The Journal of Animal & Plant Sciences, 27(1): 2017, Page: 219-226
ISSN: 1018-7081

INTEGRATING CLIMATE CHANGE INTO CONSERVATION PLANNING FOR *TAXUSCHINENSIS*, AN ENDANGERED ENDEMIC TREE PLANT IN CHINA

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ABSTRACT

Climate change has the potential to severely threaten *Taxuschinensis*, an endangered endemic tree plant in China. Hence, we need to plan conservation areas for *T. chinensis* in light of climate change. We applied the common species distribution modelling software Maxent to generate maps of current and projected future distributions of *T. chinensis*. These distributional maps with conservation planning software were used to determine priority protection areas (PPAs). Then, we evaluated the ability of existing nature reserves to conserve *T. chinensis* and performed a gap analysis for the species under climate change. The PPAs of *T. chinensis* were mainly distributed within central and southern China. Nature reserves such as Zhangjiajiedani, Yangzie, Wolong, Baishuijiang and Dabashan have the greatest potential to protect *T. chinensis* under climate change. In situ and ex situ conservation of *T. chinensis* in the PPAs of these five nature reserves should be a priority. However, existing nature reserves lag far behind the PPAs with respect to total area. Therefore, more nature reserves are urgently needed for species like *T. chinensis* to cope with rapid climate change. Meanwhile, we should strengthen protection and management of areas that will experience an increase in *T. chinensis* while enhancing both monitoring and protection activities for *T. chinensis* in PPAs that are predicted to experience decreases in population size. Finally, we suggest that climate change must be integrated into conservation planning for the endangered plant species, *T. chinensis*.

Keywords: climate change, conservation management, nature reserves, species distribution modelling, *Taxuschinensis*

INTRODUCTION

Climate change plays an important role on the protection planning of endangered plant species so that making endangered plant species harder to protect (Thuiller *et al*.,2005, Araújo *et al.,*2011, Bellard *et al.,* 2012). Integrating climate change into preserving endangered plant species is extremely urgent (Bellard *et al.,* 2012). Previous studies have shown that nature reserves are preserved and managed for conservation of endangered plant species and to provide special opportunities for study and research through both in situ and ex situ conservation (Araújo *et al.,* 2011, Hawkes *et al.,* 2012, Yu *et al.,* 2014). Hence, the establishment of more nature reserves is a direct and effective way to protect wild plant species (Araújo *et al.,* 2011). However, the conservation planningfor endangered plant species under climate change remains a challenge (Fordham *et al.,* 2013, Gillson *et al.,* 2013).

In recent years, new computational methods have been developed based on prediction algorithms that use species distribution modelling (SDM) to project the potential geographical distribution of species (Guisan and Thuiller, 2005). Predicting future species distributions and selecting appropriate nature reserves require the use of SDM programs such as Maxent and conservation planning software such as Zonation (Lehtomäki *et al.,* 2009, Moilanen *et al.,* 2011, Araújo *et al.,* 2011). Maxent uses a model that predicts the density and distribution of species; all pixels are regarded as the possible distribution space of maximum entropy (Guisan and Thuiller, 2005). Zonation is used to design wildlife reserves that minimize the amount of space in a conservation area while meeting protection requirements; it also describes regions that are priority protection areas (PPAs, Lehtomäki *et al.,* 2009, Moilanen *et al.,* 2011). These software programs are used increasingly by nature reserve planners and managers to rehabilitate species and preserve habitats (Lehtomäki *et al.,* 2009, Moilanen *et al.,* 2011). It is important to consider the current and future geographical distributions of the target species in the context of the cost required to create and to run these reserves, given the potential for range shifts over time in response to climate change. Hence, systematic conservation planning should consider the impact of climate change on the costs and benefits of preserving biological resources.

