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Habitat suitability evaluation for *Paeonia decomposita*, based on a MaxEnt model

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Keywords: Paeonia decomposita, *MaxEnt, habitat, suitability evaluation, Sichuan province*

Abstract

Paeonia decomposita is on the IUCN's Red List of endangered species, and occurs only in the northwest part of Sichuan Province, China. For the effective protection of the species, it is important to evaluate the suitability of potential habitats for *P. decomposita* and natural factors that influence the species. Based on the actual distribution points of *P. decomposita* in northwest Sichuan from 2016 to 2018, the Maximum Entropy Model (MaxEnt) was used to analyse the main factors affecting its habitat, and to predict suitable habitats. The results show that: (1) the model has high accuracy and is suitable for the prediction and evaluation of habitat suitability for *P. decomposita*; (2) temperature, slope, precipitation and moisture index will all greatly affect *P. decomposita's* distribution; (3) the areas that are potentially suitable for *P. decomposita* are mainly in Mianyang, Aba, Ganzi and Liangshan, which are greatly affected by human activities; effective protection measures have not been taken. It is proposed that new reserves for the introduction of *P. decomposita* should be established in areas of high or moderately high suitability. A programme of cultivation of this rare species should also be set up.

Introduction

Paeonia decomposita (Fang 1958) is a rare and endangered plant endemic to China (Fu, 1991; Xia et al. 2017), on the IUCN's Red List of endangered species. Its distribution area is very narrow: the plant is found only in northwestern Sichuan province (Editorial Committee of Flora of China 1997), mainly in the arid valleys of the rivers Dadu and Min, and grows in the grasslands or shrub at altitudes ranging from 2,200 to 3,100 m (Hong et al. 2017; Zhou et al. 2018). *P. decomposita* is an ideal choice for the development of new peony varieties. Peonies are appreciated not only for their flowers; peony seed oil has culinary uses, and nutritional and medicinal properties; peony root extracts also have medicinal properties (Yang et al. 2015). In recent decades, *P. decomposita* has become endangered and is likely to become extinct if not protected, due to the excessive exploitation of the plant, the destruction of its habitat conditions caused by a large number of hydropower stations, and its biological characteristics, such as the low germination rate of seeds under natural conditions (Jing & Zheng 1999).

The evaluation of habitat suitability for a species usually uses a species distribution model (SDM), which analyses the relationship between the actual species distribution area and environmental variables, and through the use of algorithms predicts the possible distribution area (Du et al. 2021). At present, the Maximum Entropy Modelling of Species' Geographical Distribution (MaxEnt) is one of the most commonly used niche models (Yang et al. 2020). Compared with other niche models, such as GARP (Genetic Algorithm for Rule-set Prediction), Bioclim (Bioclimatic Prediction System), Donmai (Domain Model) or ENFA (Ecological Niche Factor Analysis), MaxEnt needs only a small sample size and has a higher prediction accuracy (Wan et al. 2020). It is therefore widely used in modelling potential suitable areas and priority protected areas for rare and endangered plants, such as *Kingdonia uniflora*, *Taxus yunnanensis* or *Davidia involucrata* (Qu et al. 2018). The reliability of the model makes it suitable for informing the protection plan of related rare species, and to some extent also the planting of economic species.

In short, the MaxEnt model has many advantages, and we therefore used it to analyse the impact of environmental factors on *P. decomposita*, predict suitable habitat, and provide scientific advice for determining priority protection areas for *P. decomposita*.

Materials and Methods

Current distribution of species

Information on the distribution of *P. decomposita* was obtained from three field surveys that we carried out from 2016 to 2018, in Sichuan Province, China, at longitude 97°21'57"E ~ 108°31'58"E, and latitude 26°03'57"N ~ 34°19'13"N. The longitude, latitude and altitude of a total of 52 distribution points were recorded. Before analysis, we used R package spThin version 0.1.0 (Aiello-Lammens et al. 2015) to check the spatial autocorrelation of all distribution points. Finally, 11 distribution points of *P. decomposita* were retained for the creation of the MaxEnt model (Figure 1).

