INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
12–977/2013/15–4–777–781
http://www.fspublishers.org

Full Length Article

Comprehensive Environment-suitability Evaluation Model about *Carya cathayensis*

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Abstract

On the relation between the suitable environment and the distribution areas of *Carya cathayensis* Sarg., the current studies are mainly committed to qualitative descriptions, but did not consider quantitative models. The objective of this study was to establish a environment-suitability evaluation model which used to predict potential suitable areas of *C. cathayensis*. Firstly, the 3 factor data of soil type, soil parent material and soil thickness were obtained based on 2-class forest resource survey, and other factor data, which included elevation, slope, aspect, surface curvature, humidity index, and solar radiation index, were extracted from DEM (Digital Elevation Model). Additionally, the key affecting factors were defined by PCA (Principal Component Analysis), the weights of evaluation factors were determined by AHP (Analysis Hierarchy Process) and the quantitative classification of single factor was determined by membership function with fuzzy mathematics. Finally, a comprehensive environment-suitability evaluation model was established and which was also used to predict the potential suitable areas of *C. cathayensis* in Daoshi Town in the study region. The results showed that 85.6% of actual distribution areas were in the most suitable and more suitable regions and 11.5% in the general suitable regions.

Keywords: *Carya cathayensis*; PCA; AHP; DEM; Membership function; Suitability evaluation

Introduction

A lot of suitable environment evaluation methods on agriculture and forestry crop have been researched by many domestic and foreign experts and scholars, such as, fuzzy mathematics (Chen *et al*., 2002; Hu *et al*., 2008), fuzzy logic (Van Ranst *et al*., 1996), expert knowledge (Bydekerke *et al*., 1998), multi-objective evaluation method (Ceballos-Silva *et al*., 2003), fuzzy cluster analysis (Yang *et al*., 2005), the application of GIS technology (Tang *et al*., 2002; Yang *et al*., 2008) and so on.

Carya cathayensis Sarg. is an important native nut crop, which is mainly grown in the Tianmu Mount region between Zhejiang and Anhui provinces (Wen *et al*., 2010). In recent years, lots of researches on *C. cathayensis*, including its biological characters, breed technique, high and stable yield technique and product processing technique and so on, have been conducted by the domestic and foreign scholars and experts. However, the research of suitable environment evaluation on *C. cathayensis* is still staying in the qualitative stage (Liu, 2001; Cheng *et al*., 2002; Xu *et al*., 2003).

In this paper, we present a comprehensive environment-suitability evaluation model based on PCA, AHP and membership function for *C. cathayensis*. The model could be used to predict potential suitable areas and to provide technical support for industrial development of *C. cathayensis*.

Materials and Methods

Research Procedures

The fuzzy comprehensive evaluation method was used to evaluate environment-suitability about *Carya cathayensis* Sarg., and the evaluation process is shown in Fig. 1.

Study Area

The study area is a main producing area of *C. cathayensis*, which is located in Lin'an City, Zhejiang Province, southeastern China at 118°51′-119°52′E,29°56′-30°23′N., where the average temperature is 16 degree Celsius, the precipitation is about 1550 mm, and the average sunshine hours is 2000.6.

Available Data

(1) the 2004 Forest Resource Inventory data consisting of 4571 sub-compartments in Lin'an city; (2) DEM with 30 meter resolution, which was generated by the terrain contour; (3) elevation map, slope map, aspect map and other information derived from DEM; (4) the distribution map of

To cite this paper: Wu, D.S., L.J. Liu and Q.F. Yu, 2013. Comprehensive environment-suitability evaluation model about *Carya cathayensis*. *Int. J. Agric. Biol.*, 15: 777–781

C. cathayensis, the distribution map of soil type and the distribution map of soil parent material, which were generated by Arcgis according to the 2004 Forest Resource Inventory data in Lin'an city.

