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Forest Ecosystem Health Assessment on the Basis of Fuzzy Comprehensive Evaluation Model

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Abstract: Both of qualitative and quantitative methods are applied to screen the indicators for forest ecosystem health assessment in nature reserves in Beichuan County. The indicator weights are obtained by Principal Component Analysis, and the Fuzzy Model is built to assess the forest ecosystem health. The values show that the forest ecosystem is of sub-health with the health value 2.77, and the elevation is the most influential element to forest ecosystem health.

Keywords: forest ecosystem health assessment, principal component analysis, grey correlation analysis, fuzzy comprehensive evaluation

1. Introduction

Forest health characterizing a forest far from the state of the disease, evaluating specific areas of forest health, it's the basis of the work carried out forest management. Forest health has become a Forestry Science and Technology in a new direction, and gets more and more widely recognized (Kong, Zao, Ji, Lu, Deng, Ma, & Zhang, 2002). Forest ecosystem health assessment has become an important issue during the recent years (Ma, Kong, Guan, & Fu, 2001; Wang, Xiao, & Zhang, 2007).

Nature reserves in Beichuan County had been destroyed during Wenchuan Earthquake, which resulted in the degradation of the forest ecosystem function in some areas (Hilty & Merenlender, 2000); consequently, it is significant to evaluate the status of forest ecosystem health after the earthquake. In this article takes Beichuan nature reserves as the study area, to build the fuzzy comprehensive evaluation model to assess the status of forest ecosystem health, in order to contribute to further research and post-quake reconstruction of forest ecosystem as well as sustainable development.

2. Study Area

Nature reserves studied are located in latitude 30°14′~32°14′ north, and longitude 103°44′~ 104°42′ east in Beichuan county, Sichuan province, China. The land is hilly with ravines and gullies, high in the north-west and low in the south-east, and 540~4769m above sea level. The annual average temperature is 15.6 ^{0}C, the annual rainfall is 1399.11mm, the annual average frost-free period is 244~282 days, and the average sunshine duration is 931.1~1111.5 hours. The vegetation types have subtropical evergreen broad-leaved forest, subtropical deciduous broad-leaved forest, bamboo forest and subtropical evergreen coniferous forest. In addition, it is with rich water resources.

3. Methodology

3.1 Sampling Survey

Based on field survey, 20 samples were set up in accordance with the types of forest, growth and distribution. Standardized quadrat of 20m×20m has been set in vegetation survey, to take the record of elevation, slope direction, disturbance and soil, to scale each tree with height more than 1.3m, and to take the record of tree species, number of trees, height and diameter. 5 shrub quadrats of 2m×2m have been set along the diagonal line within selected samples, while 4 grass quadrats of 1m×1m have been set in the four corners, in order to take the record of variety, number, shade density and coverage(Cui &Yang, 2002).

3.2 The Indicators

Considering the status of Beichuan nature reserves, 18 indicators at three levels have been selected. Due to the relevance among the indicators primarily selected, these indicators should not be integrated directly (Cui & Yang, 2003). This study combines the qualitative and quantitative indicators, and further selects the indicators for assessment.

Analysis of principal components has been adopted in quantitative selection on 18 primary indicators. And SPSS has been applied to analyze the samples studied, and the values in table 1,combined with qualitative screening,there are 3 categories and 9 indicators for forest ecosystem health assessment of Beichuan nature reserves.

Table 1. Values and variance contribution rate for partial principal components

Principal components	Primary Values			Extraction of Factor Loading		
	Value	Variance contribution rate (%)	Accumulated Variance contribution rate (%)	Value	Variance contribution rate (%)	Accumulated Variance contribution rate (%)
1	7.322	40.680	40.680	7.322	40.680	40.680
2	3.542	19.679	60.359	3.542	19.679	60.359
3	2.069	11.494	71.853	2.069	11.494	71.853
4	1.429	7.938	79.791	1.429	7.938	79.791
5	1.050	5.833	85.624	1.050	5.833	85.624
6	0.772	4.291	89.915			

3.3 Identify the Weight of Indicators

In the present study grey relative model has been used to define the weight of indicators. The detailed steps are as followed (Chen, Dai, Ji, Deng, Hao, & Wang, 2004):

(1) Based on the value of indicators, the combined matrix R has been determined. R={r_{ij}}m×n, m as the number of samples, n as the number of indicators.

