forests

MDPI

Article

Prediction of the Potential Distribution and Conservation Strategies of the Endangered Plant *Tapiscia sinensis*

Mei Liu [1,†], Xiaoyu Li [1,†], Liyong Yang [1], Keyi Chen [1], Zixi Shama [2], Xue Jiang [1], Jingtian Yang [1,*], Guanghua Zhao [3,*] and Yi Huang [4,*]

[1] Ecological Security and Protection Key Laboratory of Sichuan Province, Mianyang Normal University, Mianyang 621000, China; liumei@mtc.edu.cn (M.L.); lixiaoyu@mnu.cn (X.L.); 2208570131@stu.mtc.edu.cn (L.Y.); chenkeyi@mnu.cn (K.C.); jiangx079@mtc.edu.cn (X.J.)
[2] College of Life Science & Biotechnology, Mianyang Normal University, Mianyang 621000, China; shamazixi@mnu.cn
[3] School of Life Science, South China Normal University, Guangzhou 510631, China
[4] China College of Science, Tibet University, Lhasa 850012, China
* Correspondence: yjtdc@mtc.edu.cn (J.Y.); 217112052@stu.sxnu.edu.cn (G.Z.); hyhy1232021@utibet.edu.cn (Y.H.)
† These authors contributed equally to this work.

Abstract: *Tapiscia sinensis* Oliv. (*T. sinensis*), known as the Yingjiao tree, belongs to the *Staphyleaceae* family. It is a deciduous tree species endemic to China and represents an ancient species from the Tertiary glacial relics, possessing significant ecological and economic value. This study is based on 154 effective distribution points of *T. sinensis* in China and 12 environmental factors. Using integrated modeling and ArcGIS software (v10.8), the potential geographic distribution of *T. sinensis* under climate change was predicted to assess its future impact on distribution and ecological niche. Additionally, on-site surveys were conducted to compare the characteristics of *T. sinensis* forest communities across different habitability zones. The study also proposes conservation strategies based on the influence of climate change on the distribution of *T. sinensis* and the characteristics of its forest communities. The results indicate that (1) the current highly suitable areas for *T. sinensis* are primarily located in the municipal regions where Chongqing, Hubei, Hunan, and Guizhou provinces meet, covering an area of 20.44×10^4 km^2. (2) In three suitable community categories, *T. sinensis* is consistently a subdominant species, with the community in moderately suitable areas being the most diverse and exhibiting higher stability and evenness. (3) Under future climate change scenarios, the potential distribution area for *T. sinensis* will gradually decrease with rising temperatures. It will shift toward northern higher latitude regions, with the degree of ecological niche migration also increasing. (4) Conservation measures for *T. sinensis* primarily involve in situ and ex situ protection approaches. These results provide a theoretical basis for the scientific management and resource conservation of *T. sinensis*.

Keywords: Biomod2; climate change; conservation strategies; endemic relict trees in China; potential distribution and change prediction

check for updates

Citation: Liu, M.; Li, X.; Yang, L.; Chen, K.; Shama, Z.; Jiang, X.; Yang, J.; Zhao, G.; Huang, Y. Prediction of the Potential Distribution and Conservation Strategies of the Endangered Plant *Tapiscia sinensis*. *Forests* **2024**, *15*, 1677. https://doi.org/10.3390/f15091677

Academic Editors: António Manuel de Sousa Xavier, Rui Manuel de Sousa Fragoso and Maria De Belém Costa Freitas

Received: 29 July 2024
Revised: 20 September 2024
Accepted: 21 September 2024
Published: 23 September 2024

1. Introduction

In the context of global climate change, the responses and feedback generated by terrestrial ecosystems have become one of the core research areas and focal issues [1,2]. Global climate change has already significantly impacted the ecological characteristics of species, geographic distribution patterns, etc., and this impact is expected to increase in the future [3,4]. Plant growth and its influencing factors have been widely discussed and studied for decades and have become a research hotspot [5–7]. Plant growth is influenced by multiple factors, such as climate, hydrology, and soil type [5,6,8]. Plant growth is primarily affected by climate change, while non-climatic factors affect short-term changes in plants [9,10]. Climate change is causing some plants and animals in China to move to higher latitudes and altitudes [11]. Since the industrial revolution, human activities have been the main cause of the continuous increase in greenhouse gas concentrations [12], which, together with natural factors, influence Earth's climate system [13]. This study uses the latest round of the International Coupled Model Intercomparison Project (CMIP6) for climate models [14]. Compared to CMIP5, CMIP6 incorporates more factors interacting with the climate, leading to simulation results closer to actual observations [15]. CMIP6 provides projections under four Shared Socio-economic Pathways (SSPs), indicating that global temperature change by 2100 could range from 3 to 5.1 degrees Celsius [16].

A Species Distribution Model (SDM) is a model that predicts a species' current and potential distribution by using known species occurrence points and associated environmental variables. It employs specific algorithms to assess the ecological requirements of a species and projects the results into specific spatial and temporal dimensions. As biodiversity conservation research has deepened in recent years, SDM has been widely applied in biodiversity conservation [17–20]. Different SDM methods have varying underlying principles and algorithms, leading to differences in applicability and predictive performance [21,22]. It is difficult to identify a single-optimal model algorithm. The Biomod2 platform based on R software (v4.2.3) provides 10 commonly used SDM algorithms, allowing users to freely combine and customize an ensemble model for their study species [23,24]. Although it is impossible to avoid individual models' inherent limitations completely, the optimal simulation effect can be achieved by assigning appropriate weights to each model within the ensemble model [25,26].

Tapiscia sinensis Oliv. (*T. sinensis*), which belongs to the family Tapisciaceae, is a unique tertiary relict plant endemic to China [27,28]. It plays a crucial role in maintaining forest biodiversity in China [28–30]. The species is significant for studying subtropical flora and Chinese angiosperm breeding systems [31,32]. It is only sparsely distributed in China's broad subtropical regions, ranging from the west to the east, from provinces such as Sichuan, Shaanxi, and Guizhou. Owing to its poor reproductive performance and natural regeneration capacity, as well as the extensive destruction caused by deforestation and land clearing [33], the wild population of this species is small and widely dispersed. Hence, strengthening protection is necessary [34]. Due to habitat loss and fragmentation, *T. sinensis* populations have declined dramatically, resulting in significant degradation of forest ecosystems, making it an important species for conservation. The extensive collection of specimen occurrence data is expected to improve the understanding of *T. sinensis*'s geographical distribution and biogeographical dynamics. *T. sinensis* has received considerable research attention because of its unique functionally dioecious breeding system, thus presenting an essential case for studying the evolution of angiosperm reproduction mechanisms [27,31]. Moreover, this species is a vital genetic resource for developing new drugs and bioproducts [35,36].

In summary, it can be observed that although there are many studies on *T. sinensis*, research on its suitable species distribution patterns and potential habitability zone are still limited. There has been no research combining the prediction of potential distribution areas of *T. sinensis* and the analysis of community characteristics in different levels of habitability zones. Therefore, in order to provide a theoretical basis for the conservation of *T. sinensis* and to offer references for the protection and restoration of endangered plants in China, this study will undertake the following research tasks: (1) analyze the suitable distribution areas of *T. sinensis* under different climatic conditions; (2) analyze the trends of ecological niche changes in *T. sinensis* under future climatic conditions; (3) analyze the community characteristics in different levels of habitability zone for *T. sinensis*; and (4) propose conservation strategies for *T. sinensis* in the context of climate change.

2. Materials and Methods

2.1. Species Distribution Data

In this study, the distribution data of *T. sinensis* in China were obtained from two sources: one part was collected from the National Plant Specimen Resource Center (NPSRC, http://www.cvh.ac.cn/, accessed on 10 December 2023) and the other part was gathered through field surveys conducted between June and September 2023. A total of 241 distribution points of *T. sinensis* were collected from these two sources. To avoid bias in the output results caused by spatial autocorrelation resulting from data overlap reduction, only one distribution point was retained per grid (5 km × 5 km). Ultimately, 154 valid samples were obtained, as shown in Figure 1a.

