

Modeling the Potential Distribution of *Machilus thunbergii* under the Climate Change Patterns in China

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Abstract

The potential geographic distribution and favorable climatic conditions of *Machilus thunbergii* under current and future predicted climates in China are predicted based on MaxEnt model and ArcGIS software. The results show that the AUC values in different time periods and emission scenarios are more than 0.9, which indicates the prediction is excellent. Precipitation of the coldest quarter, precipitation of the driest month, annual precipitation, mean diurnal range, and temperature annual range are the most important environmental factors affecting the distribution of *Machilus thunbergii*. At present, the suitable areas of *Machilus thunbergii* are mainly concentrated in the eastern subtropics of China, with a total area of 118.47×10^4 km². The medium-suitability area and the high-suitability area are concentrated in Wuyi Mountains, Luoxiao Mountains, Xuefeng Mountains, Nanling and east of Taiwan Mountains. With the change of climate, the suitable area increases, and the medium-suitability area and high-suitability area migrate and expand to the east, and the low-suitability area expands slightly to the west and north. So, the simulated distribution of *Machilus thunbergii* should be one of priorities, when instigating *in-situ* conservation. The research results can provide a theoretical reference for the popularization and planting of *Machilus thunbergii*.

Keywords

Machilus thunbergii, Species Distribution, Climate Change, Environmental Factors

1. Introduction

Due to the rapid urbanization and industrialization, a great number of forests were cut to meet the market demand for wood. The global forest area decreased from 4.28 billion hectares to 3.99 billion hectares in 1990-2015, and the forest cover rate decreased from 31.85% to 30.85% (FAO, 2015), leading to the sharp deterioration of the global ecological environment, the continuous decline of natural forest resources, and many plants became endangered species. Significant progress has been made in increasing permanent forests through natural regeneration and artificial afforestation, with the area of plantations being expected to reach 300 million hectares by 2020 (FAO, 2010). However, the status of plantation development shows that there are few large diameter timber trees and precious timber species, and the structural contradiction between supply and demand of high-quality timber is very prominent (SFA, 2014). Therefore, studying the spatial distribution and predicting the potential distribution area under the climate change is of great significance for guiding the natural regeneration and constructing plantation.

Machilus thunbergii (*Machilus Nees, Lauraceae*), is an evergreen broad-leaved tree preferring warm and humid climate. It has slightly shade tolerant, and is mostly found in the mountain broadleaved forest below 800 m, and distributes in subtropical and warm temperate zone of China (Jiang & Yu, 2001; Wu et al., 2008). *Machilus thunbergii* is also a fine timber tree with great artificial cultivation value and development potential, and is widely used in gardening, timber, spice extraction and pharmaceutical preparation (Hu, 2002; Ma & Huang, 2019; Zhang et al., 2019). Due to the destruction of natural resources and ecological environment, *Machilus thunbergii* has been listed as a third-class national key protected wild plant in China. However, previous research on *Machilus thunbergii* mainly focuses on the community structure and photosynthetic physiological characteristics (Wu et al., 2006; Zhang, 2010; Hwang et al., 2011; Kaneko et al., 2012) without a definite division of its suitable distribution. The research on the suitable distribution and environmental adaptability of *Machilus thunbergii* in China under the climate change is still in blank.

The maximum entropy modeling (MaxEnt) is widely used in the prediction of potential distribution of species in the context of climate change, environmental factor detection and risk assessment of invasive species (Adhikari et al., 2012; Yang et al., 2013; Fandohan et al., 2015; Sung et al., 2018; Chen et al., 2019), based on geographical distribution data and a variety of environmental data. Compared with other models, the MaxEnt has the advantages of less sample size, less influence by sample deviation and better accuracy (Elith et al., 2011; Kramer-Schadt et al., 2013).

Therefore, studying the spatial distribution and predicting the potential distribution area of *Machilus thunbergii* under the climate change is of great significance for determining appropriate biodiversity conservation and strategies for the recovery of *Machilus thunbergii* resources.

2. Materials and Methods

2.1. Data Collection

The geographical distribution data of *Machilus thunbergii* is derived from China Digital Herbarium (CVH, <http://www.cvh.ac.cn/>), China National Specimen Resource Platform (NSII, <http://www.nsii.org.cn/>) and the Global Biodiversity Information Network (GBIF, <https://www.gbif.org/>). After screening and eliminating some missing and duplicated data, a total of 277 effective distribution points (**Figure 1**) were obtained in China.