(2) As the matrix above, the combined matrix is a sequence of numbers for assessment. This study takes the worst status {0，0，0，……} as the reference sequence of numbers, gives a place of prominence to the factors of worse health status with impacts on entire forest ecosystem health, and then calculate the relevance between the reference sequence and the assessment sequence of numbers (Li, An, Cheng, Wang, Zhuo, & Qin, 2001). The formula for calculation is described below.

$$\xi_{ij}(t)=\frac{\min_j\min_i \Delta ij(t)+k\max_j\max_i \Delta ij(t)}{\Delta ij(t)+k\max_j\max_i \Delta ij(t)} \qquad \gamma_{ij}=\frac{1}{N}\sum_{j=1}^{N}\xi_{ij}(t)$$

In the formula above, $\zeta_{ij}(t)$ is the grey correlation coefficient of the indicator of No. j; $\Delta ij(t)=|x_j(t)-x_i(t)|$, $x_i(t)$ is the reference sequence of numbers, and $x_j(t)$ is the assessment sequence of numbers; k is the resolution ratio, for instance, the grey scale of [0, 1] is 0.5; γij is the grey correlation coefficient of the indicator of No. j in the reference sequence of numbers, N as the number of samples.

(3) Normalization of the grey correlation coefficient of all indicators, this is the weight R for the assessment indicators. Follow the steps above to define the weight of indicators at different levels. The specific results are as table 2 below.

Table 2. The weight of the indicators for assessment

Layer of Goal	Layer of Components	Layer of Indicators
Forest Ecosystem Health Assessment	Vitality of forest ecosystem（0.10）	Volume（0.110）
		Shrub richness（0.127）
		Grass richness（0.119）
	Forest ecosystem structure（0.73）	Degree of closure（0.109）
		Soil thickness（0.104）
		Elevation（0.128）
		Slope （0.103）
	Forest ecosystem resistiblity（0.17）	Level of pest and disease（0.107）
		Degree of disturbance（0.091）

3.4 Building Fuzzy Comprehensive Evaluation Model

The assessment based on the fuzzy mathematics theory (Wang, 2005): B=RoA

In the formula, B is the fuzzy subset for all levels, R is the set of weight, A is the fuzzy relation matrix on degree of membership through membership function X, and o is the operation of arithmetic product of fuzzy matrix.

Parameters of membership function are defined as follows. The overall principle is to follow the national or international standards, so as to ***Main Technical Guideline on Forest Resources Design and Planning*** by the State Forestry Administration (Lackey, 2001; Allen, 2001), take the value of existing ecosystem with minor or none disturbance as the standard value in the same geographic region. Therefore, the standard value of 5 categories of the assessment indicators, in terms of very healthy, healthy, sub-healthy and sick, has been defined with the consideration of the current status of nature reserves in Beichuan. The assessment criteria for all indicators are as table 3.

Table 3. Assessment criteria for all indicators

Indicators	I	II	III	IV	V
Volume（$m^3/400m^2$）	4.4	3.6	2.8	2	1
Shrub richness	3.5	3.0	2.5	2.0	1.0
Grass richness	4.0	3.5	3.0	2.5	2.0
Degree of closure	0.8	0.7	0.6	0.5	0.2
Soil thickness/cm	60	50	40	30	20
Elevation/m	1600	1600-2000	2000-2400	2400-2800	2800
Slope/°	5	15	25	30	35
Level of pest and disease	0.1	0.2	0.4	0.5	0.6
Degree of disturbance	1	2	3	4	5

The respective membership functions in line with 5 categories are as below.

For category I, when j=1,

$$A(x)=\left\{\begin{array}{l} 1, x\geq d_1 \\ \dfrac{x-d_2}{d_1-d_2}, d_2<x<d_1 \\ 0, x\leq d_2 \end{array}\right\}$$

For category II, III, IV, when j=2, 3, 4,

$$A(\mathrm{x})=\left\{\begin{array}{l} 0, x\geq d_{j-1} \\ \dfrac{d_{j-1}-x}{d_{j-1}-d_j}, d_j<x<d_{j-1} \\ \dfrac{x-d_{j+1}}{d_j-d_{j+1}}, d_{j+1}<x\leq d_j \\ 0, x\leq d_{j+1} \end{array}\right\}$$

For category V, when j=5,

$$A(x)=\begin{Bmatrix} 0, x \geq d_4 \\ \dfrac{d_4-x}{d_4-d_5}, d_5 < x < d_4 \\ 1, x \leq d_5 \end{Bmatrix}$$

In the formula, x is the original statistical value for each assessment indicator, and d_j is the classification value for the respective classification criteria (Yuan, Liu, & Lu, 2001).

