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# Simulation of potential suitable areas and analysis of natural reserves for four species of *Taxus* in southern China

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**Introduction:** In southern China, four species of the *Taxus* genus are distributed, and identifying their suitable habitats plays an important role in species conservation.

**Methods:** This study used the MaxEnt model to simulate and predict the potential suitable habitat distribution for these four species. The prediction model utilized 257 occurrence points from the four yew species, along with historical climate and topographic data, and incorporated the distribution of nature reserves in China. The model's accuracy was validated using the Area Under the Receiver Operating Characteristic Curve (AUC) to compare the effect of different function models on prediction accuracy.

**Results:** The results showed that the AUC values for all four yew species exceeded 0.9, indicating a high level of reliability in the model predictions. The high-suitability area for *Taxus wallichiana* var. *chinensis* is 13,943.62 km<sup>2</sup>, with nature reserves covering 7.49% of this area; *Taxus wallichiana* var. *mairei* has a high-suitability area of 11,950.97 km<sup>2</sup>, with a coverage rate of 2.44%; *Taxus wallichiana* has a high-suitability area of 9,784.43 km<sup>2</sup>, with a coverage rate of 10.52%; and *Taxus yunnanensis* has a high-suitability area of 7,226.57 km<sup>2</sup>, with a coverage rate of 6.47%. The high-suitability areas for *T. wallichiana* var. *chinensis* are concentrated in the Qinling, Wuyi, and Hengduan mountain ranges, while *T. wallichiana* var. *mairei* has a broader distribution, primarily in the Wuyi, Qinling, Hengduan, and southeastern Himalayas. The distributions of *T. wallichiana* and *T. yunnanensis* are concentrated in the Hengduan Mountains and southeastern Himalayas.

**Discussion:** The study suggests expanding the network of protected areas, constructing ecological corridors, and introducing cultivation efforts to enhance population stability within high-suitability zones. For *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis*, it is recommended to attempt more reintroduction efforts, while for *T. wallichiana* and *T. yunnanensis*, habitat protection should be prioritized. The establishment of additional natural protected areas and the construction of ecological corridors linking these protected areas are important ways to strengthen the conservation of yew species.

## KEYWORDS

*Taxus* species, MaxEnt model, habitat suitability simulation, nature reserve, Receiver Operating Characteristic Curve

## 1 Introduction

As one of the vast terrestrial ecosystems, forests play a crucial role in maintaining global ecological balance and ensuring a stable living environment for humanity. Since the Industrial Revolution, climate change and human activities have had long-term impacts on forest systems, leading to the fragmentation and degradation of plant habitats. These changes have severely affected the reproduction and growth of species, resulting in the destruction of plant resource diversity (Liu et al., 2021). Studies have indicated that habitat destruction is the primary cause of endangerment for 84.1% of rare species (Qin et al., 2020). Plant habitats are constrained by various environmental factors, with meteorological and topographical conditions being key determinants of habitat distribution and extent. Suitable climatic and topographical conditions can promote plant growth and reproduction, contributing to the expansion and stability of habitats (Zhao et al., 2021; Wu et al., 2020). Nowadays, the conservation of plant resource diversity and its sustainable development have become key research topics that are receiving significant attention from researchers worldwide (De Kort et al., 2021). Identifying potential suitable habitats based on environmental factors provides valuable insights for the formulation of conservation strategies for rare plants.

Species Distribution Models (SDMs) are tools that combine species' spatial locations with environmental factor information to identify the relationship between species distribution patterns and environmental variables, and further simulate the potential distribution of species (Melo-Merino et al., 2020; Lee-Yaw et al., 2022; Chauvier et al., 2022). These models calculate the probability of species occurrence in space, which can be used to represent species' adaptability to the environment (Li et al., 2020). The results can be extended to indicate the suitability of species' habitats (Xu et al., 2019; Zhao et al., 2021). Common SDMs include the Biomod2 Model and the GARP Model (Genetic Algorithm for Rule-set Production). The Biomod2 model integrates multiple algorithms to comprehensively predict species distribution but requires high-quality data (Hao et al., 2019). The GARP model, based on genetic algorithms, has good adaptability and predictive power, although it may have limitations when dealing with complex environmental factors (Townsend Peterson et al., 2007). MaxEnt (Maximum Entropy) is one of the most widely used models in SDMs (West et al., 2016; Yan et al., 2020; Zhang et al., 2021; Khan et al., 2022; Tang et al., 2021; Fitzgibbon et al., 2022). Its advantages lie in its ability to achieve accurate simulation and prediction even when spatial distribution data for species is limited and the relationships between environmental factors are unclear (Gebrewahid et al., 2020; Jose V and Nameer, 2020). MaxEnt has demonstrated strong predictive capabilities in studies related to establishing nature reserves, predicting the potential habitat of invasive species, and assessing the impact of climate change on species (Elith et al., 2006; Gebrewahid et al., 2020; Jose V and Nameer, 2020; Yi et al., 2016). Compared to other models, MaxEnt constructs the spatial distribution model of target species by calculating the probability distribution in the state of maximum entropy. This method is advantageous because it can make more efficient use of limited data, thereby improving the accuracy and reliability of predictions.

China is home to five species of the genus *Taxus*, among which, except for the *Taxus cuspidata*, which is distributed in the high-latitude regions of China, the other four species—*Taxus wallichiana*

var. *chinensis*, *Taxus wallichiana* var. *mairei*, *Taxus wallichiana*, and *Taxus yunnanensis*—are primarily found in the relatively rainfall-abundant southern regions. These species exhibit distinct differences in their distribution ranges (Wang et al., 2019). Due to their limited distribution and small existing population sizes, yew species are more vulnerable to the impacts of climate change, which increases their risk of extinction (Su et al., 2018; Wang et al., 2016). *Taxus* species have notable medicinal value, and research on them has primarily focused on plant characteristics at the micro level, such as the medicinal value of paclitaxel (Sun et al., 2021) and the synthesis mechanisms of paclitaxel (Wang et al., 2019). In studies related to the potential suitable habitats of yews, it has been shown that the suitable habitats of *Taxus* species in China are significantly affected by changes in climate and land use. Future human activities and climate change may lead to a 30.40–96.55% loss in the suitable habitat range for *T. wallichiana* var. *mairei*, (Wang et al., 2023), and the degradation of the suitable habitat for *T. cuspidata* may further threaten the survival of some endangered animals (Yan et al., 2020). Currently, there is no research that analyzes the conservation and reproduction status of *Taxus* species from the perspective of nature reserves.

