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Protecting China Cedar (*Cryptomeria fortunei*) Habitat Using GIS-Based Simulation, Modeling of Existence Probability, and Function Zoning

*The Tianmu Mountain National Nature Reserve (TMNNR) preserves the only primeval forest of China cedar (*Cryptomeria fortunei*) in the world. In order to assist in planning the protection of China cedar habitat and propose a scientific zoning project for TMNNR, we established a nature reserve geographic information system (NRGIS) of TMNNR using a geographic information system (GIS) and remote sensing (RS). In support of NRGIS, we produced a 3-dimensional simulation of TMNNR and obtained a predictive model through a combination of logistic regression modeling and multivariate analysis. The results demonstrate that slope direction, soil type, and annual precipitation are the main factors affecting China cedar habitat. The existence probability of China cedar increases with (converted) slope direction and annual precipitation. Yellow soil (FAO classification) is more suitable for the growth of China cedar in comparison to red soil (FAO classification). Finally, we predicted suitable habitats for China cedar using a model and function zoning for TMNNR. We suggest that it is necessary to analyze key factors affecting China cedar habitat in order to ensure appropriate conservation measures. NRGIS has been found indispensable for studying, protecting, and managing China cedar forest and TMNNR. NRGIS provides not only modeling information but also the means for monitoring this rare species, identifying suitable locations for reintroduction, and carrying out visible and dynamic management of the whole reserve.*

Keywords: *Nature reserve GIS;* Cryptomeria fortunei*; habitat; simulation; predictive model; function zoning; China.*

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Introduction

China cedar (*Cryptomeria fortunei* Hooibrenk) is a relic species from the Tertiary period, distributed generally below 1100 m, which prefers moist environment and sunshine (ECFC 1999). The China cedar forest in the Tianmu Mountain National Nature Reserve (TMNNR) is the only primeval China cedar forest left in the world and enjoys first-class protection. In the forest there are scattered golden larch (*Pseudolarix kaempferi* Gord.), wild gingko (*Ginkgo biloba* L.), and other endangered and rare species whose function in maintaining biodiversity cannot be replaced. In 1996, TMNNR joined MAB (Man and the Biosphere Program). This program requires that every reserve comprise 3 parts: a core area, a buffer area, and an experimental area. In TMNNR, the extent of these 3 functional areas has not yet been explicitly delimited.

Present research on China cedar focuses on its economic value. The biological traits of China cedar and its contribution to biodiversity maintenance have not received due consideration. Only a few researchers (Lu et al 2001; Qian et al 2001; Chen et al 2002) have noticed the climatic information that China cedar contains. Unfortunately, until now there have been no reports about habitat analysis and protection of China cedar. Additionally, lack of international dialogue and support arouses concern about the prospects of China cedar.

The widespread use of GIS and the development of more powerful statistical methods (Li et al 1999; Sánchez-Zapata and Calvo 1999; Lehmann et al 2002; Cabeza et al 2004; Engler et al 2004) have allowed researchers to develop new techniques for modeling species habitat preferences (Walker 1990; Osborne et al 2001; Store and Jokimäki 2003; Frair et al 2004; Gibson et al 2004; Jeganathan et al 2004; Johnson et al 2004). These methods have increasingly been applied to habitat studies and ecological protection (Herr and Queen 1993; Akçakaya 2000; Weber and Wolf 2000; Klemas 2001; López-López et al 2005), especially as the cost of acquiring information drops substantially, which makes this method more feasible (Klemas 2001).

The aim of our work was to investigate the topographic, climatic, and soil type factors affecting the habitat preference of this species, with the help of NRGIS. We also tried to evaluate the relative contribution of these different variables, illustrate suitable areas for the existence of China cedar, and demarcate the 3 functional zones in NRGIS.

Study area

As a state-level nature reserve, TMNNR focuses on protecting biodiversity and the subtropical forest ecosystem. It covers 4284 ha and is located southwest of Shanghai, in Lin'an County in the northeast of Zhejiang Province, China, at 119°23′47″–119°28′27″E and 30°18′30″–30°24′55″N (Figure 1). Climatologically, TMNNR belongs to the central subtropics, with a transitional climate characteristic of the central subtropics to the northern subtropics (Lou et al 2004). The annual mean precipitation varies according to altitude and seasons, with maximum values in summer and minimum values in winter.