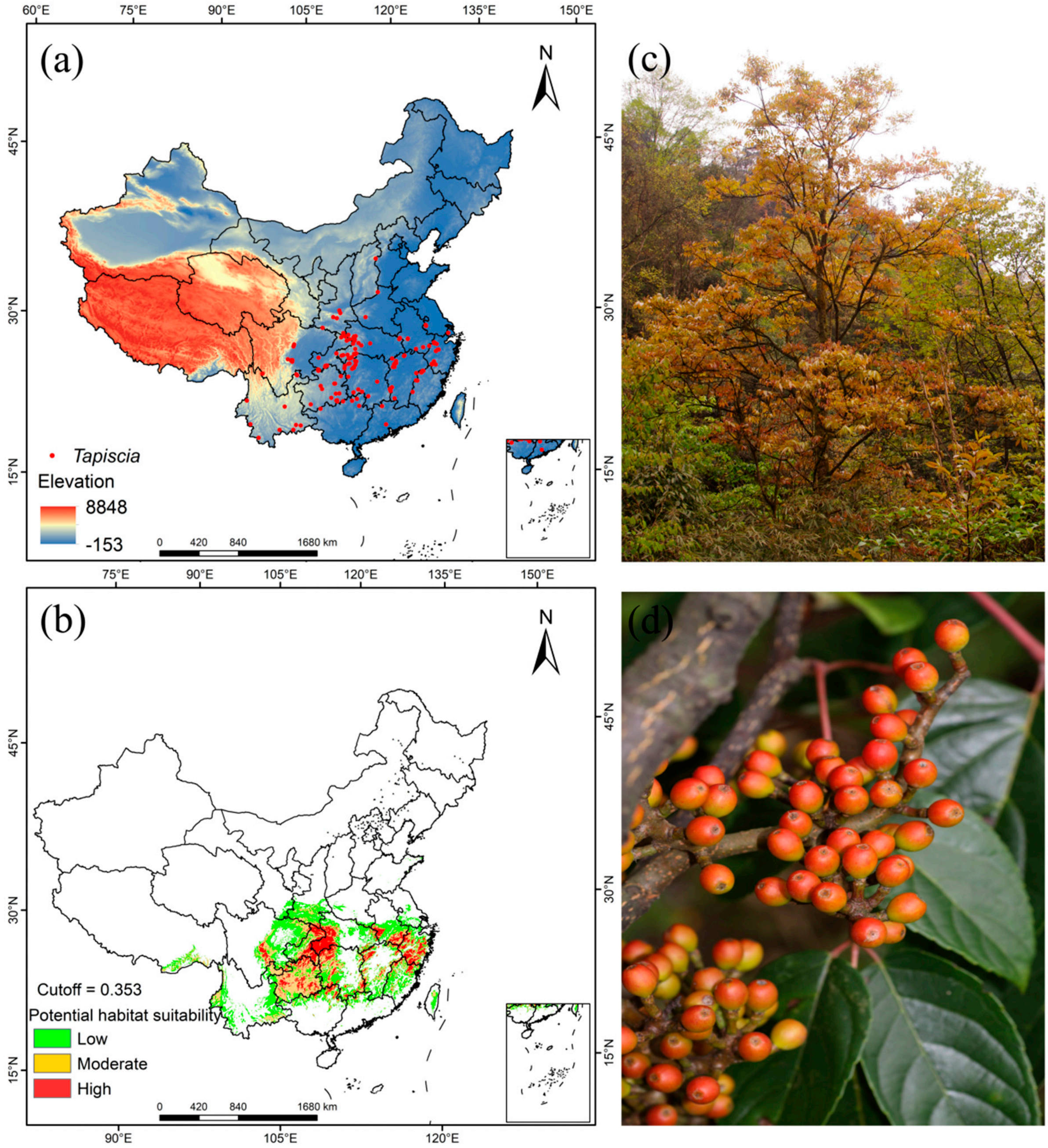

Figure 1. (**a**) Geographical distribution of *T. sinensis*; (**b**) Potential geographical distribution under current climate conditions; (**c**) Tree field morphology; (**d**) Fruits.

2.2. Selection and Processing of Environmental Factors

This study includes 34 environmental factors, including 19 climate factors, 14 soil factors, and 1 terrain factor (Table S1). Climate data were obtained from the WorldClim database (http://www.worldclim.org, accessed on 17 March 2024) [37]. Climate data for the current period cover the years 1970–2000, while future climate data under three different shared socioeconomic pathways (SSP126, SSP245, and SSP585) were sourced from the Beijing Climate Center Climate System Model (BCC-CSM2-MR) for the periods 2041–2060 (2050s) and 2080–2100 (2090s) [38]. Soil and terrain data were derived from the Food and Agriculture Organization of the United Nations' World Soil Database (HWSD) (http://www.fao.org/faostat/en/#data, accessed on 18 March 2024) [39]. China's standard map boundary data from the National Administrative Division Information Query Platform (http://xzqh.mca.gov.cn/map, accessed on 20 March 2024) were used to extract data within China's borders. All raster data were standardized to a spatial resolution of 2.5 min (5 km × 5 km) using the ArcGIS 10.8 Arc Toolbox. Current environmental data for the actual occurrence points were extracted using ArcGIS (v10.8) to prevent overfitting of the model between environmental factors [40]. Subsequently, in R software (v4.2.3), the "usdm" package was used to conduct Variance Inflation Factor (VIF) and Pearson correlation tests on the environmental factors. We selected climate factors with a Pearson correlation coefficient of less than 0.7 and a VIF value of less than 5 for the subsequent construction of the SDM [41]. The final model retained 7 climate variables, 4 soil factors, and 1 terrain variable, totaling 12 environmental factors (Table S2).

2.3. Construction of the Integrated Model

In building and evaluating SDM, certain modeling algorithms require the simultaneous use of presence data (i.e., data points where species are observed) and absence data (i.e., data points where species are not observed). Due to the lack of relevant records concerning absence points, Biomod2 employs an ensemble algorithm capable of generating absence points based on presence data. In this study, 1200 coordinate points were randomly generated in China and treated as pseudo-absence data to meet the model requirements. Cross-validation was used to process the presence of data involved in modeling. All the data were divided into a training set and a testing set, with 75% of the presence data used for the training set, combined with bioclimatic variables for model construction and training; the remaining 25% of the presence data served as the testing set to evaluate the accuracy of model predictions. The weights for the presence and pseudo-absence data were set to be equal, and this process was repeated five times, resulting in 100 model simulations. The accuracy of the predicted results was assessed using AUC and TSS. Models with TSS $\geq$ 0.7 were retained, and a weighted average method was used to construct the ensemble model [42]. Regarding model output, a 0/1 threshold (cut-off) was established; areas below the threshold were considered unsuitable, while areas above the threshold were divided into three equal parts corresponding to low, medium, and high suitability areas (cut-off = 0.353). Finally, the classification results were loaded into ArcGIS v10.4.1 for visual representation.

2.4. Changes in Ecological Niches

The point selection area under the current climate is based on *T. sinensis* points and a 1-degree buffer distance. For the future climate, the point selection area was based on the suitable area predicted by the ensemble model for *T. sinensis*. Using the points and climate data, the species model software package "ecospat" calculated the overlap between the *T. sinensis* niches and the current niche under different future climate scenarios. Changes in the niche were then observed. This analysis uses the niche parameter D (observed value), which ranges from 0 to 1, from no overlap to complete overlap, to analyze the impact of climate change on the *T. sinensis* niche [43].

2.5. Field Survey Sample Plot Settings

Based on the potential geographical distribution of *T. sinensis* under current climatic conditions, field surveys of *T. sinensis* communities were conducted using a plot-based approach in the forest area of Emei Mountain, Sichuan Province. Three plots were established in the high suitability area, three in the medium suitability area, and three in the low suitability area. The name, diameter at breast height (DBH; $\geq$1.5 cm), height ($\geq$1.2 m), and crown width of each tree species were recorded. Environmental indicators such as altitude, geographic coordinates, aspect, and slope were also recorded. The reasons for selecting the Emei Mountain forest area in Sichuan for the *T. sinensis* plots are as follows: (1) the Emei Mountain forest has three suitable areas for *T. sinensis* (Figure 1b), meeting the research needs, and (2) this forest is the closest to the research team's base that meets the research requirements.

2.6. Analysis of Significant Values

The value was based on the "Handbook of Forest Ecology" [44]. The relative frequency, dominance, and density were relative frequency = (frequency of a certain species/total frequency of all species) × 100; relative dominance = (basal area of a certain species/total basal area of all species) × 100%; relative density = (number of plants per plant species/total number of plants) × 100; and value (IV) = relative density + relative frequency + relative dominance.