To assess the potential habitat distribution of four types of *Taxus* species in southern China under current environmental conditions, this study collected 257 occurrence point coordinates for *Taxus* species. Through the simulation and classification of potential suitable habitats for these four species, the relationship between high-suitability areas for *Taxus* and nature reserves is discussed. This research aims to address the following scientific questions: (1) What are the main distribution characteristics of the potential suitable habitats for the four *Taxus* species? (2) What is the spatial relationship between nature reserves and the potential suitable habitats for *Taxus*, and which reserves could serve as key areas for *Taxus* conservation and reintroduction?

## 2 Materials and methods

### 2.1 Data sources and preprocessing

The spatial distribution data for yews used in this study were sourced from the Global Biodiversity Information Facility<sup>1</sup> and the Chinese Virtual Herbarium.<sup>2</sup> The distribution data consists of plant information and spatial coordinates. Spatial autocorrelation testing was used to eliminate data points that were too close to each other, resulting in a final yew spatial distribution dataset composed of 257 records (Figure 1), which includes 84 records for *T. wallichiana*, 104 for *T. wallichiana* var. *mairei*, 55 for *T. wallichiana*, and 14 for *T. yunnanensis*. Meteorological data were obtained from the WorldClim database (Khan et al., 2022).<sup>3</sup> The meteorological data are categorized into four groups, consisting of 56 variables, covering the period from 1970 to 2000, with a resolution of 2.5 min, as detailed in Table 1. Digital elevation data were sourced from Earth Explorer<sup>4</sup> with the same resolution of 30 m. The meteorological and elevation

1 <https://www.gbif.org/>

2 <https://www.cvh.ac.cn/index.php>

3 <https://worldclim.org/>

4 <https://earthexplorer.usgs.gov/>

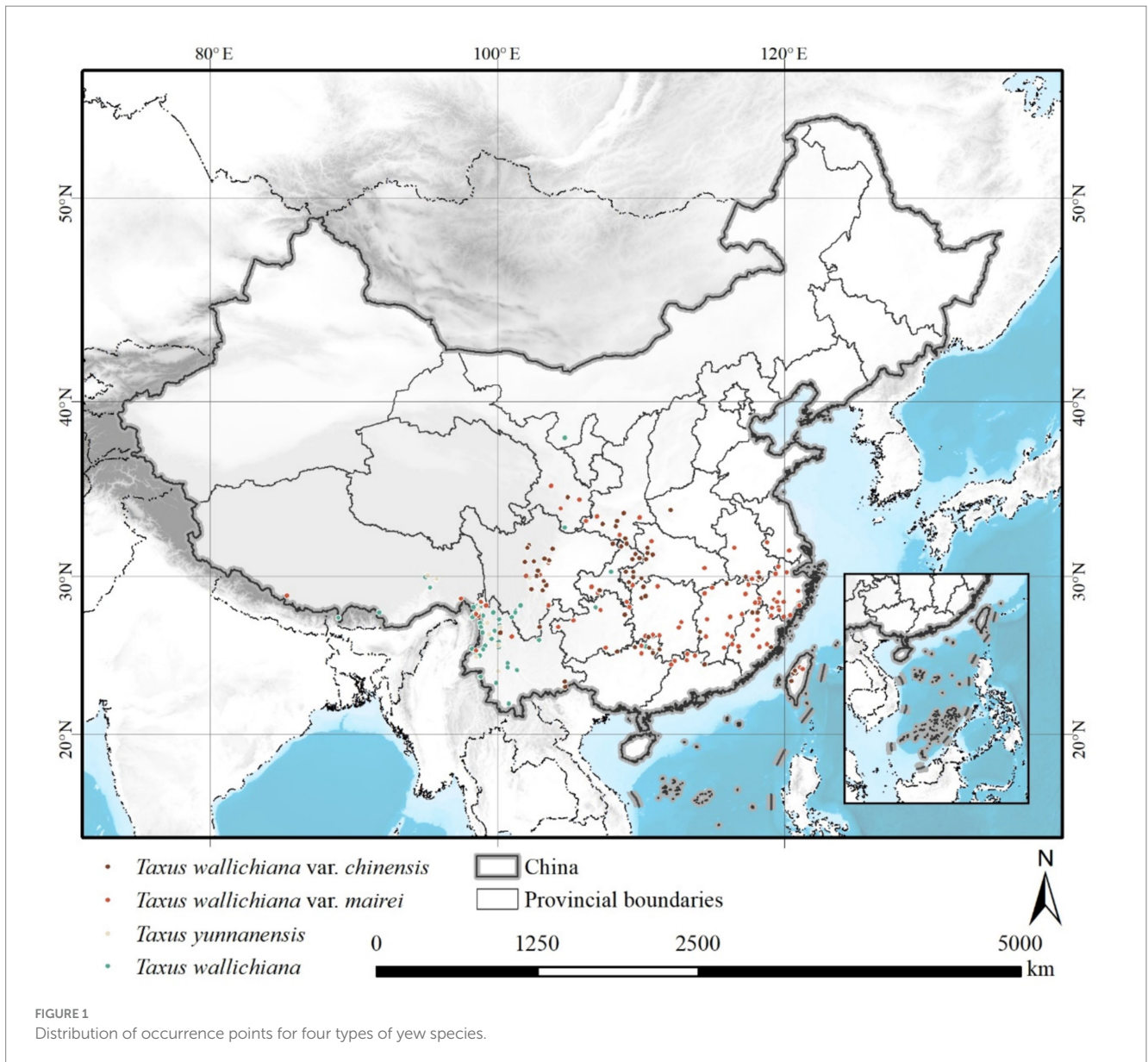


TABLE 1 Sources and attributes of research data.

Data type	Data source	Attribute	Coordinate system	Resolution
Plant occurrence points	<a href="https://www.gbif.org/">https://www.gbif.org/</a> <a href="https://www.cvh.ac.cn/index.php">https://www.cvh.ac.cn/index.php</a>	Coordinates	Latitude and longitude	/
Meteorological data	<a href="https://worldclim.org/">https://worldclim.org/</a>	Raster	WGS_1984	2.5 min
Digital elevation model	<a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a>	Raster	WGS_1984	30 m
China's nature reserves	<a href="http://www.papc.cn/">http://www.papc.cn/</a>	Vector	WGS_1984	/
Study area boundary	<a href="http://bzdt.ch.mnr.gov.cn/index.html">http://bzdt.ch.mnr.gov.cn/index.html</a>	Vector	WGS_1984	/

data were standardized through ArcGIS 10.6, involving coordinate system matching, resampling, and mask extraction. The coordinate system was uniformly projected to WGS\_1984, raster data were converted to a resolution of 2.5 min, and a mask was applied to select the geographic boundary of China, resulting in an environmental dataset for the study area.