Climate data are derived from the World Meteorological Database (Worldclim, <http://www.worldclim.org/>) with a spatial resolution of 2.5' (about 22 km²). The 19 environmental variable contains comprehensive data of temperature and precipitation, which are the most influential factors for the plant distribution (Fick & Hijmans, 2017). And the 19 environmental variables (**Table 1**) data were obtained based on ArcGIS 10.0. Select the climate data from 1950 to 2000 as the current climate, which matches the data of the specimen bank. And according to the classification of future climate by the World Meteorological Database, select the climate data of 2050s (2041-2060) and 2070s (2061-2080) as the future climate data.

Based on a CCSM system model with a high degree of fitness in China's climatic simulation (Tian & Jiang, 2013), the emission scenario (The greenhouse gas concentrations and their extensions from 1765 to 2300) selects RCP4.5 (Stable CO₂ emission scenario), RCP8.5 (the highest CO₂ emission scenario), representing CO₂ emission scenario of rising GHG concentrations in the future (Le Quéré et al., 2018; Fick & Hijmans, 2017).

2.2. Statistical Analysis

The geographical distribution data of *Machilus thunbergii* and 19 variables are imported into Maxent. In order to ensure higher reliability of result analysis,

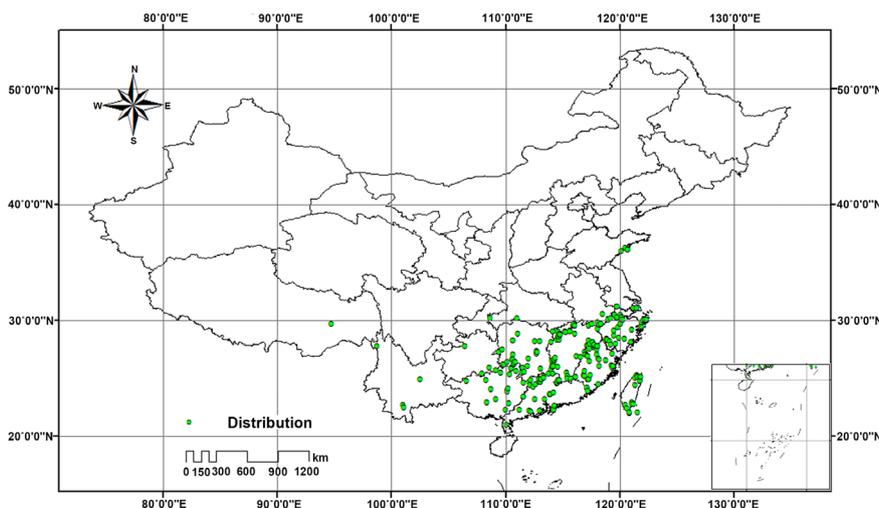


Figure 1. Geographic distributions of *Machilus thunbergii*.

Table 1. 19 environmental variables used in study.

Code	Environment variable	Unit	Code	Environment variable	Unit
Bio1	Annual mean temperature	°C	Bio11	Mean temperature of coldest quarter	°C
Bio2	Mean diurnal range	°C	Bio12	Annual precipitation	mm
Bio3	Isothermality	-	Bio13	Precipitation of wettest month	mm
Bio4	Temperature seasonality	-	Bio14	Precipitation of driest month	mm
Bio5	Maximum temperature of warmest month	°C	Bio15	Precipitation seasonality	-
Bio6	Minimum temperature of coldest month	°C	Bio16	Precipitation of wettest quarter	mm
Bio7	Temperature annual range	°C	Bio17	Precipitation of driest quarter	mm
Bio8	Mean temperature of wettest quarter	°C	Bio18	Precipitation of warmest quarter	mm
Bio9	Mean temperature of driest quarter	°C	Bio19	Precipitation of coldest quarter	mm
Bio10	Mean temperature of warmest quarter	°C	-	-	-

repeating the operation for 10 times, and selecting 75% distribution points as training data, 25% as test data. Evaluating each environmental factor by the contribution rate and the replacement important value to determine the dominant from the factor jackknife test (Elith et al., 2011; Kramer-Schadt et al., 2013).

AUC referred to the area enclosed by the ROC (receiver operation characteristic) curve and the x-coordinate. ROC curve analysis method has been widely used in the evaluation of the potential distribution prediction model of species. It was a diagnostic test evaluation index with high recognition at present. $AUC > 0.7$ indicates that the prediction result is poor, $AUC > 0.8$ indicates that the prediction result is general, and $AUC > 0.9$ indicates that the prediction result has higher accuracy (Zhang et al., 2015).