2.7. Diversity Analysis

Species diversity was analyzed using Simpson's diversity index (D), the Shannon–Wiener diversity index (H), and Pielou's evenness index (EH). The calculation formulae are as follows:

$$D = 1 - \sum_{i=1}^{s} {p_i}^2 \tag{1}$$

$$H = -\sum_{i=1}^{s} p_i \ln p_i \tag{2}$$

$$EH = H/\ln s \tag{3}$$

where S is the number of species, P_i is the number of individuals belonging to species i as a percentage of the total number of individuals, and s is the total number of individuals in the sample [28].

3. Results

3.1. Evaluation of Model Accuracy

Ten models ran successfully, resulting in 100 model results. The 'biomod_tuning' function was used to optimize the model parameters, checking these parameters in each iteration based on the selected method (ROC, Kappa, or TSS). The results show that RF is the best model for predicting the potential spatial distribution of *T. sinensis*, with an average Kappa coefficient of 0.98, average TSS of 0.99, and average ROC of 0.99 (Figure 2), followed by GAM and GBM. ANN performed the worst of all models and did not pass the model accuracy test. Based on the test results, the 21 best model results were selected to build the ensemble model (with a Kappa coefficient of 0.88, TSS of 0.95, and ROC of 0.98).

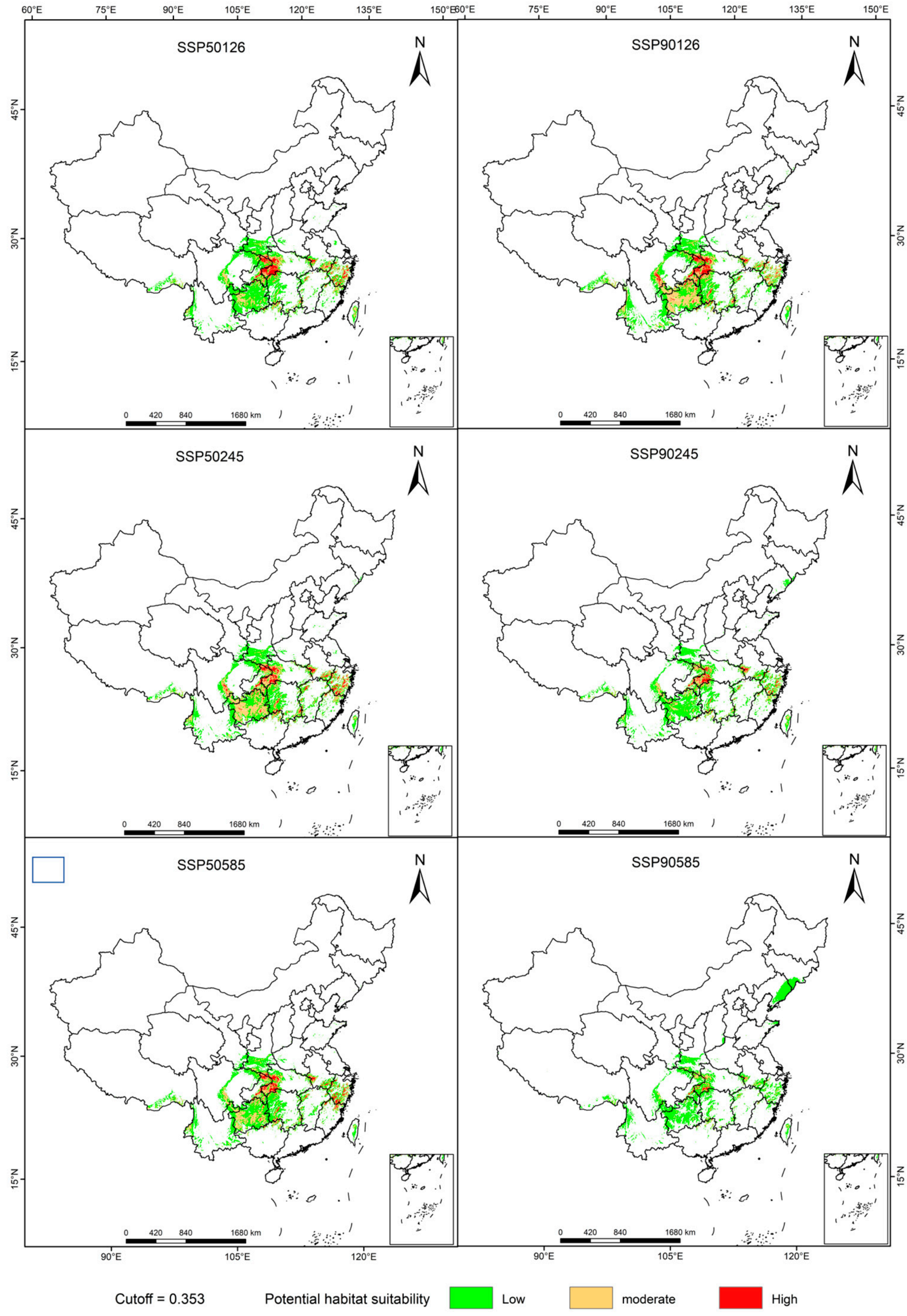

Figure 2. Potential distributions of *T. sinensis* in different future periods.

3.2. Potential Geographic Distribution of T. sinensis under Current Climatic Conditions

The ensemble model was used to simulate the potential geographical distribution area of *T. sinensis* under modern climatic conditions (Figure 1b). The total suitable habitat area for *T. sinensis* is 114.18 × 10^4 km^2, mainly located in the eastern part of Southwest China, Central China, and East China (Figure 1b, Table 1). The highly suitable habitat area for *T. sinensis* is 20.44 × 10^4 km^2, primarily located in the municipalities and regions bordering Chongqing, Hubei, Hunan, and Guizhou provinces. Another portion was distributed in narrow strips within Leshan and Yibin in Sichuan Province, with scattered distributions in Zhejiang, Jiangxi, and Anhui provinces (Figure 1b, Table 1). The moderately suitable habitat area for *T. sinensis* is 38.67 × 10^4 km^2, partially patchy around the high habitability zone, with moderate suitability surrounding the highly suitable areas. Additionally, it is block-shaped in Guizhou Province and sporadically distributed in central and southeastern China (Figure 1b, Table 1).

Table 1. Changes in the distribution area of *T. sinensis* during different periods under different scenarios (10^4 km^2).

Period	Climate Scenario	Low Habitability Zone	Moderately Habitability Zone	Highly Habitability Zone	The Total Habitability Zone
Current		55.07	38.67	20.44	114.18
2041–2060	SSP126	46.19	16.96	5.84	68.99
	SSP245	43.01	25.71	6.24	74.96
	SSP585	44	19.09	5.39	68.48
2081–2100	SSP126	43.58	26.77	6.41	76.76
	SSP245	40.49	12.68	3.23	56.4
	SSP585	42.32	6.34	0.95	49.61

In summary, the high and moderately habitability zones of *T. sinensis* are distributed in a patchy manner in our country's central and southeastern regions, which is highly consistent with its actual distribution, indicating that the simulation results of this study are relatively accurate.

3.3. Predicting the Impact of Climate Change on the Potential Geographic Distribution of T. sinensis

A set model forecasted the geographic distribution of *T. sinensis* in China for 2050 and 2090 under three emission scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5), showing potential distribution changes due to climate change (Figure 2). Table 1 reveals that the habitable areas for *T. sinensis* in 2050 and 2090 have decreased compared to current conditions, with a significant decline in highly suitable habitats under the SSP5-8.5 scenario, nearly disappearing (Figure 2). Climate change is expected to downgrade much of *T. sinensis*'s highly suitable habitat to medium, low, or unsuitable levels. Medium suitability areas will also likely degrade to low or unsuitable, and many low suitability zones may disappear (Figure 2).

3.4. Analysis of Ecological Niche Changes in Future Periods

The niche overlap of *T. sinensis* is shown in Figure 3. Under different climates in the present and future, changes in climatic niches follow the same trend as climate change. Compared to the SSP126 and SSP245 climates, the SSP585 climate had a greater migration distance and lower migration distance. Under the 2090s-SSP585 climate, the niche of *T. sinensis* shifted compared to the previous period. Future global climate change affects the *T. sinensis* niche shift, and the declining niche overlap indicates that the niche of *T. sinensis* has shifted during the future climate change process.

