Predicting Current and Future Habitat Suitability of Toxicodendron succedaneum in China Under Climate Change Using MaxEnt

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Abstract. Climate change is expected to alter the geographic distributions of many tree species, posing substantial challenges to biodiversity conservation and the sustainable management of biological resources. Toxicodendron succedaneum (L.) Kuntze is an economically and medicinally important tree species widely distributed across East and Southeast Asia, but its potential response poor understood of future climate change in China. This study by using the MaxEnt algorithm to predict the current and future habitat suitability of T. succedaneum under the SSP370 for the future periods during 2011–2040, 2041–2070, and 2071–2100. The model was developed by 511 spatially filtered occurrence records and eight chosen environmental variables. Model have good performance, the area under the receiver operating characteristic curve (AUC) around 0.802 ± 0.004, indicating it's had a reliable predictive ability for our research. However, bio14 emerged as the dominant environmental driver under future climate scenarios, suggesting that dry-season water availability will increasingly constrain species distributions as climate change intensifies drought stress. Currently, the most suitable habitats are mainly concentrated in the southern and southeastern parts of China. Future predictions indicate that the habitats will undergo redistribution rather than significant loss. By the end of the 21st century, the highly suitable areas will expand slightly, but they will still mainly be concentrated in the southern coastal regions. The findings provide important scientific evidence for climate-adaptive conservation planning and highlight the importance of species distribution modelling in guiding the conservation of economically important tree species under future climate change.

Keywords: Toxicodendron succedaneum, Climate change, Species distribution modeling.

1. Introduction

Toxicodendron succedaneum (L.) Kuntze is a deciduous dioecious tree species in the family Anacardiaceae. Mature individuals typically will grow 6–10 meters tall and produce alternate, pinnately compound leaves with 9–15 smooth leaflets [1]. Like many species of the Anacardiaceae family, the species produces a resinous latex containing urushiol, this substance is known to cause severe allergic contact dermatitis in humans [2]. T. succedaneum is widely distributed across Asia, including China, Japan, India, Myanmar, Thailand, Vietnam, Taiwan and Malaysia. In these regions, it mainly grows in temperate to subtropical environments, commonly found in forest edges, disturbed areas of forest land, and mixed forest habitats [1-3].

Toxicodendron succedaneum has value on economic, cultural, and medicinal importance etc. Its fruits are used to produce sumac wax, traditionally valued for candle making, while its resinous latex is an important raw material for lacquerware, handicraft decoration, adhesives, insulation materials, polishes, and painting applications [1-4]. In traditional medicine, different parts of T. succedaneum have been used to treat asthma, cough, fever, diarrhea, dysentery, and liver disorders [2]. In addition, bioactive compounds isolated from the species have shown antioxidant, antibacterial, antitumor, and antiviral activities [5]. These things make T. succedaneum become an important species for traditional industries and local livelihoods across parts of Asia.

Although the IUCN has classified T. succedaneum as a "least concern species", this assessment may not fully reflect the real situation of this plant, especially in China. In the Asia, the population of T. succedaneum may be affected by factors such as habitat loss, land development, agricultural expansion, construction of human settlements, road building, urbanization, and forest degradation [1].

These pressures reduce suitable forest, subtropical and temperate habitats, leading to damage of wild populations and limiting the natural regeneration capacity [1, 6]. What more, if the collection of fruits, resins, or medicinal plant parts lacks management or is unsustainable, it may further exacerbate the pressure on the wild populations [6]. Therefore, it is necessary to conduct regional habitat suitability and protection risk assessments to more accurately understand the current situation of T. succedaneum in China.

During these years, climate change has become a much more significant problem affecting the distribution of plant species, especially for those species whose habitats have been impacted by temperature, precipitation, and seasonal climate conditions [7, 8]. Changes in temperature, alterations in rainfall patterns, increased frequency of droughts, and occurrence of extreme weather events may affect the success rate of seed germination, the survival of seedlings, phenological periods, population persistence, and overall habitat suitability [7]. For T. succedaneum, rising temperatures and changes in precipitation patterns may affect the distribution of suitable forest, subtropical, and tropical habitats, causing the distribution range to shrink in some areas, while allowing it to expand to higher latitudes and altitudes, or causing changes in distribution locations in other areas. These changes are of great significance for China's species protection planning, sustainable utilization, and management of economically valuable populations.

Species distribution models (SDMs), also known as habitat suitability models or ecological niche models, are a quantitative analytical framework that predicts the potential geographical distribution range of species under climate change scenarios by correlating species distribution data with environmental covariates [9–11]. SDMs combine georeferenced species distribution records with climate, biophysical, and geographical predictor variables in order to quantify the environmental conditions that are suitable for the survival of the species and to produce maps that depict the present and future predicted climate conditions of the species' spatial habitat suitability [12]. These models are extensively used in conservation biology and have the following core applications: delineating the suitable habitats, predicting the changes in the biogeographic distribution patterns, to assess the sensitivity of the species for the climate disturbances and to support the evidence-based conservation planning and priority setting [11,13]. If the climate variables are used as the main predictive input, the output is classified as a climate envelope model. These SDMs are focused in the definition of the basic climate niche of the species and simulate the changes in the ecological niche dynamics under the different climate scenarios [14]. The output results of these models can also be used to quantify and evaluate the situations as for example the habitat contraction, the biotic distrbution reset and the population persistance in the context of the ongoing environmental changes [15].

