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Research Article

Forest Ecosystem Sustainable Development Evaluation and Prediction Based on PSR Model

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Abstract: Sustainable development of forest ecosystem is an important foundation for sustainable social and economic development. Based on PSR model, this study built a comprehensive evaluation index system of sustainable forestry development ecosystem, then quantified the weight of indicators by using entropy method and finally evaluated the level of sustainable forest ecosystem development in China from 2005 to 2013 with the integrated evaluation method. Meanwhile, by calculating the system coordination degree, the paper measured the PSR system coordination and adopted the gray system model GM (1, 1) in predicting the level of sustainable development in the next seven years (2014-2020). The results showed that the level of sustainable forest ecosystem development in China would continue to improve, which would increase from 0.4305 in 2005 to 0.3743 in 2013 with a critical unsustainable status and was also expected to reach the critical sustainable level in 2019.

Keywords: Forecast, forest ecosystem, PSR Model, sustainable development

INTRODUCTION

Forest ecosystem plays a pivotal role in mitigating climate change and reducing natural disasters. Nowadays, there is an increasing severe pressure of population growth, industrialization, urbanization and modernization, which has been bringing both social and economic development pressures as well as resource and environmental pressures and forest ecosystem capacity for sustainable development could be more challenging, which in turn leads to an increasing needs of social development in developing the forest ecosystem. While the ecological civilization is proposed after eighteen CPC National Congress, the sustainable development of forest ecosystem is subjected to further national attention. Therefore, the ability in evaluating and predicting the sustainable development of forest ecosystem has both theoretical and practical significance in the construction of ecological civilization and besides that, it also makes contributions to guarantee sustainable economic and social development.

Forest ecosystem is constructed in accordance with the internal laws and the basic properties of forestry, in order to meet a variety of needs of forestry diverse and sustainable development of society (She, 2008). At present, for the study of sustainable development, people always focus on agriculture and regional studies. Research methods included evaluation index system and energy value analysis, for instance, Daly and Cobb (1989) evaluated objectives' criteria for sustainable development policy mainly in these four aspects: environmental impact, renewable resource use, waste of human and non-renewable resources. Odum (1988) established the value theory and methods and a quantitative analysis for sustainable development as well. As for the study of evaluation of agricultural ecosystem sustainable development, FAO Food and Agriculture Organization of the United Nations, Ministry of Agriculture, Natural Management and Fisheries of the Netherlands (1991) developed the evaluation index system of sustainable agricultural development based on PSR model; Yuan and Qi (2013) selected indicators system which objectively reflected the contents of population, society, economy, resource and environment and evaluated the agricultural sustainable development in Hunan Province with the entropy method; Yang *et al*. (2012) applied Energy analysis method to analyze the complex agro-ecological system sustainable development; And La Rosa *et al*. (2008) also applied this method to evaluate resource utilization, productivity, environmental impact and sustainability of Sicily orange production. As for the evaluation of regional sustainable development, Deng (2012) constructed the evaluation index system of sustainable development based on PSR model and evaluated the level of sustainable development in the western region of China; Peng *et al*. (2012) designed regional ecological sustainability evaluation conceptual framework from the aspects of ecological stress, ecosystem health and ecological sustainability. All these showed that the studies of evaluation of sustainable development usually focus on the area of agriculture and urban development, which is to say,

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there are very few studies aimed at sustainable development of forest ecosystems. On the basis of previous studies and references, this study designed the evaluation index system of sustainable forest ecosystem development capabilities and made a comprehensive evaluation of the ability of forest ecosystem sustainable development with the PSR model and it also made predictions about forest ecosystem sustainable development from 2014 to 2020 in China.

MATERIALS AND METHODS

Data sources: The data this study used is mainly from "China Statistical Yearbook" (2004-2013) and "China Forestry Statistical Yearbook" (2004-2013). Because of the different variables with different units and different degrees of variation, in order to eliminate the influence of the dimension and the effects of variation in the size as well as the value of their size, the paper mainly used poor method for data standardization.

PSR model and build of index system:

Pressure-state-response model: PSR model is created by the Organization for Economic Cooperation and Development (OECD) and the United Nations Agency for Development Cooperation (UNEP) in the late 1980s, which is widely applied in evaluation of resource utilization and sustainable development. In the model, index "P" means pressure, always used to characterize the human economic activities and consumption patterns which lead to unsustainable development; index "S" means state, used to characterize the state of the system process of sustainable development; index "R" means response, used to characterize measures to promote the sustainable development process. It is systematic and could reflect the interaction of a causal relationship between the nature, economy and society, classify the various indicators from the view of the interaction of human economic, social and environmental impact. PSR model is widely used in various fields and could be applied to different spatial scales and scope.

