MaxEnt modelling for predicting the potential distribution of a near threatened rosewood species (*Dalbergia cultrata* Graham ex Benth)

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Abstract: Climate change will affect ecological factors that influence species distribution patterns at different spatial and temporal scales. We applied MaxEnt to predict how climate change will influence the distribution of ecologically and economically important tree species *Dalbergia cultrata* Graham ex Benth. *D. cultrata* is distributed across the tropical and subtropical zone of the Indo-China peninsula and southern Yunnan province in China. In recent decades, natural regeneration of *D. cultrata* has decreased drastically to only a limited region due to human disturbance, inter-species competition and other threats. Understanding the habitats requirements of this species, evaluating habitats quality, and predicting potential habitats are essential to ensure its conservation. We used the MaxEnt model to simulate habitats suitability and future species distribution under predicted climate change scenario using ten environmental variables. Our results showed that the modelled distribution of *D. cultrata* is mainly influenced by isothermality (Bio3), temperature annual range (Bio7), precipitation of wettest month (Bio13), and precipitation of warmest quarter (Bio18), suggesting that this species is sensitive to temperature and precipitation fluctuation. These findings indicated *D. cultrata* is likely to be highly vulnerable to climate change. Subsequent simulations of habitats suitability under doubled CO_2 levels was calculated. Overall, our results show that habitats of high suitability for *D. cultrata* is predicted to decrease in the face of climate warming. Populations at the species range edge will be particularly vulnerable

to climate change. We discuss the implications of our analysis for conservation priority setting and future restoration strategies for this important high value species across the Indo-China region. International and regional cooperation will be critical to successful conservation of this species.

Keywords: Climate change; *Dalbergia cultrata*; MaxEnt; Habitats suitability simulation

1. Introduction

The geographic distribution of a tree species is influences by multiple factors including the ecological traits of the tree and interactions with biotic and abiotic factors to define its habitats, e.g., species composition, microclimate and topography, especially for the dominating species in the forest (Chen et al., 2010; Pandey, 2015). Global climate change will have an impact on ecological factors and consequently lead to changes of species distribution patterns on different spatial and temporal scales (Root et al., 2003; Mantyka-Pringle et al., 2012). Climate change is predicted to have negative effects for some species and accelerate global extinctions (Li et al., 2013; Urban, 2015). Predictions using numerous GCMs show that at the end of this century, the average surface temperature will increase by 0.3 to 4.8 °C (IPCC, 2013). Recently, IPCC special report indicated global greenhouse gas emission have caused approximately 1°C of global warming above pre-industrial temperatures; if this continues at its current rate, warming is likely to reach 1.5 °C or even 2 °C between 2030 and 2052. The climate-related risks for natural systems are higher for global warming of 2.0 °C than at present (IPCC, 2018). Global warming will affect species survival and geo-distribution patterns because species will need to acclimatize to a longer frost-free season, changes in precipitation patterns, seasonal drought, heat waves, and other extreme weather events, as well as to the biotic stress (Hughes, 2000; Smith et al., 2009).

The dynamics of species distribution and potential adaptation are key issues in biodiversity conservation in the context of global climate change (Bai et al., 2017; Peterson et al., 2019). A SDM is a method to study changing species distribution patterns. Among the many alternative methods for species distribution modelling, the MaxEnt method is considered to have the advantages of high accuracy, small sample size and simple operation (Phillips et al.,2006). It has been used to predict species distribution in natural, potentially introduced and planted areas, the adaptation of pests and disease, the interactions between species distribution and environments (Matyukhina et al., 2014; Costa et al., 2015).

Dalbergia cultrata Graham ex Benth is a deciduous tree species belonging to the genus *Dalbergia* of family Papilionaceae, which has high ecological and exceptionally high economic value because of its precious rosewood timber with resistance to disease, insects and fire. This species is distributed in southern Yunnan province in China as well as adjacent tropical and subtropical zones in the Indo-China peninsula (Kunming Institute of Botany Chinese Academy of Sciences, KIOBCAS, 2006). Overexploitation of *D. cultrata* can be dated back to the last century, resulting from the increasing consumption demand for rosewood all over the world. The natural range of *D. cultrata* has decreased rapidly in recent decades. The species has been included on the IUCN red list with a status of

Near Threatened and on China's list of wild plants under Class II State protection. Previous studies have focused on biological characteristics (Wang et al., 2016), seed germination, seedling cultivation (Deng and Song, 2008; Qiu et al., 2015), symbiotic microorganisms (To-anun et al., 2003; Lu et al., 2011) and active components (Donnelly et al.,1972). However, few conservation biology studies for *D. cultrata* have been conducted (Liu et al., 2019). Information on the habitats distribution, population statues and conservation strategy of *D. cultrata* are scarce. The descriptive information of this species is usually general or limited to a small region (Zhang et al., 2010). The natural regeneration of *D. cultrata* has decreased substantially due to human disturbance, inter-species competition and other threats to a limited region in China (The Forestry Department of Yunnan Province, FDYP, 2005). It is necessary to develop a conservation strategy for improving its sustainable use. However, existing information is not sufficient to formulate a scientific conservation strategy for the species. Developing more detailed and accurate information on the potential distribution, environmental requirements and population status of *D. cultrata* is crucial to conserve the species.

This study used occurrence records of *D. cultrata* in Indo-China peninsula and southern Yunnan province in China to model its habitats suitability distribution to support conservation planning for this species using the following approach: (1) selecting the key environmental variables highly correlated with *D. cultrata* distribution; (2) developing tools to quantify the relationship between *D. cultrata* presence and the selected environmental variables (bioclimatic and topographical variables); (3) simulating and comparing the habitats suitability of *D. cultrata* under climate warming scenarios (2 x CO_2 climate conditions, CCM3 model). The results from this study will provide informatively habitats suitability maps for *D. cultrata*, enhance our understanding of factors influencing distribution range, and predict the potential risk from climate change. Furthermore, these findings will support natural resources surveys, conservation of forest genetic resources and planning for restoration or acclimation for *D. cultrata*.