FIGURE 1 Location of the Tianmu Mountain National Nature Reserve (TMNNR) in the Lower Yangtze Plain, eastern China. (Map by Andreas Brodbeck)

Methods

Establishing NRGIS

Before establishing NRGIS, it was necessary to grasp the overall condition of the study area, for which RS technology was indispensable. In addition, we also needed a large-scale relief map (1:10,000), field survey, and other documents to complement and verify the materials collected.

In developing the system, we used the Avenue programming language of ArcView GIS (ESRI, Inc© ArcView GIS 3.2.) as the software platform. Several steps are involved in the construction of NRGIS: setting study objectives, establishing the database, analyzing functions, and integrating systems. Though this work costs time and energy and also requires funding, NRGIS has powerful functions. Its main functional modules include 6 major subsystems for basic information, scenic resource, 3-dimensional analysis, biodiversity protection analysis, statistical data, and a help function. It can store various kinds of data individually and manage them integrally, as well as carry out effective inquiry, search, and analysis on this foundation.

In the 3-dimensional analysis subsystem, we established a digital terrain model (DTM) of TMNNR and simulated distribution of and changes in various environmental factors. This provided a good database for the establishment of a predictive model for China cedar and the simulation of suitable existence habitat areas.

Identifying habitat information

We identified the position of each China cedar (single trees) as a point, and the environmental information for this point was regarded as China cedar habitat information. We considered that the existence probability of China cedar was 1 in distribution areas and 0 in non-distribution areas. In order to define the distribution area of the primeval China cedar forest, we analyzed remote-sensed photos (TM) and aerial photos (scale 1:7000), as well as materials from field investigations.

The results showed that the primeval forest was distributed mainly in a fan-shaped region (900 m broad, 430 m long, covering 23.4 ha), at an altitude of 900–1200 m, in the vicinity of Kaishan Old Palace (Figure 2). In NRGIS, by superimposing the layers of distribution area, digital elevation model (DEM), slope direction, and slope, we discovered that the China cedar forest grows mainly on southeast- to south-facing slopes with slope direction from 100° to 210°.

Selection and adjustment of habitat factors

Based on records on Chinese flora and simulation results in NRGIS, we took account of the influences of topography, mountainous microclimate, and soil type on the habitat of China cedar, while also identifying habitat variables (Table 1). Information on topographic variables was obtained from a DEM with an accuracy of 50-m pixels in horizontal and vertical resolution. The DEM was created using a triangular irregular network (TIN) method based on vector data for contour lines with 10-m accuracy. The slope was considered as the maximum rate of change in elevation across each triangle in the TIN. From the vector data of the TIN we created a continuous raster grid from which values were obtained (López-López et al 2005). Climatic and soil type materials were obtained using 3 approaches: documents provided by local administration, papers, and field surveys.

The variation range for slope direction is 0°–360°. In the northern hemisphere, 0°–90° and 270°–360° represent shady slopes, and 90°–270° represents a sunny slope. But the volume of illumination increases with increase in slope direction within the range of 0°–180°, while the volume decreases with increase in the slope direction in the range of 180°–360°. We then transformed the slope direction (180°–360°) in order to guarantee the accuracy of results. In other words, if the original value of a point's slope direction is within 180°–360°, the value input in SPSS is substituted by the D-value between 360° and the original value. For example, if the original value of a point's slope direction is 200°, then the transformed value is 160° (360°–200° = 160°). After this transformation, the scope of all slope

TABLE 1 Description and source of variables used in the existence probability model generated by the nature reserve GIS (NRGIS).

Name of variables		Description and source [a)]
Topography	**Altitude**	Average altitude (m) above sea level from NRGIS
	Slope	Average slope from NRGIS
	Slope orientation	Average orientation from NRGIS
Climate	**Temperature**	Average temperature (°C) in January
		Average temperature (°C) in July
		Average temperature (°C) every year
		Average annual accumulated temperature (≥ 10°C)
	Precipitation	Average precipitation (mm) in January
		Average precipitation (mm) in July
		Average precipitation (mm) every year
	Evapotranspiration	Mean evapotranspiration
	Annual total radiation	Average annual total radiation
	Dry and humid index	Average dry and humid index
Soil type (FAO classification)	**Yellow soil**	From field survey
	Red soil	From field survey
	Brown soil	From field survey

a) See text for details.

direction is 0°–180°, in which scope the value is larger; China cedar is closer to sunny slopes and receives more illumination.