PSR index selection and weight: Drawing on existing research results, this study base on the guiding principles in science, integrity, goals, feasibility and data are available, combine with the specific circumstances of forest ecosystem respond to ecological pressure to determine the pressure-state-response various indicators of the model. Wherein the pressure factors are selected from the aspects of population, resources and the socio-economic and environmental dimensions, the state factors are selected from the quantity and quality of forest resource, the response factors are selected from the response of increment of forest resources, forestry investment and forestry ecological policy.

After determine the index system, we should determine the weight of the different indicators. This study entropy index weights for each assignment. Entropy is an objective weighting method, its essence is determine index weight based on the amount of duplicate information between the indices, that is, the greater degree of relative change in the index has the greater weight, on the contrary, the smaller degree of relative changes in the index has smaller weight. The method could effectively avoid the impact of subjective human empowerment, which has been widely used in practice. The calculation steps are as follows:

First of all, use poor conversion formula to normalize the system metrics to eliminate differences in the indexes dimension. Indicators related to this study include positive indicators (the bigger, the better) and negative indicators (the smaller, the better), the standardized formula is as follows:

Positive Indicators: $$X_{ij}^{'} = \frac{X_{ij} - \min_i X_{ij}}{\max_i X_{ij} - \min_i X_{ij}}$$

Negative Indicators: $$X_{ij}^{'} = \frac{\max_i X_{ij} - X_{ij}}{\max_i X_{ij} - \min_i X_{ij}}$$

In (1) and (2), $X_{ij}^{'}$ is the normalized value of index item j in the year of i, $X_{ij}^{'}$ is the actual value of index item j in the year of i, while the $\max_i X_{ij}$ and $\min_i X_{ij}$ respectively represent the maximum and minimum of item j index. Among them, $0 < i \le n$, $0 < j \le m$.

The second step is to calculate the proportion of P_{ij}:

$$P_{ij} = \frac{X_{ij}^{'}}{\sum_{i=1}^{n} X_{ij}^{'}}$$

The third step is to calculate the entropy of index j:

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln P_{ij}$$

Among them, k = 1/lnn, $e_j \in [0,1]$. e_j is the information entropy of index j, means a measure of disorder or disordered system, for a given index, the smaller of difference of X_{ij}, the bigger of e_j.

The fourth step is to define the weight of item j index (w_j):

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_i}$$

g_j is the coefficient of variation of item j index, g_j = 1-ej. According to the above steps, we can determine the weight of each index entropy weight and the selected indicators shown in Table 1.

Table 1: Indicator system and weight

Pressure (P) (0.3710)	Pressure of population	Total population (10 thousand)	0.0224
		Rural population (10 thousand)	0.0238
		Rural poor population (10 thousand)	0.0131
		Natural population growth rate (%)	0.0200
	Pressure of society and economy	Road construction mileage (10 thousand kilometers)	0.0360
		GDP (100 millions yuan)	0.0205
		Per Capita GDP (yuan)	0.0208
		Incremental value of primary industry	0.0200
		Incremental value of secondary industry	0.0232
		Urban construction land area (km^2)	0.0222
		Quantity of timber harvest (10000 m^3)	0.0389
		Rate of import and export value of forest products	0.0189
	Pressure of resource and environment	Total wastewater discharge (10000t)	0.0248
		SO2 Discharge (10000t)	0.0213
		Area of fire victims (ha)	0.0097
		Area of forest pests and diseases (10000 ha)	0.0356
State (S) (0.1080)	State of quantity of forest resources	forest area (10000 ha)	0.0192
		Forest land area	0.0169
		Protected area per capita	0.0157
		Number of nature reserve	0.0139
	State of quality of forest resources	Forest reserves	0.0233
		Forest coverage rate (%)	0.0190
Response (R) (0.5210)	Response of increment of forest resources	Increment of forest reserve	0.0246
		Incremental area of natural reserves	0.0615
		Incremental number of natural reserves	0.0782
		Total area of afforestation (1000 ha)	0.0152
	Response of forestry investment	National forestry investment (10000 yuan)	0.0492
		National forestry investment (10000 yuan)	0.0425
		Investment of forestry ecological construction and protection (million)	0.0369
	Response of forestry ecological policy	Number of major ecological forestry policy	0.0358
		Key forestry plantation area (ha)	0.0190
		Natural forest protection project afforestation area (ha)	0.0229
		Afforestation forest area (ha)	0.0557
		Shelterbelt construction afforestation area of the north and the Yangtze river basin (ha)	0.0484
		Sandstorm source control around beijing and tianjin project afforestation area (ha)	0.0311