## 2.2 Research methods

This study uses spatial coordinate data of four types of yew species in southern China, along with 56 meteorological factors from 1970 to 2000, elevation and slope data, and the boundaries of China's natural protected areas as the foundational data. The MaxEnt model is used

to simulate the potential habitats of these four species. The model’s predictive accuracy is evaluated using the AUC curve, and the simulation results are classified into different levels. Finally, the classification results are overlaid with the boundaries of China’s natural protected areas, and the results are discussed. The research approach for this study is shown in Figure 2.

### 2.2.1 MaxEnt model

The concept of “Entropy” was first introduced in 1856 to describe the degree of disorder in a system. The entropy of a closed system increases over time, leading to a transition from order to disorder. In 1948, entropy was introduced into information theory by Shannon, used to represent the uncertainty of a source of information. Information entropy represents the average amount of information obtained when an event from the information source is received. Higher information content indicates greater uncertainty of the event. The mathematical expression for calculating information entropy is as follows (Equation 1):

$$H(X) = -\sum_{i=1}^n p(x_i) \log_b p(x_i) \tag{1}$$

In the formula,  $X$  represents a random variable, and  $p(x)$  represents the probability distribution of the random variable.

In the theory of maximum entropy, a non-equilibrium living system must maintain its existence through the exchange of matter and energy with the environment. That is, any objectively existing living system is in a state of increasing system entropy, ultimately reaching equilibrium with the environment, where the system’s entropy is maximized (Tang et al., 2021). The MaxEnt model combines species distribution data with environmental factors, using Species Distribution Models (SDMs) to calculate the constraints of the species’ ecological niche (Yan et al., 2020; Khan et al., 2022). By calculating the probability distribution of the system in the state of maximum entropy, and based on this function, the distribution under the state of maximum entropy is fitted, constructing a spatial distribution model for the target species.

Let  $X_1, X_2, \dots, X_n$  be the environmental factors,  $n$  the number of environmental factors, with the constraint  $\varphi_1, \varphi_2, \dots, \varphi_m$ ,  $m$  being the

number of constraints, where  $m < n$  is the function of environmental factors, the constraints are represented as follows (Equation 2):

$$\begin{cases} \varphi_1(X_1, X_2, \dots, X_n) = 0 \\ \varphi_2(X_1, X_2, \dots, X_n) = 0 \\ \dots \\ \varphi_m(X_1, X_2, \dots, X_n) = 0 \end{cases} \tag{2}$$

Using species distribution data to construct the function  $H(X)$  of environmental variables, the formula is as follows (Equation 3):

$$H(X) = H(X_1, X_2, \dots, X_n) = -\sum_{x_i \in W_i} p(x_1, x_2, \dots, x_n) \log_b p(x_1, x_2, \dots, x_n) \tag{3}$$

The formula for  $p(x_1, x_2, \dots, x_n)$  is given by Equation 4:

$$p(x_1, x_2, \dots, x_n) = P(X_1 = x_1, X_2 = x_2, \dots, X_n = x_n) \tag{4}$$

Based on the above function, to find the value of  $H(X)$  when  $X_i (i = 1, 2, \dots, n)$  reaches its maximum, the Lagrange multiplier method is used to solve this problem, thus constructing the function  $F(X_1, X_2, \dots, X_n)$  as follows (Equation 5):

$$F(X_1, X_2, \dots, X_n) = H(X) + \lambda_1 \varphi_1 + \lambda_2 \varphi_2 + \dots + \lambda_m \varphi_m \tag{5}$$

The  $\lambda_1, \lambda_2, \dots, \lambda_m$  in Equation 5 is referred to as the Lagrange multiplier.

Next, we take the partial derivative of the function  $F(X_1, X_2, \dots, X_n)$  and set the partial derivatives equal to zero, resulting in the following set of equations (Equation 6):

$$\begin{cases} \frac{\partial F}{\partial X_1} = \frac{\partial H(X)}{\partial X_1} + \lambda_1 \frac{\partial \varphi_1}{\partial X_1} + \lambda_2 \frac{\partial \varphi_2}{\partial X_1} \\ + \dots + \lambda_m \frac{\partial \varphi_m}{\partial X_1} = 0 \\ \frac{\partial F}{\partial X_2} = \frac{\partial H(X)}{\partial X_2} + \lambda_1 \frac{\partial \varphi_1}{\partial X_2} + \lambda_2 \frac{\partial \varphi_2}{\partial X_2} \\ + \dots + \lambda_m \frac{\partial \varphi_m}{\partial X_2} = 0 \\ \vdots \\ \frac{\partial F}{\partial X_n} = \frac{\partial H(X)}{\partial X_n} + \lambda_1 \frac{\partial \varphi_1}{\partial X_n} + \lambda_2 \frac{\partial \varphi_2}{\partial X_n} \\ + \dots + \lambda_m \frac{\partial \varphi_m}{\partial X_n} = 0 \end{cases} \tag{6}$$

Combine the constraint of Equation 2 with the set of equations in (6) to find the values of  $X_1, X_2, \dots, X_n$  and  $\lambda_1, \lambda_2, \dots, \lambda_m$  when  $H(X)$  reaches its maximum. A larger value of  $H(X)$  indicates a higher likelihood of the target species’ presence in that area.

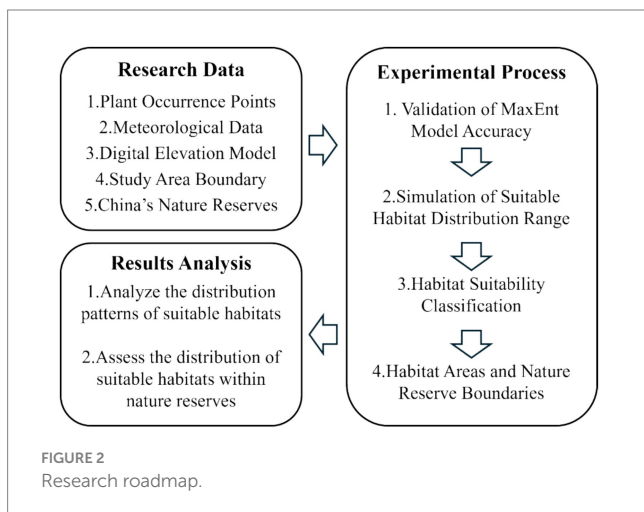


FIGURE 2 Research roadmap.