Converting the output of the model into raster data, and calculating the area of the suitable area in ArcGIS10.0. The value of the MaxEnt output is between 0 - 1, and the closer the value is to 1, the higher the probability of species existence. According to the average spacing method (Li et al., 2018), the suitability (S) is divided into four levels: the unsuitable area ($S \leq 0.2$), the low-suitability area ($0.2 < S \leq 0.4$), the medium-suitability area ($0.4 < S \leq 0.6$), the high-suitability area ($S > 0.6$).

3. Results and Analysis

3.1. MaxEnt Model Evaluation

According to the ROC curve output (Table 2), the average AUC in different climatic scenarios are all above 0.9, and the accuracy of the prediction is excellent. It indicates a high fitting degree between the distribution area and the actual distribution area under different climatic scenarios. And the geographical distribution of *Machilus thunbergii* is nonrandom, which means environmental factors have important influence on its distribution.

Table 2. ROC curves under different climatic conditions.

AUC	Current (1950-2000)	2050s (2041-2060)		2070s (2061-2080)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Training gain	0.965	0.964	0.961	0.963	0.960
Test gain	0.958	0.959	0.958	0.963	0.953

3.2. Analysis of Contemporary Simulation Prediction Results

3.2.1. Main Environmental Variables Affecting the Distribution of *Machilus thunbergii*

Under the current climate (**Table 3**), the most important environmental factor affecting the distribution was the precipitation of coldest quarter (contributing 32.2%), followed by the annual precipitation (contributing 24.7%), the Precipitation of driest month (contributing 15%), the mean diurnal range (contributing 8.7%). When referring to single variable, the Precipitation of driest month, the precipitation of coldest quarter, the Precipitation of driest quarter, the annual precipitation, and the mean diurnal range have the highest training gain, test gain and AUC value, indicating that these environmental variables are of high importance and had good compatibility. When referring to multiple variables, the temperature annual range has the smallest reduction of the highest training gain. It can be concluded that the precipitation of coldest quarter, the Precipitation of driest month, the annual precipitation, the mean diurnal range, the temperature annual range are the major climatic factors determining the distribution of *Machilus thunbergii*, and the sum of contribution rate these environmental factors reached 71.9%.

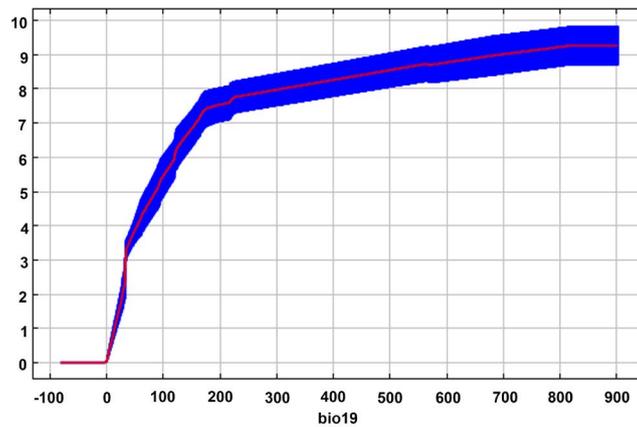
In order to definite the effects of the major environmental factors on the suitable distribution, the curves show how the logistic prediction changes as each environmental variable, keeping all other environmental variables at their average sample value (**Figure 2**). The results showed that the existence probability of *Machilus thunbergii* was dynamically changed with the index of each environmental factor. The existence probability increased sharply while the rainfall precipitation of coldest quarter ranges from 0 to 200 mm, the increase tends to be slow from 200 to 800 mm, and then tends to be stable. When the precipitation of the driest month is more than 45 mm, the existence probability increased sharply, and the range of the highest suitability is between 50 - 200 mm. The existence probability increased sharply when the annual precipitation is more than 1500 mm, and then tends to be stable between 1500 - 3500 mm. When the mean diurnal range is between 3°C and 5°C and the annual precipitation is between 7°C and 13°C, it meets the highest suitability for *Machilus thunbergii*, and the existence probability shows a sharp drop after that.