Table 2: Standard of forest ecosystem sustainability grading

Comprehensive Index	0.8-1.0	0.6-0.8	0.4-0.6	0.2-0.4	0-0.2
Grade	Sustainable	Critical sustainable	Critical unsustainable	Unsustainable	Neither sustainable

Comprehensive evaluation model: Use comprehensive index model to evaluate forest ecosystem health for the expression:

$$F = \sum_{i=1}^{3} w_i \left(\sum_{j=1}^{n} X_{ij}' w_{ij}\right)$$

where, F means forest ecosystem sustainability index; w_i means subsystem i's weight; $w_{i\ j}$ means item j of subsystem i's weight; n means the number of subsystemi. Base on the level classification of sustainable urban development (Feng and Yang, 2013), the sustainable forest ecosystem could be classified for 5 grades: sustainable, critical sustainable, critical unsustainable, unsustainable and neither sustainable, as shown in Table 2.

Evaluation of system coordination: The sustainability of forest ecosystem keeps changing correspondingly with the change of coordination degree of pressure, state and response subsystem, therefore, coordination degree evaluation rise in response to the needs of assessing the intrinsic link among the subsystems and further the entire system. Then the coordination function is introduced, namely on the basis of the distance between the systems and the degree of dispersion of systems, to measure the status of the three subsystems coordination. The formula is:

$$C = \frac{\alpha + \beta + \gamma}{\sqrt{\alpha^2 + \beta^2 + \gamma^2}}$$

where in, C is the coordinate index, α, β, γ respectively means the pressure, the state and the response subsystem corresponding score. If the value of the subsystem is closer, the C value would be closer to 1.732. At this point it shows that the degree of coordination is higher, on the contrary, it is lower.

Grey prediction model: The study calculates PSR composite index and each system's indices from 2005 to 2013, then, by distinguishing the degree of factors developing trend dissimilarity between systems, the gray model generate raw data processing to look for system changes in the law and then produces a strong regular data sequence, so that we can build a corresponding differential equation model in predicting the future trend of things.

Suppose the collected valuation index system data in n years is:

$$x^{(0)}=(x^{(0)}(1), x^{(0)}(2),\cdots, x^{(0)}(n))$$

- In order to weaken the volatility and randomness of random sequences, the paper accumulates its data and get the sequence of total output:

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2),\cdots, x^{(1)}(n))$$

where in, $x^{(1)}(t) =\sum_{n=1}^{t} x^{0}(n)$, t = 1 , 2, ⋯, n.

- Establish forest products demand differential equations:

$$\frac{dx^{(1)}}{dt}+ax^{(1)} = u$$

where in, a, u, respectively means development coefficient and gray action. As long as calculate parameters a and u, $x^{(1)}(t)$ can be calculated and further can obtain $x^{(0)}$ of the future predicted value.

- Construct matrix B and the constant term vector y_n by accumulating generated data, namely:

$$B=\begin{pmatrix} -0.5\left[x^{(1)}(1)+x^{(1)}(2)\right] & 1 \\ -0.5\left[x^{(1)}(2)+x^{(1)}(3)\right] & 1 \\ -0.5\left[x^{(1)}(n-1)+x^{(1)}(n)\right] & 1 \end{pmatrix},$$

$$y_n = [x^{(0)}(1), x^{(0)}(2),\cdots, x^{(0)}(n)]^T$$

- Use least squares method to calculate gray parameters:

$$\tilde{a} = \begin{bmatrix} a \\ u \end{bmatrix}=(B^TB)^{-1}B^Ty_n$$

- Solution of the differential equation for:

$$\tilde{x}^{(1)}(t+1) = [x^{(0)}(1)-\frac{u}{a}]\, e^{-at}+\frac{u}{a}$$

- Cumulative reduction to calculate:

$$\tilde{x}^{(0)}(t+1) = \tilde{x}^{(1)}(t+1) - \tilde{x}^{(1)}(t)$$

Then we could predict the main evaluation index by GM (1, 1).

RESULTS

Comprehensive evaluation of sustainable development's level and system:

Coordination degree: Use sustainable development "Pressure-State-Response" model as well as comprehensive evaluation based on the entropy method, the paper is able to conduct a comprehensive evaluation of the extent and level of sustainable ecosystem development in China. The outcome of its comprehensive evaluation is shown in Table 3. The annual change of trends of each system's index is shown in Fig. 1.

Table 3 shows that forestry ecological sustainability is not high, it is unsustainable from 2005 to 2008 and is critical unsustainable from 2009 to 2013. Meanwhile, trends of index change in Fig. 1 shows that the total value of comprehensive evaluation has an increase trend and also has a tendency to continue to enhance in the next few years.