4. Results and Analysis

4.1 The Forest Ecosystem Health Assessment of all Samples

Table 4 indicates that the overall status of forest ecosystem health is between II and III, and approaches to III, and demonstrates the trend from II of healthy status to III of sub-healthy status. Among 20 samples studied, the assessment value of No. 1 sample is the minimum of between I and II, while the assessment value of No. 10 sample is the maximum of between III and IV .

Table 4. The values of forest ecosystem health Assessment in all samples

Samples	I	II	III	IV	V	values of assessment	General values
1	0.46	0.32	0.22	0	0	1.76	
2	0.23	0.33	0.33	0.11	0	2.32	
3	0.17	0.26	0.38	0.19	0	2.59	
4	0.13	0.13	0.30	0.44	0	3.05	
5	0	0.20	0.20	0.60	0	3.40	
6	0.14	0.09	0.28	0.20	0.29	3.41	
7	0.32	0.32	0.22	0.14	0	2.19	
8	0.08	0.39	0.39	0.14	0	2.60	
9	0.09	0.25	0.35	0.25	0.06	2.95	
10	0	0.25	0.29	0.23	0.23	3.44	2.77
11	0.16	0.08	0.28	0.28	0.20	3.29	
12	0.15	0.21	0.19	0.20	0.25	3.18	
13	0.40	0.40	0.20	0	0	1.80	
14	0.26	0.37	0.37	0	0	2.11	
15	0.23	0.27	0.38	0.12	0	2.39	
16	0.35	0.09	0.29	0.27	0	2.48	
17	0.07	0.35	0.34	0.24	0	2.74	
18	0.15	0.14	0.31	0.10	0.30	3.26	
19	0.09	0.29	0.15	0.27	0.20	3.17	
20	0.14	0.14	0.26	0.19	0.27	3.30	

4.2 Key Factors Influencing the Forest Ecosystem Health

Table 3 indicates that among the three layers, the structure of forest ecosystem with the weight of 0.73, had the highest impacts, while resistibility of forest ecosystem comes to the next, and vitality of forest ecosystem with minimum impacts on forest ecosystem health. Therefore, the structure holds a leading position, as the most important factor influencing forest ecosystem health. Moreover, the environmental factors are with the weight of 0.43, and elevation with weight of 0.38 as the most influential factor among the three environmental factors.

Figure 1 reveals that the assessment values are increasing with the ascending of elevation, and consequently, the overall health status of forest ecosystem in the study area decreases with the ascending of elevation. The major causes could be the features of vertical distribution for the vegetation in nature reserves, and decreased percentage of trees and declined plant diversity as well as degree of stand closure with the rising of elevation, which results on reduced stability of the structure. Nevertheless, the overall health status at the elevation of 1200~1600m is superior to those of 700~1200m, which probably be because of the higher degree of disturbance at the elevation of 700~1200m.