Model formulation

Predicting species distribution is an indispensable element of conservation biology and ecosystem management. Management of endangered species (Palma et al 1999; Sánchez-Zapata and Calvo 1999), ecosystem restoration (Mladenoff et al 1997), species re-introduction, population viability analysis (Akçakaya et al 1995), and management of human–wildlife conflicts (Le Lay et al 2001) often rely on habitat suitability modeling (Hirzel et al 2001). Multivariate models are commonly used to define habitat suitability and, combined with GIS, allow creation of potential distribution maps (Guisan and Zimmermann 2000).

For the present article, we used logistic regression to model the existence probability for China cedar. Since the response variable (presence/absence of China cedar) follows a binomial distribution, we used a binary logistic regression process, the results of which predict the binary dependent variable through the regression of a set of continuous and categorical variables (Lu et al 2002). This method has been applied to some wildlife habitat studies (for example, Pereira and Itami 1991; Bradbury et al 2000; Zhang et al 2000; Gibson et al 2004).

In order to obtain modeling data, we chose 300 points randomly throughout the study area, among which 100 were in the China cedar distribution area and were made into a thematic overlap for an NRGIS habitat layer with existence points. Simultaneously, in the non-distribution area, 200 points were selected randomly and were made into another thematic overlap for a habitat layer with non-existence points. Then, in NRGIS, we obtained habitat information for each point conveniently by superimposing layers of existence points, non-existence points, and habitat factors. From the 300 points found, 220 were selected as the modeling points (72 in distribution areas, 148 in non-distribution areas), and a remnant of 80 points as the check points. All the points were selected using a random number table.

After inputting habitat information (topography, climate, and soil type) for the 220 points into SPSS, we established the modeling database and carried on stepwise regression to obtain the optimal predictive model. All computations were performed by SPSS (version 12.0 for Windows).

Results

Modeling China cedar habitat and existence probability

In logistic regression, we used the Hosmer and Lemeshow test to test the goodness-of-fit of the models, select independent variables by forward stepwise regression, and analyze correlation of variables with a correlation matrix.

The result of the Hosmer and Lemeshow test (Table 2) showed the goodness-of-fit for step 1 to be unacceptable because of its statistical significance (significance level less than 0.05), while the goodness-of-fit for steps 2 and 3 was preferable, which was attributed to statistical non-significance (significance level greater than 0.05). As the fit closeness for step 3 was better than that for step 2, we constructed a predictive model of China cedar by accepting the regression result of step 3, which identified slope direction, soil type (red soil and yellow soil), and annual precipitation as the parsimonious predictors.

The values of Cox & Snell R^2 and Nagelkerke R^2 for the model, based on the regression result for step 3, were 0.672 and 0.916, respectively, which indicates that the dependent variable can be well explained by the selected independent variables. Moreover, the omnibus test of the model was statistically significant due to the Chi-square (7.595) and the significance level (0.006). The result of verifying the precision of the model by the remnant 80 points was satisfactory: prediction precision for existence points was 89.3% and for non-existence points 76.9%. The best logistic regression model was:

$$P = \frac{e^Y}{1 + e^Y}$$

$$Y = 0.089X_1 + 0.293X_2 - 3.149X_3 + 3.165X_4 - 532.956$$

where P is existence probability of China cedar; X_1 is slope direction (transformed); X_2 is annual precipitation; X_3 is red soil; and X_4 is yellow soil.

Of all the variables, slope direction had the greatest relativity to the existence probability of China cedar because it entered the equation first. Its coefficient was 0.089, which explains that the existence probability increased with the slope direction. According to the transformed slope direction, this result also indicates that the nearer China cedar is to a sunny slope, the greater its existence probability.

The next variables that came into the model were red soil and yellow soil. From their coefficients we saw that yellow soil has a greater influence on China cedar habitat, and is more suitable than red soil.

The last variable coming into the model was annual precipitation, which has a positive correlation to the existence probability of China cedar. Field investigations revealed that the primeval forest was distributed mainly within an area ranging between 900–1200 m, which proves that China cedar prefers moistness—which must thus be considered a characteristic of its habitat. In TMNNR, the maximum value of precipitation according to altitude was found at an elevation of approximately 1000 m.

In NRGIS, we used the model to obtain a distribution map for the existence probability of China cedar for the entire study area (Figure 3A). According to Figure 3A, P is larger than 0.6 in China cedar distribution areas, with $P > 0.8$ dominant, while it is less than 0.6 in non-distribution areas, with $P < 0.25$ dominant. Therefore, we set the threshold value for suitable existence probability at 0.6 (suitable existence area for China cedar in TMNNR; Figure 3B).