The current research on T. succedaneum mainly is on its biological characteristics, medicinal value and genetic information [1, 2, 5]. The response of T. succedaneum to future climate changes in China is not clear [1, 2, 5]. Nowadays, there is not any assessment has been research on the habitat suitability of T. succedaneum in China, the conservation status and the impact of climate change to its distribution. Without this knowledge, we cannot find out which populations are vulnerable, predict the future of habitat changes, and propose appropriate conservation strategy for this species.

In order to remedy these two deficiencies, the main purpose of this study is to estimate the possible distribution range of T. succedaneum in China under different climate change scenarios. In this study, we will try to: (1) find out the important environment variables on current distribution of T. succedaneum; (2) predict the change of the area of suitable habitats under future climate scenario; (3) find the priority area for protection and sustainable management. Here, we suppose that in the background of the future climate warming, the area of suitable habitats will reduce, the distribution center will shift to higher latitude or higher altitude, the factors related to precipitation will have more impact on the habitat suitability than the factors related to temperature.

2. Methods

2.1. Species occurrence data

Occurrence records of Toxicodendron succedaneum were compiled from the Global Biodiversity Information Facility (GBIF; https://doi.org/10.15468/dl.xyx7v8) and published scientific literature, obtaining a total of 1597 points. We confirmed the species taxonomic name and its native distribution areas using Plants of the World Online and the Flora of China databases. Consequently, we cleaned the distribution records by deleting duplicate coordinates, those with missing coordinates, points located in the ocean, records with obvious georeferencing errors, and points outside the identified native study area. After this cleaning step, we were left with 533 records. To reduce spatial sampling bias and spatial autocorrelation, occurrence records were thinned using the spThin package in R [16] with a minimum distance of 500 m between retained points, resulting in 511 points used for modelling. All coordinates were standardized to WGS 1984 before modelling, and a distribution map was then drawn in ArcGIS 10.8 (Figure 1).

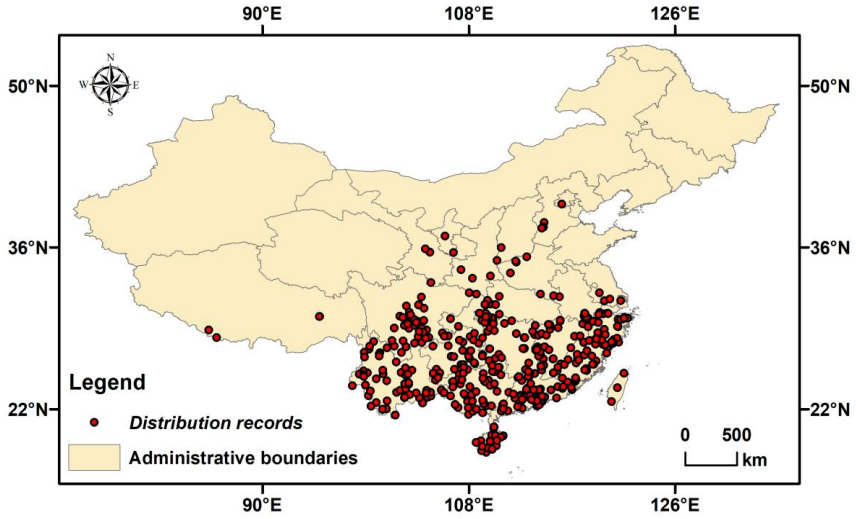


Figure 1. Geographic distribution points of the study species based on occurrence records (Picture credit: Origina)

To identify our calibration area, an alpha hull was generated around the thinned occurrence records using the alphahull package in R, and a 200 km buffer was added to allow for potential dispersal [17]. This buffered alpha hull was used to clip environmental variables. Defining the study area helped reduce overprediction and avoid training the model using regions that were environmentally or geographically unrealistic for the species [18].

2.2. Environmental data

We download 22 kinds of environmental variable data that may determine the distribution of T. succedaneum in Table 1. These included 19 different bioclimatic variables in our research, such as elevation, slope, and forest cover. Current bioclimatic variables were obtained from CHELSA for the 1981–2010 baseline period at 1 km resolution [19]. Elevation was downloaded from WorldClim [20], while slope was derived from the elevation raster tool using the Spatial Analyst toolbox in the ArcGIS version 10.8. Additionally, one forest variable was downloaded from the Global Climate Analysis and Modeling (GCAM-Demeter) database [21]. Future bioclimatic variables were downloaded from CHELSA under SSP370 for three future periods from 2011–2040, 2041–2070, and 2071–2100. SSP370 represents a moderate to high emission pathway and is commonly used to assess future climate impacts on species distributions [22]. Elevation, slope, and forest cover were kept constant across future periods. We obtained this information from the global climate model (GCM) from the Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2–0) [23]. All raster layers were resampled to the same 1 km resolution.