Principal component analysis (PCA) revealed that the first two principal components account for 76.99%–80.77% of the variance in environmental factors (PC1: 56.56%–59.46%; PC2: 20.43%–21.31%). The Mean Diurnal Range (Bio2), Max Temperature (Bio5), and Mean Temperature of the Wettest Quarter (Bio8) are key factors influencing the ecological niche of *T. sinensis*. The climatic niche center of *T. sinensis* will shift toward the Mean Diurnal Range (Bio2) and Max Temperature (Bio5).

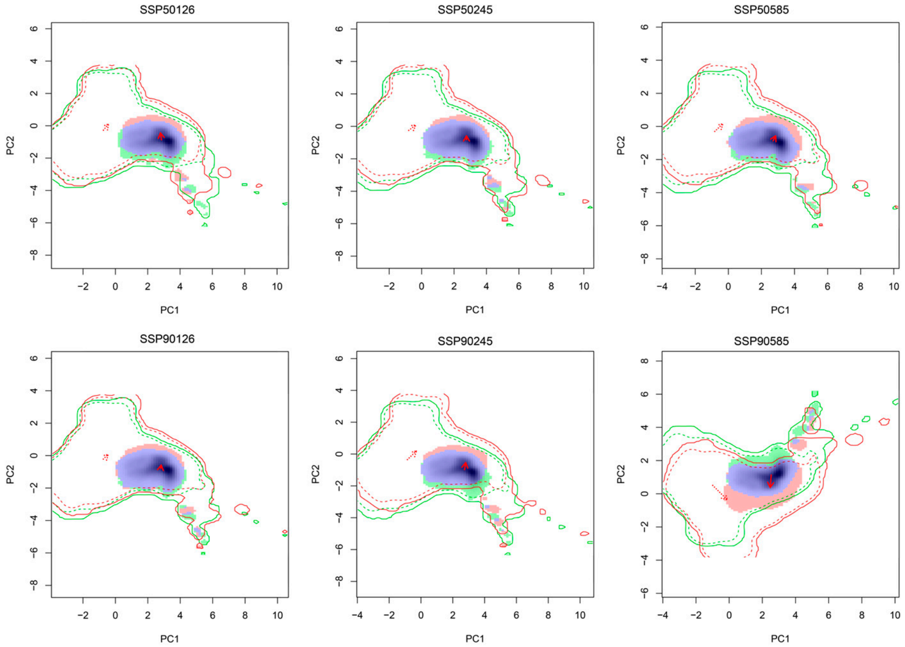

Figure 3. Future niche changes in *T. sinensis* under varying climates are depicted using the PCA axes PC1 and PC2. Species occurrence density is indicated by green (current) and red (future) shading, overlapping in blue. The solid contour line marks 100% of the environmental space, and the dashed line marks 50%. Red arrows point to *T. sinensis'* climatic niche (solid line) and the background range's center (dashed line).

3.5. Community Characteristics of T. sinensis under Different Habitability Zones

According to quadrat sampling [45], the vascular plant community associated with *T. sinensis* is highly diverse. In suitable habitats, these communities included over 90 species (Table 2). Among them, the moderate habitability zone hosts the most vascular plant species, averaging 134 species, followed by the less habitability zone, with an average of 116 species, and the high habitability zone, with the fewest, averaging 98 species (Table 2). Overall, the taxonomic composition of *T. sinensis* communities is rich, complex, diverse, and well-suited for species survival under favorable natural conditions.

Table 2. Community characteristics of *T. sinensis* under different habitability zones.

	Family	**Genus**	**Species**	**Relative Significance**	**Relative Density**	**Relative Density**	**Significant Value**
Most suitable area	45	69	101	15.55%	23.00%	15.11%	53.66%
Most suitable area	49	67	90	15.70%	21.00%	13.11%	49.81%
Most suitable area	41	67	103	16.78%	22.95%	14.52%	54.25%
Marginally suitable area	57	81	125	11.95%	14.42%	11.76%	38.13%
Marginally suitable area	59	83	145	13.90%	16.58%	12.77%	43.25%
Marginally suitable area	58	80	133	8.25%	9.48%	10.77%	28.5%
Marginally unsuitable area	53	77	119	6.30%	7.25%	7.50%	21.05%
Marginally unsuitable area	55	80	122	4.39%	5.07%	5.03%	14.49%
Marginally unsuitable area	52	75	109	3.80%	4.50%	5.00%	13.30%

When the importance value is highest in a community, it indicates the dominant species; when it exceeds 15%, it signifies subdominant species, and values between 5% and 15% denote associated species within that community [28]. Analysis of the importance values of *T. sinensis* communities revealed that the highest values were found in highly habitability zones, with an average of 52.57%. The moderate habitability zone had an average importance value of 36.63%, while the less habitability zone had the lowest at 16.28% (Table 2). This indicated that *T. sinensis* is a subdominant species within these communities.

Relative frequency indicates the evenness of the horizontal distribution of a species within a community and reflects the stability and disturbance levels of the community [46]. Regarding the relative frequency of *T. sinensis* communities, it can be observed that at all three suitability levels, the frequency grades of *T. sinensis* were lower than grade A (Raunkiaer standard frequency grade), indicating that it is not a dominant species within the community. Therefore, *T. sinensis* rarely occurs in a dense distribution. As *T. sinensis* is a deciduous tree species, reaching heights of 8–15 m [27,30], it typically occupies the uppermost vertical space in the community, significantly influencing the understory vegetation structure. Thus, although *T. sinensis* is not a dominant species in the community, it generally acts as a co-dominant species. Regarding the relative significance and density of *T. sinensis* communities, their values followed the same pattern as the relative frequency values of *T. sinensis*.

Diversity primarily focuses on the number of species within a homogeneous habitat and can effectively depict the composition and structure of a community. A single index cannot reflect the true nature of a community. Therefore, using multiple indices to describe communities of the same or similar type can more objectively reflect the development status of communities. For the diversity indices of the *T. sinensis* community, the average Simpson diversity index in the high-suitability zone was 0.62, the Shannon–Wiener diversity index was 3.17, and Pielou's evenness was 0.80 (Table 3). Table 3 shows an average Simpson diversity index of 0.91, a Shannon–Wiener diversity index of 3.50, and Pielou's evenness of 0.81 in the medium-suitability zone. In the low-suitability zone, the average Simpson diversity index was 0.87, the Shannon–Wiener diversity index was 3.62, and Pielou's evenness was 0.78 (Table 3). In summary, the *T. sinensis* community in the medium-suitability zone was species-rich, with high stability and evenness.

Table 3. Species diversity indices of *T. sinensis* at different habitability zone levels.

	Simpson's Diversity Index	Shannon–Wiener Diversity Index	Pielou Uniformity
Plot 1 in the most suitable area	0.56	3.10	0.82
Plot 2 in the most suitable area	0.65	3.21	0.79
Plot 3 in the most suitable area	0.66	3.19	0.78
Plot 1 in the marginally suitable area	0.96	3.54	0.85
Plot 2 in the marginally suitable area	0.94	3.53	0.73
Plot 3 in the marginally suitable area	0.83	3.44	0.84
Plot 1 in the marginally unsuitable area	0.85	3.56	0.79
Plot 2 in the marginally unsuitable area	0.88	3.65	0.73
Plot 3 in the marginally unsuitable area	0.89	3.64	0.82

4. Discussion

4.1. Importance of Species Distribution Modeling

The effects of climate change may include species extinction, a reduction in species diversity, and a fragilization of regional ecosystems. Some species may adapt by developing new physiological traits to cope with these effects [47,48]. In recent decades, the importance of global climate and environmental change research has been increasingly emphasized [49,50]. To mitigate the impacts of climate change on ecosystems, SDM was conducted using appropriate scientific methods to identify regions where sensitive species currently exist or may exist in the future, thereby effectively determining management strategies [51,52].

4.2. Effect of Environmental Data and Species Distribution Records on Model Accuracy

SDM associates species distribution data with corresponding environmental variables, such as climate, soil, vegetation, elevation, and host species. The relationship between species' geographic distribution and environmental variables is analyzed based on specific algorithms, and species' ecological niches in designated areas are estimated. The probability of existence is quantified to reflect species' habitat preferences and environmental requirements. SDM predicts target species distribution and projects the results into unknown geographic spaces using mathematical, statistical, or predictive models to achieve potential species distribution forecasting. Model outputs can be interpreted as the probability of species presence, population abundance, or habitat suitability for species [53]. SDM has become an important research tool widely applied in archaeology, basic ecology, applied ecology, plant conservation, and biodiversity conservation, effectively studying the relationship between species distribution and climate with notable success and impact [54–57].