For all geographic data in this paper, Xi'an 80 plane coordinate system was adopted, 3° zoning Gauss- Kruger projection with 120° central meridian was also used, and m was the unified unit for space measurement.

Experimental Environment

(1) ArcGIS 9.2 was used to store, compute and analyze the Forest Resource Inventory data and display the results; (2) ArcView 3.2a was used to calculate the solar radiation index based on the DEM; (3) MATLAB was used to calculate the weight of evaluation factors through establishing the AHP comparison matrix.

Calculation of Weights of Evaluation Factors

Determination of evaluation unit: Sub-compartment of forest resources was chosen as the evaluation unit, thus the *C. cathayensis* distribution, soil type, soil parent material, and soil thickness data were obtained from the Forest Resource Inventory results. Using the unit not only reduced the cost of data access, but also ensured the consistency between the evaluation units and business units, and it was more instructive in the actual production.

Initial Identify of Index System

From previous research results (Li, 2003), the impact index system about *C. cathayensis* growth was initially determined as follows: (1) the climatic conditions, including the annual average temperature, the hottest monthly average temperature, the coldest monthly average temperature, the absolute maximum temperature, the absolute minimum temperature, the annual frost-free period, the annual rainfall, and the annual sunshine hours; (2) the soil conditions, including soil type, parent material, soil thickness, soil organic matter content, and pH value; (3) the topography conditions, including slope, aspect, slope position, and elevation.

Reduction of Evaluation Index Set

Since the Initial index system is too complicated to carry out the quantitative analysis, the evaluation indexes should be reduced as much as possible, while it was no losing high reliability. Based on the available research results, the experience of the local scientists and the villagers who are planting the *C. cathayensis* as well as practical investigation data, we selected 8 factors as evaluation indexes which included elevation, slope, aspect, surface curvature, humidity index, solar radiation index, soil types and soil parent material (Wu *et al*., 2011).

Determination of the Main Components with PCA

The variance contribution of principal components had been drawn with PCA in SPSS (Statistical Product and Service Solutions) in the research (Wu *et al*., 2011). In the 8 factors, the variance of 4 main components of the soil types, elevation, solar radiation index and humidity index, which accounted for 27.813%, 20.638%, 19.138% and 17.575%, and the cumulative contribution rate was over 85%. Therefore, we selected the above 4 main components to analyze the degree of influence of each factor.

Establishment of Hierarchy Model

Based on the analysis to practical problems, the hierarchy model, which included target layer, rule layer and project layer was established (Wu *et al*., 2011).

Construction of the Judgment Matrix

Comparing pairwise the importance degree values of the 8 evaluation factors given by the experts, we constructed the judgment matrix and calculated the CR whose value was 0.0523, which met the requirement of $CR<0.1$, thus the consistency test was valid (Wu *et al*., 2011).

Calculation of Factor Weights

Based on the evaluation factor comparison matrix, we used MATLAB to calculate weights of evaluation factors.

Membership Function of Single Factor for Quantitative Classification

4571 sub-compartments which were from the Forest Resource Inventory data in Lin'an city had been used as the training sample data. The weight of evaluation factors was calculated by AHP in Eq. (1), and the quantitative classification of single factor was determined by membership function in fuzzy mathematics.

$$A=(A1,A2,A3,A4,A5,A6,A7,A8) \quad (1)$$

Description

1. The distribution frequencies of soil types from high to low were: yellow soil, red soil, calcareous soil, paddy soil and purple soil. And the distribution frequencies of soil parent material from high to low were: loam soil, sandy soil, and clay. Then we appropriately adjusted the weight of different soil types and soil parent material according to the expert experience, and got their membership.
2. The frequencies about elevation distribution indicated that the *C. cathayensis* were mainly concentrated in the regions where elevation was between 300 m and 700 m, and in these regions, no obvious correlation was found. However, the positive linear correlation was found when the elevation was from 100 m to 300 m, and negative linear correlation was presented when the elevation from 700 m to 900 m. In addition, the *C. cathayensis* distributed sparsely

when the elevation was lower than 100 m or higher than 900 m. On this basis, the parabolic membership function about elevation was established.