Table 1. Environmental variables used in modeling the distribution of Toxicodendron succedaneum. The tables show the variable abbreviations and meanings, measurement units, source database, and references cited. Variables with asterisks were selected for modelling.

Code	Variable Name	Measurement	Source	Reference
bio1	Annual mean temperature	°C	CHELSA	[19]
bio2*	Mean diurnal temperature range	°C	CHELSA	[19]
bio3*	Isothermality	%	CHELSA	[19]
bio4	Temperature seasonality	°C	CHELSA	[19]
bio5	Maximum temperature of warmest month	°C	CHELSA	[19]
bio6	Minimum temperature of coldest month	°C	CHELSA	[19]
bio7	Temperature annual range	°C	CHELSA	[19]
bio8*	Mean temperature of wettest quarter	°C	CHELSA	[19]
bio9	Mean temperature of driest quarter	°C	CHELSA	[19]
bio10	Mean temperature of warmest quarter	°C	CHELSA	[19]
bio11	Mean temperature of coldest quarter	°C	CHELSA	[19]
bio12	Annual precipitation	mm	CHELSA	[19]
bio13	Precipitation of wettest month	mm	CHELSA	[19]
bio14*	Precipitation of driest month	mm	CHELSA	[19]
bio15*	Precipitation seasonality	%	CHELSA	[19]
bio16	Precipitation of wettest quarter	mm	CHELSA	[19]
bio17	Precipitation of driest quarter	mm	CHELSA	[19]
bio18*	Precipitation of warmest quarter	mm	CHELSA	[19]
bio19	Precipitation of coldest quarter	mm	CHELSA	[19]
elev	Elevation	m	WorldClim	[20,24]
slop*	Slope	(º)	WorldClim	[20,24]
Frt*	Forest	%	GCAM-Demeter	[21]

To reduce multicollinearity, Pearson correlation and Variance Inflation Factor (VIF) analyses were conducted before modelling by the vifstep function in the usdm R package (ArcGIS version 1.1-18) [25]. Variables with strong correlation and high VIF values were removed, while ecologically meaningful predictors were retained. From the initial 22 variables, eight predictors were selected for the MaxEnt model. This reduced overfitting and improved ecological interpretation of the model outputs [22]. The selected variables were clipped to the calibration area and converted to ASCII format for MaxEnt analysis.

2.3. Species distribution modelling

After the data preparation and collection, we used Maxent 3.4.4 [26] with the jackknife procedure to calculate the contributions of the data and to building model current distributions of T. succedaneum. Maxent is one of the most widely applied auto learning by machine algorithms for modelling species distributions using presence-only occurrence data. Maxent relies on the maximum entropy machine-learning algorithm to estimate a probability surface that maximizes the entropy subject to the constraints imposed by all and high-yielding occurrence data. Maxent has been widely use to model current and potential distribution of tree species [22,27,28]. The model calibration was done with the logistic output, that gives as the habitat suitability values from 0 to 1 and can be directly ecologically interpreted as the relative probability of suitable environmental conditions.

We set the maximum number of background points to 10,000 and limited the maximum number of iterations to 500. And the random seed selection function was able to achive , which made each cross-validation repetition can random assign the occurrence records. In the molding parts, we used the cross-validation method for model training. We get the model repetition with five-fold cross validation [29]. In each round, four subsets are used for the model training, and the remained one subset is used as independent test data. The use of cross validation method can make a robust assessment for the model performance and can reduce the potential biases coming from one training-test split. Response curves are generated for each environmental variable to show the relationship

between the predicted values and the habitat suitability, while keeping all the other variables are constant. Then a bootstrap analysis was done to assess the relative importance of each environmental predictor. Model accuracy was assessed using the Receiver Operating Characteristic curve (ROC curve) and the Area Under the Curve (AUC). An AUC value of 0.5 means random prediction, 0.7-0.8 indicates good performance [30]. In the molding part, we set the AUC of each model more than 0.7, and we set the maximum number of background points to be 10000.

The continuous logical suitability output generated by MaxEnt was exported as ASCII raster files, which corresponded to each climate scenario respectively. Then, these files were imported to ArcGIS 10.8, converted to GeoTIFF format and projected to the WGS 1984 coordinate system. These outputs were used to produce maps and spatial analysis. We used the reclassification tool in ArcGIS to classify these outputs into five types: highly suitable, moderately suitable, low suitable and unsuitable. In this study, we classified these suitable areas for this study using the Jenks natural segmentation method and then we calculated the area of each category in square kilometers for the current period and the next three periods. The analysis was completed using R programming language and ArcGIS 10.8 software, and the modeling was using the MaxEnt.

3. Results

3.1. Model Performance

The MaxEnt model showed good predictive performance in estimating the current and future potential distribution of T. succedaneum in China, with an AUC value of 0.802 ± 0.004 (Figure 2-4). This indicates that the model reliably distinguished suitable from unsuitable habitats for T. succedaneum. Although the value was lower than the excellent AUC values reported in some recent MaxEnt studies, it still falls within the good performance range and is acceptable for a widespread tree species with broad environmental tolerance. Similar predictive performances have been reported for woody plant species modeled using MaxEnt in East Asia and other subtropical regions. The omission curve also showed close agreement between predicted and observed omission rates, indicating stable model calibration and limited overfitting, consistent with recommendations for evaluating MaxEnt performance.