3.2.2. Prediction of Geographical Distribution of Contemporary *Machilus thunbergii*

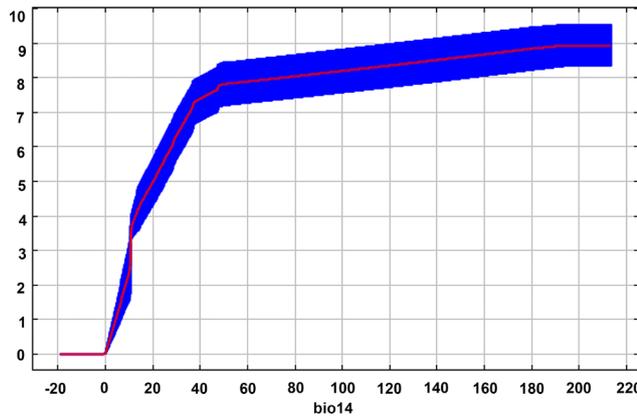
According to the prediction results (**Figure 3**), the simulated suitable area ($S > 0.2$) mainly distributed at 18°N - 32°N, 107°E - 123°E, in the southeast of China,

Table 3. Importance analysis of environmental factors by Jackknife method.

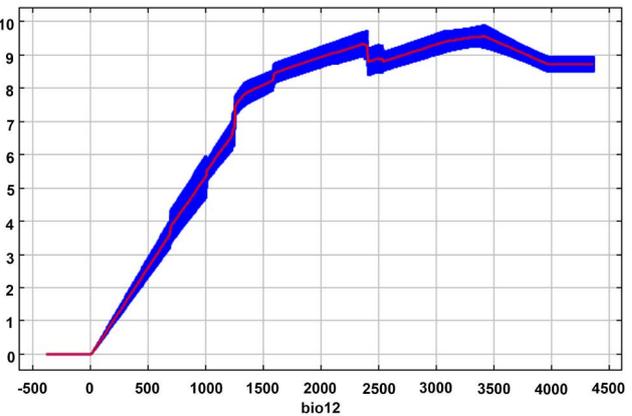
Variable code	Percent contribution	Permutation importance	Use only this factor			Use without this factor		
			Training gain	Test gain	AUC	Training gain	Test gain	AUC
Bio1	2.00	3.10	1.24	1.26	0.89	2.13	2.03	0.95
Bio2	8.70	5.30	1.49	1.48	0.91	2.13	2.02	0.95
Bio3	0.90	1.70	0.13	0.12	0.65	2.13	2.02	0.95
Bio4	1.90	4.20	0.91	0.91	0.83	2.13	2.02	0.95
Bio5	2.60	5.20	0.55	0.58	0.79	2.13	2.02	0.95
Bio6	1.70	6.30	1.47	1.47	0.89	2.13	2.02	0.95
Bio7	4.00	0.30	1.21	1.23	0.88	2.13	2.01	0.95
Bio8	0.20	2.60	0.33	0.29	0.70	2.13	2.02	0.95
Bio9	1.10	4.60	1.48	1.49	0.91	2.13	2.02	0.95
Bio10	2.00	2.20	0.70	0.71	0.81	2.13	2.02	0.95
Bio11	0.60	2.90	1.39	1.39	0.90	2.13	2.02	0.95
Bio12	24.70	10.70	1.76	1.76	0.93	2.13	2.02	0.95
Bio13	0.40	0.20	1.45	1.43	0.91	2.13	2.03	0.95
Bio14	15.00	3.10	1.92	1.94	0.95	2.13	2.02	0.95
Bio15	1.70	5.60	1.13	1.17	0.88	2.13	2.02	0.95
Bio16	0.50	0.50	1.50	1.50	0.92	2.13	2.02	0.95
Bio17	0.30	0.70	1.88	1.89	0.94	2.13	2.02	0.95
Bio18	0.30	0.40	1.28	1.26	0.89	2.13	2.02	0.95
Bio19	32.20	40.60	1.92	1.93	0.94	2.12	2.02	0.95



(a)



(b)



(c)