3. The expert experiences showed that *C. cathayensis* were mainly distributed in semi-sunny, shady and semi-shady slope, moreover in sunny slope with high elevation, there was also some distribution. The distribution frequencies of *C. cathayensis* also proved it. On this basis, we got the membership function of aspect.

4. According to the distribution frequencies, the slopes were divided into 4 grades of less than 5°, 5°–25°, 25°–35° and more than 35°. *C. cathayensis* was mainly concentrated in the regions where slope was between 5°and 25° and in this region, no obvious correlation was found. However, there was negative linear correlation when slope was from 25° to 35°. In addition, *C. cathayensis* distributed sparsely when slope was lower than 5° or higher than 35°. On this basis, the membership function about slope was established.

5. The Solar Analyst Module of ArcView software was used to calculate the simulated solar radiation (Huang *et al*., 2007) based on the DEM with resolution of 30 m, since there were no direct-measured solar radiation data. According to the distribution frequencies of simulated solar radiation, *C. cathayensis* were mainly concentrated in the regions, where simulated solar radiation was between 9.83×10^5 and 1.25×10^6, and when the solar radiation was from 9.0×10^5 to 9.83×10^5, positive linear correlation was found. In addition, when the solar radiation was lower than 9.0×10^5 or higher than 1.25×10^6, *C. cathayensis* distributed sparsely. On this basis, the membership function about solar radiation index was established.

6. Eq. (2), proposed by Beven and Kirkby (1979), was used to calculate the topographic humidity index.

$$TWI=\ln(SCA/\tan Sl) \qquad (2)$$

Where, SCA was the unit catchment area, Sl was the pixel slope, TWI was the topographic humidity index.

According to the distribution frequencies, the values of TWI were divided into 5 grades of less than or equal to -0.6, -0.6-0.6, 0.6-2.9, 2.9-4.1 and greater than or equal to 4.1. Moreover, *C. cathayensis* were mainly concentrated in the regions where TWI was between 0.6 and 2.9. When the TWI was from -0.6 to 0.6, positive linear correlation was found, and when the TWI was from 2.9 to 4.1, negative linear correlation was presented. In addition, the *C. cathayensis* distributed sparsely when the TWI was lower than -0.6 or higher than 4.1. On this basis, the membership function about humidity index was established.

7. Terrain curvature is a quantitative factor which reflects variation degree on the topography surface, and it was calculated by Eq. (3).

$$z = f(x,y) = f_{xx}{}^2 + 2f_{xy}{}^2 + f_{yy}{}^2 \qquad (3)$$

According to the terrain curvature distribution frequencies, the terrain curvature values were divided into 5 grades of less than or equal to -0.6, (-0.6, -0.3), [-0.3, 0.2], (0.2, 0.7) and greater than or equal to 0.7. *C. cathayensis* were mainly concentrated in the regions where terrain curvature was between -0.3 and 0.2. When the terrain curvature was from -0.6 to 0.2, positive linear correlation was found and when the terrain curvature was from 0.3 to 0.7, negative linear correlation was presented. In addition, *C. cathayensis* distributed sparsely in the regions where the terrain curvature was lower than -0.6 or higher than 0.7. On this basis, the membership function about terrain curvature was established.

Establishment of Comprehensive Environment-suitability Model of *C. cathayensis*

The model was obtained according to the weighted index method in Eq. (4).

$$B_i = \sum_{j=1}^{n} A_j \times R_{ij} \qquad (4)$$

Where, B_i was the comprehensive index value of the i^{th} unit about suitability evaluation, A_j was the weight of the j^{th} evaluation factor, R_{ij} was factor-score of the i^{th} unit and the j^{th} factor; n was the total number of evaluation factors.

