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PREDICTING THE POTENTIAL DISTRIBUTION OF *TAXUS WALLICHIANA* VAR. *MAIREI* UNDER CLIMATE CHANGE IN CHINA USING MAXENT MODELING

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Abstract

Understanding the spatial distribution of species is significant for the conservation management of the endangered tree species, *Taxus wallichiana* var. *mairei*. And this species attracts people's attention owing to its important biological compounds such as paclitaxel (taxol) used in many cancer therapies. Here, the potential geographical distribution of the maire yew was analyzed by using the Maxent model from Mid-Holocene to the 2070s. The results indicated that the prediction performances were excellent with an area under curve of >0.9 for model training and testing. The most significant factors were precipitation of the driest month, annual precipitation, altitude and min temperature of the coldest month, with thresholds of 22.3 to 122.5 mm, 1,100 to 2,100 mm, 50 to 1,100 m and -2 to 4℃, respectively, indicating that the maire yew seems to prefer warm and humid environment. The suitable areas of the maire yew in China are mainly distributed on southwestern, central, southern and eastern China from Mid-Holocene to the 2070s. However, proportion of the suitable habitat is predicted to be increasing gradually from Mid-Holocene to the 2070s. Most importantly, western Henan, southern Shaanxi, eastern Sichuan and the border of Yunnan and Guizhou provinces etc. were predicted to be new suitable centralized areas for its introduction and cultivation. Thus, the study should be a useful guide for management decisions of the species.

Key words: *Taxus wallichiana* var. *mairei*; Climate change; Potential geographical distribution; Maxent model.

Introduction

Taxus spp., belonging to the genus Taxus and family Taxaceae, are the highly valuable medicinal plants, because all members of the genus Taxus produce the important biological compounds such as paclitaxel (taxol) effective drugs used in many cancer therapies (Gao *et al*., 2016). Consequently, plants of this genus has been widely concerned and deeply studied（Meng *et al*., 2018; Zhang, *et al*., 2019). Now, the genus Taxus consists of nine species in the world and among them three species (*T. fuana*, *T. wallichiana*, *T. cuspidata*) and two varieties (*T. wallichiana* var. *chinensis*, *T. wallichiana* var. *mairei*) are endemic to China (Fu *et al*., 1999; Zhang *et al*., 2009). Here, the maire yew (*T. wallichiana* var. *Mairei* (Lemee & H. Léveillé) L. K. Fu & Nan Li), is a variation of the species *T. wallichiana* in the family Taxaceae (Fu *et al*., 1999). And it is classified as high-priority nationally protected plants, listed as an endangered protected plants in Red list of biodiversity of China probably due to deep dormancy of seeds difficult to germinate in natural state (Tang, 1991; Bao & Chen, 1998; Zhang & Ru, 2010) and illegal logging (Gao *et al*., 2016). At present, it is naturally distributed in the provinces to south of the Yangtze River Basin, as well as in Shanxi (Taihang and Zhongtiao Mountains) and Shaanxi (Qinling Mountains）province, China (Bao & Chen, 1998; Deng *et al*., 2008). Owing to its excellent material and beautiful color, it has long been the target of illegal logging (Gao *et al*., 2016). In recent years, taxol, an anticancer drug, has been found in leaves, branches, stems and roots of this species, so a large number of its deforestation and destruction often happen since the 1970s. As a result, the distribution regions of these communities have been gradually reduced, and so protection of this endangered plant is becoming more and more urgent in China (Zhang & Ru, 2010). Therefore, it is necessary to ascertain the potential distribution region of the maire yew, and then provide scientific suggestions for its protection and restoration in the field.

