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Potential Distribution and Priority Conservation Areas of *Pseudotsuga sinensis* Forests under Climate Change in Guizhou Province, Southwesten China

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Abstract: Priority conservation areas are the key areas of biodiversity maintenance and ecosystem conservation. Based on a Maxent model, this study predicted the potential distribution of *Pseudotsuga sinensis* under the current climate and future climate change scenarios in Guizhou province, and then, assessed three kinds of priority conservation area under climate change. The results were as follows: (1) The AUC (Area Under the Curve) values showed excellent prediction accuracy of the model. (2) The areas of the potential habitats of *P. sinensis* forests under the current climate and future climate change scenarios were 22,062.85 km^2 and 18,395.92 km^2, respectively. As for their spatial distribution, the potential habitats of *P. sinensis* forests were distributed in the Bijie, Zunyi, Tongren, Liupanshui and Xingyi regions under the current climate, and in the Kaili region, in addition to the above-mentioned cities, under future climate change scenarios. (3) The total area of priority conservation areas under climate change was 25,350.26 km^2. The area of the predicted sustainable potential habitats was 15,075.96 km^2, of the vulnerable potential habitats was 7256.59 km^2 and of the derivative potential habitats was 3017.71 km^2.

Keywords: species distribution model; climate change; *P. sinensis* forests; priority conservation areas

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1. Introduction

P. sinensis is a relic species of the Tertiary Period and an endangered species endemic to China [1]. With wide ecological adaptability, strong natural regeneration ability and low probability of pests and disease, *P. sinensis* is an important species of the water conservation forest in the subtropical mountainous area, and also an excellent artificial forest species [2].

Guizhou province is one of the main distribution area of natural *P. sinensis* forests in China. The *P. sinensis* community here plays an important role in warm temperate coniferous forests, and has become a crucial ecological barrier in mountainous karst areas. In Guizhou province, the majority of *P. sinensis* forests are distributed in nature reserves, and *P. sinensis* in these areas has a stable structure, rich biodiversity and high primitivity; meanwhile, the other *P. sinensis* forests are distributed in unprotected areas, and the *P. sinensis* forests of these areas have deteriorated gradually as a result of the inherent disadvantages of regeneration, and increasing human interference [3]. Conservation and restoration in the *P. sinensis* forests of unprotected areas have become extremely urgent.

Species distribution models (SDMs) use associations between climate and species occurrences to enable projections of potential alterations in habitats exposed to climate change, and have become a useful tool for evaluating the impact of climate change on the potential distribution of plants and vegetation [4,5]. Various SDMs have recently been developed and applied in studies on many topics, such as the impact of climate on species distribution [6–9], vegetation succession [10–12], biodiversity conservation [13] and alien species invasion [14], etc. Additionally, a few studies have applied these models to assessing the priority conservation areas of plants or vegetation under climate change. For instance, Nakao et al. [4]. assessed the priority of *Fagus crenata* in Japan based on a classification and regression tree model. Meanwhile, similar studies on endangered relict conifer species are seldomly reported.

The maximum entropy (Maxent) model is a prediction model based on the principle of maximum entropy. Based on the nonrandom relationship between environmental factors (such as climate, altitude, vegetation, etc.) and species distribution points, the distribution probability with the largest entropy is considered the optimal distribution under certain constraints, a spatial distribution model is constructed on a geographical scale and the potential distribution areas of species are predicted [15,16]. The Maxent algorithm's output is a map of habitat suitability ranging from 0 to 1 per grid cell. Relying on its convenience, its use of presence-only species records and generally excellent predictive performance, the Maxent model has some advantages compared to other species distribution models for species habitat assessment [17–19].

In this study, a Maxent model with high accuracy was applied; then, the potential distribution of *P. sinensis* forests under the current climate and future climate change scenarios in Guizhou province were predicted, and three kinds of priority conservation area under climate change were established. We aimed to provide a reference for the conservation area division and management measure formulation of *P. sinensis* forests in accordance with future climate change.

2. Methods

2.1. Study Area

Guizhou province is located in southwestern China between 103°31′–109°30′ E and 24°30′–29°13′ N, with a total area of 176,167 km^2 (Figure 1). The province has complex landforms, a typical climate and abundant biodiversity. In Guizhou Province, *P. sinensis* forests are mainly distributed in the Bijie (Weining county), Zunyi (Meitan county and Tongzi county) and Tongren regions (Songtao county and Dejiang county), among which the Bijie region (Weining county) occupies the largest area [3].

