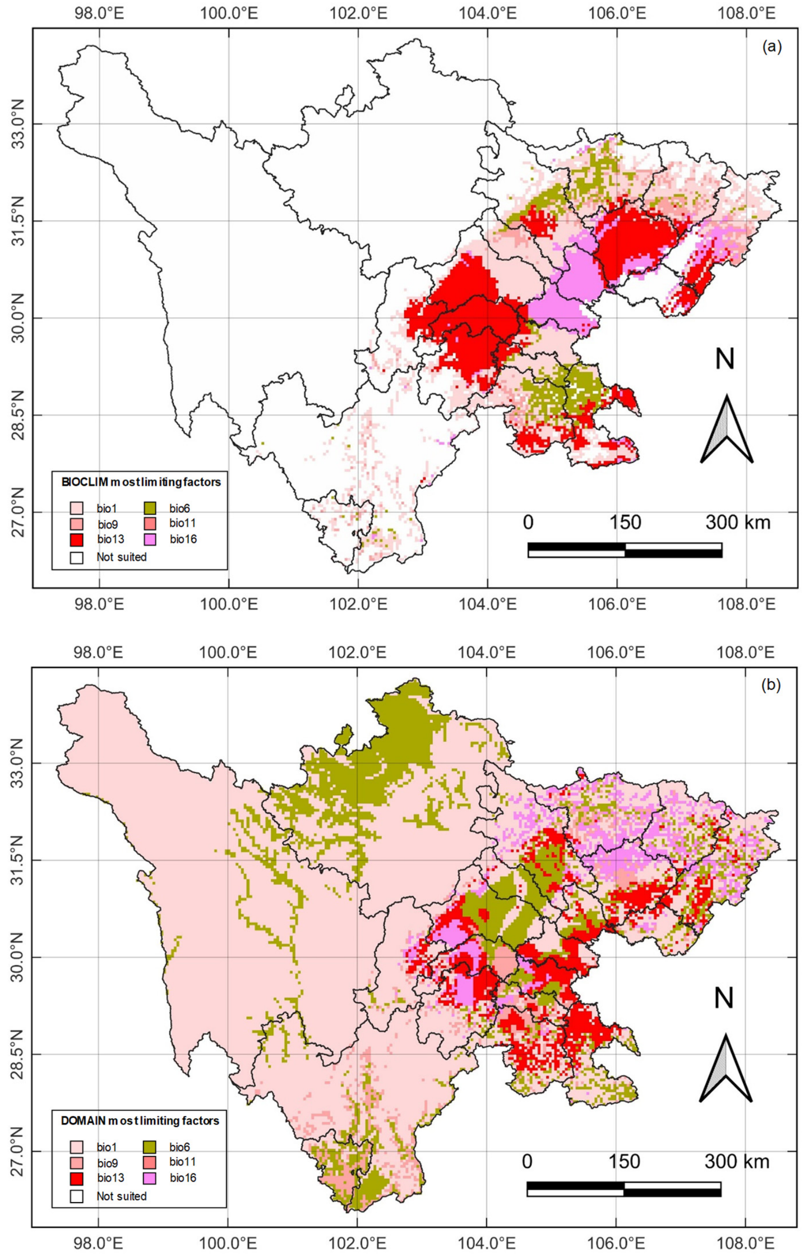

Figure 3. Distribution patterns of the limiting factors shaping the distribution areas of *Ormosia hosiei* generated by the (**a**) BIOCLIM model and (**b**) DOMAIN model. The selected six bioclimatic variables, shown in different colors, had the greatest impact on predicting suitable habitats in the distribution area. Refer to Table 1 for the meaning of the bioclimatic variables.

3.4. Predicting Changes in Suitable Habitats

The potential distribution area of *O. hosiei* in Sichuan was predicted under the future climate scenario with doubled CO_2 concentration in 2100, shown in Figure 4. Both models predicted a notable reduction in excellent and very high suitable habitats (the red and orange areas). The BIOCLIM results showed that the originally contiguous red area had been significantly fragmented. DOMAIN also yielded more scattered and fragmented orange patches. QGIS software was used to count the raster cells for each suitable habitat class (Table 3). The total area of excellent suitable habitat predicted by BIOCLIM and DOMAIN decreased from 42,218 km^2 and 738 km^2 to 30,709 km^2 and 728 km^2, respectively, denoting a 27.26% and 1.36% reduction. Compared with the current potential distribution, the center of excellent suitable habitat shifted to the east, while most of western Sichuan remained unsuitable.