Understanding the potential distribution of the species and its influencing factors is the fundamental for its conservation management (Guisan & Thuiller, 2005; Qin *et al*., 2017). The species distribution modelings (SDMs) are currently the most widely used tools for assessing the relationship between species and environment variables, and detecting the potentially suitable region for a species (Elith & Leathwick, 2009; Yang *et al*., 2013). However, of many SDMs, the Maxent model has been proved to perform better relative to other modeling methods (Phillips *et al*., 2006; Qin *et al*., 2017). The several advantages of using Maxent model are as follows: it can finishes modelling process with only the presence-only occurrence points and environmental variables; It can utilize continuous and categorical variables, and incorporate the correlations between the variables that may otherwise overestimate the reliability of results (Phillips *et al*., 2006; Khanum *et al*., 2013; Wang *et al*., 2019). Besides, the results from the Maxent model are more stable, the requirements for computer configuration are lower, and the operation is more convenient. Meanwhile, the geographical distribution of plants is the result of long-term interaction of climate, hydrology, soil, human activities and other factors (Jia *et al*., 2017). Among them, climate change have an effects on the geographical distribution of the species at the regional or global scale (Hu *et al*., 2015; Qin *et al*., 2017; Wang *et al*., 2019). The Fifth Assessment Report (AR5) of the IPCC (Intergovernmental Panel on Climate Change) predicts that the mean annual temperature on the planet will increase by 0.3–4.5°C or so at the end of the 21st century (Hu *et al*., 2015). In this study, the Maxent model is used to simulate the potential distribution of the maire yew by its known occurrence records and digital layers of environmental variables in China from Mid-Holocene to the 2070s. The objectives of our study were: (1) to ascertain the potential distribution of this specie under past, current and future environmental conditions and to identify the variables with most important influence on its potential distributions; (2) to analyse distribution trends of this species with climate change, which will be very helpful for the forestry departments to provide specific protection measures for this endangered species.

Materials and Methods

Species distribution samples: The occurrence data of the maire yew were collected in China from our field surveys using the GPS (Global Positioning System). Additionally, some points records for this species were obtained from some related references (Deng *et al*., 2008; Yue *et al*., 2010; Gao *et al*., 2016) and one databases (http://www.cvh.ac.cn/), which only offer the names of towns or villages in its growth region. The coordinate of each location were acquired by the Geographic Names Database (http://www.geonames.org/).

Here, one of the main problems of many species distribution models (SDMs) is unable to overcome spatial dependence of occurrence points (Jaryan e*t al*., 2013; Montemayor *et al*., 2015). In order to overcome spatial autocorrelation, duplicate database records were deleted and only one record within each cell was retained, so the 418 unique records were retained after checking their locations. According to the Maxent model demands, these points' records were saved in .csv format according to the demand of Maxent model.

Environmental data: Because geographical distribution of species mainly depends on its adaptability to climate, topography and other factors (Chen *et al*., 2011; Jia *et al*., 2017), so the environmental parameters including 19 bioclimatic variables and 3 topographic parameters were chosen in this present research. The 19 bioclimatic variables under the current (1950-2000) environmental condition with a spatial resolution of 30 arc-second, were downloaded from the Worldclim database (http://www.worldclim.org/), to represent annual trends, seasonality, and extreme temperature and precipitation (Hijmans *et al*., 2005). The RCPs (Representative Concentration Pathways), adopted by the IPCC (Intergovernmental Panel on Climate Change) in the fifth IPCC assessment report (AR5), represents the full bandwidth of possible future emission trajectories. And RCPs (RCP2.6, RCP4.5, RCP6.0, RCP8.5), from the Worldclim database (http://www.worldclim.com/cmip5_30s), were numbered in accordance with a possible range of radiative forcing values in the year 2100 (Hu *et al*., 2015). In the present study, the future potential habitats for the species were predicted for two periods, 2050s (average for 2041–2060) and 2070s (average for 2061–2080) under two representative concentration pathways, representing "medium" (RCP4.5 and RCP6.0) greenhouse gas emission scenarios. Three topographical parameters included altitude, slope, aspect. Altitude (digital elevation model or DEM) with the spatial resolution similar to the above, was also acquired from the Worldclim database (http://www.worldclim.org). Slope and aspect were acquired from digital elevation model by using the surface analyst function of the software ArcGIS 10.2. Finally, all above-obtained environmental data under GCS-WGS-1984 frame were extracted by China's administrative boundary in "shp" format in ArcGIS 10.2 and be converted into ASCII format in order to be compatible with the Maxent format. Based on our assumptions, three topographic variables would not change under the different environmental conditions. Additionally, China's administrative map (1: 400 million) were acquired from the National Fundamental Geographic Information System (http://nfgis.nsdi.gov.cn/).