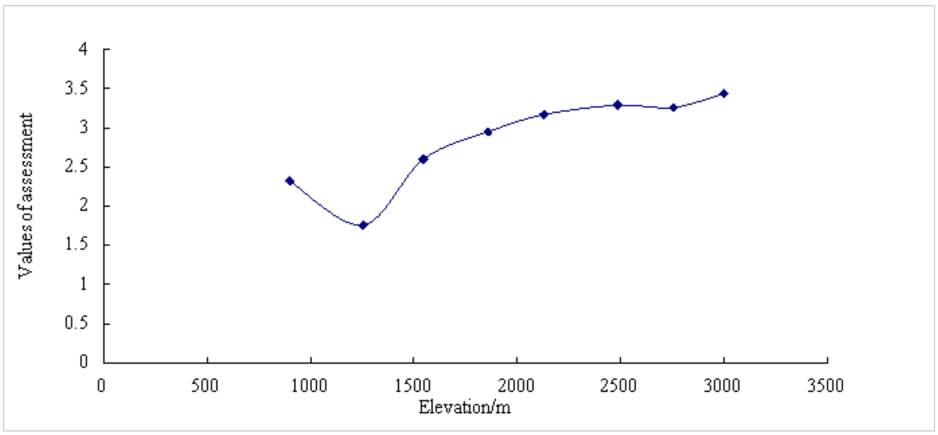

Figure 1. The relationship between elevation and the assessment result

5. Conclusions and Discussion

The weights defined based on data of 20 samples indicated that, elevation is the key factor to influence the forest ecosystem health. The negative general health of nature reserve increased with elevation, but the general health at an altitude of 1500 to 1800 meters is better than that of 1400 to 1500 meters, the perhaps reason is the human disturbance at an altitude of 1400 to 1500 meters is larger than that of 1500 to 1800 meters.

Generally, the forest ecosystem health is of sub-health, which is mainly caused by the low stability of the forest structure in nature reserves. Therefore, it was essential to enhance management of nature reserve to improve the status of forest ecosystem health in Beichuan.

However, there are some difficulties in quantification of some indicators and selection of dynamic factors due to the complex of forest ecosystem and not perfection of relative theories, and there are no unified assessment criteria for some indicators and various criteria adopted by different researchers. Moreover, there is difference among different regions, which may result in the difference in selection of membership function and assessment values of forest ecosystem health, therefore selection of more appropriate membership function shall be further studied.

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References

[1] Allen, E. (2001). Forest health assessment in Canada. *Ecosystem Health*, *7*(1), 28-34.

[2] Chen, G., Dai, L., Ji, L., Deng, H., Hao, Z., & Wang, Q. (2004). Assessing forest ecosystem health IModel, method, and index system. *Chinese Journal of Applied Ecology*, *15*(10), 1743-1749.

[3] Cui, B., & Yang, Z. (2002). Indicator system for wetland ecosystem health assessment. *Acta Ecologica Sinica, 22*(7), 1005-1011.

[4] Cui, B., & Yang, Z. (2003). Temporal-spatial scale characteristic of wetland ecosystem health. *Chinese Journal of Applied Ecology*, *14*(1), 121-125.

[5] Hilty, J., & Merenlender, A. (2000). Faunal indicator taxa selection for monitoring ecosystem health. *Biological Conservation*, *92*(2), 185-197. doi:10.1016/S0006-3207(99)00052-X

[6] Kong, H., Zao, J., Ji, L., Lu, Z., Deng, H., Ma, K., & Zhang, P. (2002). Assessment method of ecosystem health. *Chinese Journal of Applied Ecology*, *13*(4), 486-490.

[7] Li, j., An, S., Cheng, X., Wang, Y., Zhuo, Y., & Qin, F. (2001). Advances in Assessment of Ecosystem Health. *Chinese Joural of Plant Ecology*, *25*(6), 641-647.

[8] Ma, K., Kong, H., Guan, W., & Fu, B. (2001). Ecosystem health assessment: methodology and trend. *Acta Ecologica Sinica, 21*(12), 2106-2116. doi:10.3321/j.issn:1000-0933.2001.12.020

[9] Lackey, R. T. (2001). Values, policy and ecosystem health. *BioScience*, *51*(6), 437-443.

[10] Wang, Y. (2005). *Assessment of forest ecosystem health in Tanjiang watershed Guangdong*. Ph.D paper of Zhongshan Univversity.

[11] Wang, Y., Xiao, W., & Zhang, X. (2007). Current Status and Development Tendency of Forest Health Monitoring and Evaluation. *Scientia Silvae Sinicae*, *43*(7), 78-85. doi:10.3321/j.issn:1001-7488.2007.07.014

[12] Yuan, X., Liu, H., & Lu, J. (2001). Assessment of ecosystem health - concept framework and indicator selection. *Chinese Journal of Applied Ecology*, *12*(4), 627-629.

[13] Yong, W., Gang, W., & Feng, S. (2012). The Dynamic Model Prediction Study of the Forest Disease, Insect Pest and Rat Based on BP Neural Networks. *Journal of Agricultural Science, 4*(3), 291-297.