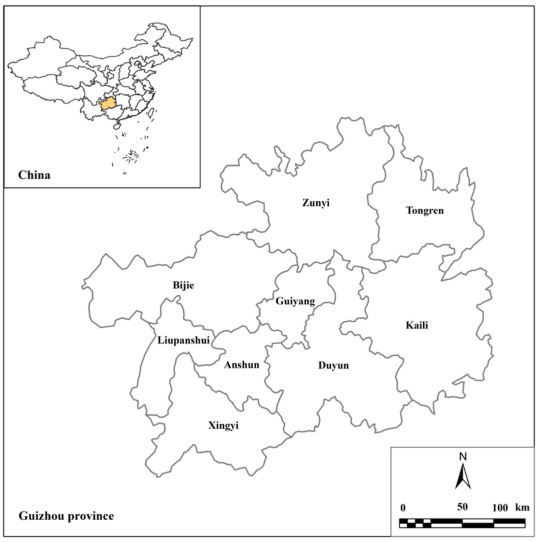

Figure 1. Location and administrative division of Guizhou province.

2.2. Data Sources

Distribution data for *P. sinensis* forests were obtained based on field investigation. The information on sampling points regarding longitude, latitude, elevation and terrain was record using a handheld GPS, separated by greater than 1 km, and then, exported to Microsoft Excel software and saved in CSV format, with a resolution of 30″ × 30″, though Arc GIS [20]. Finally, 107 effective sampling points of *P. sinensis* forest that covered various elevation ranges, administrative regions, and geological and geomorphologic types were extracted to build the prediction model.

A set of 19 bioclimatic factors, including current and future climate scenario (the RCP8.5 scenario for 2070–2099, the most extreme scenario) were downloaded from the WorldClim database (www.worldclim.org), and then, extracted through the administrative boundary of Guizhou province. In order to reduce the variables and avoid the impacts of collinearity on the prediction model, jackknife and Spearman (or Pearson) correlation analysis are frequently applied [13,17,21,22]. Nevertheless, as the statistical correlation relationship cannot completely explain the biological and ecological processes, some variables that have important biological and ecological significance in plants would be eliminated through these treatments. Therefore, all 19 bioclimatic variables were selected to construct the prediction model in this study.

The WGS84 projection coordinate system was used and exported in ASC format, preparing for the prediction model of *P. sinensis* forests.

2.3. Prediction Model

The Maxent algorithm was employed to predict the potential distribution of *P. sinensis* forests in Guizhou Province, owing to its operational convenience, excellent performance and superior accuracy [16,19]. A distribution probability diagram was exported after importing the distribution points and climate data, setting the parameters and operating the prediction model [23]. As for the parameter settings, 75% of the sampling points were extracted as training data, and the residual 25% were used as test data for model testing. The cross validation was selected as replicated types and run 10 times. The max number of background points was set at 200, to approach the value of the sampling points.

The AUC (Area Under the Curve) value, derived from the ROC (Receiver Operating Characteristic) analysis, was applied to evaluate the performance of the prediction model. The values of the AUC ranged from 0.5 to 1, with values above 0.9 indicating excellent accuracy of the prediction model. The AUC was considered the most popular measure of the accuracy for presence–absence predictions [24–26].

2.4. Potential Habitat Classification

Based on the actual distribution of *P. sinensis* forests, the areas where the predicted distribution probability was larger than 0.5 were defined as the potential habitats, and the others were defined as non-habitats. Then, the potential habitat distribution maps were drawn and their attribute tables were exported according to the classification results based on the current climate and future climate change scenarios. Spatial analysis was conducted to reveal their geographical distribution characteristics.

2.5. Priority Conservation Area Assessment under Climate Change

In this study, the priority conservation areas under climate change were composed of three parts: areas of common potential habitats under both the current climate and future climate change scenarios were defined as sustainable potential habitats, where potential habitats under the current climate that were predicted to become non-habitats under future climate change scenarios were defined as vulnerable potential habitats, and where non-habitats under the current climate that were predicted to become potential habitats under the future climate change scenarios were defined as derivative potential habitats [4].

Each type of priority conservation area had different significance in the protection and management of *P. sinensis* forests under climate change. Sustainable potential habitats need long-term protection under each climate condition. Vulnerable potential habitats require strategies and measures to mitigate the potential impacts of climate change on protected objects. Derivative potential habitats could be considered supplements for the future planning and adjustment of nature reserves.

3. Results

3.1. Prediction Accuracy, and Potential Habitats under Current Climate and Future Climate Change Scenarios

The AUC values of the training data and text data were 0.974 and 0.921, respectively, and showed excellent performance according to the evaluation criteria.