2. Materials and methods

2.1 Occurrence sources

A total of 316 occurrence records of *D. cultrata* were obtained by field survey and information retrieval. Of these, 69 current occurrence records were obtained by field surveys in southern Yunnan province during March 2018. These occurrence data were mainly distributed in areas with elevation ranging from 600 to 1400 m, which lies between 21°58' N to N22°40' N latitude and 99°57 'E to 101°30' E longitude. Another 213 historical occurrence records were collected from the database of the CVH (http://www.cvh.org.cn/) and the database of the GBIF (http://www.gbif.org). These data, distributed in China, Thailand, Myanmar, Laos, Vietnam, are from the specimen and observation record of *D. cultrata*. Additionally, 34 occurrence records were obtained from records in the literature (Winfield et al., 2016).

2.2 Data processing

The occurrence records were transformed to uniform latitude and longitude coordinates, and all latitude and longitude data default to east longitudes and north latitudes being positive and west longitudes and south latitudes being negative. To decrease the effect of sampling bias, these occurrence data were proofread and screened. Since the spatial resolution of the environmental variable is 2.5 arc-minutes (approximately 4.5 km^2), when the distance between the two occurrence records was less than 3 km, only one of them was retained (Wang et al., 2017). Finally, 181 occurrence records of *D. cultrata* were selected to model the suitability of habitats. Among them, there were 67 records from the field survey, 48 records from CVH (http://www.cvh.org.cn/), 33 records from GBIF (http://www.gbif.org), and 33 records from other literature.

2.3 Environmental and map data

Environmental variables are meaningful to explain the habitats distribution ecologically based on the ecological niche of the species. Nineteen bioclimatic variables for the present (1950-2000) and future climate warming scenarios (2 x CO_2 climate conditions, CCM3 model) and a topographical factor (altitude) were collected from the diva-gis database (http://www.diva-gis.org/climate), and are shown in Table 1. The data spatial resolution was 2.5 arc-minutes. All the environmental datasets were converted to ASC II raster files, which are necessary for MaxEnt. The vector map of the world was downloaded from the diva-gis official website (http://www.Diva-gis.org/gdata).

2.4 Variable selections

We used the ROC analysis in MaxEnt to evaluate the model performance using the AUC (Phillips et al., 2006). The variables with high contribution percentages were considered. Then, Pearson correlation analysis was conducted and variables with correlation coefficients >0.8 or <−0.8 were excluded (Fourcade et al., 2014).

2.5 MaxEnt model

MaxEnt (version 3.3.3) was obtained from http://www.cs.princeton.edu/schapire/MaxEnt. The training data were 75% of the sample data selected randomly, and the test data were the remaining 25%. The habitats suitability curves for each variable were calculated, and the contributions of each variable to the *D. cultrata* habitats model were calculated using the software's built-in jackknife test with ten repetitions (Hill et al., 2012). The results of the built-in jackknife test reflect how much gain is obtained from each variable in isolation or from all the variables in combination. A greater gain value with an individual variable indicates that more information or contribution towards species habitats distribution is contained in the variable (Wang et al., 2017). The evaluation of the Species Distribution Model performance was calculated by the AUC. The area under the curve was positively correlated with the performance of the prediction model (Elith et al., 2006). In this study, the average AUC based on ten calculation results serves as a criterion to evaluate model performance. In general, the AUC should be between 0.5 and 1: when the AUC equal to 0.5, the performance of the model is equivalent to pure guessing; thus, the model performance is graded as fail (0.5-0.6), poor (0.6-0.7), fair (0.7–0.8), good (0.8–0.9), or excellent (0.9–1) (Phillips et al.,2006).

After the MaxEnt modelling analysis, the export file was uploaded to ArcGIS v10.1. The grades of suitable habitats were reclassified using Spatial Analyst Tools equidistance classification. Then, the results were mapped to vector layers of the world map.

2.6 Habitats prediction for future elevated CO_2 level

Elevated CO_2 level is considered a major reason for global warming and climate change. Elevated CO_2 will change the water supply, transportation, energy, and ecosystem balance (IPCC, 2013). When the concentration of CO_2 doubles, the average surface temperature may increase by 3.0 ± 1.5 °C (Schmidt, 2012). Projections of the most relevant climate layers in 2 x CO_2 climate conditions, based on the CCM3 model, were extracted from the diva-gis dataset and used to estimate the habitats distribution of *D. cultrata* in the future global warming scenario (Govindasamy et al., 2003).

3. Results

3.1 Variable selection

To eliminate multiple linearity between variables and improve model performance, the cumulative variable contributions were calculated and are indicated in Table 2. The result shows that six bioclimatic variables had no contribution to the species distribution model, and these variables were removed, including Bio9, Bio16, Bio8, Bio6, Bio10, Bio5. Then, the Pearson correlation coefficient of the remaining bioclimatic variables was calculated. A correlation value of correlation coefficient >0.8 or <−0.8 is considered a strong correlation between pairwise variables, and a variable with less contribution to the model was eliminated e.g., Bio1. The correlation coefficient of pairwise variables is shown in Table 3. Finally, only ten environmental variables were selected for further modelling.

3.2 Model performance and variable contributions

The calculated ROC showed that the average AUC value of the datasets was 0.988 (Fig. 1), which indicated the model is graded as good for our dataset. The contribution of the ten variables calculated by the jackknife test is shown in Fig. 2, where the gains of six variables are greater than 1.0, e.g., Bio3, Bio4, Bio7, Bio13, Bio15 and Bio18. The results suggest that these variables may have more useful information than the others. Temperature and precipitation are the primary ecological factors that affect plant survival and distribution (Smith et al., 2009). Bio2 and Bio19, had moderate gains when used independently, and Bio14 and altitude had lower gain.