Simulated results depend highly on the quality of geographic distribution data and the modeling and algorithms used [50,58]. SDM often performs worse with fewer samples [59]. First, the level of uncertainty associated with parameter estimation (e.g., mean, mode, median, and probability of occurrence) decreases as the sample size increases [60]. When the sample size is small, outliers have a higher weight in the analysis, which provides more data to buffer their abnormal impact [61]. Additionally, since species' ecological niches are highly dimensional and complex, large sample sizes can accommodate a broader range of development conditions [62]. Empirical studies have shown that species responses to environmental gradients can be skewed or multimodal, and the interaction between environmental variables is important in evaluating the species-environment relationship [63]. Large datasets can better capture complex relationships [64]. However, models that excel with large samples may struggle with small ones, necessitating an examination of the trade-offs between sample size and model complexity.

In this study, 241 valid records were used. The accuracy of the detection ensemble model was assessed using ROC, TSS, and Kappa, all of which reached "excellent" levels (Figure S2), and the potential of *T. sinensis* in China under climate change using the Biomod2 ensemble model was feasible and reliable. Based on field reviews (referencing several relevant studies on *T. sinensis* in these regions), combined with herbarium specimen data from the Chinese Virtual Herbarium (https://www.cvh.ac.cn, accessed on 17 March 2024) and Plant Wisdom (https://www.iplant.cn, accessed on 17 March 2024) and the species of *T. sinensis* on these platforms, it is confirmed that *T. sinensis* is in Sichuan, Chongqing, Hubei, Hunan, and Guizhou, all of which are located within the predicted suitable area. This further confirmed the results obtained for *T. sinensis*.

4.3. Impact of Climate Change on T. sinensis

Under three emission scenarios for 2050 and 2090, the potential geographic range of *T. sinensis* is expected to decrease compared to current conditions. In particular, the high-suitability areas exhibited a sharp declining trend. Research by Thomas et al. shows that by 2050, 15%–37% of species in sampled areas could face extinction under a medium emission scenario. While some species may benefit from climate warming, *T. sinensis* is negatively affected, highlighting the dual impact of climate change on species distribution and growth.

Regarding the niche shifts of *T. sinensis*, the niche dynamics revealed that the degree of niche overlap for all pairwise comparisons between current and future scenarios decreased with climate change intensity. The Mean Diurnal Range (Bio2), Max (Bio5), and Mean of Wettest Quarter (Bio8) were the primary factors in the *T. sinensis* niche, with factors affecting the growth of *T. sinensis* described in its seed dormancy strategy [65]. Studies on *T. sinensis* indicate that its growth is primarily limited by rainfall, consistent with the present study's findings [66,67].

Based on Figure 3, it is evident that under the climate background of 2090s-SSP585, there is a very significant shift in the ecological niche of *T. sinensis* compared to the previous period; as shown in Figure 2 and Table 2, it can be observed that in the climate background of 2090s-SSP585, the suitable habitat for *T. sinensis* has significantly decreased compared to other periods and times, with the high suitability zone nearly disappearing. Therefore, it can be seen that with further temperature rises, the ecological niche shift of *T. sinensis* will be more significant, potentially leading to a further decrease in its population and even extinction. Hence, the population of *T. sinensis* in this scenario requires priority attention and protection.

Many studies have shown that most species migrate northward in the context of global warming. For example, Bellard et al. simulated the potential geographic distribution of 100 of the world's most invasive non-native species, and the results showed a general trend of their potential geographic distribution expanding northward [4]. Thuiller et al. found that most species migrate northward in the context of global warming, except for those initially distributed in northern regions [68]. From the above research, it can be inferred that the suitable habitats for many species will shift under climate change. Many other scholars have also researched specific species, demonstrating that these species will migrate northward in the context of climate warming. For instance, Zhao et al. used the MaxEnt model to predict the response of suitable habitat for *jujube* to climate change in China, and the simulation results showed that the centroid of the suitable habitat of *jujube* tended to migrate to higher latitudes, with the habitability zone shifting to the North China Plain and Northeast China Plain [69]. Gao et al. constructed an integrated model using 10 SDM to simulate the potential distribution and niche of *Larix gmelinii* and found that as the concentration of greenhouse gases increased, the changes in the suitable habitat area of *L. gmelinii* occurred and manifested in the more pronounced impact of climate change on *L. gmelinii*, with the continued warming of the climate causing the temperate forest vegetation to migrate toward higher latitudes [70]. The changing trend in the future suitable habitat of *T. sinensis* is consistent with the above studies. The shared socioeconomic pathways (SSPs) proposed in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change indicate that the range and magnitude of global warming will be more pronounced and that temperature has an important influence on the growth of *T. sinensis*. Under the SSP5-8.5 emission scenario, the increase in temperature caused by the increase in emission concentration may lead to more significant changes in the suitable habitat of *T. sinensis*, which may be the main reason for the maximum loss of its high-suitability area in this scenario, as well as the reason for its largest niche shift. The impact of climate warming on the potential geographic distribution of species is mainly manifested in the shift of the potential geographic distribution area toward higher latitudes or higher altitudes, as well as the expansion and contraction of the potential geographic distribution area. The trend of the potentially suitable habitat of *T. sinensis* shifting toward higher latitudes and northeastern regions in future climate change scenarios is consistent with this characteristic.

4.4. Reasons for Differences in Community Diversity of T. sinensis in Different Habitat Areas

In this study, the diversity of the *T. sinensis* community in the moderately suitable habitat was significantly higher than that in the high and less habitable zone, with the lowest diversity in the highly suitable habitat. This may be because the growth of *T. sinensis* is excellent in highly suitable areas, where it absorbs more nutrients, blocks more light, and intercepts more precipitation. The diversity of the *T. sinensis* community in the less suitable habitat was slightly lower than in the moderately suitable habitat. The reason for the lower latitude selected in this study is that although various environmental factors influence changes in species diversity, studies have shown that species diversity generally decreases with increasing latitude [71]. There are studies on the significant differences in plant species diversity due to changes in latitude and elevation from regional to global scales. However, the conclusions of these studies differ to some extent. Some studies have shown that species diversity decreases with increasing latitude and elevation [72], while others have shown that species diversity increases with increasing latitude and elevation or is higher at medium latitudes and elevations [72]. The analysis of the species diversity of the *T. sinensis* community in this study differs to some extent from these research conclusions, and the reason for this may be the differences in the microclimate of *T. sinensis* forests with different habitability zones, which affects the plant species composition of the community. Further in-depth exploration of the species diversity of *T. sinensis* communities with different habitability zones will help us better understand and predict the species characteristics of *T. sinensis*.

4.5. Conservation Strategies for T. sinensis Communities

T. sinensis, an endemic species in China and a relic species from the tertiary period, has significant scientific and economic value and broad application prospects. It is an excellent tree species for ecological restoration and native plant configuration. However, the current *T. sinensis* population faces habitat fragmentation, slow regeneration, and lack of heterogeneity, posing a risk of extinction and thus deserving of protection [73]. The main conservation measures for *T. sinensis* include in situ and ex situ conservation.

(1) In situ conservation: *T. sinensis* is scattered throughout China's subtropical mountainous and tropical regions, with small population sizes. Understanding its population distribution and survival status is inadequate, and anthropogenic disturbances have accelerated the reduction in the population size and individual numbers of *T. sinensis*. This study was conducted in the forested area of Emeishan City, Sichuan Province, and it was found that due to insufficient public awareness and weak conservation efforts, farmers often cut down *T. sinensis* for firewood and charcoal in some mountain areas not yet designated as protected areas. Considering the distribution characteristics of the *T. sinensis* population, it is recommended to establish reserves or protected areas at confirmed *T. sinensis* distribution points. Within the core protection area where *T. sinensis* communities are located in this study, human disturbances are minimal, and hydrothermal conditions are suitable, making it a favorable habitat for *T. sinensis* populations. However, *T. sinensis* in this area is relatively small and does not dominate the community. Moreover, because the designated protection area is large and encompasses many protected species, the survival status of each population is yet to be fully understood, hindering the proposal of further conservation measures. Therefore, it is recommended that additional protected areas for the *T. sinensis* populations studied in this research be established and further monitoring and research based on this foundation be conducted.