China has a great abundance of plant species, encompassing more than 10% of the world's vascular plant species (Liu and Diamond, 2005, López-Pujol *et al.,* 2006). Endangered plants in China will be substantially impacted by future climate change (Chen *et al.,*2005, Zhang *et al.,* 2014). The conservation of endangered species and their habitats is one of the most urgent tasks necessitated by climate change (Chen *et al.,* 2005). *Taxuschinensis* is an important endangered tree species. It is an endemic species that is often distributed in broad-leaved forests from sub-tropical to warm temperate zones in China (Pyo *et al.*, 2004, Zhang and Ru, 2010, Wan *et al.*, 2014a). Taxol from *T. chinensis* plays an extremely important role in modern cancer therapies (Pyo *et al.*, 2004). Because of its restricted range, small population and severely fragmented habitat, the species has been classified as 'Endangered' according to the Red List criteria (www.iucn.org) and is listed as a national first-class protected plant in China (http://www.gov.cn/gongbao/content/2000/content_60072.htm). To conserve wild populations of *T. chinensis*, a forestpark has been established in Guangdong province, China. However, the number and scale of nature reserves could not support the conservation of the entire *T. chinensis* species range. Furthermore, conservation plans should consider the impact of climate change on the distribution of *T. chinensis*. To address this issue, we must perform two tasks: (1) evaluate the ability of existing nature reserves to conserve *T. chinensis* and (2) make a gap analysis of *T. chinensis* distributions based on PPAs with respect to climate change.

Here, we first used Maxent to model the current and future potential distributions of*T. chinensis*, and then used Zonation to plan the conservation areas for *T. chinensis* under climate change projections. Second, we performed a gap analysis of *T. chinensis* distributions based on the map of Chinese nature reserves and the conservation areas indicated by Zonation. Finally, we propose effective suggestions for conservation planning of *T. chinensis* in China.

MATERIALS AND METHODS

Species data: Occurrence data, especially geographic coordinates, for *T. chinensis* including *Taxuschinensis* var. *chinensis* were obtained from the Global Biodiversity Information Facility (GBIF; http:/ /www.gbif.org/), Chinese Virtual Herbarium (CVH, http:/ /www.cvh.org.cn/) and a previous study by Wan *et al.* (2014a). Duplicate occurrences of recorded data for species within 2.5-arc-minute grid cells (4.3 km at the equator) were removed to avoid geo referencing errors. The occurrence records of species that could cover the actual distributions were examined according to the *T. chinensis* distribution information from *The Flora of China* (http://frps.eflora.cn/).

Environmental variables: The current and future bioclimatic variable data (according to a 2.5-arc-minute grid), elevation data (again, to a 2.5 arc-minute grid) and soil data (to a 0.5 arc-minute grid) were used for modelling, comprising the environmental layer input for SDM. Eight bioclimatic variables (the same as the current and future variables) were downloaded from the WorldClim database (www.worldclim.org). These variables included annual mean temperature (Bio1), mean diurnal range (Bio2), isothermality (Bio3), temperature seasonality (Bio4), mean temperature of the wettest annual quarter (Bio8), annual precipitation (Bio12), and precipitation: the driest month (14), precipitation seasonality (Bio15) and precipitation of the warmest annual quarter (Bio18). We also downloaded data for nine soil factors according to a 0.5-arc-minute spatial resolution from SoilGrids1km (http://soilgrids.org/). The nine soil factors included bulk density, cation exchange capacity, soil texture fraction clay, coarse fragments volumetric, soil organic carbon stock, soil organic carbon content, soil pH, soil texture of the silt fraction and soil texture of the sand fraction. The elevation data at a 2.5-arc-minute spatial resolution was also downloaded from WorldClim database. These variables, whose Pearson correlation coefficients with each other were between 0.8 and -0.8, are important because they are considered critical parameters for modelling the geographical distributions of plant species.

The evolutionary potential of tree populations needs to be consistent with selection pressures associated with climate change (Hoffmann and Sgro, 2011). A population of tree species is likely more persistent or tolerant to directional climate changes than a population of the other plant species because the time to produce individuals adapted to the new climate conditions is longer when you have a large pool of populations available (Jump and Penuelas, 2005, Aitken *et al.*, 2008). Hence, to model the future potential distribution of species in 2080s (2071–2099), the average map of four global climate models (GCMs; i.e. bcc_csm1_1, csiro_mk3_6_0, gfdl.cm3 and mohc_hadgem2_es) and two greenhouse gas concentration scenarios with representative concentration pathways (RCPs) of 4.5 and 8.5, representing low and high greenhouse gas concentration scenarios, respectively (http://www.ccafs-climate.org), was used. An RCP value of 8.5 describes a larger cumulative concentration of carbon dioxide than an RCP value of 4.5. Thus, each scenario will cause different climate changes due to variant anthropogenic concentrations of greenhouse gases and other pollutants (http://www.ipcc.ch/).