3.3 Potential habitats distribution

Based on equal interval classification, the suitability of *D. cultrata* habitats distribution was reclassified into four grades: habitats not suitable ($P<0.10$), habitats of low suitability ($0.10<P<0.30$), habitats of normal suitability ($0.30<P<0.60$), and habitats of high suitability ($P>0.60$). The P value is the habitats suitability of the species on the model. Moreover, the potential and suitable habitats distribution of *D. cultrata* is illustrated in Fig. 3. The areas with habitats suitability above 0.6 are located in eastern Myanmar, northern Thailand, northwestern Laos, and southern Yunnan, China. These results indicate that the tropical and subtropical zones in the north central Indo-China Peninsula are the main distribution areas for *D. cultrata* (14°N-26°N; 94°E-112°E). The climatic features of these areas are high precipitation, humidity and mean annual temperature. e.g., in southern Yunnan province, the average annual temperature in Simao city ranged from 16.0 °C to 20 °C and its average annual precipitation ranged from 1200 mm to 2000 mm; the average annual temperature in Jinghong city ranged from 20.0 °C to 24.0 °C and its average precipitation ranged from 1200 mm to 1600 mm; Chiangmai city located in northern Thailand, its annual average temperature is 25°C, the highest average temperature is 36°C, and the lowest average temperature is 13.4°C; In the eastern part of Myanmar, annual precipitation can reach more than 1200 mm (Editorial committee of Climate Change Prediction and Impact Assessment Report for Yunnan in the Next 10-30 Years, 2014).Interestingly, we found that a few habitats of high suitability (P>0.60) of *D. cultrata* are also distributed sporadically along the northeast coast of Australia, east and southern Africa (Zimbabwe, Tanzania and South Africa), and the north central coast of Mexico (Fig. 3).

3.4 Variable response curves

The response curves show the relationship between environmental variables and habitats suitability and can enable us to understand the ecological niche of a species. The ranges of suitability for environmental variables were identified by the threshold of normal suitable habitats. The response curves of ten variables to habitats suitability of *D. cultrata* are illustrated in Fig. 4, and the suitable range for each variable is shown in Table 4. The suitable temperature annual range (Bio7) for *D. cultrata* was from 17.86 °C to 25.61 °C, with an optimal temperature of 20 °C, and the suitable range for precipitation of warmest quarter (Bio18) was from 393 to 1356 mm, with optimal precipitation of 686 mm. Whereas the suitable range of isothermality (Bio3) was from

48.12 to 59.34%, with an optimum value of 52.83%.

3.5 Effect of elevated CO_2 level on suitable habitats for *D. cultrata*

To understand the implications of climate change on *D. cultrata* habitats, we used 2 scenarios (present and 2 x CO_2 level condition, CCM3 model) to model habitats suitability. The result showed that the distribution patterns of the *D. cultrata* habitats had a subtle change on the global scale (Fig. 3, Fig. 5). The total area of *D. cultrata* habitats will increase in the global warming scenario from 3.96×10^6 to 4.43×10^6 square kilometres, and the extended area percentage will be above 14.9%. The increased areas with habitats of low suitability ($0.10<P<0.30$) and habitats of normal suitability ($0.30<P<0.60$) may largely profit from climate warming. However, other data show that the areas of habitats of high suitability ($P>0.60$) in the future will be reduced by 8.8×10^4 square kilometres (Table 5), and the compression percentage will be close to 14.6%. Meanwhile, habitats of high suitability ($P>0.60$) will disappear from the American Continent and increase in the South Asian Sub-Continent (Fig. 5).

4. Discussion

4.1 Modelling performance

Variables selection has a remarkable effect on species distribution modelling (Araújo and Guisan, 2006; Fourcade et al., 2017). Removing redundant variables can eliminate multiple linearity between variables, and contribute more predictive power to the model (Ashcroft et al., 2011; Yi et al.,2016). Preliminary analysis of gain or permutation importance by MaxEnt gives us a more objective tool to select the variables through assessing their effect on the accuracy of modelling. On the basis of preliminary analysis, the highly correlative variables have been screened and removed by Pearson's correlation coefficient. The built-in jackknife test from MaxEnt showed that isothermality (Bio3) and temperature annual range (Bio7) have more contributions to species distribution modelling, and the second most important environmental variable for modelling is precipitation (Bio13 and Bio18). This result indicates that temperature fluctuation and precipitation in rainy season may be primary limiting factors for the distribution of *D. cultrata*. These findings are similar to the environmental requirements of *Pterocarpus angolensis*, distributed in tropical areas of Africa (Cauwer et al., 2014).

4.2 Variable responses to suitability

The response curves of variables and suitability will provide more detailed information on the habitats requirement of species if the predictive statistical response for distribution is in close proximity to the real ecological response of species. Therefore, these values could serve as a reference range for population ecology and biology research. Both temperature and precipitation were considered the most important ecological factors for plant distribution and expansion potential (Manske, 2003), and isothermality (Bio3) may be useful and significant for the species distribution in pantropical areas (O'Donnell and Ignizio, 2012). Isothermality (Bio3) indicates how large the day-to-night temperature oscillation is relative to summer-to-winter oscillation, it reflects larger or smaller temperature fluctuation within month to year. Additionally, the temperature seasonality (Bio4) is an alternative measure of temperature change over the course of the year, the larger the standard deviation, the greater the variability of temperature.

The training gain of both variables and the optimal predictive value indicated that *D. cultrata* may prefer an even and warm environment. The predictive suitable temperature annual range (Bio7) was from 17.8 °C to 25.6 °C, which is similar to the annual temperature range of the realized habitats (17 °C to 21.7 °C) recorded in the literature (Wang et al., 2016). The average minimum temperature in the coldest month must be above 12 °C for *D. cultrata* (The Forestry Department of Yunnan Province, FDYP, 2005). According to the response curve of minimum temperature of coldest month (Bio6) from preliminary tests, this species might suffer but can survive below 7 °C, which indicates that this species could be introduced and planted to the border areas of the natural range. Altitude is also an important factor for species distribution. The results show that the optimal suitable range of altitude was 1200 m, which is very close to the altitude range of the actual distribution, from 600 to 1600 m in China (Qiu et al., 2015). The spatial and temporal variation of precipitation also influences species distribution (Jiang and Ma, 2014). The response curves evaluating suitability to precipitation seasonality (Bio15) and precipitation of driest month (Bio14) indicate that *D. cultrata* may have a relatively strong potential for acclimating to water stress. The precipitation seasonality (Bio15) is an index that provides a percentage of rainfall variability, in which larger percentages represent greater precipitation variability, and the precipitation of driest month (Bio14) indicates the extreme precipitation condition during the year. This result also explains why many *D. cultrata* individuals are capable of growing on shallow and poor soil, e.g., side slopes of highways. This kind of habitats has been observed in our field survey and reported in previous literature (Zhang et al., 2010).