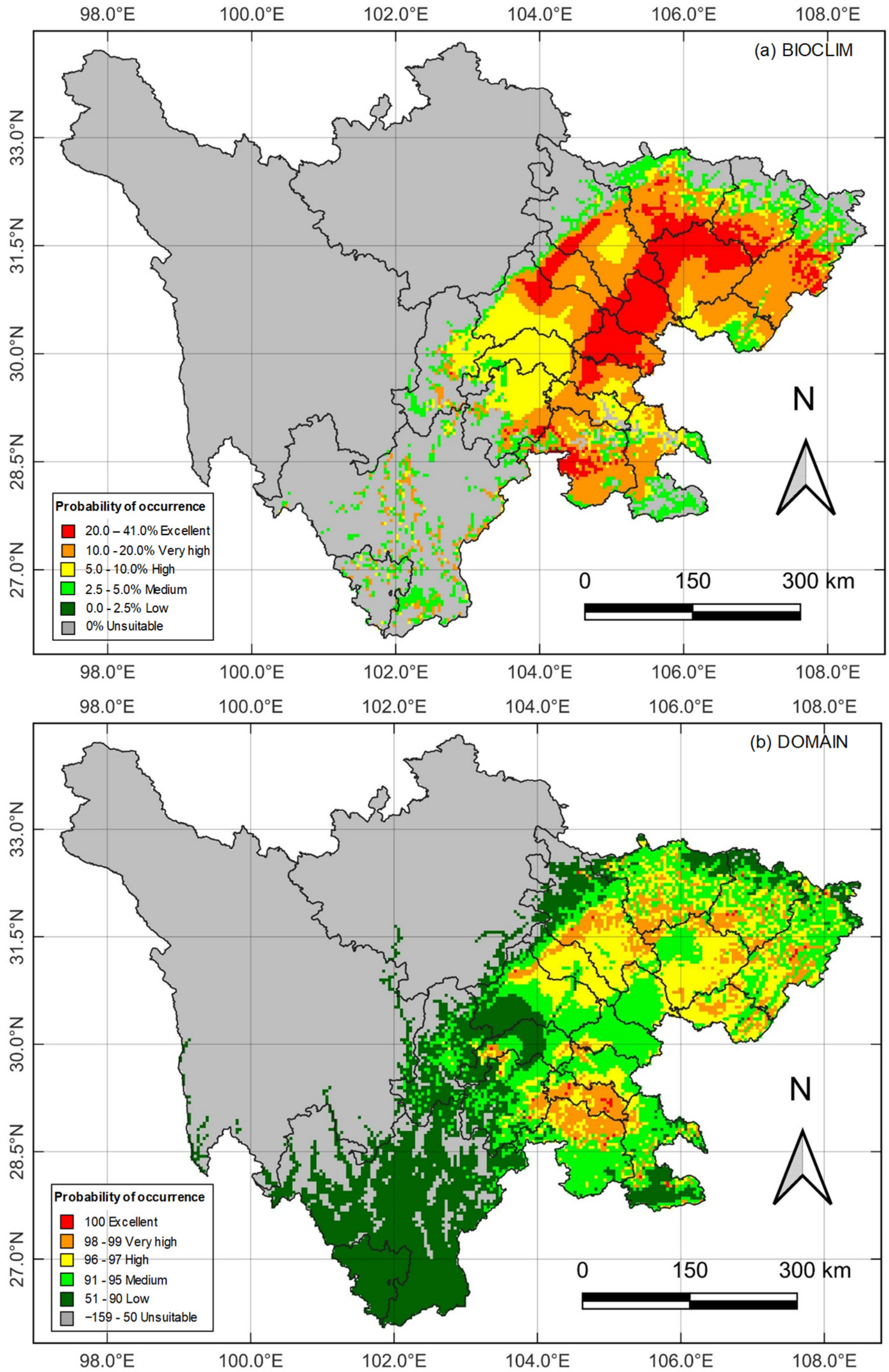

Figure 4. Potential suitable habitats of *Ormosia hosiei* under the climate change scenario (double CO_2 concentration) in 2100 generated by the (**a**) BIOCLIM model and (**b**) DOMAIN model. The six categories of potential suitability habitats are explained in the legend.

Table 3. Predicted suitable areas (km^2) for *Ormosia hosiei* under the current and future climate scenarios are classified into six suitability categories generated by the BIOCLIM and DOMAIN models.