Predicting potential distribution: In this study, based on 22 environmental variables and 418 occurrence localities of this species, potential distribution of the maire yew was simulated by the Maxent model (Version 3.4.1, http://biodiversityinformatics.amnh.org/open_source/maxent/). Specifically, the presence-only occurrence data together with the predictor variables can be directly imported into "samples" and "environmental layers" in the Maxent model. Based on some document (Phillips *et al*., 2006; Xu *et al*., 2014), 75% of all the species records was randomly chosen for model training and the other 25% for model testing. Meanwhile, a maximum of iterations (500) and 10,000 background points were utilized and all other parameter were kept as default. The prediction results were generated in logistic format and ASCII types. For display and further analysis, the model prediction for the presence of this species were imported into the software ArcGIS 10.2 and then transformed into raster format that ranged from 0 to 1.0. The 10th percentile logistic training threshold was used as the threshold value, widely applied to define a binary suitable/unsuitable map (Johnson *et al*., 2016; Wei *et al*., 2019). In this present study, based on the 10th percentile logistic training threshold as the cutoff value (greater (suitable) or less than (unsuitable)), we create a binary suitable/unsuitable map under different climate scenarios. Specifically, the suitable habitat is assigned as 1 and the unsuitable habitat is 2 in Mid-Holocene predictions, while in other predictions the suitable habitat is assigned as 3 and the unsuitable habitat is 4. Then, the two raster data are multiplied in raster calculator of ArcGIS 10.2, so that the pixel value of 3 is not suitable for the two periods, 4 indicates that it is only the suitable habitat for one period, 6 indicates that it is only the suitable habitat for another period, and 8 indicates the common suitable habitat for the two periods. Finally, all kinds of habitat area are calculated after projection conversion.

Model performance and influencing factors: The area under the curve of the receiver operating characteristic (ROC) plot or AUC was utilized to estimate the accuracy of the model, widely utilized in ecological researches (Phillips *et al*., 2006; Qin *et al*., 2017), and the value of AUC ranged from 0 to 1.0. It is now generally believed that values ranging from 0.9 to 1.0 are indicative of excellent model performance, values from 0.8 to 0.9 are considered to be good, 0.7-0.8 is ordinary and 0.5-0.7 is poor (Kumar *et al*., 2014; Hu *et al*., 2015).

Based on predictor contributions, the main influencing factors for habitat suitability were able to be identified for this species in the prediction procedure (Qin *et al*., 2017). In addition, by using individual response curves, the relationships between environmental variable and the probability of the presence can be obtained (Hu *et al*., 2015).

Result

Modeling evaluation: In the present study, the prediction performances were excellent with an area under curve of >0.9 under past, current and future environmental conditions (Table 1). These results indicated that these Maxent models could provide satisfactory results for this species.

Table 1. The modeling prediction precision of AUC.

Environmental parameters	AUC of training data	AUC of testing data	AUC of random prediction
Mid-Holocene (CCSM4)	0.936	0.927	0.5
Current (1950-2000)	0.940	0.920	0.5
Future CCSM4-rcp4.5 (2050s)	0.935	0.941	0.5
Future CCSM4-rcp6.0 (2050s)	0.936	0.918	0.5
Future CCSM4-rcp4.5 (2070s)	0.934	0.941	0.5
Future CCSM4-rcp6.0 (2070s)	0.935	0.922	0.5

Importance of current environmental variables and their threshold: Among the 22 environmental parameters, precipitation of the driest month (bio14) made the largest contribution (55.3%); and then followed by annual precipitation (Bio-12), with 14.6%. The percent contributions of altitude variable and min temperature of coldest month (bio06) were 7.3% and 4.4%. The cumulative contributions of these four parameters reached to 81.6% (Table 2). Based on predictor contributions, the above top four parameters were regarded as the major environmental parameters. By using response curve for four different variables alone, the threshold was determined for these four main parameters (probability of presence >0.5): precipitation of the driest month varied from 22.3 to 122.5 mm, annual precipitation from 1100 to 2100 mm, altitude variable from 50 to 1100 m and min temperature of coldest month from -2 to 4°C.