## 2.2.2 Determining model parameters using AUC curve

To ensure the accuracy of the MaxEnt model in predicting potential suitable habitats for the four types of *Taxus* species, this study used the Area Under the Receiver Operating Characteristic Curve (AUC) to evaluate the performance of different model parameters. The AUC value is an indicator of model prediction accuracy, with values closer to 1 indicating higher accuracy. In the parameter optimization process, occurrence data for *Taxus* species was combined with 56 climate data variables, as well as elevation and slope topographic data, to construct two explanatory variable models: a linear function model and a quadratic function model. The MaxEnt model was run using ArcGIS Pro 3.0 software, generating ROC curves for the two different function settings. The AUC values under different function conditions were calculated and compared. AUC values range from 0.5 to 1, with values closer to 1.0 indicating higher model accuracy; a value of 0.5 indicates the lowest accuracy and has no practical application.

## 2.2.3 Classification of suitable habitats and overlay analysis with nature reserves

Using *Taxus* distribution data and environmental factors, this study constructed a habitat suitability map for *Taxus* species in China. By overlaying this with the ranges of nature reserves across various regions, the study provides conservation recommendations from a macro-level geographic perspective. The methodology includes the MaxEnt model and overlay analysis, implemented using ArcGIS 10.6 and the MaxEnt model in ArcGIS Pro 3.0. By gathering the spatial location data of *Taxus* occurrences, the distribution data of potential suitable habitats for *Taxus* were constructed. The suitable habitats were then classified into different levels, and an overlay analysis was conducted with the boundaries of nature reserves. This identified nature reserves suitable for *Taxus* growth and assessed which reserves could serve as key areas for conservation and reintroduction of *Taxus*.

For the classification of suitable habitats, this study referred to the classification standards for species suitability evaluation set by the IPCC (Intergovernmental Panel on Climate Change). The MaxEnt model results for *Taxus* habitats were classified into four levels of suitability: habitat suitability ( $p < 0.05$  as unsuitable;  $0.05 \leq p < 0.33$  as low suitability;  $0.33 \leq p < 0.66$  as medium suitability; and  $p \geq 0.66$  as high suitability (Kong et al., 2021).

The ultimate goal of overlay analysis is typically to provide information for decision-making. Nature reserves in China are designated to protect biodiversity, representative natural ecosystems, and natural resources. Due to their inclusion within the boundaries of ecological protection red lines, these areas are less likely to be affected by social activities, and their natural environments generally exhibit strong stability. In this study, nature reserves were used as units, and the reserve boundaries were overlaid with the simulated potential suitable habitats for *Taxus* species to identify highly suitable reserve areas, providing a basis for targeted conservation decisions for *Taxus* species. Overlay Analysis is a spatial analysis method used to integrate multiple geographic datasets and generate results within a single dataset. Through overlay analysis, users can evaluate the spatial relationships between different datasets to support decision-making. The principle of overlay analysis essentially involves superimposing the features of one geographic dataset with those of another to

determine their relationships or interactions (Unwin, 1996; Walke et al., 2012).

## 3 Results

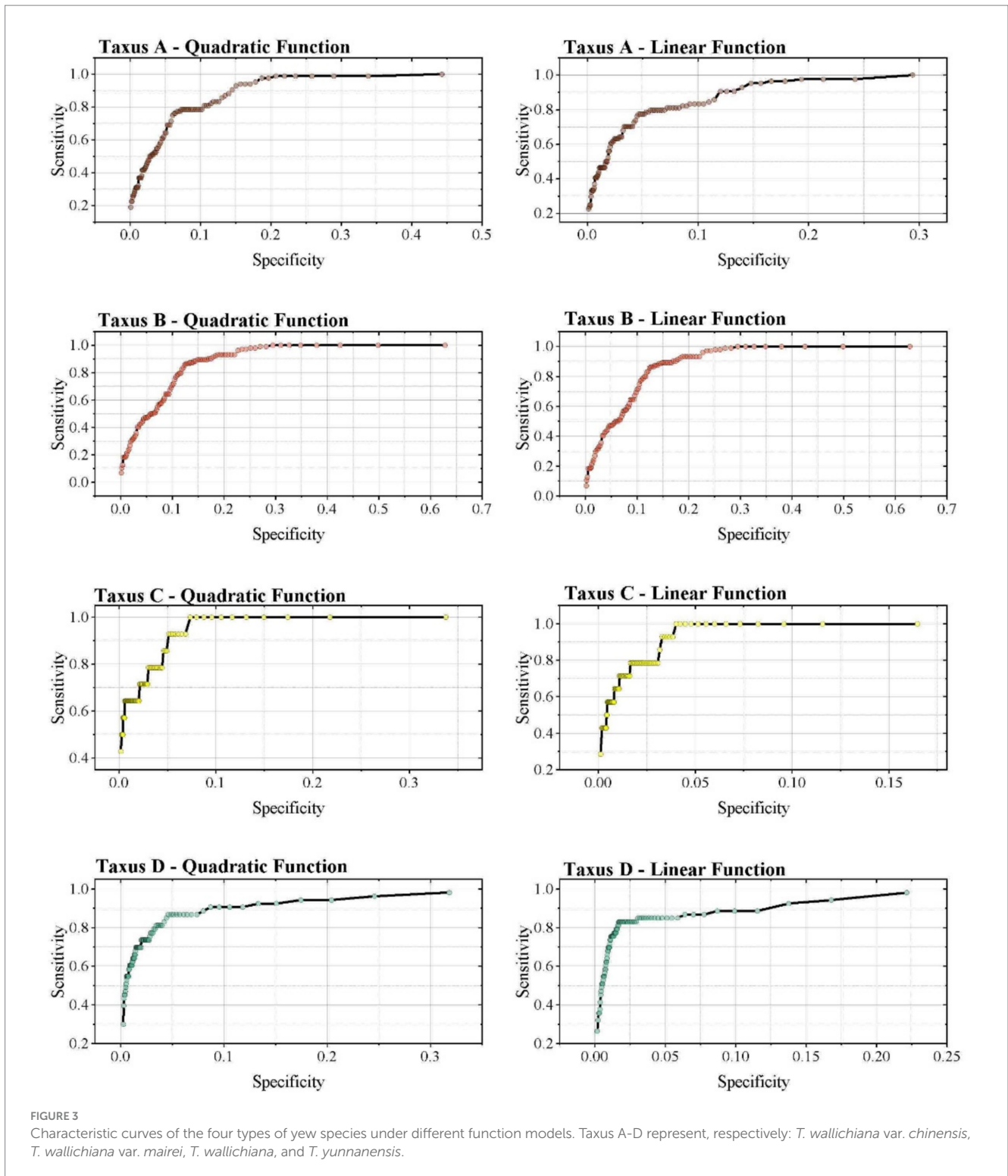
### 3.1 Accuracy assessment and function selection for the MaxEnt model