Environmental variables and preconditioning

Climate has been reported to be the most significant factor affecting species' geographical distributions (Jochum et al. 2007). For our study, climatic variables were obtained from the Data Registration and Publication System of the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn/DOI) (referred to hereinafter as the DRPS), with a resolution of 500 m × 500 m. The dataset we downloaded, based on mete-

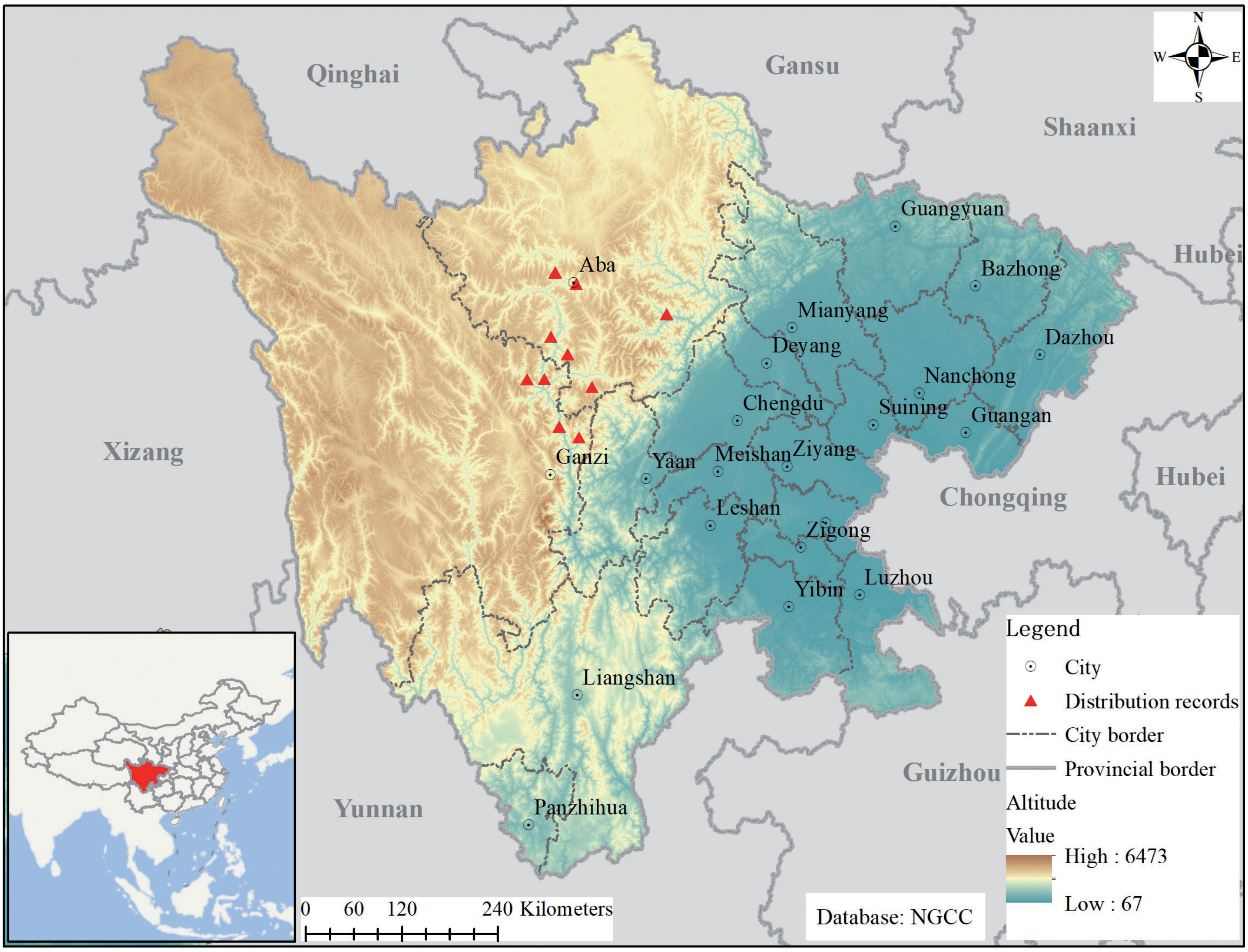

Figure 1 – Distribution records of Paeonia decomposita *in Sichuan province.*

orological data from 1 915 stations in China, included mean annual temperature, mean annual precipitation, the sum of the annual temperatures above 0°C, the sum of the annual temperatures above 10°C, the aridity index and the humidity index (Table 1).