4.3 The dynamic trend of suitability in global warming

Our models indicate that the habitats suitability of *D. cultrata* will change slightly under global warming. The total area of suitable habitats will grow. However, habitats of high suitability (P>0.60) will shrink to border areas among Yunnan China, Myanmar, Laos, and Thailand. The decreased area will become habitats of normal suitability (0.30<P<0.60) and habitats of low suitability (0.10<P<0.30) (Fig. 5, Table 5), e.g., eastern Myanmar, northern Laos. This finding indicates that climate change in these regions may affect survival and distribution of habitats of the species. It is generally acknowledged that elevated CO_2 and temperature are favourable for plant growth in a short-term physiological response, e.g., improving growth due to higher rate of photosynthesis per unit leaf area and less specific leaf area (Poorter and Navas, 2003). However, a few reports confirmed that elevated CO_2 and temperature will be to the disadvantage of plants, e.g., warming reduces flower number and seed production for some species (Liu et al., 2012), and elevated CO_2 reduces the nitrogen concentration of plant tissues (Cotrufo et al., 1998). Considering climate change as key threat in tropical areas in Asia, there may be an increasing number of extreme weather events in tropical and subtropical regions, e.g., long-term and large-scale drought and floods (Jiang and Ma, 2014), and these changes may influence the survival and distribution of *D. cultrata*

4.4 Other threats

Species distribution modelling always considers climate and geographic factors; however, other factors are able to affect species distribution, e.g., adaptability, interspecies competition, and land use change etc. (Cauwer et al., 2014). As we didn't consider other potential threats than climate change, it is likely that habitats of high suitability (P>0.60) for *D. cultrata* will decrease in a wider range or more drastically as our model results predict. From our field survey, the natural distribution of *D. cultrata* decreased rapidly because of overharvesting, land use change and interspecies competition. In 2005, the distribution area of *D. cultrata* was only approximately 6,000 hectares in southern Yunnan, China, e.g., Simao, Lancang, and Xishuangbanna (The Forestry Department of Yunnan Province, FDYP, 2005). In recent years, large areas of natural forest were transformed into planted land, and the area of rubber plantations vigorously grew to over 578.87 km^2 in southern Yunnan (Fan et al., 2015); unfortunately, these areas also overlapped with habitats of high suitability (P>0.60) for natural distribution of *D. cultrata*. We found that most of the mature trees of *D. cultrata* are distributed sporadically at edge of the forest, and only a few small populations inhabit the forest in southern Yunan (Fig. 6). The previous survey showed that because of overharvesting the diameter at breast height of a majority of trees was less than 10 cm in the lower reaches of the Lancang River (Zhang et al., 2010), which was consistent with our field survey.

5. Conclusion

Suitable habitats for *D. cultrata* was predicted with good accuracy by using species distribution modelling. The results provide detailed information on the potential distribution and on the environmental requirements of the species, which will be considered in the forest resource survey and in the biology character research. The potential and realized distribution are very similar in southern Yunnan, China at least. The distribution of *D. cultrata* is mainly influenced by isothermality (Bio3), temperature annual range (Bio7), precipitation of wettest month (Bio13), and precipitation of warmest quarter (Bio18), which suggests that this species is sensitive to temperature fluctuation and precipitation in rainy season; thus, this species is likely to be threatened by climate change. Meanwhile, simulation results for *D. cultrata* in doubled CO_2 level conditions showed that habitats of high suitability (P>0.60) will decrease, and climate warming will not be an advantage for this species; however, *D. cultrata* prefers warm and humid environments. Meanwhile, also habitats fragmentation may lead to genetic drift and decrease the population genetic diversity due to anthropogenic activity disturbance. We conclude that the populations on the edge of the present high suitability patterns will be particularly vulnerable to climate change. Hence, these populations should be prioritized for ex situ conservation and a population restoration plan should be developed in the near future. Southern Yunnan, eastern Myanmar, north-western Laos and northern Thailand seem stable and highly suitable for *D. cultrata* in the global warming scenario, so long-term in situ conservation plans can be implemented in these regions through broad international and regional cooperation.

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Author contributions

Dr Yu Liu contribute to field surveys and data analysis, and Dr Ping Huang contribute to designed and performed the experiments and wrote the manuscript, Mr. Furong Lin and Dr Wenyun Yang contribute to the field survey, Hannes Gaisberger and Kettle Christopher revised the manuscript, Yongqi Zheng conceived the study and revised the manuscripts.

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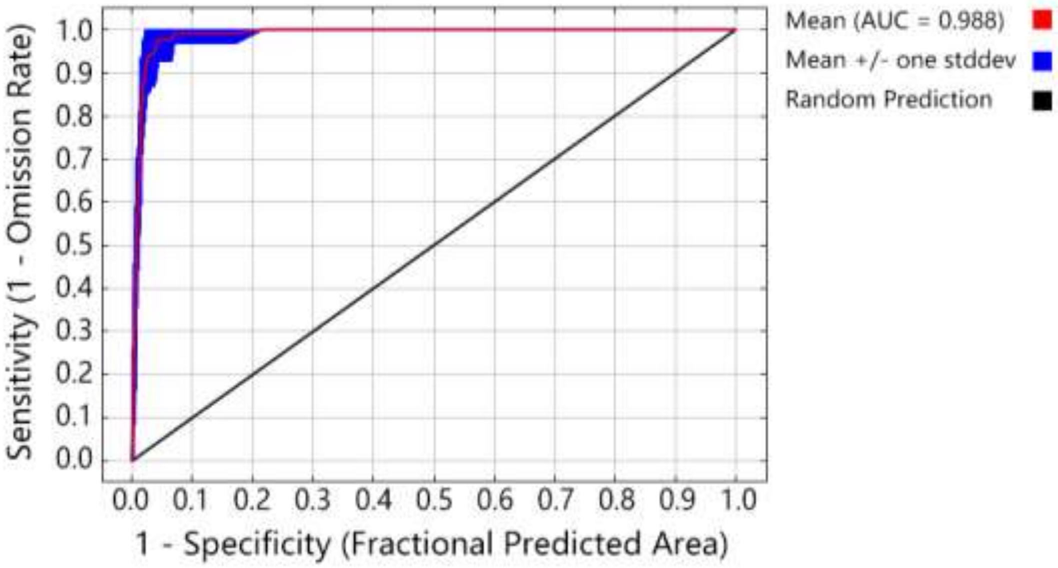


Fig. 1. The AUC curves in the developing *D. cultrata* distribution model. (The red (training) line shows the “fit” of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data and is the real test of the model’s predictive power.).