Potential distribution pattern under different environmental condition: According to the 10th percentile logistic training threshold, the final potential species distribution maps were classified into "suitable habitat" and "unsuitable habitat". From Mid-Holocene to the period of 2050s and 2070s, model results show that there are similar distribution areas in the suitable geographic distribution of the maire yew in China. Specifically, the suitable areas are mainly concentrated on southwestern China (Chongqing, Guizhou and eastern Sichuan), central China (Hunan, western and eastern Hubei), southern China (northern Guangxi and Guangdong), and eastern China (Fujian, Jiangxi, westsouthern of Zhejiang and Anhui) (Fig. 1). Although the location of the suitable geographic distribution of the maire yew are very similar, its geographic distribution will expand under projected levels of climate change because the increased area is greater than the reduced area in the study area (Table 3). For example, under the current climate condition, the areas of suitable areas are predicted to be increasing by 40,393 km^2, accounting for 2.37% of the suitable area relative to Mid-Holocene (6000 year before) even if 8.63% (147,036 km^2) of suitable areas for the maire yew were identified as decreased suitable areas while 11.00% (187,429 km^2) were identified as increased suitable areas relative to Mid-Holocene. And in the future period of 2050s, 7.32% (124,700.7 km^2) and 6.47% (1,536,83.2 km^2) of suitable areas for the maire yew are identified as increased suitable areas in two greenhouse gas emission, i.e. RCP4.5 and RCP6.0, while in the future period of 2070s, 16.64% (283,675 km^2) and 13.83% (235,670.7 km^2) are identified as increasing suitable areas, indicating that the suitable habitat areas in China were predicted to be increased gradually from Mid-Holocene to future climate scenarios. The results also show that compared with the suitable area in Mid-Holocene, the increased suitable areas are mainly concentrated on western Henan, southern Shaanxi, eastern Sichuan and the border of Yunnan and Guizhou provinces (Fig. 1).

Table 2. The environmental factors used in this study and their contribution under current environmental condition.

Code	Description	Percent contribution	Code	Description	Percent contribution
Bio14	Precipitation of driest month	**55.3**	Bio19	Precipitation of coldest quarter	0.7
Bio12	Annual precipitation	**14.6**	Bio05	Max temperature of warmest month	0.6
Alt	Altitude	**7.3**	Asp	Aspect	0.4
Bio06	Min temperature of coldest month	**4.4**	Bio13	Precipitation of wettest month	0.3
Bio11	Mean temperature of coldest quarter	3.4	Bio10	Mean temperature of warmest quarter	0.3
Bio08	Mean temperature of wettest quarter	3.3	Bio17	Precipitation of driest quarter	0.3
Bio07	Temperature annual range	2.8	Bio16	Precipitation of wettest quarter	0.2
Bio03	Isothermality	1.7	Bio01	Annual mean temperature	0.1
Bio02	Mean diurnal range	1.6	Bio18	Precipitation of warmest quarter	0.1
Bio04	Temperature seasonality	1.6	Bio09	Mean temperature of driest quarter	0
Slo	Slope	1.1	Bio15	Precipitation seasonality	0

Table 3. Changes of the suitable habitat for the maire yew under different environmental conditions.

Climate scenarios	Comparative periods	Decreased habitat		Increased habitat		Total habitat change	
		Suitable area/km^2	Percentage %	Suitable area/km^2	Percentage %	Suitable area/km^2	Percentage %
Current	Past-Current	147,036	8.63	187,429	11.00	40,393	2.37
RCP4.5	Past-2050s	99,237.3	5.82	223,938	13.14	124,700.7	7.32
	Past-2070s	103,672	6.08	387,347	22.73	283,675	16.64
RCP6.0	Past-2050s	112,373	6.59	222,659	13.06	153,683.2	6.47
	Past-2070s	88,966.3	5.22	324,637	19.05	23,5670.7	13.83