The occurrence points for the four types of yew species, along with all environmental variables, were input into the MaxEnt model in ArcGIS Pro 3.0. This included 56 sets of climate data, as well as digital models for elevation and slope. The explanatory variables were set as linear functions and quadratic functions, respectively. The accuracy of the MaxEnt model was evaluated using the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve (Phillips et al., 2017; Soilhi et al., 2022). By comparing the AUC values of each species under different explanatory variable functions, the most suitable model for this study was determined. The horizontal axis of the ROC curve represents the false positive rate (specificity), while the vertical axis represents the true positive rate (sensitivity) (Shcheglovitova and Anderson, 2013). A larger AUC value indicates higher precision and accuracy, and when the AUC value exceeds 0.8, the prediction is considered good. By calculating the ROC curves for the four yew species under the two different explanatory variable functions (Figure 3), it was found that the AUC values calculated using the quadratic function were significantly higher than those calculated using the linear function (Table 2). Therefore, this study selected the suitability range calculated using the quadratic function as the research result. The AUC values of the MaxEnt models for the four types of yew species were 0.9604 (*T. wallichiana* var. *chinensis*.), 0.9410 (*T. wallichiana* var. *maireri*.), 0.9777 (*T. wallichiana*.), and 0.9893 (*T. yunnanensis*.), indicating that the prediction results are reliable (Table 2).

### 3.2 Simulation and classification of potential suitable habitats for *Taxus*

Using the distribution records of yew species (Figure 1) and six key environmental factors, the MaxEnt model was applied to simulate the potential suitable habitats for the four *Taxus* species. The simulation results indicate that the potential suitable habitats for yews are predominantly located between 26°N and 31°N latitude, where the spatial heterogeneity of suitable habitats is quite high.

According to the IPCC's classification standards for species suitability, the suitable habitats were divided into three levels: high suitability, medium suitability, and low suitability. In terms of habitat area, *T. wallichiana* var. *maireri* has the largest suitable habitat area in China, with a total area of 2,237,457.75 km<sup>2</sup>, including 490,320.25 km<sup>2</sup> of high-suitability areas, 884,111.93 km<sup>2</sup> of medium-suitability areas, and 863,025.57 km<sup>2</sup> of low-suitability areas. *T. wallichiana* var. *chinensis* has the second largest suitable habitat area, with a total area of 1,365,378.06 km<sup>2</sup>, including 186,138.08 km<sup>2</sup> of high-suitability areas, 381,170.26 km<sup>2</sup> of medium-suitability areas, and 798,069.72 km<sup>2</sup> of low-suitability areas. In comparison, the suitable habitat areas for *T. wallichiana* and *T. yunnanensis* are smaller and relatively similar. The total suitable habitat area for *T. wallichiana* is 497,992.74 km<sup>2</sup>, with



93,042.34 km<sup>2</sup> of high-suitability areas, 121,033.5 km<sup>2</sup> of medium-suitability areas, and 283,916.90 km<sup>2</sup> of low-suitability areas. *T. yunnanensis* has a total suitable habitat area of 615,323.74 km<sup>2</sup>, including 111,707.75 km<sup>2</sup> of high-suitability areas, 113,437.28 km<sup>2</sup> of medium-suitability areas, and 390,178.71 km<sup>2</sup> of low-suitability areas (Table 3). In terms of spatial distribution, *T. wallichiana* var. *mairei* has a broad suitable habitat range, covering Jiangxi, Fujian, Zhejiang, Chongqing, Hunan, Sichuan, Yunnan, and Tibet. The suitable habitat of

*T. wallichiana* var. *chinensis* is concentrated in the Qinling-Daba Mountains (bordering Chongqing, Hubei, and Shaanxi), the Wuyi-Dabie-Nanling Mountains (surrounding Jiangxi), and the Hengduan Mountains in Sichuan. The distribution of *T. wallichiana* and *T. yunnanensis* is similar, primarily concentrated in the northwestern Hengduan Mountains in Sichuan and the southeastern Himalayas in Tibet. Overall, high-altitude mountainous regions are more suitable for the growth of *Taxus* species (Figure 4 and Table 4).

### 3.3 Overlay analysis of potential suitable habitats of yews and nature reserves

Nature reserves play a critical role in maintaining the most pristine and intact forest ecosystems, as well as the richest biodiversity. Protecting biodiversity through nature reserves can achieve significant results both in terms of ecosystem diversity and species and genetic diversity. To assess the relationship between the suitable habitats of yews and domestic nature reserves, an overlay analysis was conducted, superimposing the suitable habitat areas with the boundaries of nature reserves (Figure 5), and the distribution of high-suitability areas within each nature reserve was calculated. The calculation results show that the area of high-suitability zones for *T. wallichiana* var. *chinensis* within nature reserves is 13,943.62 km<sup>2</sup>, covering 7.49% of its high-suitability areas. The area of high-suitability zones for *T. wallichiana* var. *mairei* within nature reserves is 11,950.97 km<sup>2</sup>, covering 2.44%. For *T. wallichiana*, nature reserves cover 9,784.43 km<sup>2</sup> of high-suitability areas, accounting for 10.52%, while for *T. yunnanensis*, reserves cover 7,226.57 km<sup>2</sup>, or 6.47%, of its high-suitability areas. *T. wallichiana* has the highest proportion of high-suitability zones within nature reserves, followed by *T. wallichiana* var. *chinensis*, then *T. yunnanensis*. *T. wallichiana* var. *mairei* has the lowest proportion, primarily due to the relatively large size of its overall suitable habitat (Table 4).

The high-suitability areas of *T. wallichiana* var. *chinensis* covered by nature reserves are mainly concentrated in two regions: the Qinling and Dabie Mountain areas, and the Wuyi Mountains and Nanling region. However, the central Sichuan region of the Hengduan Mountains, where there is a broader distribution of high-suitability areas for *T. wallichiana* var. *chinensis*, has relatively low coverage by nature reserves. It is recommended to explore conservation and reintroduction efforts for *T. wallichiana* var. *chinensis* in this region, particularly in Sichuan Wolong National Nature Reserve, Sichuan Fengtongzhai National Nature Reserve, and Sichuan Baishuihe National Nature Reserve. The high-suitability areas for *T. wallichiana*

var. *mairei* covered by nature reserves are mainly concentrated in the Wuyi Mountains and Nanling region. In southern Tibet, the Yarlung Zangbo Grand Canyon National Nature Reserve and the Qomolangma National Nature Reserve also have relatively high coverage. However, the high-suitability areas in the Qinling and Dabie Mountains, as well as the Hengduan Mountains, have relatively low coverage by nature reserves. The coverage of high-suitability areas for *T. wallichiana* and *T. yunnanensis* by nature reserves is similar. In southwestern Hengduan Mountains, nature reserves such as the Gaoligong Mountains National Nature Reserve, Yunlong Tianchi National Nature Reserve, and Cangshan Erhai National Nature Reserve, as well as the Yongde Snow Mountain National Nature Reserve, have a higher coverage of these areas. In southern Tibet, *T. wallichiana* enjoys a much higher degree of coverage compared to *T. yunnanensis*.