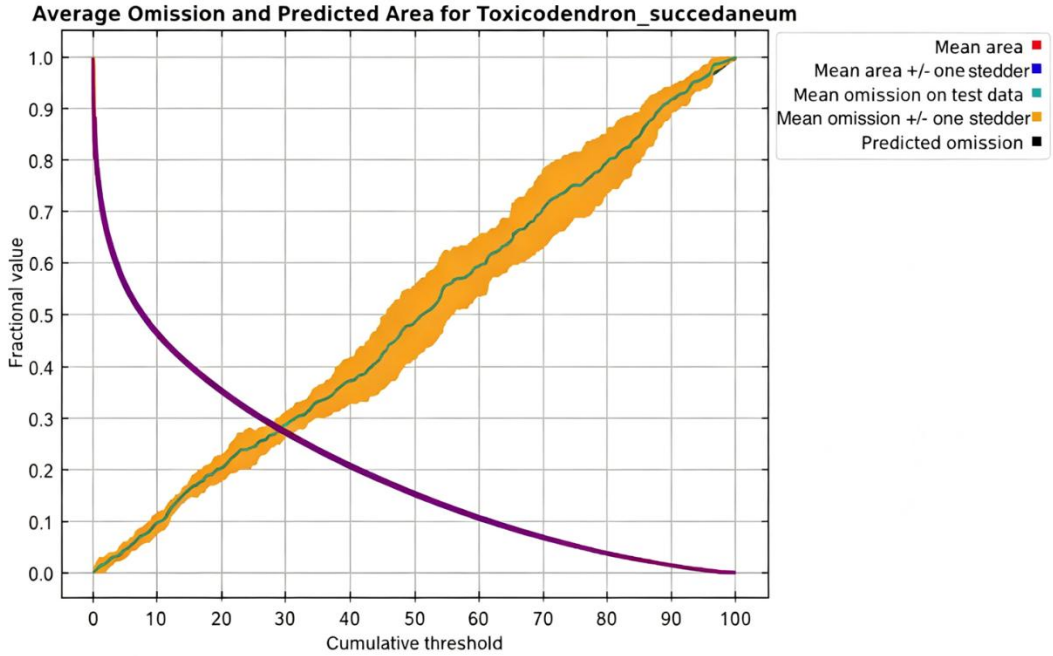


Figure 2. Omission Rate and Predicted Area for Toxicodendron succedaneum under Current Climatic Conditions (Picture credit: Origina)

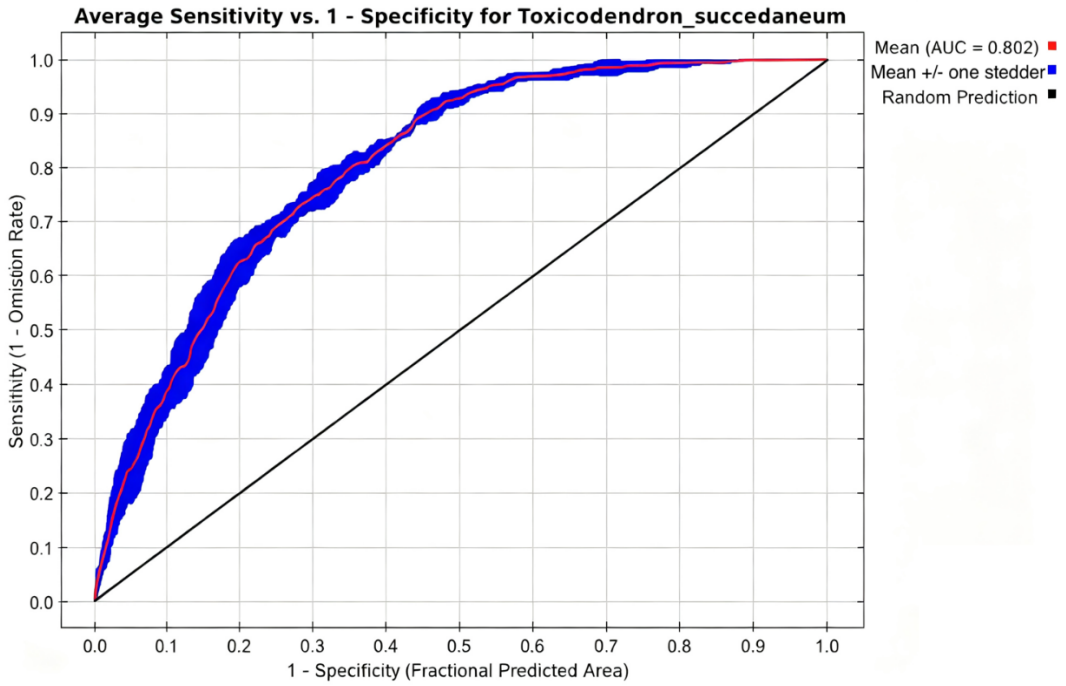


Figure 3. Receiver Operating Characteristic (ROC) Curve for Toxicodendron succedaneum under Current Climatic Conditions (Picture credit: Origina)