Results

Main Components

The result showed that there were 2 factors with great influence in each of the four components, namely, soil type (0.840) and soil parent material (0.755) in the first principal component, elevation (0.869) and slope (0.683) in the second, aspect (0.769) and solar radiation index (0.683) in the third, and humidity index (0.776) and surface curvature (-0.658) in the last.

Weights of Evaluation Factors

The result showed that weights of evaluation factors calculated by PCA were shown in Table 1 (Wu *et al*., 2011), and the weight matrix A was given in Eq. (5).

$$\begin{aligned}A&=(A1,A2,A3,A4,A5,A6,A7,A8)\\&=(0.1888,0.0911,0.1387,0.0309,0.0452,0.0697,0.2373,0.1983)\end{aligned} \qquad (5)$$

Quantitative Classified Results of Single-index Factor

The value of single factor in every evaluation unit, was calculated and classified according to the membership function from Table 2.

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The values of B_i, which were calculated by Eq. (4), reflected the suitable level between *C. cathayensis* and its

Table 1: The weight of each evaluation factor

Elevation	slope	aspect	surface curvature	humidity index	solar radiation index	soil types	soil parent material
0.1888	0.0911	0.1387	0.0309	0.0452	0.0697	0.2373	0.1983

Table 2: Membership function of single factor for quantitative classification

No.	Evaluation factors and their weights	membership function for quantitative classification of single factor
1	Soil type (0.2373)	$S_{st} = \begin{cases} 1.0 & yellow\ soil \\ 0.8 & red\ soil \\ 0.6 & calcareous\ soil \\ 0.4 & paddy\ soil \\ 0.2 & purple\ soil \end{cases}$
2	Soil parent material (0.1983)	$S_{pm} = \begin{cases} 1.0 & loam\ soil \\ 0.5 & sandy\ soil \\ 0.0 & clay \end{cases}$
3	Elevation (0.1888)	$S_{ev} = \begin{cases} 0.9(900-x)/200+0.1 & 700 \le x < 900 \\ 1.0 & 300 < x < 700 \\ 0.9(x-100)/200+0.1 & 100 < x \le 300 \\ 0.1 & x \le 100, x \ge 900 \end{cases}$
4	Aspect (0.1387)	$S_{hs} = \begin{cases} 1.0 & semi-sunny\ slope \\ 0.8 & shady\ slope \\ 0.6 & semi-shady\ slope \\ 0.4 & sunny\ slope \end{cases}$
5	Slope(0.0911)	$S_{sl} = \begin{cases} 1.0 & 5 \le x \le 25 \\ 0.9(35-x)/10+0.1 & 25 < x \le 35 \\ 0.1 & x < 5, x > 35 \end{cases}$
6	Solar radiation index(0.0697)	$S_{sri} = \begin{cases} 1.0 & 9.83\times10^5 < x < 1.25\times10^6 \\ 0.9(x-9.0\times10^5)/(0.83\times10^5) & 9.0\times10^5 < x \le 9.83\times10^5 \\ 0.1 & x \le 9.0\times10^5, x \ge 1.25\times10^6 \end{cases}$
7	humidity index(0.0452)	$S_{hi} = \begin{cases} 0.9(4.1-x)/1.2+0.1 & 2.9 \le x < 4.1 \\ 1.0 & 0.6 < x < 2.9 \\ 0.9(x+0.6)/1.2+0.1 & -0.6 < x \le 0.6 \\ 0.1 & x \le -0.6, x \ge 4.1 \end{cases}$
8	surface curvature(0.0309)	$S_{hc} = \begin{cases} 0.9(0.7-x)/0.5+0.1 & 0.2 \le x < 0.7 \\ 1.0 & -0.3 < x < 0.2 \\ 0.9(x+0.6)/0.3+0.1 & -0.6 < x \le 0.3 \\ 0.1 & x \le -0.6, x \ge 0.7 \end{cases}$