## 4 Discussion

### 4.1 Distribution characteristics of the potential habitats of four species of yew in southern China

This study focuses on four species of yew in southern China and uses the MaxEnt model to simulate the distribution characteristics of their potential habitats. The simulation results indicate that *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis* have relatively wide distribution in suitable habitats within China, particularly concentrated in mountainous areas between latitudes 26°N and 31°N. These areas include the Wuyi Mountains, Dabie Mountains, Qinling Mountains, and Nanling Mountains ranges. Among these, *T. wallichiana* var. *mairei* has the broadest range, with high-suitability areas covering most of Jiangxi, Fujian, and Zhejiang provinces, and also forming a significant distribution around the Qinling region in Chongqing, Sichuan, and Yunnan. This distribution pattern reflects *T. wallichiana* var. *mairei* strong environmental adaptability and potential for reintroduction. The suitable habitat for *T. wallichiana* var. *chinensis* is primarily concentrated in the Qinling, Daba, and Wuyi Mountains. Although its distribution range and suitable habitat area are noticeably smaller than those of *T. wallichiana* var. *mairei*, the presence of multiple, non-contiguous areas demonstrates substantial potential for population expansion. In contrast, the suitable habitats of *T. wallichiana* and *T. yunnanensis* are more spatially restricted. Both are mainly distributed in the Hengduan Mountains in northwestern Sichuan and the southeastern Himalayas in Tibet, where these areas exhibit spatial connectivity and share similar climatic environments. Geographically, these regions are distant from major human activity areas. The harsh natural

TABLE 2 AUC values of the four types of yew species under different function models.

Name	AUC value under linear function	AUC value under quadratic function
<i>T. wallichiana</i> var. <i>chinensis</i> .	0.9480	0.9604
<i>T. wallichiana</i> var. <i>mairei</i> .	0.9284	0.9410
<i>T. wallichiana</i> .	0.9739	0.9777
<i>T. yunnanensis</i> .	0.9836	0.9893

TABLE 3 Area of different suitability levels for the four types of yew species.

Name	High suitability areas (km <sup>2</sup> )	Medium suitability areas (km <sup>2</sup> )	Low suitability areas (km <sup>2</sup> )	Gross area (km <sup>2</sup> )
<i>T. wallichiana</i> var. <i>chinensis</i>	186,138.08	381,170.26	798,069.72	1,365,378.06
<i>T. wallichiana</i> var. <i>mairei</i>	490,320.25	884,111.93	863,025.57	2,237,457.75
<i>T. wallichiana</i>	111,707.75	113,437.28	390,178.71	497,992.74
<i>T. yunnanensis</i>	93,042.34	121,033.50	283,916.90	615,323.74



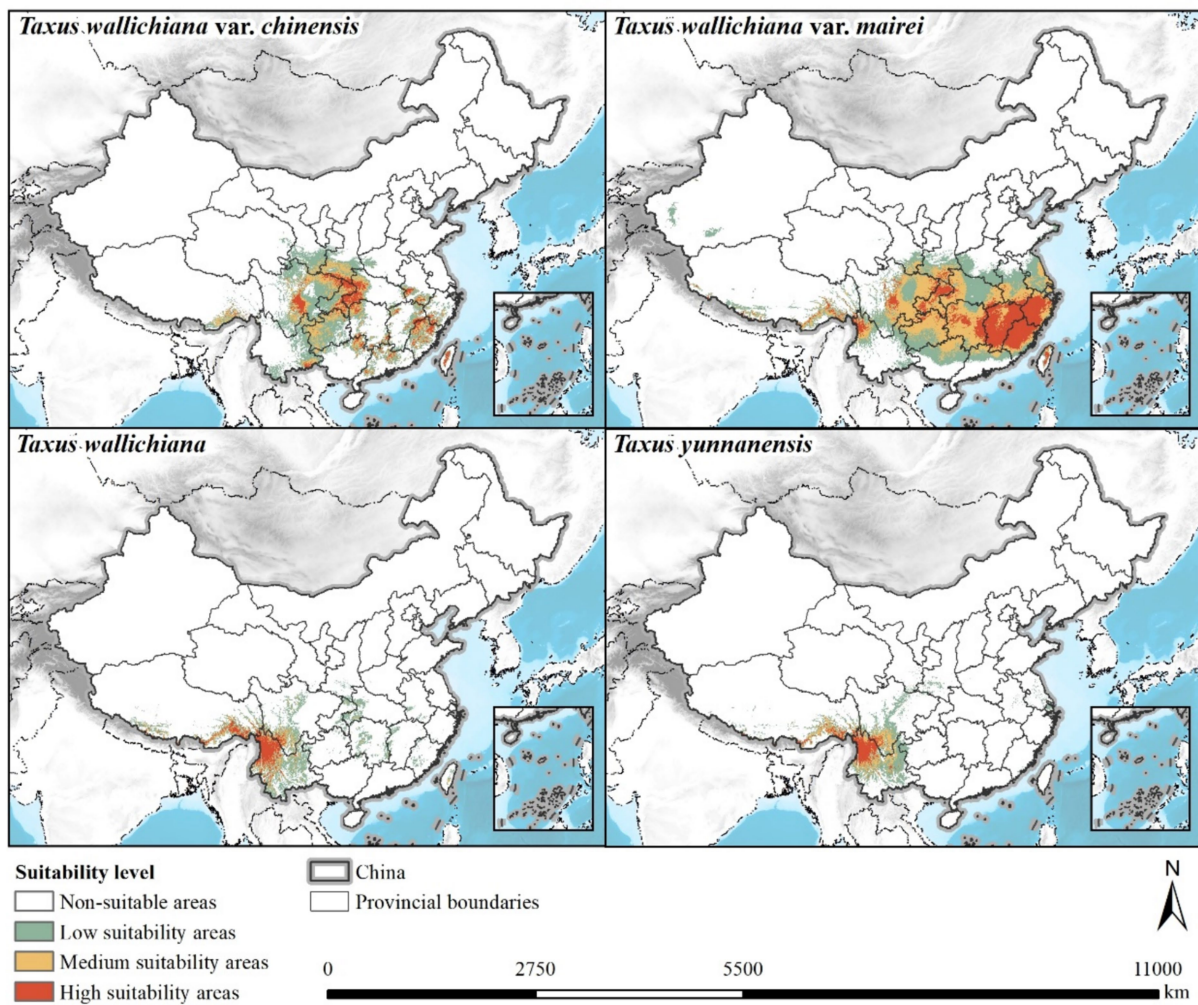


FIGURE 4 Distribution map of suitable habitats for the four types of yew species.