(2) Translocation conservation: *T. sinensis*, being shade-tolerant, requires minimal light for 1–2-year-old seedlings, while 3–6-year-old saplings need increasing light and can only survive on forest edges or clearings. It is difficult for them to regenerate naturally into mature forests [74]. In the sample plots of *T. sinensis* in Guanshan, few young seedlings were less competitive in natural forests. Introducing them for more comprehensive survival is a suitable strategy. Using *T. sinensis* for roadside trees or fast-growing forest species expansion is suitable for preserving genetic diversity.

Therefore, in situ analysis of *T. sinensis* is essential. The method of areas was adopted, focusing on the *T. sinensis* habitat. Further research should be conducted in areas such as *T. sinensis* ecology and genetic breeding. However, targeted *T. sinensis* in regions of China should be used to leverage its timber value.

5. Conclusions

This study predicts the potential geographic distribution of *T. sinensis* in China. The results are an essential first step for macro-level planning, crucial for the scientific management of *T. sinensis,* and for providing the species' habitability zones and breeding grounds. The prediction results indicate that the current areas of high and moderate suitability for *T. sinensis* are primarily located in regions such as Chongqing, Hubei, Hunan, and Guizhou. In the context of global warming, the potential distribution area for *T. sinensis* will continue to decrease and migrate toward higher latitude regions. Its climatic ecological niche will gradually shift accordingly. A comparative investigation of the characteristics of *T. sinensis* found that *T. sinensis* communities in moderately suitable areas exhibit rich species diversity and high stability and evenness, with significant differences in plant diversity characteristics under varying habitability zones. Therefore, the Chinese government must implement relevant policies to strengthen the conservation efforts for *T. sinensis*. Additionally, it is necessary to designate key protected areas based on the current distribution range of high and moderate suitability to minimize the impact of human activities on *T. sinensis* communities. However, expanding or contracting the research area may alter the range of environmental factors limiting the growth of *T. sinensis*. Other environmental factors, such as vegetation coverage, also influence the potential geographic distribution of plants. Due to the inability to accurately predict future vegetation coverage in China, it has not been included in predicting *T. sinensis*'s geographic distribution. This means that some of the identified potential distribution areas may not be suitable for *T. sinensis* survival. Climate change indirectly affects plant populations and distribution characteristics by directly impacting ecosystems. In addition to the significant influence of climate change on plants' potential geographic distribution, several other factors, such as agricultural development, rising tourism activities, hydropower development, and other industrial activities, will also significantly impact the potential geographic distribution of plants. Therefore, practical applications must consider local conditions.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/f15091677/s1: Figure S1: 1200 pseudo-existence data points for model simulation (blue points are real existence data points and tan points are pseudo-existence data points); Figure S2: Evaluation scores of the individual models used in the ensemble modeling; Figure S3: Response curves of existence probability of *Tapiscia sinensis* for environmental variable; Figure S4: Contribution of environmental factors to the distribution of *Tapiscia sinensis* in different models; Figure S5: Multifactorial ANOVA for community diversity indices in *Tapiscia sinensis*; Figure S6: Multifactorial ANOVA of plant families, genera, and species in the *Tapiscia sinensis* community; Figure S7: Multifactor ANOVA for relative significance, relative density, relative frequency, and importance values of plants in the *Tapiscia sinensis* community; Table S1: Environmental factors used in the study; Table S2: Environmental variables in model; Table S3: Plant similarities and differences among the nine sample plots in the tertiary habitat area; and Table S4: Relative dominant species in nine sampling plots of the three-level habitat area.

Author Contributions: Conceptualization, M.L.; Methodology, M.L. and X.J.; Software, X.L. and J.Y.; Formal analysis, X.L. and Z.S.; Investigation, L.Y. and K.C.; Data curation, M.L.; Writing—original draft, X.L.; Writing—review and editing, M.L., G.Z., X.J. and Y.H.; Supervision, G.Z. and Y.H.; Project administration, M.L. and X.J.; Funding acquisition, M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Sichuan Science and Technology Program (2023ZYD0102), the Scientific Research Initiation Project of Mianyang Normal University (QD2021A37 and QD2023A01), and the Sichuan Provincial Science and Technology Department Project (2023NSFSC0750).

Data Availability Statement: The data were downloaded from and are freely available in the World Climate Database and the Harmonized World Soil Database.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

References

1. He, J.K. Global low-carbon transition and China's response strategies. *Adv. Clim. Chang. Res.* **2016**, *7*, 204. [CrossRef]
2. Rajkhowa, S.; Sarma, J. Climate change and flood risk, global climate change. *Glob. Clim. Chang.* **2021**, 321–339. [CrossRef]
3. Termaat, T.; Van Strien, A.J.; Van Grunsven, R.H.A.; De Knijf, G.; Bjelke, U.; Burbach, K.; Conze, K.-J.; Goffart, P.; Hepper, D.; Kalkman, V.J.; et al. Distribution trends of European dragonflies under climate change. *Divers. Distrib.* **2019**, *25*, 936. [CrossRef]
4. Bellard, C.; Bertelsmeier, C.; Leadley, P.; Thuiller, W.; Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **2012**, *15*, 365–377. [CrossRef]
5. Zhao, G.; Cui, X.; Sun, J.; Li, T.; Wang, Q.I.; Ye, X.; Fan, B. Analysis of the Distribution Pattern of Chinese Ziziphus Jujuba under Climate Change Based on Optimized Biomod2 and MaxEnt Models. *Ecol. Indic* **2021**, *132*, 108256. [CrossRef]
6. Chen, F.H.; Dong, G.H.; Zhang, D.J.; Liu, X.Y.; Jia, X.; An, C.B.; Ma, M.M.; Xie, Y.W.; Barton, L.; Ren, X.Y.; et al. Agriculture Facilitated Permanent Human Occupation of the Tibetan Plateau after 3600 B.P. *Science* **2015**, *347*, 248–250. [CrossRef]
7. Cao, B.; Bai, C.; Zhang, M.; Lu, Y.; Gao, P.; Yang, J.; Xue, Y.; Li, G. Future Landscape of Renewable Fuel Resources: Current and Future Conservation and Utilization of Main Biofuel Crops in China. *Sci. Total Environ.* **2022**, *806*, 150946. [CrossRef] [PubMed]
8. Brooks, T.M.; Mittermeier, R.A.; Da Fonseca, G.A.B.; Gerlach, J.; Hoffmann, M.; Lamoreux, J.F.; Mittermeier, C.G.; Pilgrim, J.D.; Rodrigues, A.S.L. Global Biodiversity Conservation Priorities. *Science* **2006**, *313*, 58–61. [CrossRef]