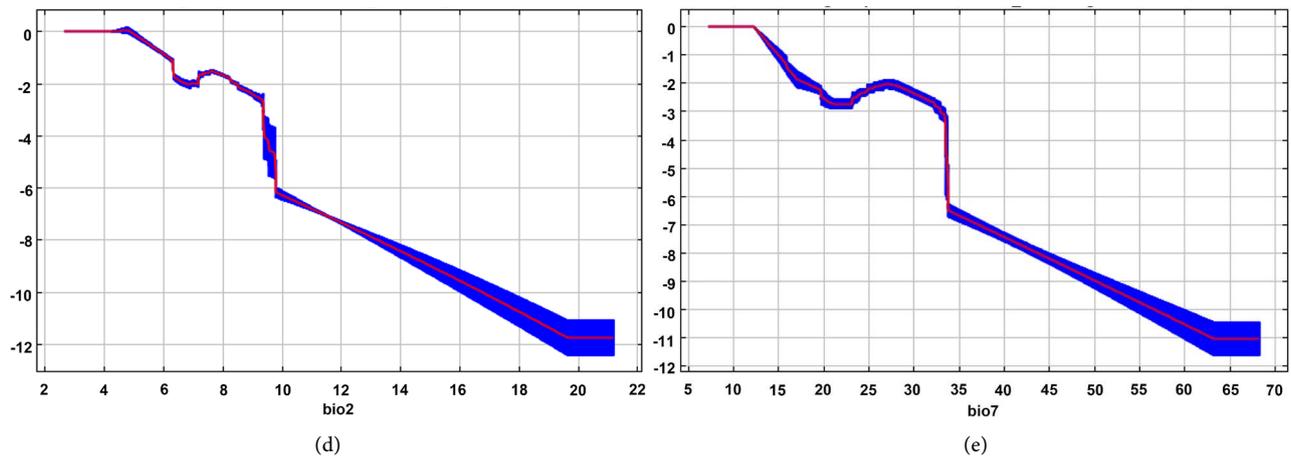


Figure 2. Response curves of major environmental factors. (a) Curve of the precipitation of coldest quarter (bio19); (b) Curve of the Precipitation of driest month (bio14); (c) Curve of the annual precipitation (bio12); (d) Curve of the mean diurnal range (bio2); (e) Curve of the temperature annual range (bio7).

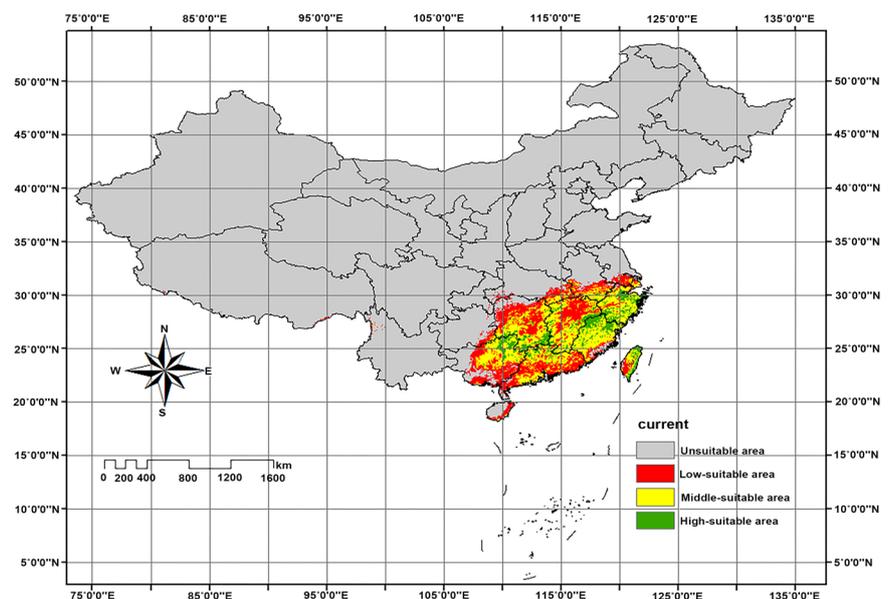


Figure 3. Distributions of *Machilus thunbergii* under current climatic conditions.

including Zhejiang, Fujian, Jiangxi, Hunan, Guangdong, eastern Taiwan, eastern Guangxi and southern Anhui. The total suitable area is $118.47 \times 10^4 \text{ km}^2$, with the areas of low-suitability area, medium-suitability area and high-suitability area account for 39.83%, 45.6%, 14.57% respectively. Under the current climatic, the distribution of suitable area of different levels is basically continuous, the medium-suitability area and high-suitability area are concentrated in Wuyi mountains, Luoxiao Mountains, Xuefeng Mountains, Nanling, and the east and north of the Taiwan Mountains.