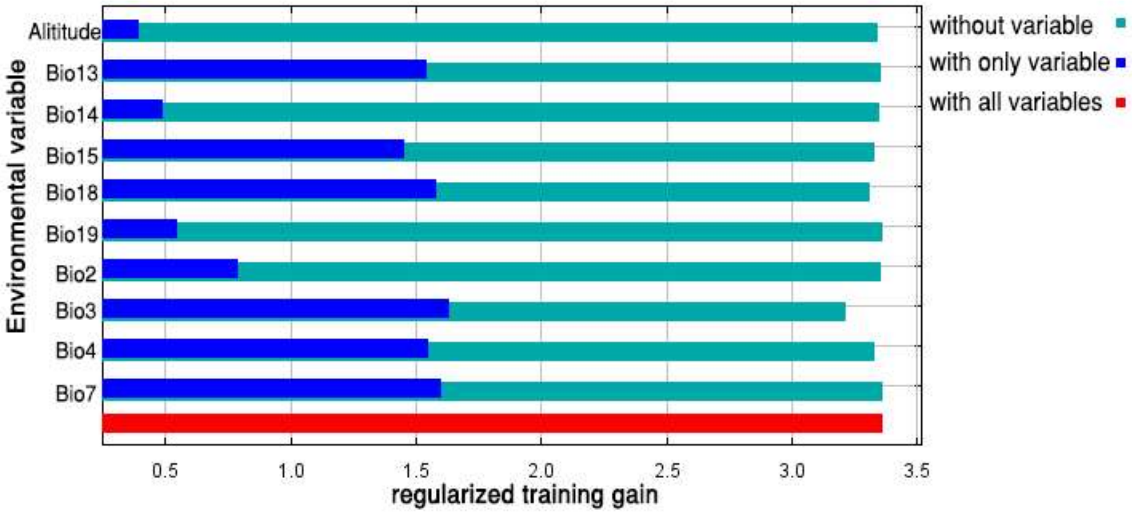


Fig. 2. The results of the jackknife test for the contributions of variable in *D. cultrata* habitats distribution modelling. (The regularized training gain describes how much better the MaxEnt distribution fits the present data compared to a uniform distribution. The dark blue bars indicate the gain from using each variable in isolation, the light blue

bars indicate the gain lost by removing a single variable from the full model, and the red bar indicates the gain using all variables).