Modelling potential species distributions: Maxent software(ver.3.3.3k; http://www.cs.princeton.edu/~schapire/maxent/) was used to model the current and future potential distributions of *T. chinensis* based on current and future bioclimatic variable data, elevation data and soil data (Phillips and Dudík,2008, Elith *et al.*, 2011). When modelling future potential distributions of species, the elevation data and soil data remain unchanged. Maxent is well suited to this type of modelling for a variety of reasons: (1) it has the ability to handle small sample sizes, which drastically impacts both the performance and the adjustment of SDM; (2) it is insensitive to the geographic size of occurrence input data and (3) it provides the relative contribution of each variable (Merow *et al.*, 2013).

When using Maxent to predict map cells, cell values of 1 indicate the highest occurrence probability, whereas values of 0 indicate the lowest occurrence probability (Merow *et al.*,2013). In our study, 75% of records were used for model training and 25% were used for model testing (Fand *et al.*, 2014).The set of Maxent parameters from Merow *et al.* (2013) is suitable for most studies, as they are associated with highly accurate SDM. Models based on a random background across China require less extrapolation. Hence, the maximum number of background points was set to 10000 to accommodate the scope of China. The convergence threshold was set to 0.0001, and auto features were used. The regularisation multiplier was fixed at two (Radosavljevic and Anderson,2014), and four replicated run types were cross validated to determine estimates of uncertainty for the response curves, predictions and area under the curve (AUC). Default settings were used for all other parameters (Elith *et al.*, 2011). Finally, the fixed "10 percentile presence'' threshold of Maxent was used as the potential species distribution (Radosavljevic and Anderson,2014).

The analysis produced a receiver operating characteristic curve, which regards each value of the prediction results at a possible judging threshold; the corresponding sensitivity and specificity of the predicted results were obtained through further calculations. The precision of the model was evaluated by calculating the area under the receiver operating characteristic curve. The models were either graded as poor (AUC < 0.8), fair (0.8 < AUC < 0.9), good (0.9 < AUC < 0.95) or very good (0.95 < AUC < 1.0; Wan *et al.*, 2014b).

The determination of priority protection areas: Zonation conservation planning software (http://cbig.it.helsinki.fi/software/) was used to develop plans to protect *T. chinensis* from the effects of climate change. Zonation is usually used as a spatial conservation framework to prioritize large-scale conservation projects that involve many species and to determine maps that maps that prioritize valuable areas for endangered species (Lehtomäki and Moilanen,2013). Target PPAs with a high priority ranking for *T. chinensis* conservation were input. In this study, the reverse heuristic algorithm in Zonation was used to establish protection areas for *T. chinensis* across large spatio temporal scales. The highest priority areas for conservation were confirmed by identifying the top-ranking cells after computation (Lehtomäki and Moilanen, 2013). The geographic distance between the current and future distributions of *T. chinensis* richness were minimized and the influence of climate change on the future *T. chinensis* distribution was considered when selecting potential sites for reserves (Wan *et al.*, 2014b). Hence, Zonation was used to plan PPAs for*T. Chinensis* based on the potential distribution under the current conditions as well as under the low and high greenhouse gas concentration scenarios (Wan *et al.*, 2015). The original core-area cell removal rule to model marginal loss; this aims to balance the solution across all features at each removal step. The potential species distributions in the current, low and high greenhouse gas concentration scenarios were regarded with equal weights as inputs for Zonation (Lehtomäki and Moilanen, 2013).Thus, a pixel map of prioritization protection rank was obtained for *T. chinensis*.

Next, the areas that would protect 75% of the ecological region were modelled according to the target defined by Target 7 of the Global Strategy for Plant Conservation (GSPC; http://www.cbd.int/gspc/). Based on the rank map from Zonation, ArcGIS 10.2 (Esri; Redlands, CA, USA) was used to determine the 75% of priority protection areas for *T. chinensis* in China, and the average cell value of each nature reserve was extracted.