3.3. Potential Distribution under Different Climate Scenarios in the 2050s, 2070s

The simulated suitable areas of *Machilus thunbergii* under two scenarios of

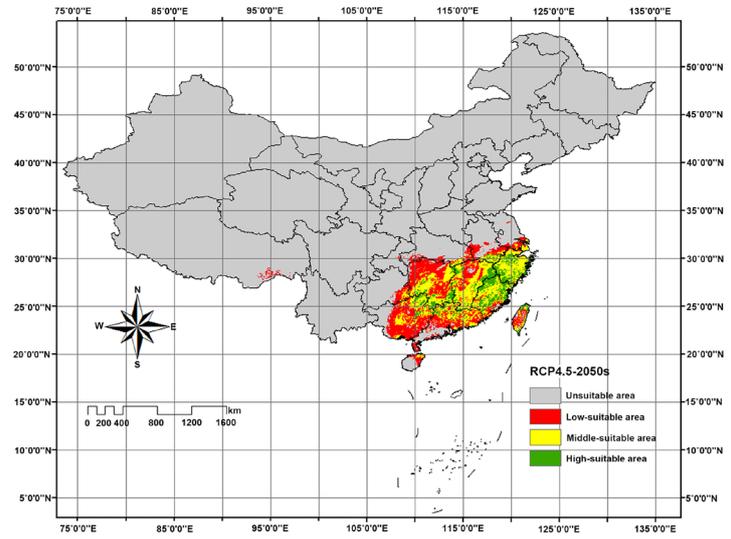
greenhouse gas emission (RCP4.5 and RCP8.5) in the 2050s (2041-2060 years) and the 2070s (2061-2080 years), show that the distribution area is basically continuous, and gradually gathers and distributes. Compared with the current, the total suitable areas in the future increases of different degrees (Table 4, Figure 4).

Under the RCP4.5, the high-suitability areas tend to expand to the northeast, and gather in southern Anhui, western Zhejiang and northern Fujian, with decentralized distribution in some other areas such as Guangxi and Hunan. The medium-suitability and low-suitability areas move northward, and the fitness decreased in Guangxi and Guangdong. In the 2050s, the total suitable area of *Machilus thunbergii* increased by 1.33×10^4 km², in which the high-suitability area and the low-suitability area increased by 2.33×10^4 km², and 5.11×10^4 km², respectively, while the medium-suitability area decreased by 6.11×10^4 km². Compared with the 2050s, the total suitable area increased by 1.09×10^4 km², in the 2070s, with the high-suitability and low-suitability areas increased by 2.13×10^4 km², and 0.54×10^4 km², respectively, and the medium-suitability areas decreased by 1.58×10^4 km². Overall, the areas of high-suitability and low-suitability showed an upward trend, and the increase of low-suitability area was greater than that of high-suitability area.

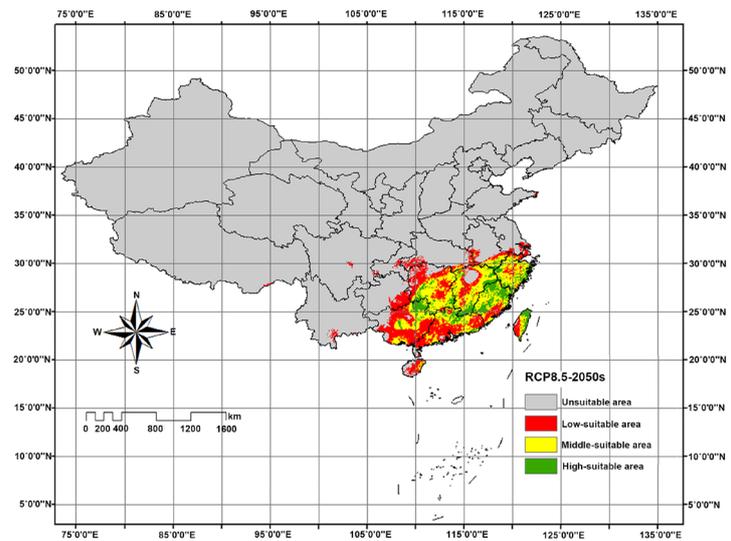
Under the RCP8.5, the medium-suitability and high-suitability areas migrated to the northeast in China, concentrated in Zhejiang, Fujian, northern Guangdong, southern Anhui and northeastern Taiwan. Compared with the current, the suitability of areas in Guangxi will decline significantly. The low-suitability areas expand in Guangxi, Hunan, western Guizhou and southern Jiangsu, but receded in northern Jiangxi. In the 2050s, the total suitable area of *Machilus thunbergii* increased by 2.3×10^4 km², in which the high-suitability area and the low-suitability area increased by 3.96×10^4 km², and 5.16×10^4 km², respectively, while the medium-suitability area decreased by 6.82×10^4 km². Compared with the 2050s, the total suitable area increased by 10.87×10^4 km², in the 2070s, with the low-suitability areas increased by 14.5×10^4 km², and the medium-suitability

Table 4. Predicted suitable areas for *Machilus thunbergii* under different climatic conditions.