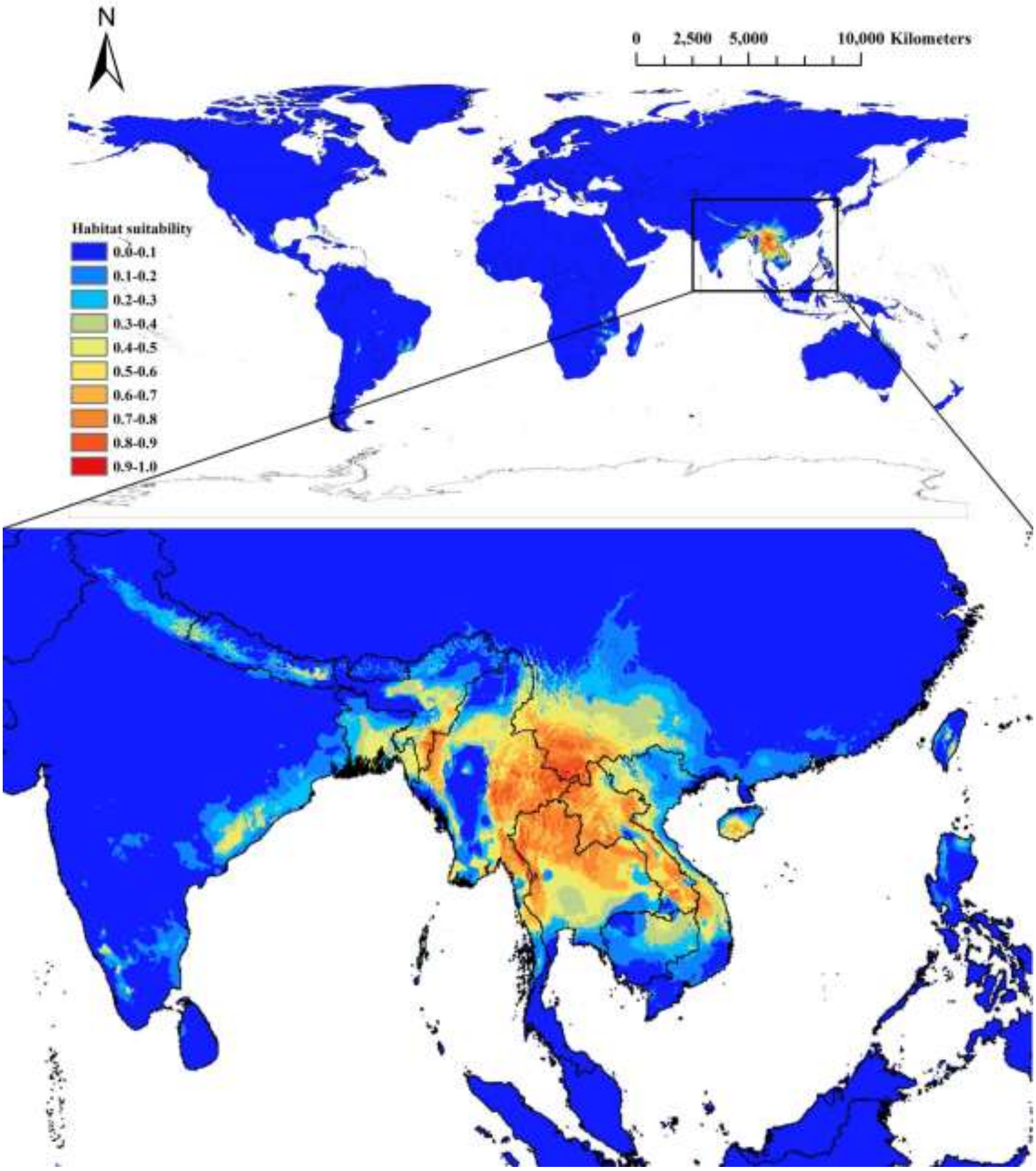
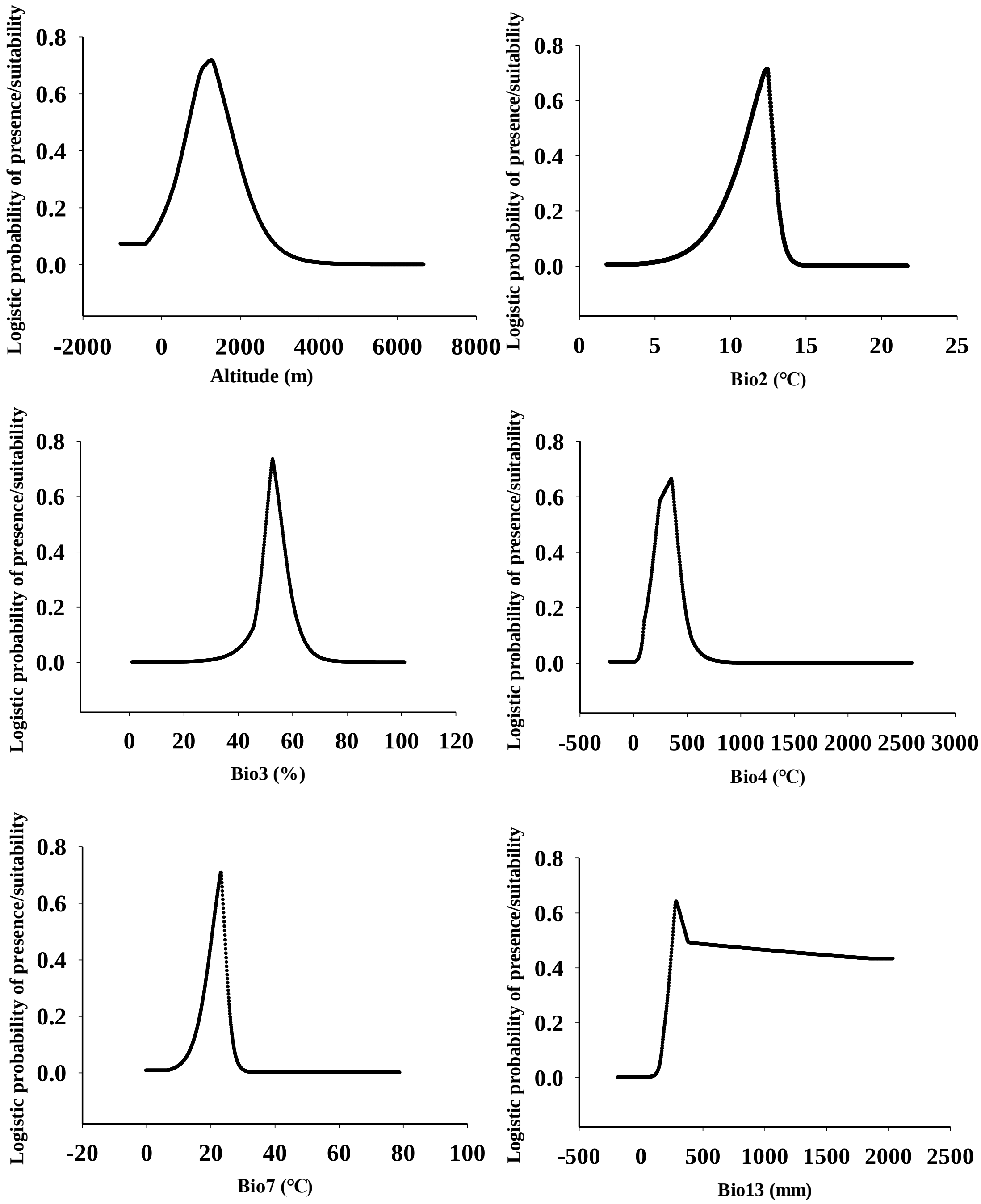


Fig. 3. Predicted suitable habitats distribution of *D. cultrata* in the world.


Logistic probability of presence/suitability
0.8
0.6
0.4
0.2
0.0
-2000
0
2000
4000
6000
8000
Altitude (m)
0
5
10
15
20
25
Bio2 (°C)
20
40
60
80
100
120
Bio3 (%)
-500
500
1000
1500
2000
2500
3000
Bio4 (°C)
-20
Bio7 (°C)
Bio13 (mm)