Function zoning

In light of MAB, areas with different functions are supposed to have different scopes and requirements. Based on the simulation of China cedar habitat and its existence probability through NRGIS, we determined the function zoning for TMNNR, as shown in Figure 3C.

Conclusions and recommendations

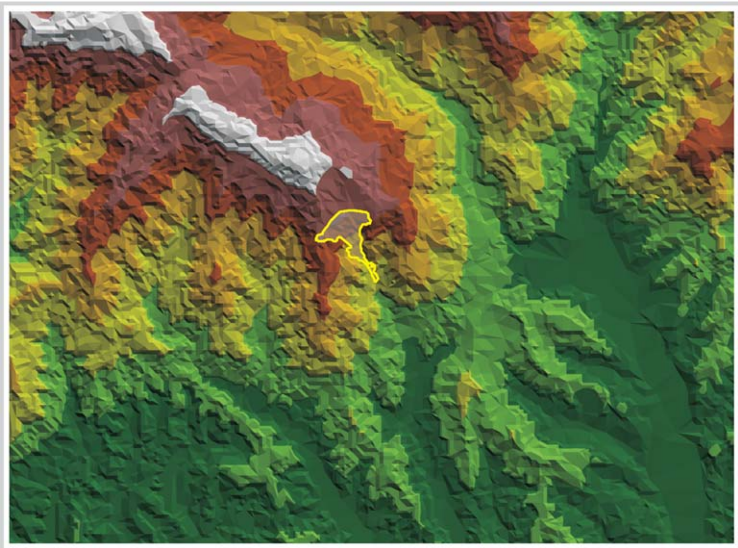
Based on the premise that protecting China cedar habitat is the basic approach to protecting this primeval forest, and dividing functional areas scientifically is the prerequisite for habitat protection, we established a nature reserve GIS based on RS and GIS and projected the virtual reality of the reserve after collecting data from many different sources. The NRGIS that we developed not only gave us an overall view of the reserve, but also provided the information necessary for modeling and predicting habitat through vector data. We established a predictive model of existence probability using a logistic regression model with the help of NRGIS and SPSS.

TMNNR and the distribution area of China cedar are 3-dimensional spaces with horizontal and vertical variation, in which habitat factors interact with each other and affect the distribution of China cedar as a whole. From the results of factor analysis and probability prediction, we found that slope direction is the most

TABLE 2 Hosmer and Lemeshow test used for logistic regression.

Step	Chi-square	df	Significance level
1	18.364	8	.019
2	13.105	8	.108
3	5.292	8	.726

FIGURE 2 Distribution of primeval China cedar (*Cryptomeria fortunei* Hooibrenk) forest (yellow area). (Map by authors)