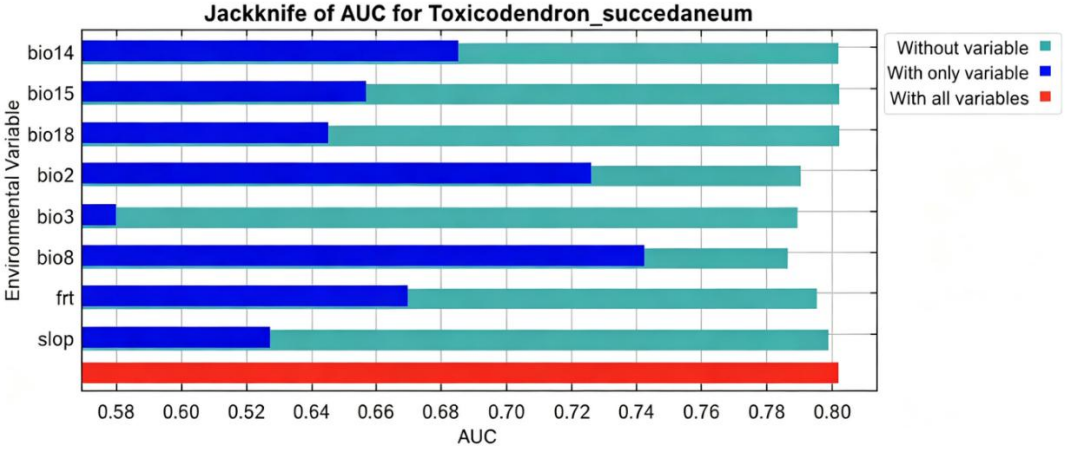


Figure 4. Jackknife Test of Variable Importance for Toxicodendron succedaneum under Current Climatic Conditions (Picture credit: Origina)

3.2. Key Environmental Drivers of Habitat Suitability

The distribution of T. succedaneum was mainly controlled by temperature and precipitation variables. In the current period, mean temperature of the wettest quarter (bio8) had the highest contribution (27.6%), followed by precipitation of the driest month (bio14; 26.9%), mean diurnal range (bio2; 14.9%), and forest cover (14.5%). Slope contributed 9.1%, while bio3, bio15, and bio18 contributed less (Table 2; Figure 6). Permutation importance (Table 2) showed that bio2 was the most influential variable across all periods, indicating that daily temperature stability is important for the species. The jackknife test further confirmed that bio8, bio14, and bio2 are the most contributing variables in the distribution of the species (Figure 4).

Table 2. Percent contribution and permutation importance of environmental variables influencing the distribution of the study species for the current period in the MaxEnt model. Definitions of abbreviations are presented in Table 1.

Variable	Percent contribution	Permutation importance
bio8	27.6	23.8
bio14	26.9	6.2
bio2	14.9	31.6
frt	14.5	8.2
slop	9.1	7.6
bio3	4.5	10.7
bio15	1.9	10.8
bio18	0.5	1

In contrast to the current period, bio14 (precipitation of the driest month) became the dominant environmental driver in the three future scenarios, followed by bio8, frt, and then bio2 (Figure 5). This shift suggests that while current species distribution is primarily constrained by temperature during the growing season, future habitat suitability will be increasingly limited by dry season water availability as climate change intensifies drought stress.

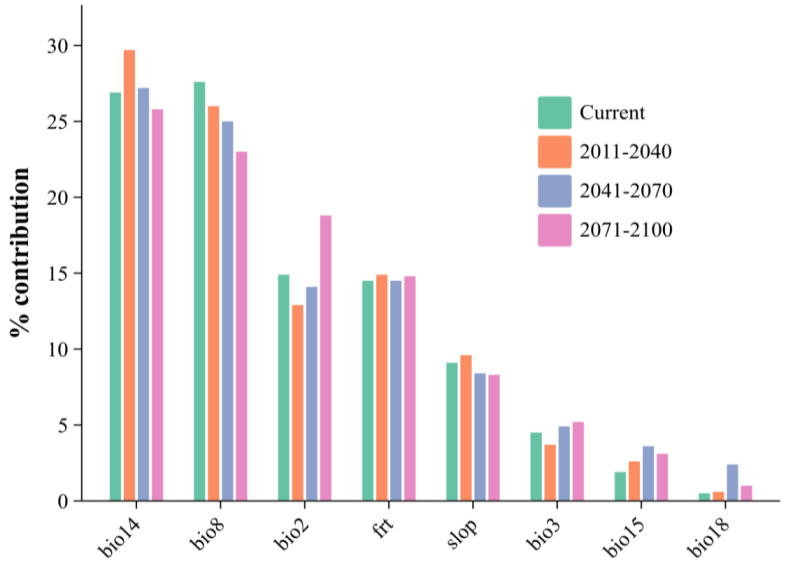


Figure 5. Percentage contributions importance of the eight selected environmental variables in predicting the distribution of *Toxicodendron succedaneum* in the current period. Abbreviations: bio14, precipitation of driest month; bio8, mean temperature of the wettest quarter; bio2, mean diurnal temperature range; frt, forest; slop, slope; bio3, isothermality; bio15, precipitation seasonality; bio18, precipitation of the warmest quarter (Picture credit: Origina)