Figure 2 shows the predicted potential habitats of *P. sinensis* forests under the current climate and future climate change scenarios in Guizhou province. The potential habitats under the current climate were distributed in the Bijie, Zunyi, Tongren, Liupanshui and Xingyi regions. Additionally, those under future climate change scenarios were distributed in the Kaili region, in addition to the above-mentioned cities.

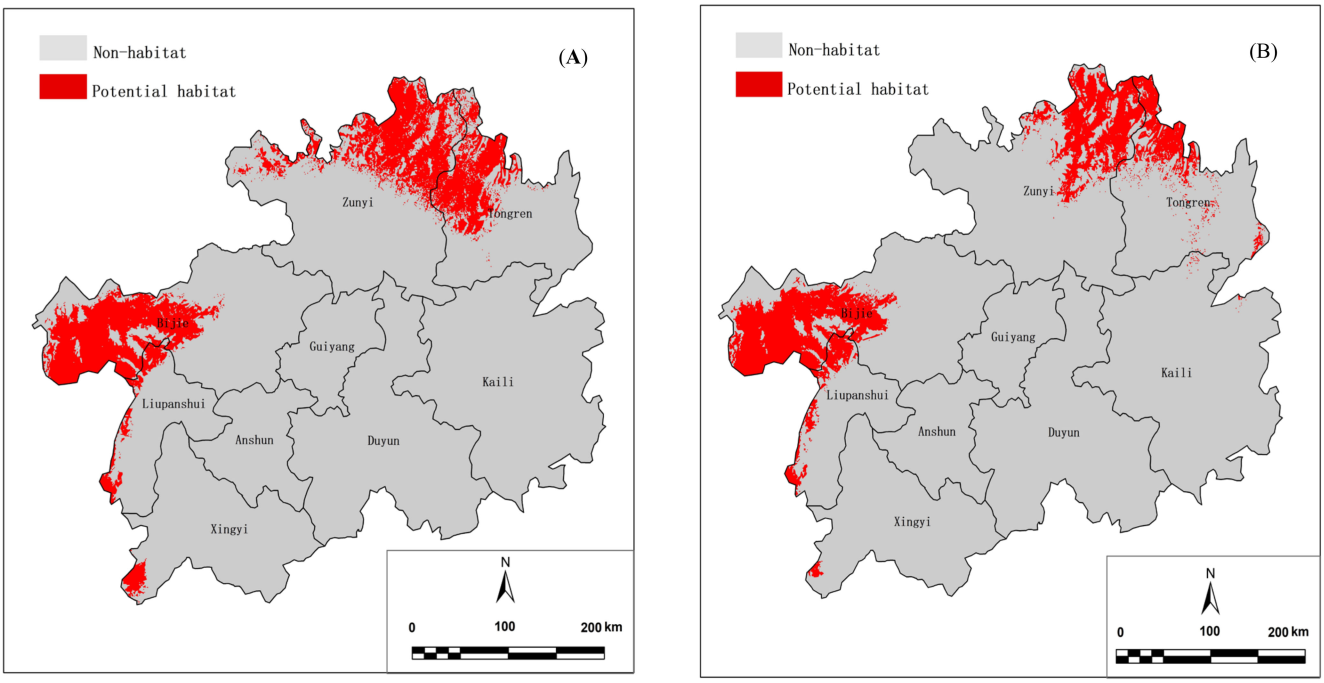

Figure 2. (**A**) Potential habitats under current climate; (**B**) Potential habitats under future climate change scenarios.

The statistical results (Table 1) show that the areas of the potential habitats under the current climate and future climate change scenarios were 22,062.85 km^2 and 18,395.92 km^2, respectively. The Bijie, Zunyi and Tongren regions occupied a considerable proportion under either climate condition.

Table 1. Areas of the potential habitats under current climate and future climate change scenario (RCP 8.5).

Administrative Region	Potential Habitats (km^2)			
	Current Climate	%	Climate Change Scenarios	%
Bijie	8310.50	37.67	8111.20	44.09
Zunyi	7632.40	34.59	5797.35	31.51
Tongren	4456.83	20.20	2827.50	15.37
Liupanshui	1157.16	5.24	1443.06	7.84
Xingyi	505.96	2.29	119.31	0.65
Kaili	0.00	0.00	97.35	0.53
Total	22,062.85	100.00	18,395.92	100.00

3.2. Priority Conservation Areas under Climate Change

The total area of priority conservation areas under climate change was 25,350.26 km^2. Sustainable potential habitats covered the largest area (15,075.96 km^2) among the three types of priority conservation area, and were mainly distributed in Bijie (7612.44 km^2) and Zunyi regions (4481.32 km^2). Subsequently, vulnerable potential habitats were mainly distributed in the Zunyi (3147.95 km^2) and Tongren regions (2650.73 km^2), with a total area of 7256.59 km^2. Derivative potential habitats had the smallest area, were mainly distributed in Zunyi (1312.90 km^2) and Tongren regions (1021.40 km^2), with a total area of 3017.71 km^2.