Note:
1. $S_s \rightarrow S_{sri}$
2. $0.9(x-9.0\times10^5)/0.83\times10^5 \rightarrow 0.9(x-9.0\times10^5)/(0.83\times10^5)$

environment. In order to facilitate the analysis, the suitable levels were classified as the most suitable level when B_i was between 0.9 and 1, suitable level when B_i was greater than or equal to 0.8 and less than 0.9, generally suitable level when B_i was greater than or equal to 0.7 and less than 0.8, and unsuitable level, when B_i was less than 0.7. Meanwhile, considering unsuitability for planting the *C. cathayensis* unsuitable level areas, which also included the construction land, roads, rivers and lakes, their B_i were set to 0.

Table 3: Prediction distribution of *C. Cathayensis* in the Daoshi Town

Area characteristics	Actual area	Percentage
Total areas	436946	100%
The most suitable areas	208462	47.7%
Suitable areas	165664	37.9%
Generally suitable areas	50060	11.5%
Unsuitable areas	12760	2.9%

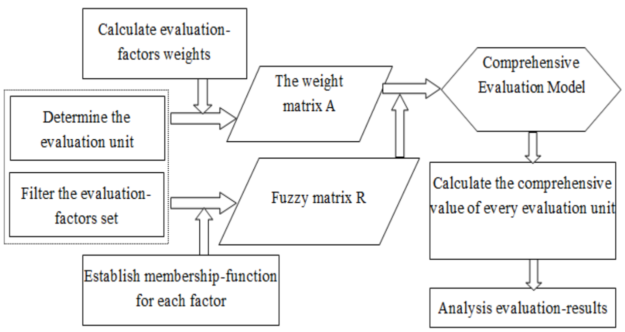

Fig. 1: Research procedures

Predicts potential suitable areas of *C. cathayensis* in Daoshi Town in the Study Region

From the results of Daoshi Town in Table 3, in actual distribution areas of *C. cathayensis* we found that there were 208462 acres in the most suitable area, 165664 acres in more suitable area, 50060 acres in generally suitable area, and 12760 acres in unsuitable area. In summary, 85.6% of *C. cathayensis* was located in most suitable and suitable areas, 11.5% was located in the general suitable area. It follows that the prediction results were quite in accord with the actual distribution.

Discussion

In this paper, we presented a comprehensive environment-suitability evaluation model about *C. cathayensis*. The 3 factor data of soil type, soil parent material and soil thickness were obtained based on 2-class forest resource survey, and other factor data, which included elevation, slope, aspect, surface curvature, humidity index, and solar radiation index, were extracted from DEM with resolution of 30 m. It follows that the sources of the research data were reliable and valid. Considering the outstanding experience in the research methods, the model was developed by using PCA, AHP (Wu *et al.*, 2011) and membership function in fuzzy mathematics (Van Ranst *et al.*, 1996). The model also used to predict the *C. cathayensis* distribution area of Daoshi Town, and it showed that 97.1% of actual distribution area of *C. cathayensis* was in the most suitable regions, suitable regions, and general suitable regions. Although in this study, the model was only used to predict potential suitable areas of *C. cathayensis* it should be easily extended to the suitability evaluation for other crops in agricultural field.

In conclusion, the comprehensive environment-suitability evaluation model could be used to predict quantitatively potential-suitable areas of *C. cathayensis*. The result indicated that 97.1% of the existing distribution areas located in the potential-suitable areas, it had reached a very high accuracy. The model should provide technical support for industrial development of *C. cathayensis*.

Acknowledgement

This work was financially supported by Zhejiang province major science and technology project (2011C12047) and Zhejiang province education department project (Y201225717). We also appreciated Huang Jian Qin and Wang Zheng Jia for their assistance in constructing the judgment matrix of AHP.

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(Received 28 September 2012; Accepted 19 February 2013)