Suitability Category	BIOCLIM			DOMAIN		
	Current	Future	Area Change %	Current	Future	Area Change %
Excellent	42,218	30,709	−27.26	738	728	−1.36
Very high	50,832	63,909	25.73	30,304	23,387	−22.82
High	28,717	34,048	18.56	51,569	47,456	−7.98
Medium	26,762	27,943	4.41	58,265	67,597	16.02
Low	0	0	0.00	87,056	90,984	4.51
Unsuitable	337,470	329,392	−2.39	258,069	255,847	−0.86

Both models indicated that the excellent suitable habitat of *O. hosiei* under the future climate scenario in Aba, Ganzi, Liangshan, and Panzhihua had 0 or nearly 0 values (Table 3 and Figure 4). Such results indicated that these areas could not provide excellent suitable habitat despite climatic warming. BIOCLIM predicted an increase in excellent suitable habitat in six areas, including Bazhong, Dazhou, and Guangyuan. However, ten areas, including Chengdu, Deyang, and Leshan, would encounter a reduction. DOMAIN also found an increase or decrease in excellent suitable habitat in five and nine areas, respectively. Despite some differences in the predicted changes in excellent suitable habitat in various parts of Sichuan obtained by the two models, the overall reduction trend in excellent suitable habitat was consistent.

3.5. Model Accuracy

The BIOCLIM and DOMAIN models were applied to predict the suitable habitats of *O. hosiei* in Sichuan under the current and future climate scenarios. The results showed that the AUC values of both models were 0.881 and 0.873, and 0.871 and 0.867, respectively, under the current and future climate scenarios. These AUC values were significantly higher than the random distribution model (0.5). Thus, the models were tested to be accurate, indicating that the predicted potential distribution areas were very close to the actual distribution areas, and the research results were reliable.

4. Discussion

Exploring the response of rare and endangered species to the current and future climate can enhance the understanding of their survival risks with substantial scientific value to formulate targeted conservation strategies [4,41]. This study used the geographical distribution points of *O. hosiei* in Sichuan to predict its potential suitable distribution under current and future climate change scenarios based on the BIOCLIM and DOMAIN models. Moreover, the alternative areas for *O. hosiei* growth were predicted, providing a scientific reference for conservation management, introduction area selection, and sustainable utilization of its wild resources.

Both models predicted consistent outcomes for very high and excellent suitable habitats and the same species distribution concentration in the eastern Sichuan region. However, some differences in specific results at the local scale were generated. First, the DOMAIN and BIOCLM models output different values, producing classification confidence rather than species suitable habitat probability [15,39]. After obtaining this value, the suitable threshold needs to be customized according to the study's actual situation. In this study, if the results of the suitable habitat classification were automatically assigned by DOMAIN, almost no excellent suitable habitat could be found in Sichuan (Table 3), which is inconsistent with actual investigations. Therefore, we suggested that it is unnecessary to be too harsh when analyzing the DOMAIN modeling results. Instead, the top two high and excellent classes can be considered together. Secondly, the two models' algorithms are fundamentally different. BIOCLIM belongs to the "environmental envelope" type [42,43], which identifies and determines the locations where the environmental values occur within the range of measured values. Additionally, it uses the 5–95% probability envelope as the boundary to ignore the lowest and highest 5% of each climatic index to reduce the outliers' impact on the prediction results [10]. DOMAIN derives a point-to-point similarity measure and assigns a value to the potential distribution point based on the degree of similarity between it and the most similar point in the environmental space. It then uses the sum of the standardized distances between the two points of each environmental prediction variable to quantify the similarity between two distribution points [15,44]. Therefore, judging from the prediction map, the excellent regional assignment of the DOMAIN model is significantly less than the BIOCLIM model (Figure 2).

Temperature is a crucial limiting factor for species distribution, especially extreme low temperatures (bio6) (Table 2 and Figure 3). The effects of extreme low temperatures on species distribution depend on the natural environment, domestication status, and species growth form. The organs and tissues of different plants have dissimilar low-temperature tolerances, which vary by season and life-cycle phase [45]. For example, tropical plants never experience temperatures below 0 °C and could be killed at 0–10 °C [46]. The study of European linden (*Tilia cordata* Mill.) distribution in the UK concerning temperature found that low temperature significantly affected the distribution by limiting the ability to flower or reducing the ability of embryos to fertilize [47]. The evergreen cultivated shrub *Vaccinium bracteatum* Thunb. is significantly less cold-tolerant than heat-tolerant. Therefore, low temperature may be a key factor limiting its spread to high-latitude areas in north China [48]. Similar situations also occur in plants such as *Rhodomyrtus tomentosa* (Ait.) Hassk. [40] and *J. mimosifolia* [13].

Our principal component analysis showed that extreme low temperature (bio6) had the largest loading among the 19 bioclimatic factors (Table 1), indicating its considerable impact on *O. hosiei* distribution in Sichuan. The current geographical distribution of *O. hosiei* extends from the eastern coastal areas of Fujian, Zhejiang, and Jiangsu to western areas, such as Guizhou, Sichuan, and Shaanxi, covering China's central subtropical and north subtropical climatic zones. The national distribution pattern indicates that *O. hosiei* has a relatively high temperature demand. The lack of natural distribution in western Sichuan supports that low temperature is a key factor limiting its westward spread to higher elevations (Figure 2). In addition, the first principal component explains over 50% of the variance. Its high-ranking factors are related to temperature, indicating that temperature factors impact *O. hosiei* distribution in Sichuan more than precipitation factors.