TABLE 4 Area of different suitability levels for the four types of yew species within nature reserves.

Species	High suitability areas (km <sup>2</sup> )	Proportion of suitable area within nature reserves	Medium suitability areas (km <sup>2</sup> )	Proportion of suitable area within nature reserves	Low suitability areas (km <sup>2</sup> )	Proportion of suitable area within nature reserves
<i>T. wallichiana</i> var. <i>chinensis</i>	13,943.62	7.49%	16,945.46	4.45%	42,579.36	5.34%
<i>T. wallichiana</i> var. <i>mairei</i>	11,950.97	2.44%	46,334.25	5.24%	49,129.89	5.69%
<i>T. wallichiana</i>	9,784.43	10.52%	10,985.04	9.08%	34,963.79	12.31%
<i>T. yunnanensis</i>	7,226.57	6.47%	9,389.93	8.28%	22,422.05	5.75%

conditions and ecological sensitivity from the southeastern Himalayas to the northern Hengduan Mountains make these areas susceptible to social influences, creating a unique natural environment. The distinctive natural conditions and relatively extreme climate limit biological movement, constraining the distribution and suitable habitat range of these two yew species.

In summary, *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis* exhibit greater reintroduction potential and are suitable for

expansion and propagation in a broader range of environments. In contrast, *T. wallichiana* and *T. yunnanensis* are restricted to specific environments and regions, with limited suitable habitat indicating a high dependence on their habitats. These findings have implications for developing targeted conservation strategies for different yew species. For the widely distributed *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis*, it is advisable to expand the protected area network to strengthen population stability. For the more



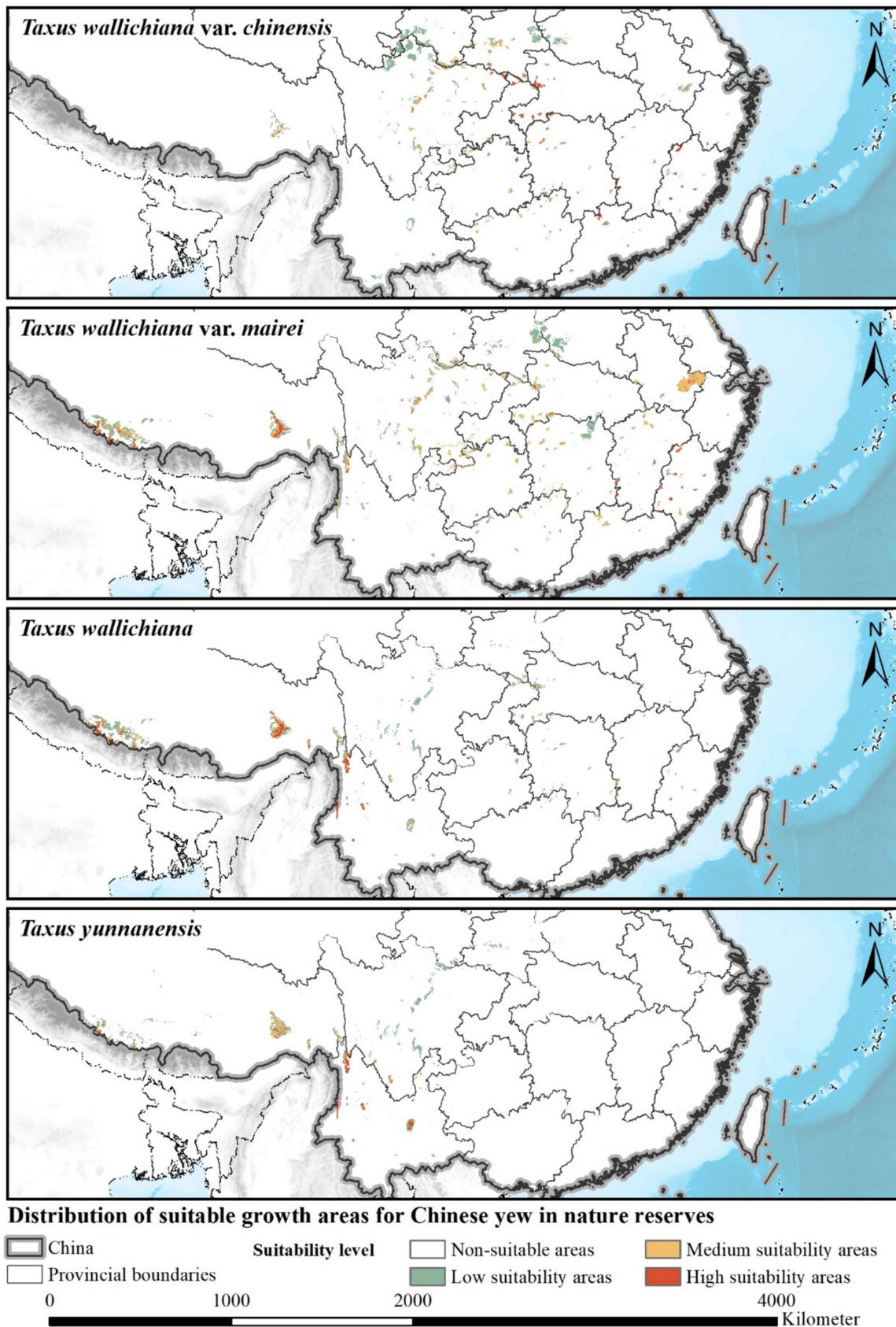


FIGURE 5  
 Distribution of suitable habitats for the four types of yew species within nature reserves.

restricted *T. wallichiana* and *T. yunnanensis*, habitat protection should be intensified to mitigate potential threats from external disturbances and environmental changes.

## 4.2 Conservation of four yew species in southern China

Based on the overlay analysis results in section 3.3, the overlap between potential *Taxus* habitats and domestic nature reserves was identified. The results indicate that nature reserves within major mountainous regions in southern China, primarily the Qinling, Hengduan, Wuyi, and Himalayan mountain ranges, provide ideal habitats for the survival and propagation of *Taxus* species. These reserves, characterized by rich biodiversity and intact forest ecosystems, offer a highly naturalized environment that provides stable growth space for flora and fauna and suitable natural conditions for *Taxus* propagation and reintroduction.