Topography is also an important factor that determines vegetation growth, especially in mountainous areas, where solar radiation, soil moisture and surface rivers are all affected by topography (Zhou et al. 2018). Topographic data included slope gradient, slope direction and slope position (see Table 1), obtained from the Geospatial Data Cloud (http://www.gscloud.cn/), with a resolution of 90 m.

Vegetation cover is one of the most important monitoring indicators that reflects the quality of land surface ecosystems and environments (Sun et al. 2019); vegetation cover can be represented numerically by the Normalized Difference Vegetation Index (NDVI). The annual NDVI for 2018 was obtained from the DRPS (http://www.resdc.cn/DOI), with a resolution of 1,000 m.

We processed all the above data and distribution points of *P. decomposita* in ArcGIS 10.2, and projected all data to the unified coordinate system (WKID: 3857, WGS_1984_Web_Mercator_Auxiliary_Sphere). All data was clipped with the boundary of the Sichuan administrative region in order to obtain the variable layers of the study area.

The existence of multicollinearity among the environmental variables used to predict species distribution may adversely affect the prediction results (Wan et al. 2020). Therefore, we performed a Pearson correla-

Table 1 – Environmental variables related to the distribution of Paeonia decomposita.

Description	Source	Unit
Mean annual temperature	DRPS http://www.resdc.cn/DOI	°C
Sum of temperatures above 0°C		°C
Sum of temperatures above 10°C		°C
Aridity index		-
Moisture index		-
Mean annual precipitation		mm
Slope gradient	The Geospatial Data Cloud http://www.gscloud.cn/	°
Slope direction		°
Slope position		-
Annual NDVI of 2018	DRPS http://www.resdc.cn/DOI	-

Table 2 – Environmental variables used in this study and their percentage contribution to species distribution.

Environmental variables	Percentage contribution
Mean annual temperature	34.0
Slope gradient	25.1
Mean annual precipitation	21.2
Moisture index	10.9
Annual NDVI in 2018	5.6
Aridity index	2.9
Slope direction	0.4

Table 3 – Percentage of areas with Paeonia decomposita *in the main distribution areas.*

Habitat suitability	Distribution areas [km²]	Proportion [%]
Unsuitable	437 762.30	89.93
Low habitat suitability	26 796.99	5.51
Moderate habitat suitability	15 774.69	3.24
High habitat suitability	6 438.46	1.32

tion analysis (SPSS V20.0) on environmental variables, and deleted the variables whose correlation coefficient was greater than 0.8 (Yang et al. 2020). To run the maximum entropy model software (MaxEnt V3.3.3), we chose *do jackknife to measure variable importance* (this is a built-in feature of the software), and deleted the variables whose contribution rate was 0 (Ma et al. 2020). Finally, we reserved 7 environmental variables to predict the potential distribution area and evaluate habitat suitability for *P. decomposita* (Table 2).

Model description

Maximum entropy theory can be understood as follows: a species will spread as far as possible to other areas when suitable conditions prevail, and will finally be distributed almost uniformly (Phillips et al. 2006). Based on this theory, we used MaxEnt software to predict species distribution (http://biodiversityinformatics.amnh.org/open_source/maxent/). After using the *jackknife* function (as described above), three-quarters of the species distribution data were identified for use as training data for the model; the remainder were used for model validation (Du et al. 2021). The MaxEnt software needs only two groups of variables – sample variables (species distribution) and environmental variables – to establish the potential distribution model of a species. Finally, we used ArcGIS 10.2 to convert the results file generated by the MaxEnt software into raster format for further analysis.