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) clearly states that, by 2050, all climate scenarios could cause global warming to rise by 1.5 °C [49]. If greenhouse gas emissions do not significantly decrease, global surface temperatures are expected to increase by at least 2.1 °C by 2100 compared to 1850–1900 [50]. Current research also indicates that, when global warming reaches 1.5 °C, 4%–8% of species worldwide will be at risk of extinction. If the temperature increases to 2 °C and 3.2 °C, the percentage of species facing extinction will rapidly increase to 8%–18% and 26%–49%, respectively [5].

When global warming exceeds 1.5 °C, the natural global climate control solutions will become ineffective, and ecosystems will reach their absolute adaptation limit [51]. Therefore, the impact of climate change on biodiversity distribution patterns is profound. The geographical distribution pattern of species echoes the products of the evolutionary performance of adaptation to the environment [52]. However, the accelerating global warming process over the past century has induced the lagging of species evolution behind the pace of the temperature rise [53]. Consequently, their suitable habitats have been greatly reduced in recent years, especially rare and endangered species sensitive to temperature [54]. For example, according to the MaxEnt model prediction, the suitable distribution area of the sal tree (*Shorea robusta* C. F. Gaertner) in Purba Bardhaman, Bangladesh, will decrease by more than 20% by 2070 [55]. A rare endangered plant, *Manihot walkerae* Croizat, in Central and North America is expected to lose 9% and 14% of its suitable habitat by 2050 and 2070, respectively [56]. The temperature-sensitive *Rosa arabica* Crép. in Egypt will disappear below 1500 m above sea level and migrate to higher altitudes [35]. Most species that lack effective and rapid migration capabilities will struggle to find suitable habitats to permit range shifts and face aggravated extinction risk [57].

Our modeling results implied that the excellent suitable habitat for *O. hosiei* in Sichuan had significantly decreased (Figure 4). The pattern generated by DOMAIN was more fragmented than BIOCLIM, indicating a telltale sign of a declining species population. These degradation changes align with the response of endangered plants to climate change observed in other regions of the world. Therefore, specific strategies should be developed to address the potential impact of climate change on the adaptive habitat of *O. hosiei* in Sichuan.

A study of the potential distribution area of *O. hosiei* at a larger scale (the whole of China) showed that the range of *O. hosiei* declined by 35.9% from the Last Glacial Maximum to the Mid-Holocene using MaxEnt, losing 54.1% of suitable habitats. Under future climate scenarios, the area of suitable habitats shrank sharply compared to the current climate scenario (decline by 49.3%–49.5% under RCP 8.5, and 14.1%–17.4% under RCP 2.6) [28]. Moreover, the predicted results obtained by our two models (BIOCLIM and DOMAIN) showed a notable reduction in the suitable area of *O. hosiei* in Sichuan. Therefore, with the validation of the three models, the decline of the suitable habitats of *O. hosiei* under the climate warming scenario could be considered an indisputable fact.

The accuracy of predictions from various SDMs has been debated. It is generally believed that the MaxEnt model is superior to DOMAIN, DK-GARP, and BIOCLIM [14]. All SDM prediction methods show a certain degree of model-specific bias. Some algorithms such as DOMAIN produce rather embracive predictions, while others such as BIOCLIM present more restrictive predictions [7]. However, the DOMAIN model has been found to perform well once sensitivity and omission errors are taken into account [58]. The evaluation by the ROC curve verified that the BIOCLIM model predicted the distribution of *Cerasus schneideriana* (Koehne) Yü et Li in China accurately and reliably (AUC = 0.998) [59]. Combining the results of this and previous studies [28], we believe that the prediction results of DOMAIN and BIOCLIM on the potential distribution of *O. hosiei* in Sichuan are reliable.