Specifically, *T. wallichiana* has the highest proportion of its high-suitability area covered by nature reserves (10.52%), followed by *T. wallichiana* var. *chinensis* at 7.49%, *T. yunnanensis* at 6.47%, and *T. wallichiana* var. *mairei* at 2.44%, which is lower due to its larger high-suitability area. Spatially, the high-suitability areas for *T. wallichiana* var. *chinensis* are primarily concentrated in the Qinling, Dabie, Wuyi, and Nanling mountain regions, with some areas located within existing nature reserves. However, central Sichuan's Hengduan Mountains have less coverage in high-suitability areas. To increase conservation coverage for *T. wallichiana* var. *chinensis* in this region, it is recommended to implement reintroduction and cultivation efforts within national nature reserves such as Wolong, Fengtongzhai, and Baishuihe to support its expansion potential. The suitable habitat for *T. wallichiana* var. *mairei* is widely distributed, with major reserves located in the Wuyi Mountains, southeastern Himalayas, and Nanling. In southern Tibet, the Yarlung Zangbo Grand Canyon and Qomolangma National Nature Reserves cover large high-suitability areas for *T. wallichiana* var. *mairei*. For regions with numerous nature reserves, such as the Qinling, Wuyi, and Hengduan mountains, it is suggested to establish ecological corridors connecting the reserves to protect biodiversity and optimize the habitat for *Taxus* propagation.

*Taxus wallichiana* is mainly distributed in the southern Himalayas, where high altitude and ecological fragility make it dependent on reserves to maintain ecosystem stability. The coverage of *T. wallichiana* within reserves in this region is significantly higher than elsewhere, making the Yarlung Zangbo Grand Canyon and Qomolangma National Nature Reserves valuable seed sources for enhancing population stability and sustainability.

For *T. yunnanensis*, high-suitability areas are concentrated in the southwestern Hengduan Mountains, including reserves such as Gaoligongshan, Yunlong Tianchi, Cangshan Erhai, and Yongde Snow Mountain National Nature Reserves, providing ample space for *T. yunnanensis* propagation. It is recommended to continue reintroduction and conservation projects within these reserves to strengthen the population structure of *T. yunnanensis*.

Overall, nature reserves within *Taxus* suitable habitat ranges should be prioritized as key areas for *Taxus* population development. Nature reserves in the Qinling, Hengduan, southern Himalayas, and Wuyi Mountains should be targeted for *Taxus*

reintroduction and cultivation. From the perspective of reserve management, enhancing protection within reserves, increasing biodiversity, and strengthening ecosystem stability will provide long-term protection for *Taxus* populations.

The research results indicate that the habitats of many species of yew are currently not effectively protected, and human activities have significantly impacted species distribution (Kong et al., 2021). Protected areas are an effective means of safeguarding species from the continuous threats of human activities, but changes in environmental factors can still lead to shifts in their distribution ranges (Gao et al., 2022). Landscape patches and habitat fragmentation can become obstacles to plant dispersal (Tucker et al., 2018), while the construction of ecological corridors can promote the spread of plants through animal propagation (Fricke et al., 2022). Therefore, natural protected areas within the suitable habitats of yew, especially in regions such as the Qinling Mountains, Hengduan Mountains, southern Himalayas, and Wuyi Mountains, should be prioritized as key areas for future yew population cultivation. Conservation efforts for yew species should not be limited to current protected area distributions; the establishment of small protected areas can increase the coverage of protected zones (Kong et al., 2021). For adjacent protected areas, constructing ecological corridors can enhance regional biodiversity and strengthen the stability of ecosystems.

## 4.3 Impact of this study on conservation planning

The distribution of potential habitats for plants at large scales is the result of multiple factors. Temperature and precipitation are important factors influencing plant growth and reproduction. Previous studies have suggested that, compared to common species, endangered species are more vulnerable to climate change and human activities due to their small existing population sizes and limited habitat areas (Hetem et al., 2014; Köster et al., 2013). Relevant studies have shown that changes in temperature (Rathore et al., 2019), precipitation (Moir, 1999), and solar radiation (Dhar et al., 2006) can significantly affect the distribution of yew species, and changes in habitat can be considered a major alteration of forest site conditions (Falk and Mellert, 2011). Since forests play a crucial role in the global carbon cycle (Pan et al., 2011), research on suitable climate space changes and tree species distribution can provide valuable information for forest carbon management.

## 4.4 Future research directions

SDM models simulate the habitat range of target species, but they cannot represent the actual habitat distribution of the species (Falk and Mellert, 2011). The MaxEnt model used in this study, when predicting the potential habitat distribution of multiple species, did not fully consider various factors that affect species survival and reproduction, such as interspecies competition and the role of animals in aiding plant propagation and expansion (Deb et al., 2017). However, due to the lack of available data, some parameters that may influence the distribution of yew species in

southern China were not considered. Therefore, the future direction of this study will involve multi-model coupling and the application of multi-source parameters (Elith et al., 2006).

## 5 Conclusion

This study conducted a systematic simulation of the potential suitable habitat distribution for four types of *Taxus* species in southern China and analyzed the coverage rate of high-suitability areas by nature reserves. The results showed that *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis* have a relatively wide distribution of suitable habitats, mainly concentrated in the Qinling, Wuyi, and Nanling mountain regions, with numerous areas available for reintroduction and propagation. In contrast, the suitable habitats for *T. wallichiana* and *T. yunnanensis* are more limited, primarily concentrated in the Hengduan and southern Himalaya mountain ranges. For future *Taxus* conservation efforts, the reserve network should be expanded to strengthen population stability for *T. wallichiana* var. *mairei* and *T. wallichiana* var. *chinensis*, with active efforts for reintroduction in multiple areas. For *T. wallichiana* and *T. yunnanensis*, habitat protection efforts should be intensified to address environmental changes and human activity disturbances. The coverage rate of high-suitability areas by nature reserves varies among the yew species, with *T. wallichiana* having the highest coverage rate, followed by *T. wallichiana* var. *chinensis* and *T. yunnanensis*, while *T. wallichiana* var. *mairei* has the lowest due to its widespread suitable habitat. Nature reserves provide a favorable environment for *Taxus* species, but the coverage of high-suitability areas remains insufficient. It is recommended to use high-suitability areas as a basis for expanding the reserve network, establishing ecological corridors, and implementing reintroduction and cultivation to enhance population stability. The limitations of this study are that the simulation results mainly rely on climate and topography data, without fully considering the impact of ecological factors such as human interference, soil factors, and interspecies competition on *Taxus* distribution. Future studies should integrate more environmental variables and use dynamic monitoring methods to further optimize the layout of nature reserves, providing more comprehensive scientific support for

the sustainable conservation of *Taxus* species and the construction of ecological corridors.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

## Author contributions

YZ: Writing – original draft, Writing – review & editing. JH: Data curation, Formal analysis, Supervision, Writing – review & editing. GX: Resources, Writing – review & editing. YS: Writing – review & editing. ML: Data curation, Formal analysis, Funding acquisition, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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