Finally, the maps representing theexisting nature reserves were superimposed on the Zonation maps in order to identify and confirm the most important protection zones. A China map of the IUCN I–VI nature reserves was downloaded from the World Database on Protected Areas (WDPA; www.wdpa.org). This step employed a gap analysis to help establish appropriate measures to plan the construction of new protection areas. A 2D scatter plot between the areas and the mean protection rank of PPAs for nature reserves was used to evaluate the ability of the existing nature reserves to protect *T. chinensis* from negative effects of climate change. Here, the nature reserves with large PPAs were considered first, followed by the mean protection rank.

RESULTS

We modelled the current and future potential distribution of *T. chinensis* with Maxent modelling, and the model fitted perfectly based on the AUC (average AUC value = 0.909).The area of potential distribution (i.e., the total number of cells) and the average cell probability of *T. chinensis* were predicted to decrease as the greenhouse gas concentration increases in China (Table 1). The current and future potential distributions of *T. chinensis* included southern and central China mainly (Fig. 1). However, the southern border of potential distributions of *T. chinensis* tended to shift northward as the greenhouse gas concentration increases (Fig. 1).

Using Zonation based on climate change, PPAs of *T. chinensis* were mainly distributed in central and southern China (Fig. 2). However, the existing nature reserves did not cover most PPAs (number of cells: 4925 for nature reserves, 72894for PPAs; Fig. 2).

Zhangjiajiedani, Yangzie, Wolong, Baishuijiang and Dabashanare the most important nature reserves based on their high PPA coverage and high protection ranks (Fig. 3). Although Dayaoshanshuiyuanlin, Sanjiangyuan, Yaluzangbudaxiagu, Manzetangshidi, Yanboyezeshan and Huangheshouqu had the low protection ranks, they had the largest PPA coverage, indicating these nature reserves have the greatest potential of the existing nature reserves to protect *T. chinensis* during climate change (Fig. 3).

Table 1. The area of potential distribution (i.e., the total number of cells) and the average cell probability of *T. chinensis* in China. Current: the present days; Low: low concentration scenario; High: high concentration scenario.