Note: the suitable areas in Past (6000 yr before) is 1,704,430 km^2

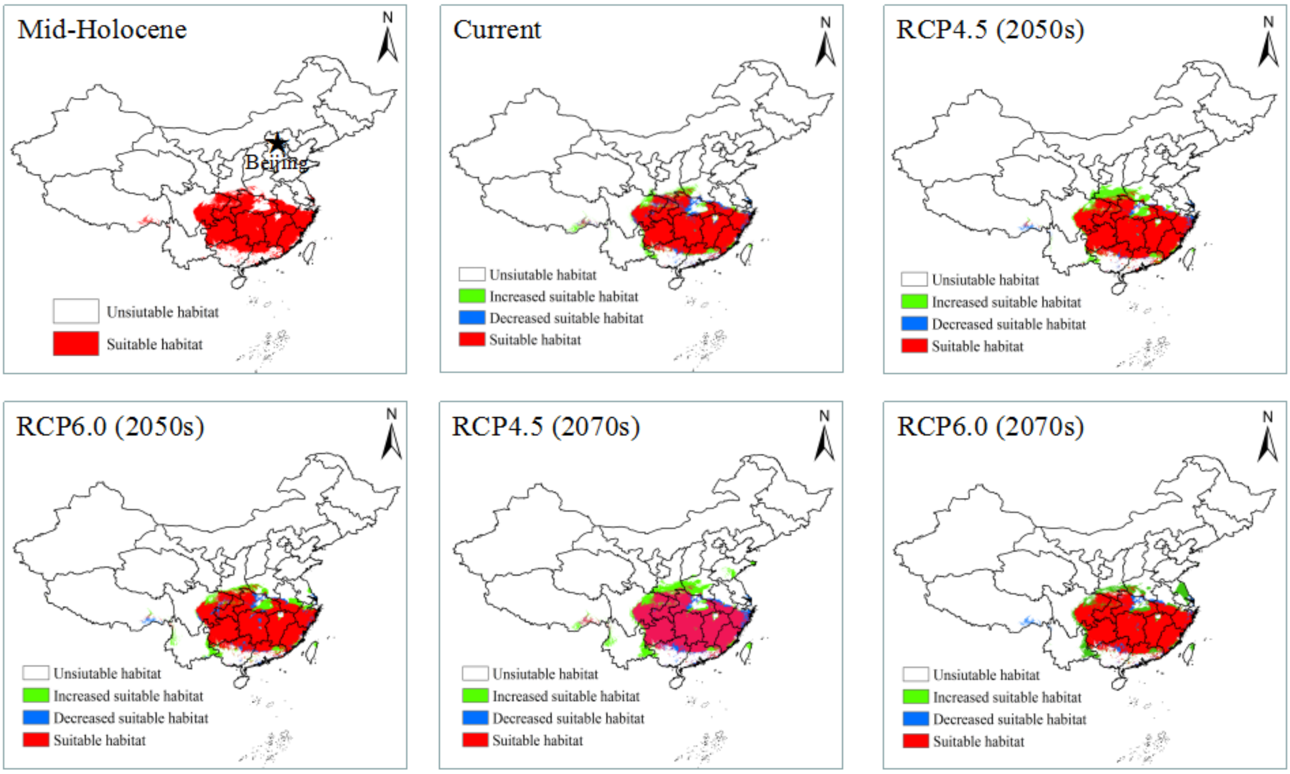

Fig. 1. Distribution of habitat suitability for the maire yew under different climate change scenarios (including 3 topographic variables).