The response curves suggest that T. succedaneum prefers warm and humid environments but becomes less suitable under extreme climatic conditions (Figure 4). Suitability increased with warm wet-season temperature, declined under high diurnal temperature range, and responded strongly to dry-season precipitation. These patterns are consistent with other MaxEnt studies, indicating that precipitation and temperature have a strong influence on the distribution of trees in China's subtropical forests. The contribution of forest coverage also shows that merely having suitable climate is not enough; appropriate forest habitats are still crucial for the persistence of species. During the driest months when precipitation is low, the suitability of T. succedaneum remains at a relatively high level (Bio14); however, when the precipitation exceeds approximately 70 millimeters, its suitability suddenly drops and then only briefly increases afterwards. This pattern indicates that T. succedaneum has adapted to the drier regions in the middle of the year. During this period, if there is excessive rainfall, it may reduce the suitability of its habitat by altering soil moisture or increasing the competitive pressure on other forest species.

The response curve of the biological indicator bio8 indicates a significant positive correlation between habitat suitability and the average temperature of the wettest quarter. As the temperature of the wettest quarter increases, habitat suitability gradually rises; when the temperature reaches the maximum value of 30°C, suitability tends to stabilize. This relationship suggests that warm and humid growing conditions are conducive to physiological processes such as photosynthesis, flowering, and fruit development. Since the wettest quarter usually coincides with the main growing period in southern China [31], the appropriate temperature during this period is crucial for the successful growth and reproduction of T. succedaneum. In contrast, as the average daily temperature difference (bio2) increases, habitat suitability continues to decline. Higher suitability is associated with relatively stable daytime temperatures, while temperature fluctuations lead to a decrease in predicted suitability. The high importance of bio2 indicates that the stability of daytime temperatures is one of the key characteristics affecting the habitat suitability of T. succedaneum. Forest cover has a significant impact on habitat suitability. The response curve shows that when forests are present, habitat suitability rises rapidly, but when the forest coverage value is extremely high, suitability gradually decreases. This pattern may reflect the ecological characteristics of T. succedaneum, which is usually distributed in forest edges, secondary forests, and mixed broadleaf forests. Moderate forest coverage can provide good light conditions, suitable soil moisture, and reduce competition, while maintaining the stability of a favorable microclimate conducive to successful establishment.

Overall, these findings indicate that the climatic zone to which T. succedaneum is adapted is relatively narrow. Its characteristics include warm growing season temperatures, moderate precipitation in the driest months, small daily temperature differences, and a medium level of forest coverage. The strong influence of temperature and precipitation variables suggests that future predicted climate changes are likely to alter the spatial distribution pattern of suitable habitats within China.

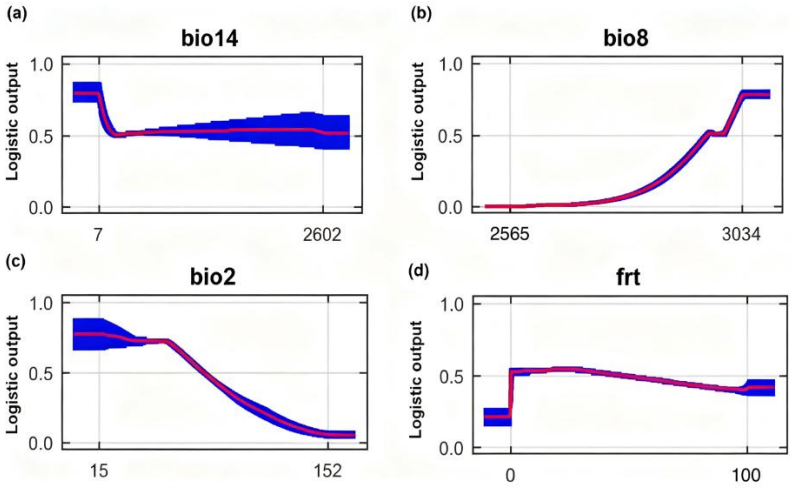


Figure 6. The curves showing the influence of the four most influential environmental predictors generated by the MaxEnt model on the prediction of habitat suitability for the study species. The red lines represent the average response values, and the blue shading indicates the range of ±1 standard deviation in the repeated model runs. The y-axis represents the logical output (the predicted habitat suitability, ranging from 0 to 1), and the x-axis represents the values of each environmental variable (Picture credit: Origina)

3.3. Current and Future Habitat Suitability Pattern Under Climate Scenarios

Rhus succedanea are found in the southern, central, eastern and subtropical regions of China. The predicted distribution range is highly consistent with the known distribution records (Figure 1), indicating that the MaxEnt model successfully identified the actual ecological niche of this species and identified more suitable areas at different times. The high suitability habitats are mainly concentrated in the southern and southeastern provinces, including Hainan, Guangxi, Guangdong, and the coastal areas of Fujian and Zhejiang; the medium suitability areas extend to Guizhou, Hunan,