9. Avasthi, A. California Tries to Connect Its Scattered Marine Reserves. *Science* **2005**, *308*, 487–488. [CrossRef]
10. Alkemade, R.; Bakkenes, M.; Eickhout, B. Towards a General Relationship between Climate Change and Biodiversity: An Example for Plant Species in Europe. *Reg. Environ. Chang.* **2011**, *11*, 143–150. [CrossRef]
11. Wan, X.R.; Cheng, C.Y.; Bai, D.F.; Zhang, Z.B. Ecological impacts of climate change and adaption strategie. *Bull. Chin. Acad. Sci.* **2023**, *38*, 518–527. [CrossRef]
12. Clark, P.U.; Shakun, J.D.; Marcott, S.A.; Mix, A.C.; Eby, M.; Kulp, S.; Levermann, A.; Milne, G.A.; Pfister, P.L.; Santer, B.D.; et al. Consequences of Twenty-First-Century Policy for Multi-Millennial Climate and Sea-Level Change. *Nat. Clim. Chang.* **2016**, mboxemph6, 360–369. [CrossRef]
13. Li, X.Z.; Liu, X.D.; Ma, H.Y. Regulation of human activities on orbital-scale precipitation in global monsoon regions. *J. Earth Environ.* **2023**, *14*, 557–572. [CrossRef]
14. Zhao, Z.C.; Luo, Y.; Huang, J.B. The detection of the CMIP5 climate model to see the development of CMIP6 earth system models. *Clim. Chang. Res.* **2018**, *14*, 643–648. [CrossRef]
15. Zhu, H.; Jiang, Z.; Li, L. Projection of Climate Extremes in China, an Incremental Exercise from CMIP5 to CMIP6. *Sci. Bull.* **2021**, *66*, 2528–2537. [CrossRef] [PubMed]
16. Fan, Z.; Zhou, B.; Ma, C.; Gao, C.; Han, D.; Chai, Y. Impacts of Climate Change on Species Distribution Patterns of *Polyspora* Sweet in China. *Ecol. Evol.* **2022**, *12*, e9516. [CrossRef]
17. Huang, D.; An, Q.; Huang, S.; Tan, G.; Quan, H.; Chen, Y.; Zhou, J.; Liao, H. Biomod2 Modeling for Predicting the Potential Ecological Distribution of Three Fritillaria Species under Climate Change. *Sci. Rep.* **2023**, *13*, 18801. [CrossRef]
18. Sharma, M.K.; Ram, B.; Chawla, A. Ensemble Modelling under Multiple Climate Change Scenarios Predicts Reduction in Highly Suitable Range of Habitats of *Dactylorhiza Hatagirea* (D. Don) Soo in Himachal Pradesh, Western Himalaya. *S. Afr. J. Bot.* **2023**, *154*, 203–218. [CrossRef]
19. Wu, Y.M.; Shen, X.L.; Tong, L.; Lei, F.W.; Mu, X.Y.; Zhang, Z.X. Impact of Past and Future Climate Change on the Potential Distribution of an Endangered Montane Shrub *Lonicera Oblata* and Its Conservation Implications. *Forests* **2021**, *12*, 125. [CrossRef]
20. Xie, C.; Chen, L.; Li, M.; Jim, C.Y.; Liu, D. BIOCLIM Modeling for Predicting Suitable Habitat for Endangered Tree *Tapiscia sinensis* (Tapisciaceae) in China. *Forests* **2023**, *14*, 2275. [CrossRef]
21. Abhin Sukumar, P.; Sanjo Jose, V.; Ramesh, S.V.; Bhat, R. Predicting current and future climate suitability for arecanut (*Areca catechu* L.) in India using ensemble model. *Heliyon* **2024**, *4*, e26382. [CrossRef]
22. Wen, X.; Zhao, G.; Cheng, X.; Chang, G.; Dong, X.; Lin, X. Prediction of the Potential Distribution Pattern of the Great Gerbil (*Rhombomys Opimus*) under Climate Change Based on Ensemble Modelling. *Pest. Manag. Sci.* **2022**, *78*, 3128–3134. [CrossRef]
23. Thuiller, W.; Lafourcade, B.; Engler, R.; Araújo, M.B. BIOMOD—A Platform for Ensemble Forecasting of Species Distributions. *Ecography* **2009**, *32*, 369–373. [CrossRef]
24. Duque-Lazo, J.; Navarro-Cerrillo, R.M.; Van Gils, H.; Groen, T.A. Forecasting Oak Decline Caused by Phytophthora Cinnamomi in Andalusia: Identification of Priority Areas for Intervention. *For. Ecol. Manag.* **2018**, *417*, 122–136. [CrossRef]
25. Hao, T.; Elith, J.; Guillera-Arroita, G.; Lahoz-Monfort, J.J. A Review of Evidence about Use and Performance of Species Distribution Modelling Ensembles like BIOMOD. *Divers. Distrib.* **2019**, *25*, 839–852. [CrossRef]
26. Jian, W.L.; Hai, B.J.; Ming, J.X.; Chuan, T.S.; Chun, G.H.; Hong, F.B.; Lian, X.S. Functional characteristics and habitat suitability of threatened birds in northeastern China. *Ecol. Evol.* **2024**, *6*, e11550. [CrossRef]
27. Zhou, X.J.; Ren, X.L.; Liu, W.Z. Genetic Diversity of SSR Markers in Wild Populations of *Tapiscia sinensis*, an Endangered Tree Species. *Biochem. Syst. Ecol.* **2016**, *69*, 1–5. [CrossRef]
28. Wang, Q.; Chen, J.R.; Xiong, Y.; Liu, Z.; Liu, W.Q.; Liao, W.B. Characteristics of *Tapiscia sinensis* Community in Guanshan Nature Reserve, Jiangxi and Its Protection Strategy. *Subtrop. Plant Sci.* **2021**, *50*, 125–132.
29. Li, D.J.; Hu, T.; Yu, D.H.; Zheng, D.M.; Gu, D.H.; Liao, J. Analysis of Population Structure Dynamics of *Tapiscia sinensis* in Leigongshan Nature Reserve. *Rural. Econ. Sci.-Technol.* **2022**, *33*, 54–57.
30. Zong, S.; Yang, Z.; Tao, J. Study on the Ecological Characteristics of *Tapiscia sinensis*. *Chin. J. Plant Ecol.* **1985**, *9*, 192.
31. Xin, G.L.; Liu, J.Q.; Liu, J.; Ren, X.L.; Du, X.M.; Liu, W.Z. Anatomy and RNA-Seq Reveal Important Gene Pathways Regulating Sex Differentiation in a Functionally Androdioecious Tree, *Tapiscia sinensis*. *BMC Plant Biol.* **2019**, *19*, 554. [CrossRef] [PubMed]
32. Lü, W.; Liu, W. Pollination Biology in Androdioecious Species *Tapiscia sinensis* (Staphyleaceae). *Chin. Bull. Bot.* **2010**, *45*, 713. [CrossRef]
33. Zhang, J.; Li, Z.; Fritsch, P.W.; Tian, H.; Yang, A.; Yao, X. Phylogeography and Genetic Structure of a Tertiary Relict Tree Species, *Tapiscia sinensis* (Tapisciaceae): Implications for Conservation. *Ann. Bot.* **2015**, *116*, 727–737. [CrossRef] [PubMed]
34. Zhou, X.J.; Wang, Y.Y.; Xu, Y.N.; Yan, R.S.; Zhao, P.; Liu, W.Z. De Novo Characterization of Flower Bud Transcriptomes and the Development of EST-SSR Markers for the Endangered Tree *Tapiscia sinensis*. *Int. J. Mol. Sci.* **2015**, *16*, 12855–12870. [CrossRef] [PubMed]
35. Xie, C.P. A Review of Research Advances in Rare and Endangered Plant *Tapiscia sinensis*. *Subtrop. Plant Sci.* **2006**, *35*, 71–74.
36. Suryani, F.; Bakhtra, D.D.A.; Fajrina, A. Cytotoxic Activity of Endophytic Fungus against HeLa Cells (Cervical Cancer Cells): A Article Review. *Asian J. Pharm. Res. Dev.* **2022**, *10*, 25–28. [CrossRef]
37. Fick, S.E.; Hijmans, R.J. World Clim 2: New 1-Km Spatial Resolution Climate Surfaces for Global Land Areas. *Int. J. Climatol.* **2017**, *37*, 4302–4315. [CrossRef]