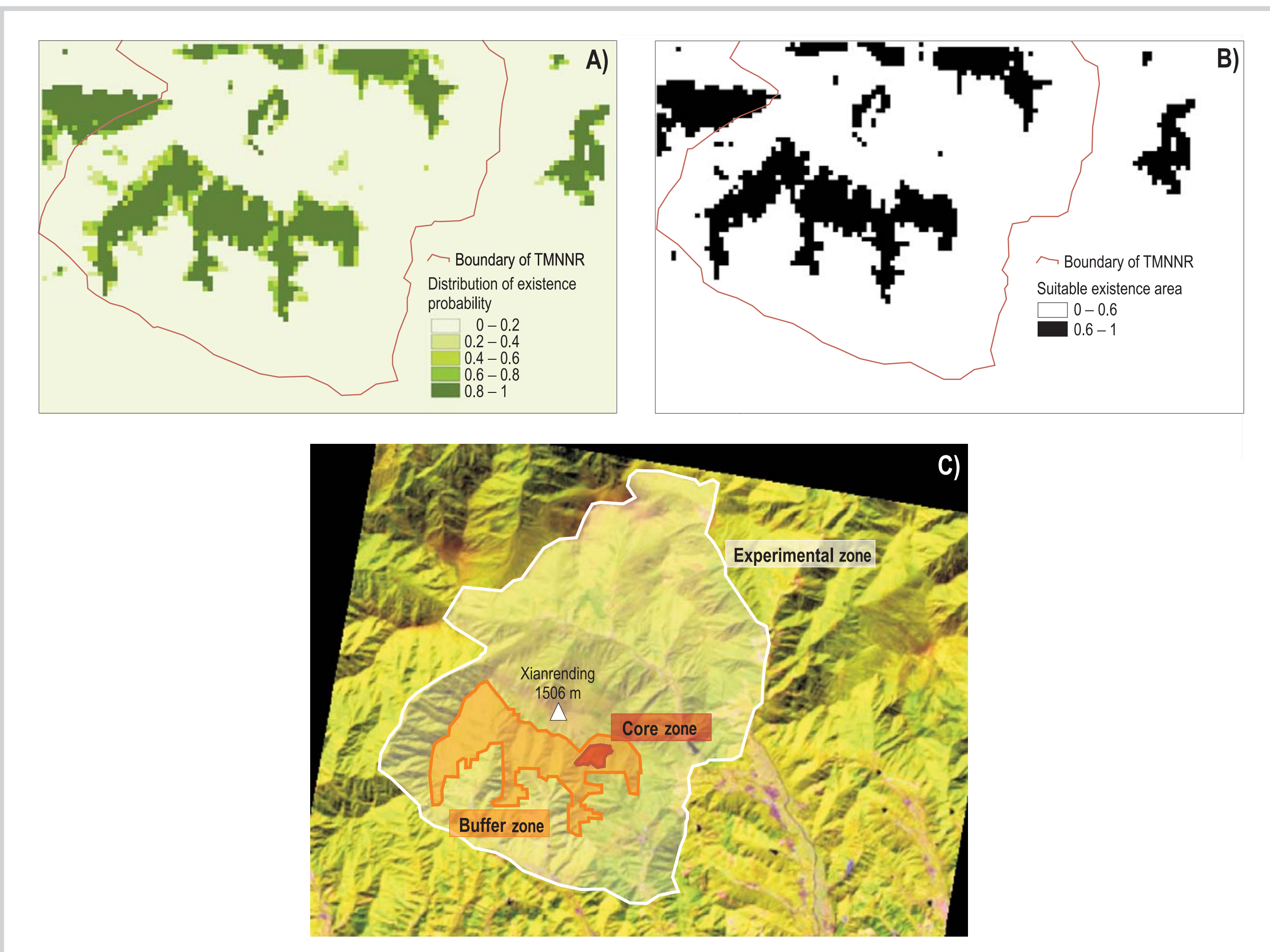


important factor affecting the existence probability of China cedar. Other important factors were found to be annual precipitation, yellow soil, and red soil. From the model, we predicted suitable existence regions for China cedar in NRGIS. There are several suitable areas in TMNNR, with the biggest one around Kaishan Old Palace, and others scattered throughout the entire reserve (Figure 3B).

Our work indicates that the best function zoning for TMNNR (Figure 3C) is the following:

1. **Core zone:** The current distribution area of the primeval China cedar forest should form the core zone of TMNNR. It is located in a concave valley, between 900–1200 m, in the vicinity of Kaishan Old Palace on the south slope of Tianmu Mountain, in an area that has hardly been affected by human intervention to date.
2. **Buffer zone:** Located on the periphery of the core zone, the buffer zone has the function of mitigating

FIGURES 3A–3C A) Distribution of the existence probability of China cedar. B) Suitable existence areas for China cedar. C) Suggested function zones in TMNNR. (Maps by authors)



negative effects on the core zone. Because it is an interface zone between anthropogenic influence and the course of nature, it is very difficult to delimit its boundary. In our opinion, the buffer zone for TMNNR should tally with the scope of the suitable habitat at least, and provide adequate space for the expansion of the primeval China cedar forest. Enlargement of the scope would result in improvement. Therefore, we defined the suitable habitat area around the core zone as the buffer zone, eliminating other suitable existence areas where there was no China cedar, to reduce the difficulty of management.

3. **Experimental zone:** This is distributed on the periphery of the buffer zone, where activities that have no negative effect on this region are allowed. The experimental zone is favorable for exploiting local resources, promoting the indigenous economy, and mitigating the conflict between protection and development. In our work, we considered the region between the buffer zone and the boundaries of TMNNR as the experimental zone.

Beyond designing these function zones to make the scope and responsibility of each area clear in a more scientific way, NRGIS will also allow more effective monitoring of the development and change of vegetation patterns, thus enhancing protection of the habitat of China cedar and future management of the reserve. We also recommend further multi-disciplinary research, involving botany, ecology, geography, RS, GIS, and computer programming as was the case for this study, to enhance habitat protection of such rare and precious mountain species as China cedar.

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