Code	Area	Probability
Current	72894	0.4492
Low	64503	0.4430
High	45931	0.4137

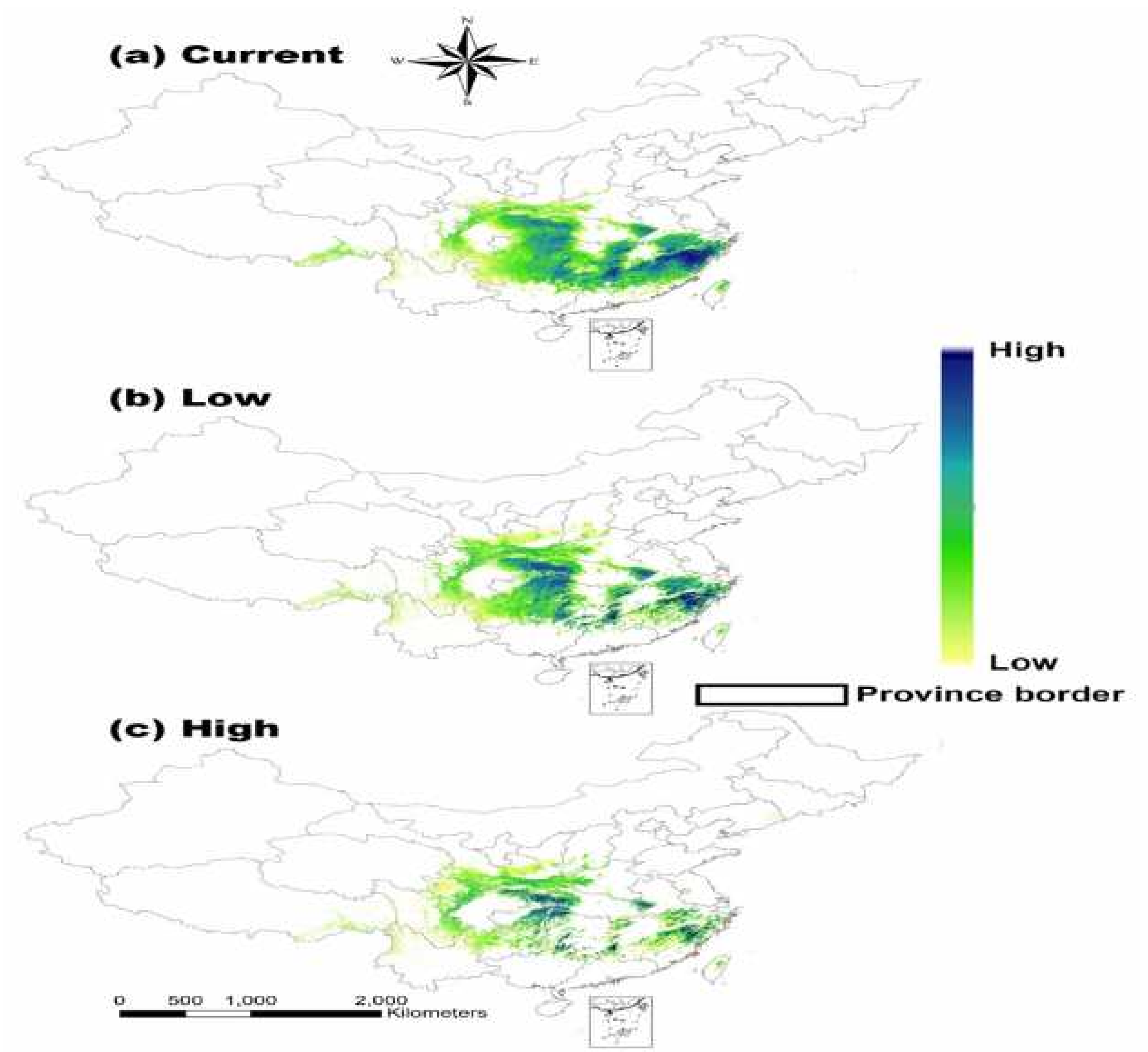

Fig. 1. Potential distributions of *Taxuschinensis* in current concentration scenario (a), low concentration scenario (b) and high concentration scenario(c).The color, ranging from shallow to dark, represents increasing potential distribution probability of *T. chinensis*. Current: the present days; Low: low concentration scenario; High: high concentration scenario. Fig. 1a represents the current potential distributions, and Figs. 1b and c together represent the future potential distributions.