38. Sun, C.; Zuo, J.; Shi, X.; Liu, X.; Liu, H. Diverse Inter-Annual Variations of Winter Siberian High and Link with Eurasian Snow in Observation and BCC-CSM2-MR Coupled Model Simulation. *Front. Earth Sci.* **2021**, *9*, 761311. [CrossRef]
39. Milovac, J.; Ingwersen, J.; Warrach-Sagi, K. Global Top Soil Texture Data Compatible with the WRF Model Based on the Harmonized World Soil Database (HWSD) at 30 Arc-Second Horizontal Resolution Version 1.21. 2018. Available online: https://www.wdc-climate.de/ui/entry?acronym=WRF_NOAH_HWSD_world_TOP_ST_v121 (accessed on 18 March 2024).
40. Tao, W.; Ting, J.Z.; Wei, B.A.; Zai, L.W.; Chuan, R.L. Predicting the Potential Geographic Distribution of Invasive Freshwater Apple *SnailPomacea canaliculate* (Lamarck, 1819) under Climate Change Based on Biomod2. *Agronomy* **2024**, *14*, 650. [CrossRef]
41. Yang, J.; Huang, Y.; Su, M.; Liu, M.; Yang, J.; Wu, Q. Spatial Distribution Patterns of the Key Afforestation Species *Cupressus* funebris: Insights from an Ensemble Model under Climate Change Scenarios. *Forests* **2024**, *15*, 1280. [CrossRef]
42. Elith, J.; Graham, C.H.; Anderson, R.P.; Dudík, M.; Ferrier, S.; Guisan, A.; Hijmans, R.J.; Huettmann, F.; Leathwick, J.R.; Lehmann, A. Novel Methods Improve Prediction of Species' Distributions from Occurrence Data. *Ecography* **2006**, *29*, 129–151. [CrossRef]
43. Allouche, O.; Tsoar, A.; Kadmon, R. Assessing the Accuracy of Species Distribution Models: Prevalence, Kappa and the True Skill Statistic (TSS). *J. Appl. Ecol.* **2006**, *43*, 1223–1232. [CrossRef]
44. Di Cola, V.; Broennimann, O.; Petitpierre, B.; Breiner, F.T.; D'Amen, M.; Randin, C.; Engler, R.; Pottier, J.; Pio, D.; Dubuis, A.; et al. Ecospat: An R Package to Support Spatial Analyses and Modeling of Species Niches and Distributions. *Ecography* **2017**, *40*, 774–787. [CrossRef]
45. Wang, B.S.; Yu, S.X.; Peng, S.L. *Handbook of Plant Community Experiment*; Guangdong Higher Education Press: Guangzhou, China, 1996; pp. 1–15.
46. Li, B.; Yang, C.; Lin, P. *Ecology*; Higher Education Press: Beijing, China, 2000; p. 127.
47. Wang, Y.F.; Yu, S.X.; Liu, W.Q. A new species diversity index and its fractal analysis. *Acta Phytoecol. Sin.* **2002**, *26*, 391–395.
48. Rushing, C.S.; Rubenstein, M.; Lyons, J.E.; Runge, M.C. Using Value of Information to Prioritize Research Needs for Migratory Bird Management under Climate Change: A Case Study Using Federal Land Acquisition in the United States. *Biol. Rev.* **2020**, *95*, 1109–1130. [CrossRef] [PubMed]
49. Wang, H.; Zhi, F.; Zhang, G. Predicting Impacts of Climate Change on Suitable Distribution of Critically Endangered Tree Species *Yulania zenii* (W. C. Cheng) D. L. Fu in China. *Forests* **2024**, *15*, 883. [CrossRef]
50. Carosi, A.; Ghetti, L.; Padula, R.; Lorenzoni, M. Population Status and Ecology of the *Salmo Trutta* Complex in an Italian River Basin under Multiple Anthropogenic Pressures. *Ecol. Evol.* **2020**, *10*, 7320–7333. [CrossRef]
51. Karypidou, M.C.; Almpanidou, V.; Tompkins, A.M.; Mazaris, A.D.; Gewehr, S.; Mourelatos, S.; Katragkou, E. Projected Shifts in the Distribution of Malaria Vectors Due to Climate Change. *Clim. Chang.* **2020**, *163*, 2117–2133. [CrossRef]
52. Yang, J.; Jiang, X.; Ma, Y.; Liu, M.; Shama, Z.; Li, J.; Huang, Y. Potential Global Distribution of *Setaria Italica*, an Important Species for Dryland Agriculture in the Context of Climate Change. *PLoS ONE* **2024**, *19*, e0301751. [CrossRef]
53. Liu, M.; Yang, L.; Su, M.; Gong, W.; Liu, Y.; Yang, J.; Huang, Y.; Zhao, C. Modeling the Potential Distribution of the Energy Tree Species *Triadica Sebifera* in Response to Climate Change in China. *Sci. Rep.* **2024**, *14*, 1220. [CrossRef]
54. Elith, J.; Leathwick, J.R. Species Distribution Models: Ecological Explanation and Prediction across Space and Time. *Annu. Rev. Ecol. Evol. Syst.* **2009**, *40*, 677–697. [CrossRef]
55. Xu, Z.L.; Peng, H.H.; Peng, S.Z. The development and evaluation of species distribution models. *Acta Ecol. Sin.* **2015**, *35*, 557–567.
56. Mi, C.; Ma, L.; Yang, M.; Li, X.; Meiri, S.; Roll, U.; Oskyrko, O.; Pincheira-Donoso, D.; Harvey, L.P.; Jablonski, D. Global Protected Areas as Refuges for Amphibians and Reptiles under Climate Change. *Nat. Commun.* **2023**, *14*, 1389. [CrossRef]
57. Huang, L.; Li, S.; Huang, W.; Xiang, H.; Jin, J.; Oskolski, A.A. Glacial Expansion of Cold-Tolerant Species in Low Latitudes: Megafossil Evidence and Species Distribution Modelling. *Natl. Sci. Rev.* **2023**, *10*, nwad038. [CrossRef] [PubMed]
58. Jiang, P.; Jiang, J.; Yang, C.; Gu, X.; Huang, Y.; Liu, L. Climate Change Will Lead to a Significant Reduction in the Global Cultivation of Panicum Milliaceum. *Atmosphere* **2023**, *14*, 1297. [CrossRef]
59. Pecchi, M.; Marchi, M.; Burton, V.; Giannetti, F.; Moriondo, M.; Bernetti, I.; Bindi, M.; Chirici, G. Species Distribution Modelling to Support Forest Management. A Literature Review. *Ecol. Modell.* **2019**, *411*, 108817. [CrossRef]
60. 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]
61. Naimi, B.; Hamm, N.A.S.; Groen, T.A.; Skidmore, A.K.; Toxopeus, A.G. Where Is Positional Uncertainty a Problem for Species Distribution Modelling? *Ecography* **2014**, *37*, 191–203. [CrossRef]
62. Wisz, M.S.; Hijmans, R.J.; Li, J.; Peterson, A.T.; Graham, C.H.; Guisan, A.; NCEAS Predicting Species Distributions Working Group. Effects of Sample Size on the Performance of Species Distribution Models. *Divers. Distrib.* **2008**, *14*, 763–773. [CrossRef]
63. Austin, M.P. Spatial Prediction of Species Distribution: An Interface between Ecological Theory and Statistical Modelling. *Ecol. Modell.* **2002**, *157*, 101–118. [CrossRef]
64. Natale, E.; Zalba, S.M.; Reinoso, H. Presence—Absence versus Invasive Status Data for Modelling Potential Distribution of Invasive Plants: Saltcedar in Argentina. *Écoscience* **2013**, *20*, 161–171. [CrossRef]
65. Thomas, C.D.; Cameron, A.; Green, R.E.; Bakkenes, M.; Beaumont, L.J.; Collingham, Y.C.; Erasmus, B.F.; De Siqueira, M.F.; Grainger, A.; Hannah, L. Extinction Risk from Climate Change. *Nature* **2004**, *427*, 145–148. [CrossRef] [PubMed]
66. Teng, L. Fruit Development of *Tapiscia sinensis*. Master's Dissertation, Northwest University, Xi'an, China, 2009.
67. Meng, C.J. Measuring Method Selection of Photosynthesis In Vitro and Photosynthetic Eco-Physiological Characteristics of 6 Kinds of Rare and Endangered Plants in Qinling Mountains. Doctoral Dissertation, Northwest University, Xi'an, China, 2021.

68. Thuiller, W.; Lavorel, S.; Araújo, M.B.; Sykes, M.T.; Prentice, I.C. Climate Change Threats to Plant Diversity in Europe. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 8245–8250. [CrossRef]
69. Zhao, G.; Cui, X.Y.; Wang, Z.; Jing, H.L.; Fan, B.G. Prediction of Potential Distribution of Ziziphus jujuba var. spinosa in China under Context of Climate Change. *Sci. Silvae Sin.* **2021**, *57*, 158–168. [CrossRef]
70. Gao, M.; Zhao, G.; Zhang, S.; Wang, Z.; Wen, X.; Liu, L.; Zhang, C.; Tie, N.; Sa, R. Priority Conservation Area of Larix Gmelinii under Climate Change: Application of an Ensemble Modeling. *Front. Plant Sci.* **2023**, *14*, 1177307. [CrossRef]
71. Brown, J.H.; Lomolino, M.V. *Biogeography*; Sinuer Associates Publishers: Sunderland, MA, USA, 1998.
72. Yuan, H.Y.; Sheng, R.; Hu, H.-F.; Chen, A.-P.; Ji, C.-J.; Zhu, B.; Zuo, W.-Y.; Li, X.-R.; Shen, H.-H.; Wang, Z.-H.; et al. Plant Species Richness of Alpine Grasslands in Relation to Environmental Factors and Biomass on the Tibetan Plateau. *Biodivers. Sci.* **2004**, *12*, 200. [CrossRef]
73. Yang, K. Carbohydrate Metabolism and Gene Regulationduring Anther Development in Anandrodioecious Tree, *Tapiscia sinensis*. Ph.D. Thesis, Northwest University, Xi'an, China, 2017.
74. Wang, S.Y.; Liu, X.J.; Zhou, P.Z.; Liu, Q.L. Preliminary Report on the Ex Situ Conservation Experiment of *Tapiscia sinensis*. *Shaanxi For. Sci. Technol.* **1987**, *2*, 17–18.