Figure 3 and Table 2 describe the priority conservation areas of *P. sinensis* forests under climate change in Guizhou province.

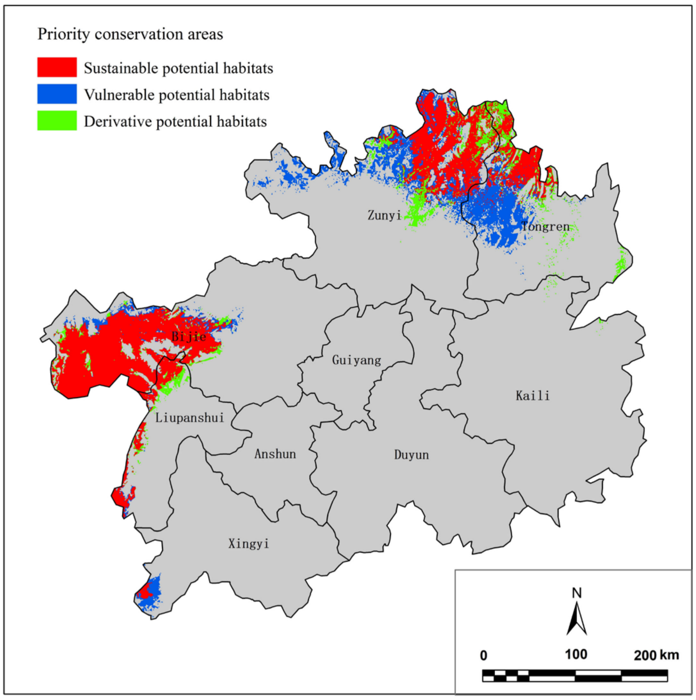

Figure 3. Priority conservation areas under climate change.

Table 2. Statistics of priority conservation areas under climate change.

Administrative Region	Priority Conservation Areas (km^2)		
	Sustainable Potential Habitats (%)	Vulnerable Potential Habitats (%)	Derivative Potential Habitats (%)
Zunyi	4481.32 (29.72)	3147.95 (43.38)	1312.90 (43.51)
Bijie	7612.44 (50.49)	694.88 (9.58)	495.58 (16.42)
Liupanshui	1066.68 (7.08)	376.38 (5.19)	90.48 (3.00)
Tongren	1796.21 (11.91)	2650.73 (36.53)	1021.40 (33.85)
Xingyi	119.31 (0.79)	386.65 (5.33)	0.00 (0.00)
Kaili	0.00 (0.00)	0.00 (0.00)	97.35 (3.23)
Total	15,075.96 (100.00)	7256.59 (100.00)	3017.71 (100.00)

4. Discussion

(1) Nature reserves form the basis of modern conservation systems [27], while climate change creates new challenges for their biodiversity conservation. Species distributions are already responding to recent climate change, which has caused obvious ecological shifts [28]. Range shifts due to climate change may cause species to exceed the current boundaries of nature reserves [29]; thus, current nature reserves will not be suitable for all the species they were designed to protect. It is important to modify our

biodiversity protection strategies to deal with climate change. The results of this study could provide references for the delineation and adjustment of nature reserves, so that the *P. sinensis* forests can obtain more targeted, efficient and reasonable protection, even under climate change.

(2) The impacts of climate change on only the priority conservation areas of *P. sinensis* forests were taken into account; consequently, the predicted priority conservation areas were much larger than the possible distribution areas because other factors (the land use dynamics, human disturbance, topography factors, etc.) could not be excluded. With a view to mitigating the impacts of land use on the assessment of priority conservation areas, a few studies utilized land use datasets to mask predicted potential habitats based on an optimal land use rate threshold [4,30]. The foundation of this treatment was that the species could barely grow in areas of high land use, regardless of climate. While this was dependent on the assumption that the current land use situation would continue even under future climate change, the impacts derived from unpredictable future land use dynamics could not be avoided through this treatment. Therefore, we did not imitate it in this study.

(3) It would be significant to conduct a comparison between predicted priority conservation areas and current conservation status, although we did not implement this analysis because it is currently difficult for us to obtain distribution data from nature reserves all over Guizhou province. We will conduct this analysis in the future once these data are available.

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