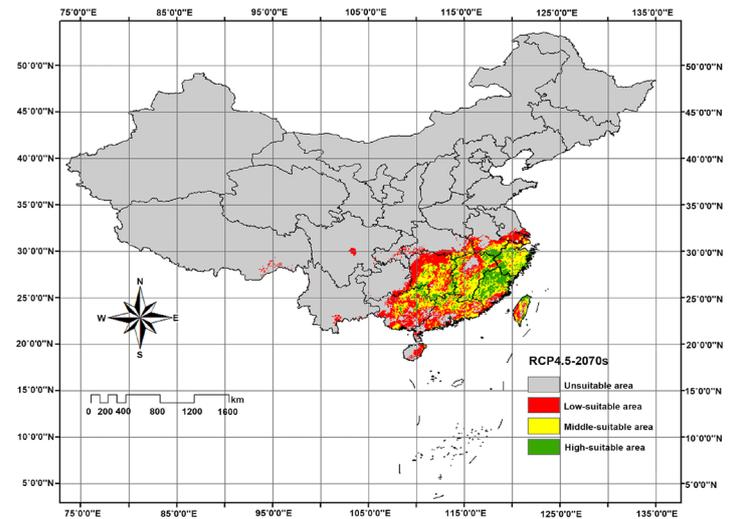
Decade	Climate scenarios	Low-suitable area (10 ⁴ km ²)	Middle-suitable area (10 ⁴ km ²)	High-suitable area (10 ⁴ km ²)	Total Area (10 ⁴ km ²)
Current (1950-2000)	-	47.19	54.02	17.26	118.47
2050s (2041-2060)	RCP4.5	52.30	47.91	19.59	119.80
	RCP8.5	52.35	47.20	21.22	120.77
2070s (2061-2080)	RCP4.5	52.84	46.33	21.72	120.89
	RCP8.5	66.85	44.27	20.52	131.64



(a)



(b)



(c)

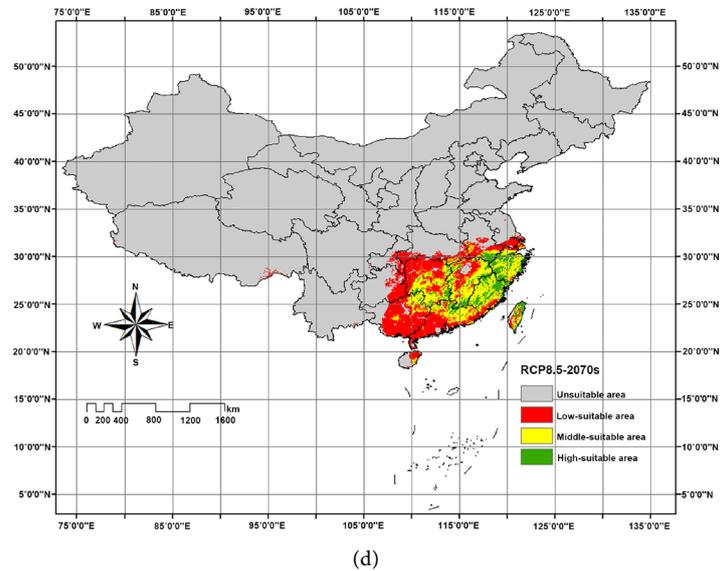


Figure 4. Potential distributions of *Machilus thunbergii* under future climatic conditions. (a) Distributions of 2050s under RCP4.5; (b) Distributions of 2050s under RCP8.5; (c) Distributions of 2070s under RCP4.5; (d) Distributions of 2050s under RCP8.5.

and high-suitability areas decreased by $0.7 \times 10^4 \text{ km}^2$, and $2.93 \times 10^4 \text{ km}^2$, respectively. In general, the area of the high-suitability increases first and then decreases, and the area of the medium-suitability area decreases more significantly under the RCP8.5.

4. Discussion

4.1. Main Climatic Factors Affecting the Distribution of *Machilus thunbergii*

Under the current climate, *Machilus thunbergii* is mainly distributed in southeastern China, roughly correspond with the geographical distribution of *Machilus thunbergii* with the previous research (Takyu & Ohsawa, 1997; Utteridge, 2010; Kaneko et al., 2012).

According to the influence of environmental variables on the distribution of *Machilus thunbergii*, the Precipitation of coldest quarter (Bio19), the Precipitation of driest month (Bio14), the Annual precipitation (Bio12), the Mean diurnal range (Bio2), the Temperature annual range (Bio7), are the most important environmental factors affecting the distribution of *Machilus thunbergii*. It shows that *Machilus thunbergii* has high requirements for precipitation and temperature, and the influence of precipitation is greater than temperature. It shows that precipitation is the limiting factor determining the distribution of *Machilus thunbergii*. There is abundant rainfall in the eastern of subtropical China, which is coincident with the suitable area of *Machilus thunbergii*.