The holotype of *O. hosiei* collected from Chengdu has special significance in taxonomy. It also carries a profound traditional Chinese cultural connotation, regarded as the "longing" tree by Chinese people since time immemorial. Therefore, we suggest the following scientific and practical measures to enhance the conservation of *O. hosiei* resources in Sichuan: (1) Research institutions can strengthen the collection of germplasm resources and establish important resource sites. Knowledge of the geographical distribution of *O. hosiei* could identify suitable sites for collecting germplasm materials from its wild populations in different regions. The same knowledge base could allow precision relocation of the species and protect individuals with excellent traits. (2) Researchers can strengthen the conservation biology studies of *O. hosiei*. The critical reasons for the endangerment of *O. hosiei* include its low fruiting rate, poor dispersal ability [21,27], and susceptibility to human interference. Therefore, targeted research on the reproductive biology, seed germination, and seedling establishment of *O. hosiei* should be boosted. The findings can inform complementary strategies for the conservation of wild populations. (3) Relevant government departments should increase the introduction and promotion of *O. hosiei* in suitable areas in Sichuan. As a native species, *O. hosiei* has a beautiful form, strong adaptability to the local environment, and a special Chinese cultural undertone. Therefore, relevant government entities in Sichuan should provide scientific guidance to the seedling production nurseries to increase the breeding, domestication, and production of meritorious planting materials for *O. hosiei*. The species can be more vigorously promoted for planting in courtyards, streets, parks, squares, and other suitable urban sites.

5. Conclusions

O. hosiei is mainly distributed in the eastern region of Sichuan with the characteristics of a tree species in Central Asia's subtropical humid climate zone. The temperature has a greater impact on the distribution of *O. hosiei* in Sichuan than precipitation, and extreme low temperatures are the key limiting factor. Precipitation factors reflected the climate profile of *O. hosiei*, preferring warm and humid conditions, but it was not the key limiting factor for its geographical distribution. The simulation results of the species distribution models under the current climatic scenario illustrated that the potential suitable area in Sichuan was similar to the current natural distribution pattern, and the eastern part of Sichuan would remain the main distribution area. However, a significant reduction trend in the distribution area was detected under the future climate scenario of doubling CO_2 concentration. Therefore, specific conservation measures are urgently needed to strengthen the conservation and expand the planting program of *O. hosiei* in Sichuan.

Author Contributions: Data curation, C.X., L.C. and M.L.; Methodology, C.X.; Software, C.X., C.-Y.J. and M.L.; Writing—original draft, C.X.; Validation, C.X. and C.-Y.J.; Formal analysis, C.-Y.J.; Writing—review and editing, C.-Y.J.; Visualization, D.L. and C.X.; Investigation, L.C., M.L. and D.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Science Foundation of Hainan Province (grant number: 423MS061), the Education Department of Hainan Province (project number: Hnky2023ZD-17), the National Natural Science Foundation of China (grant number: 32071782), and Tropical Biodiversity and Bioresource Utilization Laboratory, Qiongtai Normal University (grant number: QTPT21-5).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We are grateful to Chenghui Nan for providing the photos of *O. hosiei* for this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shitara, T.; Fukui, S.; Matsui, T.; Momohara, A.; Tsuyama, I.; Ohashi, H.; Tanaka, N.; Kamijo, T. Climate change impacts on migration of *Pinus koraiensis* during the Quaternary using species distribution models. *Plant Ecol.* **2021**, *222*, 843–859. [CrossRef]
2. Fang, J.; Lechowicz, M.J. Climatic limits for the present distribution of beech (*Fagus* L.) species in the world. *J. Biogeogr.* **2006**, *33*, 1804–1819. [CrossRef]
3. Wang, F.; Xiong, Z.; Yan, X.; Dai, X.; Wang, L.; Li, Y. Geographical distribution pattern of species diversity of the genus *Populus* L. in China. *Acta Ecol. Sin.* **2018**, *38*, 282–290. [CrossRef]
4. Sintayehu, D.W. Impact of climate change on biodiversity and associated key ecosystem services in Africa: A systematic review. *Ecosyst. Health Sustain.* **2018**, *4*, 225–239. [CrossRef]
5. Warren, R.; Price, J.; Graham, E.; Forstenhaeusler, N.; VanDerWal, J. The projected effect on insects, vertebrates, and plants of limiting global warming to 1.5 °C rather than 2 °C. *Science* **2018**, *360*, 791–795. [CrossRef] [PubMed]
6. Ramírez-Preciado, R.P.; Gasca-Pineda, J.; Arteaga, M.C. Effects of global warming on the potential distribution ranges of six *Quercus* species (Fagaceae). *Flora* **2019**, *251*, 32–38. [CrossRef]
7. Sarquis, J.A.; Cristaldi, M.A.; Arzamendia, V.; Bellini, G.; Giraudo, A.R. Species distribution models and empirical test: Comparing predictions with well-understood geographical distribution of *Bothrops alternatus* in Argentina. *Ecol. Evol.* **2018**, *8*, 10497–10509. [CrossRef]
8. Yang, J.; Jiang, P.; Huang, Y.; Yang, Y.; Wang, R.; Yang, Y. Potential geographic distribution of relict plant *Pteroceltis tatarinowii* in China under climate change scenarios. *PLoS ONE* **2022**, *17*, e0266133. [CrossRef] [PubMed]
9. Dyderski, M.K.; Paź, S.; Frelich, L.E.; Jagodziński, A.M. How much does climate change threaten European forest tree species distributions? *Glob. Chang. Biol.* **2018**, *24*, 1150–1163. [CrossRef]
10. Booth, T.H.; Nix, H.A.; Busby, J.R.; Hutchinson, M.F. Bioclim: The first species distribution modelling package, its early applications and relevance to most current MaxEnt studies. *Divers. Distrib.* **2014**, *20*, 1–9. [CrossRef]
11. Booth, T.H. Why understanding the pioneering and continuing contributions of BIOCLIM to species distribution modelling is important. *Austral Ecol.* **2018**, *43*, 852–860. [CrossRef]