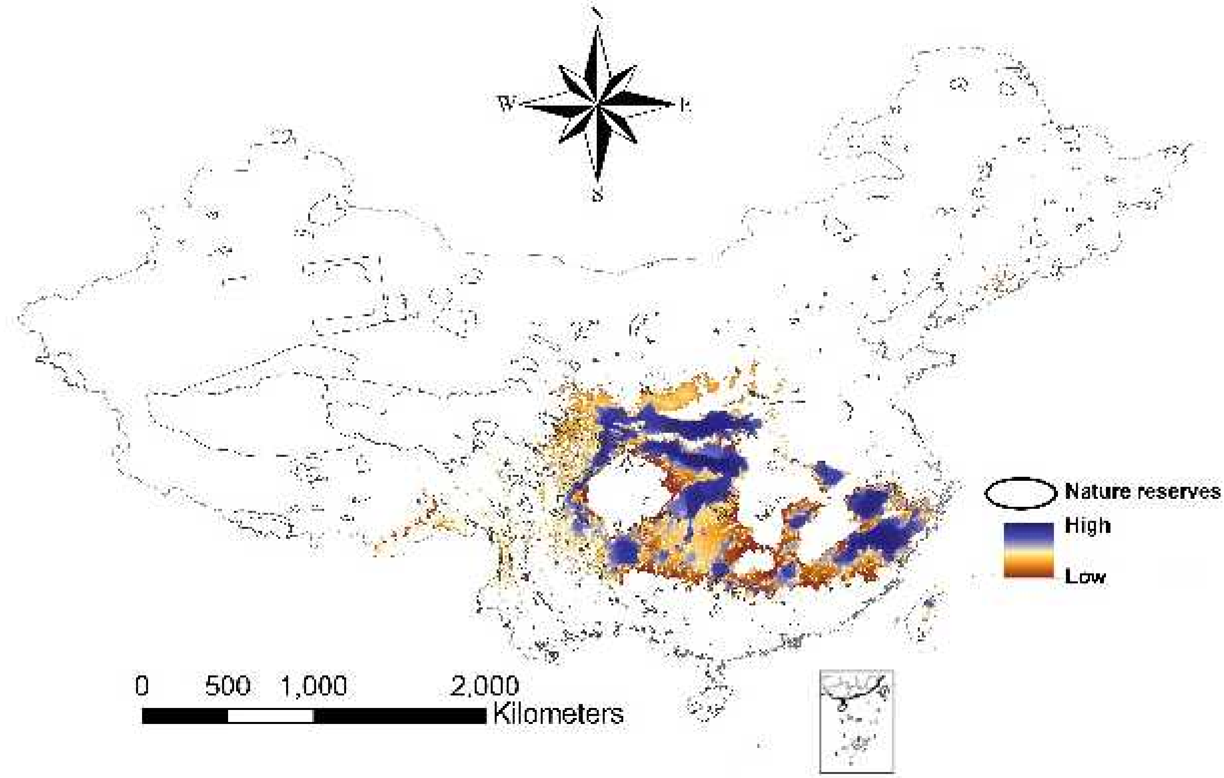

Fig. 2.The priority protection areas for *T. chinensis* in China.The color, ranging from brown to mazarine, represents increasing protection priority of *T.chinensis*.

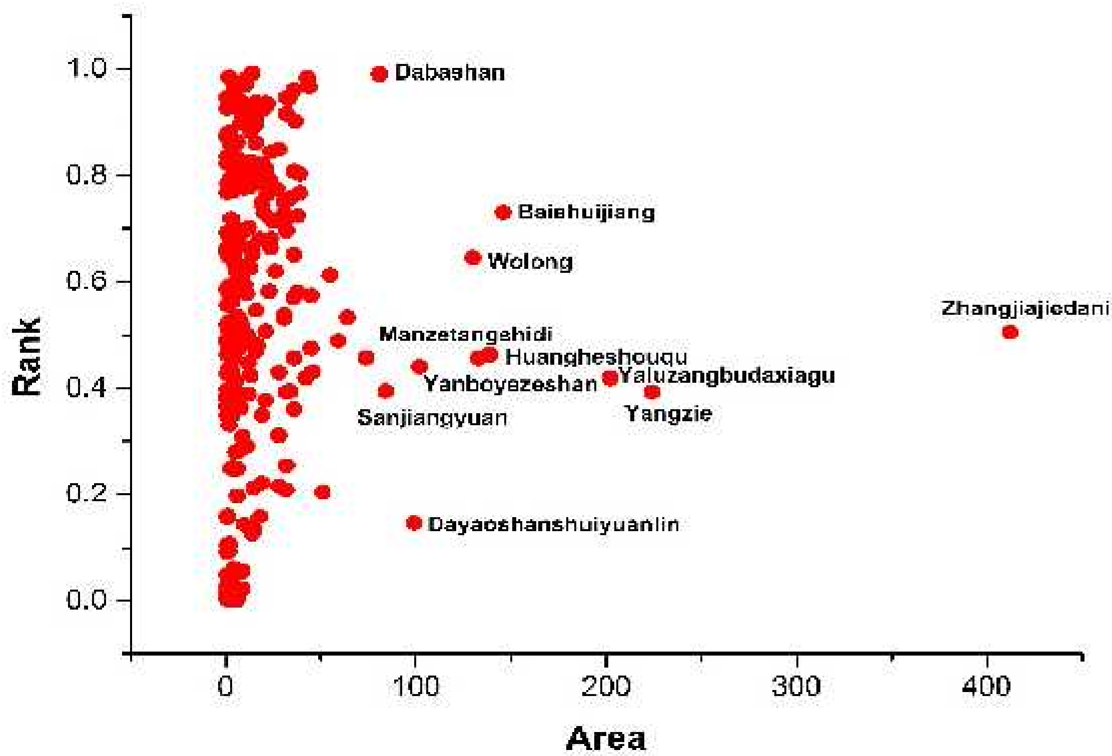

Fig. 3.The ability of existing nature reserves to conserve *T. chinensis* under climate change. Rank: the mean protection rank of PPAs for nature reserves; Area: the areas of PPAs for nature reserves.