Chongqing and Jiangxi, etc. The suitability in other central and eastern regions of China is relatively low, while the northern and western parts of China are predicted to be mostly unsuitable (Figure 5a). These provinces are characterized by a humid subtropical monsoon climate and relatively stable environmental conditions, which are conducive to the growth of various temperate and warm temperate tree species. Specifically, the high suitability habitats form relatively continuous distribution patches in the southern part of China, while the medium suitability habitats mainly occur in the transitional zones between subtropical and temperate climates. The low suitability areas are more scattered, usually located in the north and west of the species' distribution area. Rhus succedanea is naturally distributed in regions with warm climates, abundant summer rainfall, and rich broad-leaved forests. The southern part of China belongs to a humid subtropical monsoon climate, with relatively mild winters and a longer growing season, which are conducive to seed germination, vegetative growth and reproductive development. In addition, the mountain landscapes in this region provide various microclimates, buffering seasonal temperature fluctuations, and creating a favorable environment for the species. The importance of climatic conditions is supported by response curve analysis, which shows that warm rainy season temperatures, moderate precipitation in the driest month, and relatively stable daily temperature differences are the main environmental factors leading to high habitat suitability. Similar distribution patterns are also seen in another economically valuable species of the genus, Toxicodendron vernicifluum, which is also distributed mainly in the humid subtropical regions of East Asia. These similarities indicate that closely related species in this genus have similar climatic requirements and ecological tolerances.

Table 3. Areas of suitable habitat for the study species as projected by the ecological niche models under current and the three different year periods in the future

Period	Area (km^2)			
	Highly suitable	Medium suitable	Low suitable	Unsuitable
Current	514,734	1,028,974	1,078,607	970,059
2011-2040	497,038	1,008,421	1,112,640	977,160
2041-2070	542,593	990,867	1,058,159	922,952
2071-2100	579,850	983,089	1,035,540	915,276

According to the future projections under the SSP370 scenario, the suitable habitats will not disappear, but their distribution range will change. During the period from 2011 to 2040, the suitability is similar to the today, with only a little decrease in the high suitability and medium suitability areas (Table 3). From 2041 to 2070 and 2071 to 2100, the high distribution areas will significantly expand, while the medium and low suitability areas will contract. Obviously, in the entire distribution range, some areas will obtain suitable habitats, while others may lose suitable environments in the future (Table 3; Figure 5). These changes are consistent with other studies on the space distribution of plant species, indicating that climate warming may reduce the habitat quality in some areas and increase it in others. Should be notice that the high suitability areas that remain stable throughout the periods are mainly located in the coastal areas of China, especially in place such as Hainan, Guangxi, Guangdong, Fujian, and Zhejiang (Figure 5), suggesting that these areas may become long-term habitable regions in the context of future climate change. These findings indicate that the climatic conditions for this species will remain generally suitable in the future. In the three future time periods, the areas classified as highly suitable, moderately suitable, and low suitable have undergone slight changes, reflecting the continuous redistribution of the suitable habitats for the species. Some newly predicted suitable habitats in certain areas provide the possibility for the expansion of the natural population, which merely requires their ability to spread. However, since T. succedaneum is a tree species with a long lifespan and a relatively slow migration rate, its natural colonization in the new suitable habitats may lag behind the rapid pace of climate change. It is worth noting that due to the habitat fragmentation and barriers caused by mountains, rivers, etc. in this region, without artificial assisted migration and habitat connectivity, these potential range shifts may not become the actual distribution areas of the species.

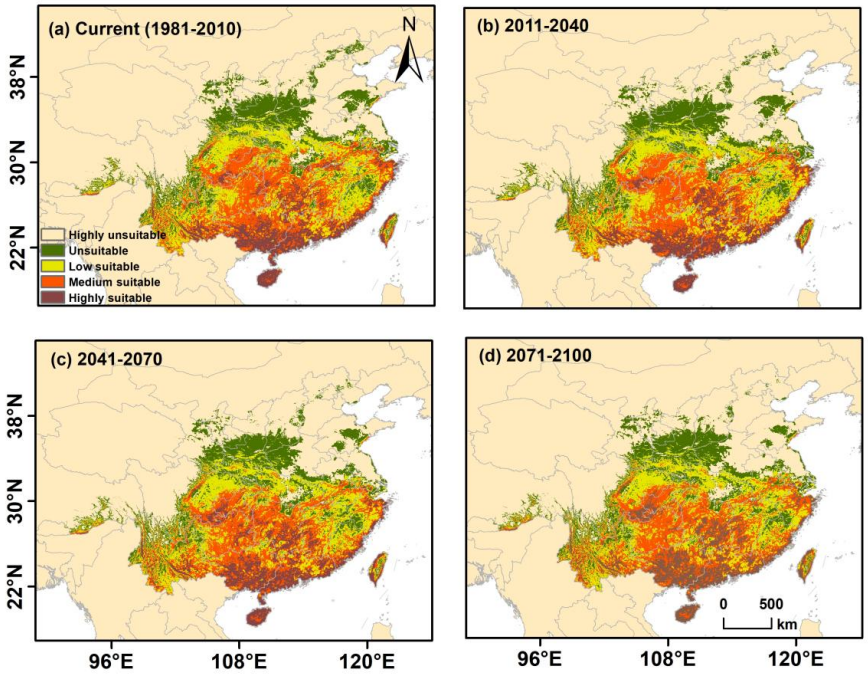


Figure 7. Potential suitable areas for T. succedaneum under current climatic and future climatic conditions in China. (a) Current period, (b, c, and d) projected distribution ranges for the year 2011-2040, 2041-2070, and 2071-2100, respectively (Picture credit: Origina)