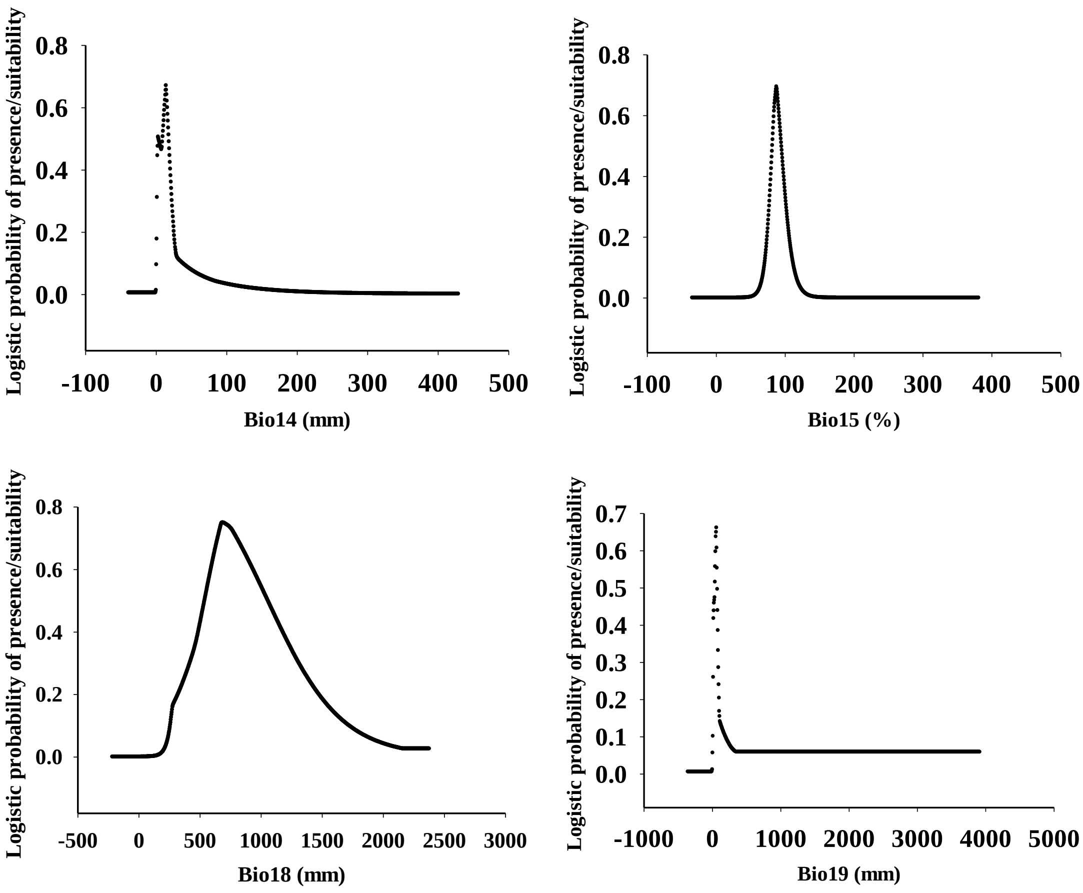


Fig. 4. Response curves of 10 environmental variables in the *D. cultrata* distribution model. (Altitude (m); Bio2: Mean Diurnal Range (°C); Bio3: Isothermality (%); Bio4: Temperature Seasonality (°C); Bio7: Temperature Annual Range (°C); Bio13: Precipitation of Wettest Month (mm); Bio14: Precipitation of Driest Month (mm); Bio15: Precipitation Seasonality (%); Bio18: Precipitation of Warmest Quarter (mm); Bio19: Precipitation of Coldest Quarter (mm)).

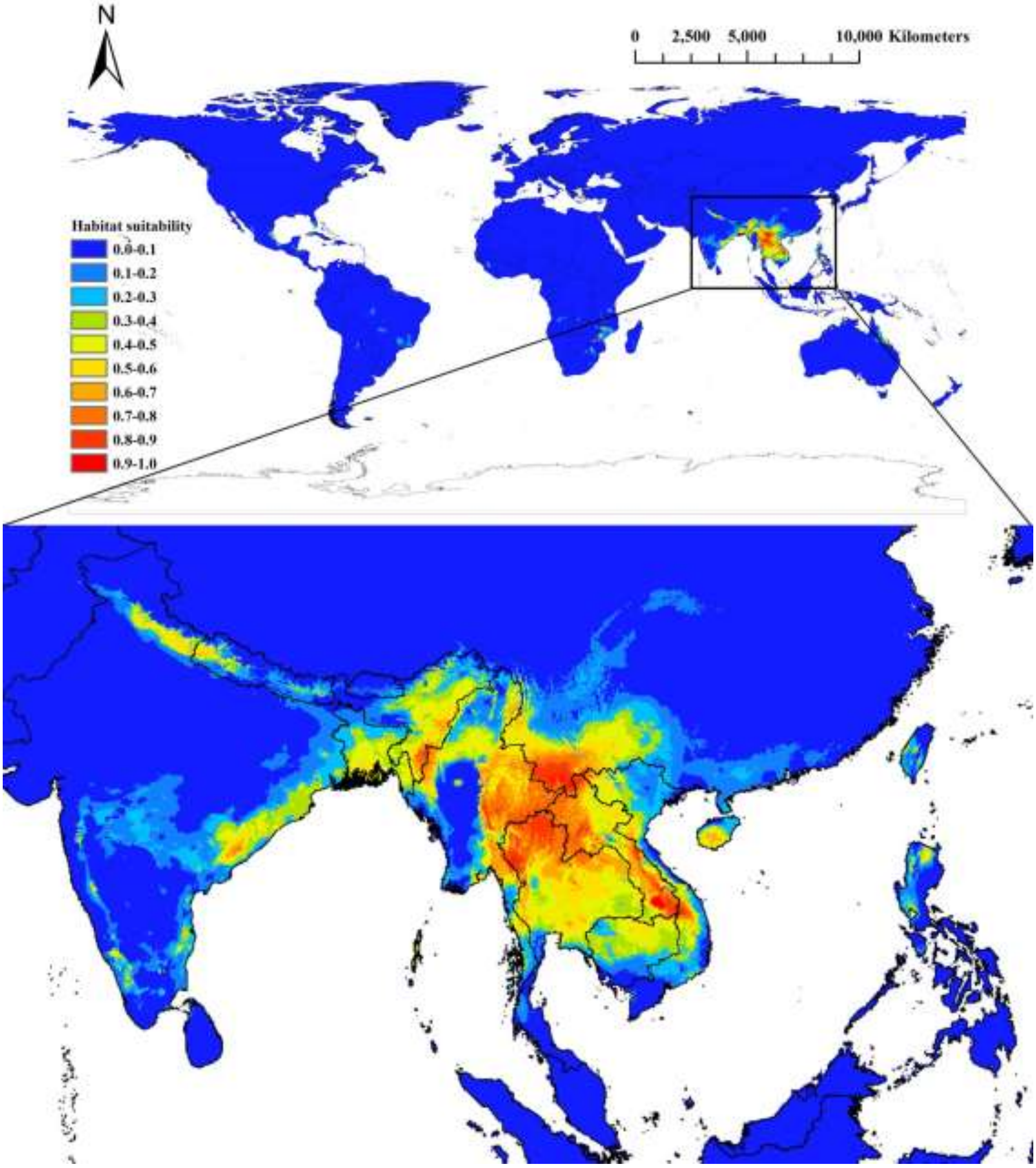


Fig. 5. Predicted suitable habitats distribution of *D. cultrata* under 2 x CO_2 level condition (CCM3).