Discussion

The maire yew (*T. wallichiana* var. *mairei*), a species endemic to China, is one of the endangered, and Category I protected species in China (Bao & Chen, 1998; Zhang & Ru, 2010). At present, it has attracted global attention owing to its important biological compounds (paclitaxel), commercial timber and ornamental value (Zhang *et al*., 2009; Gao *et al*., 2016). As a result, the conservation of the tree species is urgent owing to excessive logging for obtaining paclitaxel in China. However, so far, very little is known about concrete information on the potential distribution areas of the maire yew and its affecting factors. Fortunately, with the development of applied ecology, SDMs have been widely used to evaluate and predict the potential distribution of a species (Wang *et al*., 2010; Qin *et al*., 2017). Among them, Maxent model widely applied in many fields can estimate correctly the potential distribution of a species based on maximum entropy principle (Phillips *et al*., 2006; Qin *et al*., 2017). The design principle of the model is that species may exist in regions with suitable climate conditions and lack in unsuitable climate ones (Guisan & Zimmermann, 2000; Hu *et al*., 2015), In the present study, the predictions performances obtained from the Maxent model were excellent and accurate, with AUC values of >0.9 for model training and testing under past, current and future environmental conditions. The result also showed that the potential geographical distribution of the maire yew were almost similar in past, current and future environmental conditions (Fig. 1). Namely, under different climate conditions, the suitable potential distribution predicted by the model are consistent with the real distribution except for northern China (Shanxi) and northwest China (Gansu), which has some sporadic records (Bao & Chen, 1998; Gao *et al*., 2016) and the distribution area is decreasing owing to the cold climate of Shanxi province. It shows that the maire yew seems to have a special fondness for warm and humid environments as are shown by the percent contribution. However, proportion of the suitable areas are predicted to be increasing (increased area subtract decreased one) from Mid-Holocene to the 2070s (Table 3), indicating that the suitable habitat areas in China were predicted to be increased gradually relative to Mid-Holocene. In addition, western Henan, southern Shaanxi, eastern Sichuan and the border of Yunnan and Guizhou provinces etc. were predicted to be new suitable centralized areas for introduction and cultivation of the species. Climate in southern Shaanxi province is similar to that of Sichuan and western Henan, because western Henan and northeastern Sichuan provinces are adjacent to southern Shaanxi province. These conditions support the fact that the maire yew is suitable to live in warm and humid environment. This information reminds us that besides the traditional distribution area, these above-mentioned four regions should be utilized for the maire yew's restoration. However, actually it was difficult for the species to aggressively colonize all suitable areas and the distribution areas of its communities have been progressively reduced even if its suitable geographic distribution would expand, by guess, besides the cause of plant nature, it may be due to other environmental factors for instance soil, interspecies competition, human interference and so on. One past study shows that natural and human disturbances influence the distribution of the rare tree (*Thuja sutchuenensis* Franch) (Tang *et al*., 2015). However, we should carry out such work via avoiding human interference.

The geographical distribution of the species mainly relies on its adaptability to climate, topography and other environmental factors (Wang *et al*., 2010; Jia *et al*., 2017). The result of percent contribution in the Maxent model showed that the main environmental parameters were precipitation of the driest month, annual precipitation, altitude variable and min temperature of the coldest month, with thresholds of 22.3 to 122.5 mm, 1100 to 2100 mm, 50 to 1100 m and -2 to 4°C, respectively. The above-mentioned top two main factors, up to 69.9% in total are closely related to precipitation, indicating that precipitation probable is the main factor affecting the geographical distribution of the maire yew. This is consistent with the past study that the maire yew in Sichuan province is suitable for living in abundant rain and precipitation from 50 to160 mm in July (Li *et al*., 2018). And altitude variable from 50 to 1100 m happened to support the maire yew to be suitable to live in a place with the abundant precipitation. Min temperature of the coldest month with the thresholds of -2 to 4°C may prevent frostbite of seedlings, which is basically consistent with the research result in Sichuan province (Li *et al*., 2018).

In short, predicted results based on Maxent model generate important information for the conservation management of the endangered tree species (Li *et al*., 2014). For example, it could help to identify additional localities where the maire yew may already exist, but has not yet been detected or where it is likely to spread to or the priority selection area for introduction and cultivation of this rare tree. Consequently, the scope of key protected areas of the maire yew could be found out so as to strengthen the supervision and management of key areas, avoid blind protection, and minimize human activities. Meanwhile, it provides a reference for the selection of its artificial breeding and planting rescue sites. The numerical range of the main environmental variables can provide reference for the construction of wild growth environment for its breeding and planting areas, so as to make it grow in the appropriate environment, reduce the pressure of protection and realize the rational development and utilization of this resources.

Conclusions

(1) The suitable distribution areas of the maire yew in China are mainly distributed on southwestern, central, southern and east China from Mid-Holocene to the 2070s; (2) The suitable growth areas in China were projected to be increased gradually relative to Mid-Holocene. Most importantly, western Henan, southern Shaanxi, eastern Sichuan and the border of Yunnan and Guizhou provinces etc were predicted to be new suitable centralized regions for conservation and cultivation of this species; (3) The most significant factors were precipitation of the driest month of 22.3 to 122.5 mm, annual precipitation of 1100 to 2100 mm, altitude variable of 50 to 1100 m and min temperature of the coldest month of -2 to 4°C, respectively.

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