Evaluation of the model's results and habitat suitability

The evaluation of a model's results is an important step in constructing a model of the potential distribution of a species. The most commonly used evaluation method is the Receiver Operating Characteristic curve (ROC). The horizontal axis of the ROC curve is the false positive rate, and the vertical axis is the true positive rate. The area under the ROC curve is the AUC value, which can reflect the value of the diagnostic test directly. The ROC curve was not affected by the diagnostic threshold, and the accuracy of the two diagnostic tests could be comprehensively compared. The AUC value was between 0.5 and 1.0. The closer the AUC value is to 1, the better the model's performance and the greater the reliability of the results (Swets 1988; Vanagas 2004). Finally, the output of the MaxEnt software for the probability of species distribution was converted into the habitat suitability index for species distribution, which is between 0 and 1. We used the sensitivity-specificity and sum maximization approach to determine the threshold, which we considered superior to other threshold partitioning methods (Jiménez-Valverde & Lobo 2007). The threshold value of the existence probability of *P. decomposita* was 0.53; an area giving a value of less than 0.53 is considered unsuitable as a habitat area. Therefore, the habitat suitability index for *P. decomposita* was reclassified into four different grades, using the ArcGIS reclassification tool: unsuitable (0–0.53), low habitat suitability (0.52–0.65), moderate habitat suitability (0.65–0.77), and high habitat suitability (0.77–1.0).

Results

Model evaluations

The MaxEnt software was used to predict the potential distribution of *P. decomposita*; the ROC curve evaluation results gave an AUC value of 0.863 (see Figure 2). According to the AUC evaluation standard, the result of the model was accurate and considered *excellent*. An AUC value of more than 0.85 (which is far greater than the AUC value in the case of random prediction) indicates that the model is adequate for evaluating habitat suitability for *P. decomposita*.

Important environmental variables

The results of the MaxEnt model's jackknife test showed that mean annual temperature (explaining 34.0% of variation), slope gradient (explaining 25.1% of variation), mean annual precipitation (explaining 21.2% of variation), moisture index (explaining 10.9% of variation) and annual NDVI in 2018 (explaining 5.6% of variation) were the main variables affecting distribution of *P. decomposita*; the cumulative contribution rate reached 96.8% (Table 2). In other words, even if the influence of just one single environmental variable on the distribution of *P. decomposita* is considered, the variable contains important information.

The response curves drawn by the MaxEnt model reflect the impact of environmental variables on the distribution of *P. decomposita*. The horizontal axis of the response curve is the variation range of the environmental variables, while the vertical axis is the probability of the existence of *P. decomposita* (Figure 3). The

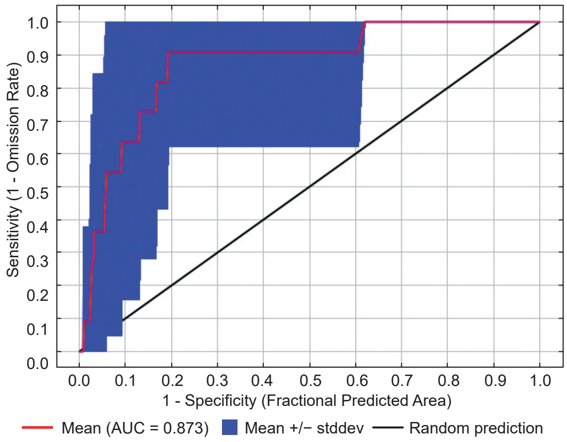

Figure 2 – Reliability test of the distribution model created for Paeonia decomposita.

greater the probability, the more suitable the range of variables is for the survival of *P. decomposita*. Our results show that when the probability of existence is greater than 0.53, the corresponding variable range is suitable for the survival of *P. decomposita*. The mean annual temperature range suitable for *P. decomposita* is 4.5 to 15.0°C; the greater the slope gradient, the greater the probability of *P. decomposita*'s existence, and the most suitable gradient is greater than 60°; the mean annual precipitation range suitable for *P. decomposita* is 180–990 mm, and with an increase of mean annual precipitation, the existence probability of *P. decomposita* decreases; the moisture index range suitable for *P. decomposita* is −25 to +68. In addition, the mean annual temperature was 8°C, the slope gradient was 6–65°, the mean annual precipitation was 180–350 mm, and the moisture index was 0, which is the combination of environmental variables that provides the most suitable habitat for *P. decomposita*.