12. Semwal, D.P.; Pandey, A.; Gore, P.G.; Ahlawat, S.P.; Yadav, S.K.; Kumar, A. Habitat prediction mapping using BioClim model for prioritizing germplasm collection and conservation of an aquatic cash crop 'makhana' (*Euryale ferox* Salisb.) in India. *Genet. Resour. Crop Evol.* **2021**, *68*, 3445–3456. [CrossRef]
13. Xie, C.; Zhang, G.; Jim, C.; Liu, X.; Zhang, P.; Qiu, J.; Liu, D. Bioclimatic suitability of actual and potential cultivation areas for *Jacaranda mimosifolia* in Chinese cities. *Forests* **2021**, *12*, 951. [CrossRef]
14. Wisz, M.S.; Hijmans, R.J.; Li, J.; Peterson, A.T.; Graham, C.H.; Guisan, A.; Group, N.P.S.D.W. Effects of sample size on the performance of species distribution models. *Divers. Distrib.* **2008**, *14*, 763–773. [CrossRef]
15. Carpenter, G.; Gillison, A.N.; Winter, J. DOMAIN: A flexible modelling procedure for mapping potential distributions of plants and animals. *Biodivers. Conserv.* **1993**, *2*, 667–680. [CrossRef]
16. Wang, G.; Gen, Q.; Xiao, M.; Zhang, M.; Zhang, Y.; Wang, Z. Predicting *Pseudolarix amabilis* potential habitat based on four Niche models. *Acta Ecol. Sin.* **2020**, *40*, 6096–6104. [CrossRef]
17. Hijmans, R.J.; Guarino, L.; Cruz, M.; Rojas, E. Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genet. Resour. Newsl.* **2001**, *127*, 15–19.
18. Chu, X.; Fu, Y.; Yan, W. Genetic conservation for rare plant of *Ormosia hosiei* and research progress in its fine silviculture. *Chin. Wild Plant Resour.* **2021**, *40*, 61–65. [CrossRef]
19. Zhang, R.; Zhou, Z.; Du, K. Genetic diversity of natural populations of endangered *Ormosia hosiei*, endemic to China. *Biochem. Syst. Ecol.* **2012**, *40*, 13–18. [CrossRef]
20. Zhai, D.; Fang, Z.; Wu, J.; Yao, Q.; Bai, X.; Yang, L.; Gao, Q.; Zhang, Y. Analysis on the character diversity of *Ormosia hosiei* seeds from different producing regions. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2019**, *62*, 63–69. [CrossRef]
21. Liu, P.; Que, S.; Liu, L.; Huang, X. Research status and endangered conservation strategy of *Ormosia hosiei*. *Subtrop. Plant Sci.* **2017**, *46*, 96–100. [CrossRef]
22. Zhang, J.-Q.; Jiang, M.-Y.; Zhu, D.-D.; Zhang, J.-L.; Zheng, J.-Z.; Deng, C.-Y. Characterization of the complete chloroplast genome of an endemic species of pea family in China, *Ormosia hosiei* (Fabaceae). *Conserv. Genet. Resour.* **2019**, *11*, 443–446. [CrossRef]
23. Xu, H.; Qiu, Y.; Chen, J.; Shi, Y.; Zhang, X.; Song, Q.; Huang, M.; Wu, Z.; Ni, L. Chemical constituents and their activities from the seeds of *Ormosia hosiei*. *Nat. Prod. Commun.* **2019**, *14*, 1–4. [CrossRef]
24. Pouny, I.; Batut, M.; Vendier, L.; David, B.; Yi, S.; Sautel, F.; Arimondo, P.B.; Massiot, G. Cytisine-like alkaloids from *Ormosia hosiei* Hemsl. & E.H. Wilson. *Phytochemistry* **2014**, *107*, 97–101. [CrossRef] [PubMed]
25. Chu, X.; Luo, X.; Zhou, Z. Exponential fertilization on red-seed tree (*Ormosia hosiei*) seedlings subjected to contrasting light conditions: Do we really need intensive nutrient loading? *Not. Bot. Horti Agrobot. Cluj-Napoca* **2021**, *49*, 12244. [CrossRef]