Fig. 6. Field survey of *D. cultrata* in southwestern of Yunnan in China. (a) The habitats survey showed that a small population of *D. cultrata* inhabits the edges of rubber tree (*Hevea brasiliensis*) plantations; (b) Biotic stress on natural regeneration for *D. cultrata*; (c) Natural regenerated seedlings of *D. cultrata* were found in good soil conditions.

Table 1 Bioclimatic variables and topographical factor.

Variables and description	Unit
Bio1 = Annual Mean Temperature	°C
Bio2 = Mean Diurnal Range	°C
Bio3 = Isothermality	%
Bio4 = Temperature Seasonality	°C
Bio5 = Max Temperature of Warmest Month	°C
Bio6 = Min Temperature of Coldest Month	°C
Bio7 = Temperature Annual Range	°C
Bio8 = Mean Temperature of Wettest Quarter	°C
Bio9 = Mean Temperature of Driest Quarter	°C
Bio10 = Mean Temperature of Warmest Quarter	°C

Bio11 = Mean Temperature of Coldest Quarter	°C
Bio12 = Annual Precipitation	mm
Bio13 = Precipitation of Wettest Month	mm
Bio14 = Precipitation of Driest Month	mm
Bio15 = Precipitation Seasonality	%
Bio16 = Precipitation of Wettest Quarter	mm
Bio17 = Precipitation of Driest Quarter	mm
Bio18 = Precipitation of Warmest Quarter	mm
Bio19 = Precipitation of Coldest Quarter	mm
Alt = Altitude	m

Table 2 Accumulated contribution of each environmental variable to the potential distribution of *D. cultrata* defined by MaxEnt.

Environmental variables	Percentages of contribution (%)	Accumulating percentages of contribution (%)	Environmental variables	Percentages of contribution (%)	Accumulating percentages of contribution (%)
Bio13	32.00	32.00	Bio11	0.30	99.30
Bio3	26.10	58.10	Bio19	0.30	99.60
Bio15	13.20	71.30	Bio2	0.20	99.80
Bio18	13.00	84.30	Bio1	0.20	100.00
Bio14	5.20	89.50	Bio9	0.00	100.00
Bio12	4.50	94.00	Bio16	0.00	100.00
Altitude	2.30	96.30	Bio8	0.00	100.00
Bio17	1.40	97.70	Bio6	0.00	100.00
Bio4	0.90	98.60	Bio10	0.00	100.00
Bio7	0.40	99.00	Bio5	0.00	100.00

Table3 Pair-wise Pearson's correlation coefficients of environmental variables.

Environmental variables	Bio2	Bio3	Bio4	Bio7	Bio13	Bio14	Bio15	Bio18	Bio19
Bio3	0.187*								
Bio4	0.136	-0.733**							
Bio7	0.695**	-0.554**	0.675**						
Bio13	-0.362**	0.157*	-0.187*	-0.429**					
Bio14	0.014	-0.149*	0.607**	0.205**	-0.029				
Bio15	-0.053	-0.029	-0.197**	-0.076	0.625**	-0.535**			
Bio18	0.08	-0.224**	0.641**	0.215**	0.269**	0.446**	0.146*		
Bio19	-0.239**	0.359**	-0.087	-0.352**	0.195**	0.560**	-0.218**	-0.018	
Altitude	0.305**	-0.183*	0.465**	0.368**	-0.088	0.282**	-0.026	0.631**	-0.137

“*” Means significant difference at $P < 0.05$ level; “’**” Means significant difference at $P < 0.01$ level.

Table 4 Suitable range and optimum value of each environmental variable for *D. cultrata*.

Environmental variables	Suitable range	Optimum value
Bio3: Isothermality (%)	48.12-59.34	52.83
Bio7: Temperature Annual Range (°C)	17.86-25.61	23.32
Bio18: Precipitation of Warmest Quarter (mm)	393.48-1356.01	686.65
Bio4: Temperature Seasonality (°C)	155.35-459.57	355.35
Bio13: Precipitation of Wettest Month (mm)	214.83-2037.20	285.95
Bio15: Precipitation Seasonality (%)	76.35-102.95	87.57
Bio2: Mean Diurnal Range (°C)	9.90-13.10	12.45
Bio19: Precipitation of Coldest Quarter (mm)	19.94-92.59	62.67
Bio14: Precipitation of Driest Month (mm)	1.72-23.24	14.35
Altitude (m)	310.31-2174.97	1273.46

Table 5 Predicted areas of *D. cultrata* habitats in present and 2 x CO_2 level condition.

	Habitats of low suitability (km^2)	Habitats of normal suitability (km^2)	Habitats of high suitability (km^2)	Total area(km^2)
Present	2.30×10^{6}	1.06×10^{6}	6.02×10^{5}	3.96×10^{6}
2 x CO_2 level condition	2.59×10^{6}	1.33×10^{6}	5.14×10^{5}	4.43×10^{6}

Appendix A

Table S1 Abbreviations list

Abbreviation	Full Name
AUC	Area Under the Curve
CCM3	Community Climate Model 3 model
CVH	Chinese Virtual Herbarium
FDYP	The Forestry Department of Yunnan Province
GBIF	Global Biodiversity Information Facility
GCMs	Global Climate Models
KIOBCAS	Kunming Institute of Botany Chinese Academy of Sciences
IPCC	The Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
ROC	Receiver Operating Characteristics
SDM	Species Distribution Model