Potential distribution of *Paeonia decomposita*

Habitat suitability of *P. decomposita* was classified in ArcGIS, and the results can be seen in Figure 4. These show an area of high habitat suitability for *P. decomposita* in Sichuan Province of 6438.46 km^2; the area of moderate habitat suitability was 15774.69 km^2; the area of low habitat suitability was 26796.99 km^2; all other areas were unsuitable. The areas calculated amount to 1.32%, 3.24%, 5.51% and 89.93% of the total area of Sichuan Province respectively (computed using the zonal statistics tool in ArcGIS 10.2) (Table 3). Areas of high and moderate habitat suitability were considered to be viable for *P. decomposita*. Combined, these equate to just 4.56% of the total area, and only a few are located in existing nature reserves.

The areas of high habitat suitability for *P. decomposita* were mainly to the north of Mianyang city, in the southwest and northeast of Aba Autonomous Prefecture, and in the east of Ganzi Autonomous Prefecture. The areas of moderate habitat suitability were found mainly north of Mianyang city, in the southwest and northeast of Aba Autonomous Prefecture, in the east of Ganzi Autonomous Prefecture, and in the east of Liangshan Autonomous Prefecture. They are distributed mostly along the upper reaches of the Yalong, Dadu, Min and Fu rivers, or along their tributaries (Figure 5).

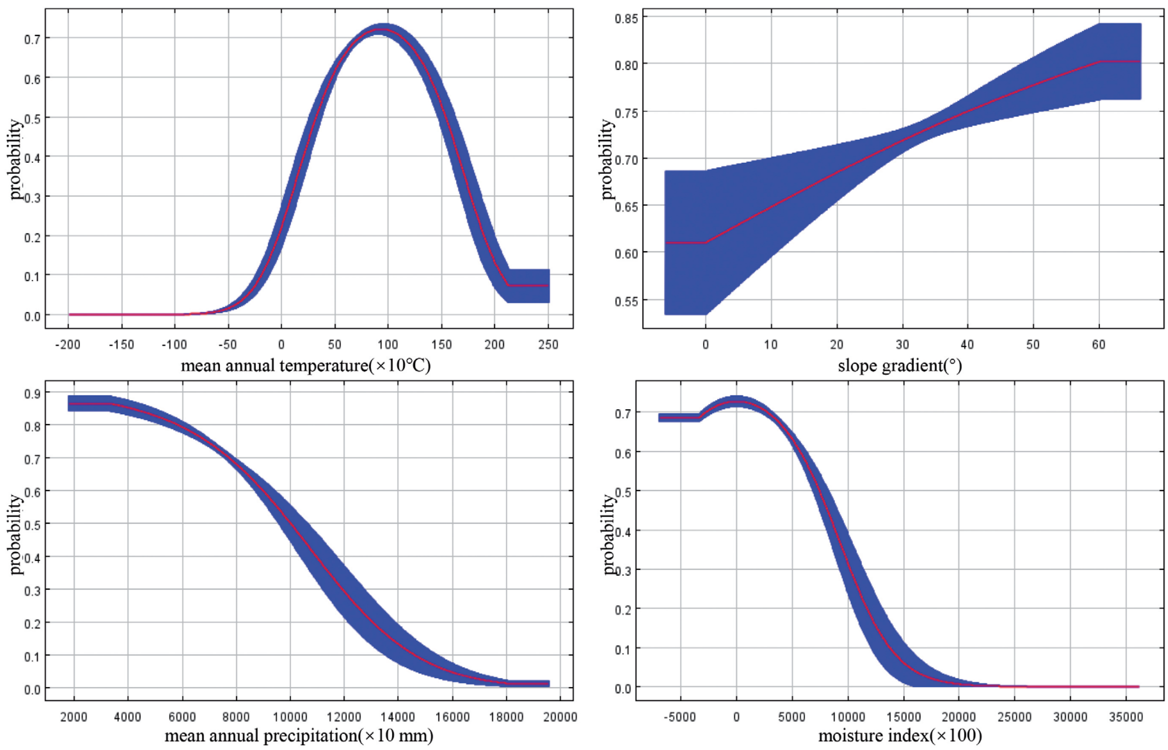

Figure 3 – Response curves for the probability of the presence of Paeonia decomposita.