26. Xiao, D.; Deng, Z.; Luo, Q.; Xu, Z.; Shen, B.; Chen, H.; Xu, H.; Zhou, Z. Growth and form-quality traits diversity analysis of young *Ormosia hosiei* family. *For. Res.* **2021**, *34*, 152–157. [CrossRef]
27. Liu, X.; Wang, Z.; Xiao, Z. Patterns of seed predation and dispersal of an endangered rare plant *Ormosia hosiei* by Edward's long-tailed rats and Chinese white-bellied rats. *Biodivers. Sci.* **2011**, *19*, 93–96. [CrossRef]
28. Qiu, H.; Sun, J.; Xu, D.; Jiao, J.; Xue, M.; Yuan, W.; Shen, A.; Jiang, B.; Li, S. The distribution dynamics of *Ormosia hosiei* under different climate change scenarios since the Last Glacial Maximum. *Acta Ecol. Sin.* **2020**, *40*, 3016–3026. [CrossRef]
29. Almas, A.D.; Conway, T.M. The role of native species in urban forest planning and practice: A case study of Carolinian Canada. *Urban For. Urban Green.* **2016**, *17*, 54–62. [CrossRef]
30. Wu, Z.; Raven, P.H. *Flora Reipublicae Popularis Sinicae*; Science Press: Beijing, China, 1994; Volume 40.
31. Fick, S.E.; Hijmans, R.J. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *Int. J. Climatol.* **2017**, *37*, 4302–4315. [CrossRef]
32. Bazzato, E.; Rosati, L.; Canu, S.; Fiori, M.; Farris, E.; Marignani, M. High spatial resolution bioclimatic variables to support ecological modelling in a Mediterranean biodiversity hotspot. *Ecol. Model.* **2021**, *441*, 109354. [CrossRef]
33. Rodríguez-Núñez, J.R.; Campos-Rojas, E.; Andrés-Agustín, J.; Alia-Tejacal, I.; Ortega-Acosta, S.A.; Peña-Caballero, V.; Madera-Santana, T.J.; Núñez-Colín, C.A. Distribution, eco-climatic characterisation, and potential growing regions of *Annona cherimola* Mill. (Annonaceae) in Mexico. *Ethnobiol. Conserv.* **2021**, *10*, 1–17. [CrossRef]
34. Huang, Z.; Xie, L.; Wang, H.; Zhong, J.; Li, Y.; Liu, J.; Ou, Z.; Liang, X.; Li, Y.; Huang, H.; et al. Geographic distribution and impacts of climate change on the suitable habitats of *Zingiber* species in China. *Ind. Crops Prod.* **2019**, *138*, 111429. [CrossRef]
35. Abdelaal, M.; Fois, M.; Fenu, G.; Bacchetta, G. Using MaxEnt modeling to predict the potential distribution of the endemic plant *Rosa arabica* Crép. in Egypt. *Ecol. Inform.* **2019**, *50*, 68–75. [CrossRef]
36. Hammer, Ø.; Harper, D.A.; Ryan, P.D. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* **2001**, *4*, 9.
37. Duan, R.-Y.; Kong, X.-Q.; Huang, M.-Y.; Fan, W.-Y.; Wang, Z.-G. The predictive performance and stability of six species distribution Models. *PLoS ONE* **2014**, *9*, e112764. [CrossRef] [PubMed]
38. Moyroud, N.; Portet, F. Introduction to QGIS. In *QGIS and Generic Tools*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2018; pp. 1–17.
39. Sheng, Q.; Wang, C.; Wang, L.; Liu, Y.; Geng, X.; Zhu, Z. Prediction of suitable habitat of *Paeonia suffruticosa* Andr. in China by DIVA-GIS. *Nonwood For. Res.* **2022**, *40*, 205–213, 248. [CrossRef]
40. Xie, C.; Huang, B.; Jim, C.Y.; Han, W.; Liu, D. Predicting differential habitat suitability of *Rhodomyrtus tomentosa* under current and future climate scenarios in China. *For. Ecol. Manag.* **2021**, *501*, 119696. [CrossRef]