DISCUSSION

This study established an effective evaluation system for the protection of *T. chinensis*, an endangered endemic tree plant, as the climate changes. Protecting *T. chinensis* from environmental threats over large geographical spaces and over a long period of time is a significant challenge for forest managers and ecologists in China. The development of SDMs and conservation planning software provides new insight into the conservation of endangered plants (Pyo *et al.,* 2004). We assessed the status of each nature reserve in China and compared the current and future maps of the potential distributions of *T. chinensis,* temporal patterns and PPAs. These analyses suggested that biological conservationists and government regulators should integrate climate change into conservation planning for *T. chinensis*.

The use of IPCC climate change scenarios provided plausible climate change projections for the 2080s using the RCP 4.5 and 8.5 scenarios (Villarini and Vecchi,2012). Based on the AUC values, our prediction model can be considered highly reliable and may accurately reflect the species distribution (Merow *et al.,* 2013, Wan *et al.,* 2014b). The predicted differences in the current and potential distribution of *T. chinensis* for low and high concentration scenarios, and the projected overall decrease in *T. chinensis* in response to an increasing gas concentration indicated that it will be important to consider climate change and increases in greenhouse gas concentrations in the conservation of *T. chinensis*. The influence of climate change on the distribution of *T. chinensis* is significant; therefore, we must take effective measures to protect the wild population of the species (Lemos *et al.,* 2014). Native forest areas are drastically decreasing owing to excessive deforestation andhabitat fragmentation caused by human activities, and species populations are decreasing, increasing the risk of extinction (Mori *et al.,* 2013, Berecha *et al.,* 2015). Climate change and human activities contribute to the decreases in wild populations of *T. chinensis* (Brodie *et al.,* 2012). Therefore, effective PPAs are necessary to account for the effects of climate drivers and human activities.

To implement Target 7 of GSPC, we need to establish conservation areas for *T. chinensis* based on PPA planning. However, existing nature reserves could not cover most PPAs, indicating that the conservation requirements of *T. chinensis* are not being met. Previous studies have shown that nature reserves play an important role in the in situ and ex situ conservation of forest plants (Xu*et al.,* 2012, Yu *et al.,* 2014). Establishing additional nature reserves is a direct and effective way to protect wild species (Araújo *et al.*, 2011, Yu *et al.,* 2014). However, the feasibility and operability of protection plans are poor and often demand the immediate resolution of issues, including validating protected species, determining conservation sites and selecting protection areas (Mascia and Pailler, 2011, Beatty *et al.,* 2014). Therefore, there is an urgent need for a practical solution to the conservation of *T. chinensis* with respect to changes in the species distribution. We found that some nature reserves, such as Zhangjiajiedani, Yangzie, Wolong, Baishuijiang and Dabashan are more effective for the conservation of *T. chinensis* populations, suggesting that these nature reserves could provide suitable areas for in-situ and ex-situ conservation of *T. chinensis*. Despite this, the nature reserves could not support the conservation of *T. chinensis*. Obviously, the establishment of nature reserves represents an immediate conservation measure for *T. chinensis*. Our principles for establishing protected areas are as follows: (1) cope with the impact of climate change on habitats, (2) promote smooth population gene flow, (3) make full use of existing nature reserves, (4) meet the requirements of in-situ and ex-situ conservation, (5) plan coherent protection areas, and (6) make sure these areas are easily managed (Araújo *et al.*, 2011, Grodzinska-Jurczak and Cent, 2011, Lockwood *et al.,* 2012). Additionally, we should strengthen the protection and management of areas with increasing *T. chinensis,* and enhance monitoring and prevention activities in areas with decreasing trends in PPAs.

In conclusion, we characterized an endangered endemic tree plant in China. Additionally, our findings suggest innovative strategies that can be used to protect endangered endemic tree plants by guiding effective and efficient forest management planning based on nature reserves. The methods used in this study can be applied to species protection worldwide. However, there are still many issues with this new method. We are constantly improving the model accuracy and increasing the number of evaluated nature reserves, not only those in the WDPA database. Overall, the results of our study are not only useful for protecting endangered endemic tree plants, but can also be used for general forest management, ecological construction and geographical surveying.

Acknowledgements: We thank the reviewers for the valuable comments on an early version of the manuscript. This research was supported by the Fundamental Research Funds for the Central Universities (BLYJ201606) and the entrusted project of protection division under State Forestry Bureau “The gap analysis and establishment of regulatory database for three important endangered plant species”.

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