4. Discussion

4.1. Conservation Implications for *T. succedaneum* in China

Although T. succedaneum is not currently listed as a globally endangered species, its ecological and economic importance still requires the implementation of proactive conservation plans, especially considering the potential changes in its suitable habitats in the future. The MaxEnt model predicts that climate change is unlikely to cause the complete disappearance of suitable habitats, but the distribution of this species will go through significant changes in the future. These predicted changes highlight the necessity of developing adaptive conservation strategies, which should consider both current and future environmental conditions. Our research results indicate that conservation efforts should prioritize areas that can maintain stable climatic conditions both now and in the future. The coastal areas in southern and eastern China (Figure 5) can be regarded as safe zones for T. succedaneum, as they provide relatively stable environmental conditions, allowing the species to survive and maintain genetic diversity during climate change [32, 33]. The conditions of these areas should be protection, which helps ensure the long-term survival of the wild population and preserves valuable genetic resources for future restoration and offspring. It is also necessary to record the areas where the expected degree of adaptation will decline, as these populations may face weakened reproductive capacity, slow growth, and increased sensitivity to environmental stress. Given the economic value of T. succedaneum, the reduction of climate suitable habitats not only affects the conservation of natural populations but may also impact communities that rely on the species for plantation or sustainable utilization. Therefore, the protection measures should strike a balance between protecting biodiversity and sustainable resource management, encouraging responsible logging and planting in suitable environments, and maintaining diverse genetic seed resources.

This study provides some suggestions for future afforestation and ecological restoration projects. In climate scenarios in the future, areas that are still highly suitable should be prioritized for afforestation and tree planting, as these regions are more likely to support the long-term survival of populations. On the other hand, establishing plantations in areas where habitat suitability is expected to decline significantly may increase management costs and reduce productivity. Therefore,

incorporating future species distribution into planning provides a scientific basis for selecting appropriate planting locations in the context of climate change. Finally, this study supports the inclusion of climate change predictions in national biodiversity conservation strategies. Future protection planning should not only rely on the current distribution of species, but should anticipate changes in distribution ranges in the future and identify areas that may still be suitable in the coming decades. This proactive planning is particularly important for economically valuable tree species, as their ecological, medicinal, and commercial values extend beyond biodiversity conservation and can enhance the adaptability of these populations in the context of climate change.

4.2. Limitation of the Study and Suggestion for Future Studies

Although the model in this study showed relatively high AUC, it must be recognized that such studies themselves are still unsure. The selected environmental variables may not have fully covered all the environmental factors that will affect the T. succedaneum species. Factors such as competition, dispersal ability, and migration barriers also affect its distribution, but these factors are difficult to using into the model. If genetic diversity can be used as an indicator to forecast the adaptability of populations and species to future climate and habitat changes, then this model will be much more valuable. Go through these limitations, this study still provides useful basic information for assessing the current and future habitat suitability of T. succedaneum in China. Our research should serve as a guide for protecting T. succedaneum and other species. Comprehensive measures need to be taken from multiple aspects, such as protecting existing habitats, rebuild degraded habitats, strictly enforcing forest logging bans, and raising public awareness. In addition, such as seed banks and botanical gardens, play an important role in preserving genetic resources in future restoration and research. Future research should also combine SDMs with field verification, genetic studies, population statistical monitoring, and landscape connectivity analysis to better guide protection and sustainable management.

5. Conclusion

This study employed the MaxEnt model to predict the future distribution of Toxicodendron succedaneum (L.) Kuntze in China under the SSP370 scenario. The model performed well, with an AUC remaining within 0.802 ± 0.004. This confirmed that the selected environmental variables were suitable for predicting habitat suitability. The most significant drivers were bio8, bio14, bio2, and forest coverage, indicating that warm and humid seasonal temperatures, drought season precipitation, stable daily temperature differences, and forest habitats have a significant impact on species distribution. The current suitable habitats of Toxicodendron succedaneum (L.) Kuntze are mainly concentrated in the southern regions and the southeastern coastal areas, such as Hainan, Guangxi, Guangdong, Fujian and Zhejiang provinces. According to the model's prediction, climate change will cause changes in the habitat locations, but it will not lead to a reduction. Most of the suitable areas will remain stable, only losing some possible habitats, while other areas may increase. In conservation efforts, priority should be given to protecting stable and suitable areas to ensure the sustainable utilization of high-economic-value species. Overall, this study provides important geographical spatial information for China's conservation planning, habitat restoration and climate adaptation strategies for T. succedaneum.

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