41. Foden, W.B.; Young, B.E.; Akçakaya, H.R.; Garcia, R.A.; Hoffmann, A.A.; Stein, B.A.; Thomas, C.D.; Wheatley, C.J.; Bickford, D.; Carr, J.A.; et al. Climate change vulnerability assessment of species. *WIREs Clim. Chang.* **2019**, *10*, e551. [CrossRef]
42. Santika, T.; Hutchinson, M.F. The effect of species response form on species distribution model prediction and inference. *Ecol. Model.* **2009**, *220*, 2365–2379. [CrossRef]
43. Hijmans, R.J. Cross-validation of species distribution models: Removing spatial sorting bias and calibration with a null model. *Ecology* **2012**, *93*, 679–688. [CrossRef] [PubMed]
44. Hernandez, P.A.; Graham, C.H.; Master, L.L.; Albert, D.L. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* **2006**, *29*, 773–785. [CrossRef]
45. Körner, C. Significance of temperature in plant life. *Plant Growth Clim. Chang.* **2006**, *100*, 48–66.
46. Strimbeck, G.R.; Schaberg, P.G.; Fossdal, C.G.; Schröder, W.P.; Kjellsen, T.D. Extreme low temperature tolerance in woody plants. *Front. Plant Sci.* **2015**, *6*, 884. [CrossRef] [PubMed]
47. Woodward, F.I.; Fogg, G.E.; Heber, U.; Laws, R.M.; Franks, F. The impact of low temperatures in controlling the geographical distribution of plants. *Philos. Trans. R. Soc. London B Biol. Sci.* **1997**, *326*, 585–593. [CrossRef]
48. Zhang, M.; Chen, Q.; Huang, J.; Zhou, P. Geographic distribution and potential distribution of *Vaccinium bracteatum*. *J. Jiangsu For. Sci. Technol.* **2019**, *46*, 1–8. [CrossRef]
49. Matthews, H.D.; Wynes, S. Current global efforts are insufficient to limit warming to 1.5 °C. *Science* **2022**, *376*, 1404–1409. [CrossRef] [PubMed]
50. Ming, A.; Rowell, I.; Lewin, S.; Rouse, R.; Aubry, T.; Boland, E. *Key Messages from the IPCC AR6 Climate Science Report*; Cambridge University Press: Cambridge, UK, 2021. [CrossRef]
51. Mycoo, M.A. Beyond 1.5 °C: Vulnerabilities and adaptation strategies for Caribbean Small Island Developing States. *Reg. Environ. Chang.* **2018**, *18*, 2341–2353. [CrossRef]
52. Rangel, T.F.; Edwards, N.R.; Holden, P.B.; Diniz-Filho, J.A.F.; Gosling, W.D.; Coelho, M.T.P.; Cassemiro, F.A.S.; Rahbek, C.; Colwell, R.K. Modeling the ecology and evolution of biodiversity: Biogeographical cradles, museums, and graves. *Science* **2018**, *361*, eaar5452. [CrossRef]
53. Lippmann, R.; Babben, S.; Menger, A.; Delker, C.; Quint, M. Development of wild and cultivated plants under global warming conditions. *Curr. Biol.* **2019**, *29*, R1326–R1338. [CrossRef] [PubMed]
54. Kempel, A.; Bornand, C.N.; Gygax, A.; Juillerat, P.; Jutzi, M.; Sager, L.; Bäumler, B.; Eggenberg, S.; Fischer, M. Nationwide revisitation reveals thousands of local extinctions across the ranges of 713 threatened and rare plant species. *Conserv. Lett.* **2020**, *13*, e12749. [CrossRef]
55. Shishir, S.; Mollah, T.H.; Tsuyuzaki, S.; Wada, N. Predicting the probable impact of climate change on the distribution of threatened *Shorea robusta* forest in Purbachal, Bangladesh. *Glob. Ecol. Conserv.* **2020**, *24*, e01250. [CrossRef]
56. Garza, G.; Rivera, A.; Venegas Barrera, C.S.; Martinez-Ávalos, J.G.; Dale, J.; Feria Arroyo, T.P. Potential effects of climate change on the geographic distribution of the endangered plant species *Manihot walkerae*. *Forests* **2020**, *11*, 689. [CrossRef]
57. Varol, T.; Canturk, U.; Cetin, M.; Ozel, H.B.; Sevik, H. Impacts of climate change scenarios on European ash tree (*Fraxinus excelsior* L.) in Turkey. *For. Ecol. Manag.* **2021**, *491*, 119199. [CrossRef]
58. Natale, E.; Zalba, S.M.; Reinoso, H. Presence—Absence versus invasive status data for modelling potential distribution of invasive plants: Saltcedar in Argentina. *Ecoscience* **2013**, *20*, 161–171. [CrossRef]
59. Zhu, H.; You, L.; Li, Y.; Wang, H.; Wang, X. Modeling the geographical distribution pattern and climatic limited factors of *Cerasus schneideriana*. *J. Trop. Subtrop. Bot.* **2017**, *25*, 315–322. [CrossRef]