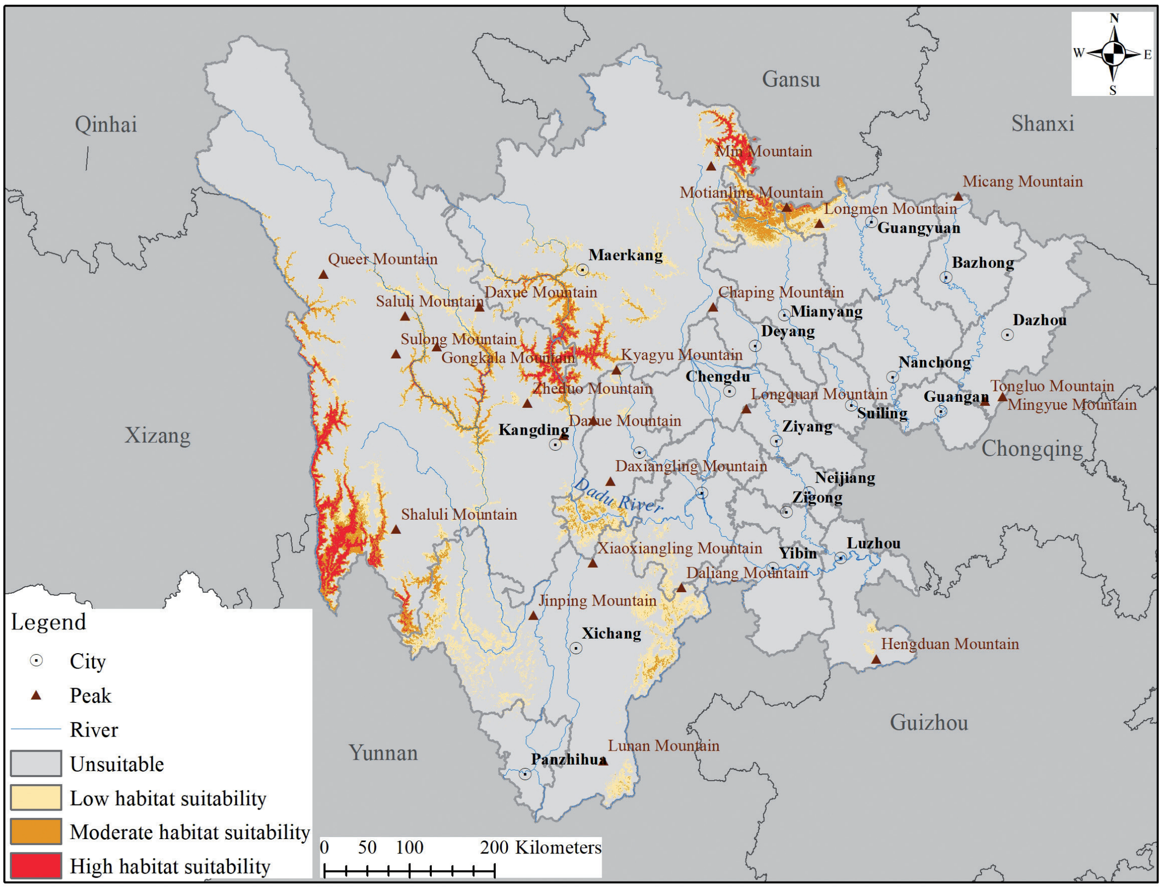

Figure 4 – Current and potential habitats for Paeonia decomposita *in Sichuan.*

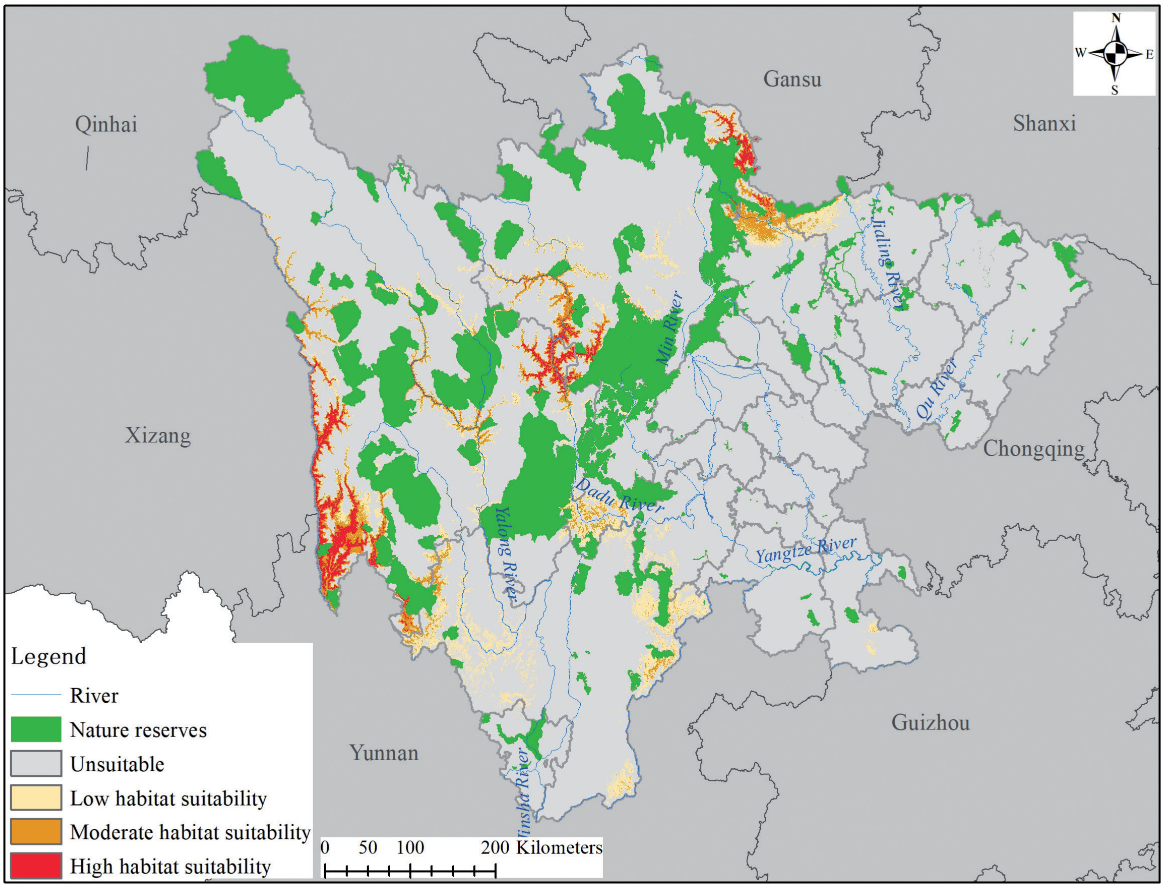

Figure 5 – The relationship between suitable habitat areas for Paeonia decomposita *and nature reserves.*

Discussion

P. decomposita is an endemic species in China. It is an important part of the local ecosystem and an important traditional medicinal plant, growing among the shrubs of arid valleys in northwest Sichuan province. In recent years, human activities such as engineering construction and logging have had a great impact on *P. decomposita* and its habitat (Hong et al. 2017). To prevent its extinction, suitable habitats of the species must be identified, using a niche model, and the species must be protected.