The flower bud differentiation period generally from August to September. It blooms in February, and enters fruit maturation period from June to July. The

seeds can germinate in a suitable environment when they fall to the ground (Kaneko et al., 2012; Xu, 2014). Adverse meteorological during flowering, such as low temperature in winter and late frost in spring, can lead to severe freezing injury on flower buds. Low temperature or high temperature, drought, water logging and so on during the young fruit-growing period will cause a lot of fruit drop.

Some studies have pointed out that precipitation makes a difference on reproduction and physiology of *Machilus thunbergii* (Jiang, 2011). A high germination rate requires a moisture content of *Machilus thunbergii* seeds above 40% (Lin & Chen, 1995; Jiang et al., 2005). The annual precipitation can influence on the fruit size (Jiang, 2011), which is an important reason for the biennial bearing (Wang et al., 2010). Under natural conditions, precipitation is the decisive factor that directly affects the air humidity and water content of soil in the community environment. The air which is too dry and soil with low water content will become the limiting factors of photosynthesis (Tranquillini et al., 1979). Compared with the western plateau and the northern plain with greater environmental changes, the climate in the third ladder of China's topography (Zhejiang, Fujian, Jiangxi, Taiwan and other places) and the islands on the East China Sea, and the islands on the East China Sea is relatively mild. It can be inferred that the distribution of the suitable areas is related to the stable climate in the east of China. Indicating that precipitation, especially in winter, and stable temperature environment determine the geographical distribution of *Machilus thunbergii* by influencing its growth and renewal.

With global warming and increasing precipitation, the suitable area of *Machilus thunbergii* will expand in the future. However, the environmental factor response curve (Figure 2) shows that the distribution probability of *Machilus thunbergii* increases with the increase of environmental factors within a certain range, and decreases after the peak. Therefore, under the RCP4.5, the increased area between the 2050s and 2070s is not obvious. And under the RCP8.5, the low-suitability area continues to expand, while the medium-suitability and high-suitability areas tend to stabilize and even decline.

It indicates that, with the climate change, the suitable area of *Machilus thunbergii* will not continue to increase, and may even restrain its expansion after reaching a certain peak.

4.2. Nonclimatic Factors Affecting the Distribution of *Machilus thunbergii*

According to the simulation, the medium-suitability area and the high-suitability area are mainly concentrated in Wuyi Mountains, Luoxiao Mountains, Xuefeng Mountains, Nanling and Taiwan Mountains, maintaining a relatively stable state. The distribution area is mainly hilly mountains with complex terrain (Dordel et al., 2011), where the microclimate can maintain a relatively stable habitat and reduce the impact of climate change on *Machilus thunbergii*.

In addition, the northward migration of the suitable area of *Machilus thun-*

bergii may relate to vegetation type. It can be seen that, in the future, the distribution area of *Machilus thunbergii* moves northward, preferring areas with more deciduous trees. With the climate change, the interspecific and intraspecific competition may become more intense. And studies have shown that when the neighboring plants are deciduous broad-leaved species, the basal diameter growth and tree height of *Machilus thunbergii* is significantly greater (Massey et al., 2006; Tong et al., 2013), because deciduous broad-leaved humus can promote the growth of saplings better than evergreen leaved humus (Koorem et al., 2011).

Furthermore, the rate of spread of the communities may not keep pace with the rate of global climate change. Under the scenario of global climatic change, leading to warming, altered precipitation patterns and extreme weather events (drought, flood) will increase their impact on forest ecosystems (growth, migration and disappearance, species invasion, etc.) in the future, posing a serious threat to forest security (Yang, 2017). In addition, climate warming will cause some unexpected events, such as wildfire caused by extreme high temperature and drought, leading to the extinction of species, the rapid loss of forest and other unpredictable harm, and further aggravate the rate of climate change. Therefore, the migration and expansion of the suitable zone of *Machilus thunbergii* in the future may not proceed as the simulation results.

4.3. Conservation and Development Strategies for *Machilus thunbergii*

The research results can provide theoretical reference for the promotion and planting of *Machilus thunbergii*. The medium-suitability and high-suitability areas such as Zhejiang and Fujian can be given priority and emphasis for planting division and germplasm resources protection when making planting area plan, while the planting scale can be appropriately expanded in the low-suitability areas. Carrying out germplasm resource protection in the relatively stable distribution area and setting up protective forest belt in the periphery of the area is of significance to form a transition area for the development and expansion of natural *Machilus thunbergii*.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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