MaxEnt is a superior method of species distribution prediction (Elith et al. 2006). We used MaxEnt software to predict the potential distribution area of *P. decomposita* and to classify habitat suitability. We analysed the contribution of each environmental variable to the MaxEnt model and ranked it using jackknife. The ROC curve was used to evaluate the applicability of the MaxEnt model, and the AUC value was used to judge the model's reliability. The results show an AUC value of 0.863, which means that the performance of our model is *excellent* (Vanagas 2004), and the model can reliably be used to predict habitat suitability for *P. decomposita*.

The areas of high and moderate habitat suitability for *P. decomposita* measured 6,438.46 km^2 and 15,774.69 km^2 respectively, accounting for 1.32% and 3.24% of the evaluation area. The niche of *P. decomposita* is thus very small. Some studies have shown that the results of the MaxEnt model simulation may be over-estimates of the actual situation (Hernadez et al. 2008; Boubli & Lima 2009). This means that the area suitable for *P. decomposita* may be smaller than the modelled results. The most suitable combination of environmental variables for *P. decomposita* was a mean annual temperature of 8°C, a slope gradient of 60 to 65°, a mean annual precipitation of 180 to 350 mm, and a moisture index of 0, demonstrating further the very limited area suitable for *P. decomposita*, which has very strict requirements for growth. Previous research has demonstrated that the distribution of *P. decomposita* is affected by temperature, precipitation, slope gradient and other factors (Xia et al. 2017; Hong et al. 2017).

The MaxEnt simulation results showed that areas of high and moderate habitat suitability for *P. decomposita* were located mainly to the north of Mianyang, southwest and northeast of Aba, east of Ganzi, and east of Liangshan, mostly along the Yalong, Dadu, Min and Fu and their tributaries (Figure 5). These river valleys are also the main residential areas, and so are greatly affected by human activities. Generally, in the same habitat area, banded distribution has a longer perimeter, a larger range of contact with external disturbance, and is subject to more external influence (Yang et al. 2020). The field investigation found that the *P. decomposita* distribution area was strongly disturbed by human activities such as grazing, logging, construction of roads, and hydropower plants. The attractiveness of the plant and its medicinal value also lead to its serious depletion in the field and difficulty in protecting it. In addition, the plant's biological and seed-germination characteristics (Jing et al. 1995; Jing & Zheng 1999) have also led to natural regeneration difficulties in *P. decomposita*. Its current precarious status may therefore be the result of both internal and external factors.

Results from earlier research showed that human activities contributed significantly to species endangerment (Schemske et al. 1994). In recent years, a large number of hydropower stations have been built in western Sichuan province, which often causes irreversible damage to the habitat of *P. decomposita*. Therefore, protection of *P. decomposita* needs to be carried out *ex-situ*, for which the most difficult problem is to identify the most appropriate habitat areas among those with high or at least medium suitability.

The construction of nature reserves, as one of the main protection measures for endangered plants, would be a good way to provide in-situ protection for *P. decomposita*. Areas of high to moderate suitability for *P. decomposita* occupy only 4.56% of the total area of Sichuan province, and only a small proportion are located within existing nature reserves (Figure 4 and Figure 5). We therefore suggest that areas of high or moderate suitability for the species should become potential priority protection areas, to be included in nature reserves areas, or that new reserves should be established to effectively protect *P. decomposita*. Artificial breeding and cultivation of *P. decomposita* should also be encouraged in areas of high or moderate habitat suitability. In addition, the precise ecological status of *P. decomposita* should be determined promptly, and ordinary people should be encouraged to participate in its protection to avoid extinction.

Conclusions

The mean annual temperature, slope gradient, mean annual precipitation and moisture index greatly affect *P. decomposita's* distribution. The best combination of environmental variables for *P. decomposita* was: mean annual temperature of 8°C, slope gradient of 60–65°, mean annual precipitation of 180–350 mm, and moisture index of 0. *P. decomposita* has a narrow distribution area. The areas suitable for the species are very few and mostly outside existing nature reserves. It is important to set up new nature reserves for *P. decomposita* and to carry out artificial cultivation in areas of high or moderately high suitability. Taken together, our conclusions about areas suitable for *P. decomposita* will provide a theoretical reference to protect the species.

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