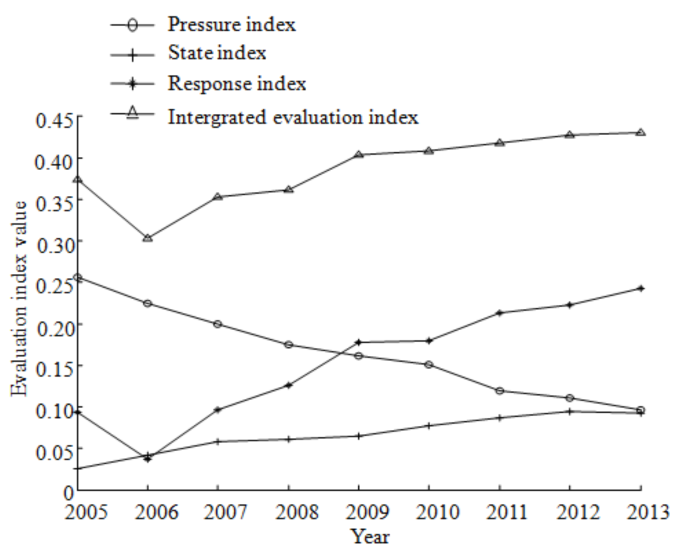

Fig. 1: Change trend of index of forestry ecological system

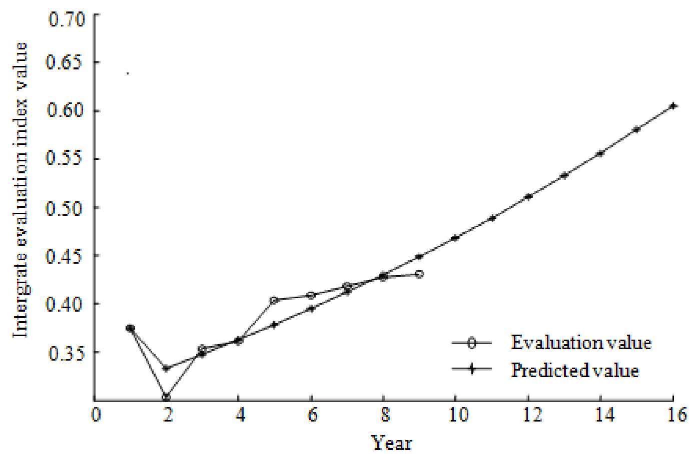

Fig. 2: Level evaluation and prediction of forest ecosystem sustainable development

Table 3: Calculated value of forest ecosystem sustainability assessment index in China

Year	Pressure	State	Response	Total	Coordination	Sustainability
2005	0.256	0.025	0.093	0.374	1.368	Unsustainable
2006	0.225	0.042	0.037	0.303	1.310	Unsustainable
2007	0.199	0.058	0.096	0.353	1.544	Unsustainable
2008	0.174	0.061	0.126	0.361	1.616	Unsustainable
2009	0.162	0.064	0.178	0.404	1.623	Critical unsustainable
2010	0.151	0.077	0.180	0.408	1.651	Critical unsustainable
2011	0.119	0.086	0.213	0.418	1.616	Critical unsustainable
2012	0.110	0.094	0.223	0.428	1.607	Critical unsustainable
2013	0.096	0.092	0.242	0.431	1.557	Critical unsustainable

Population growth, economic development and the deterioration of environment make enormous pressure to forestry resource ecosystem. Table 3 shows that pressure value is smaller, means pressure system heavily threats to the sustainability of forest ecosystem, that is, there is a growing demand of forestry ecological sustainability. When quantifying stress index we can find that indices of road construction mileage, timber harvest and forest pest area are relatively large share of the weight, while indices of the area of the fire victims and the poor population in rural area are relatively small share of the weight, therefore, infrastructure as well as traditional demand for wood produces have a greater impact on the system pressure. While the fire does a great harm to the ecological environment, but with the development of science and technology as well as the country's increasing stringent fire control, fire occurrence area has become smaller and smaller and has less pressure on the environment.

The quantity and quality of forest resource have an important influence to sustainability of forest ecosystem. As we can see from Fig. 1, the state of forestry ecological system has a growing trend, but has stabilized in recent years. As for representing state index, the forest reserves have the largest weight, shows that forest reserves visibly affect the index of forest state.

For the growing ecological pressure, forestry conducted a number of response and mainly in three aspects: the incremental response of forest resources, forestry investment response and forestry ecological policy response. Wherein, forestry policy response has the largest share of the weight, indicating that policy response is the most important indicator in response system. Incremental indicators of nature reserve area share a great weight, means that as one of the important forestry ecological response indicators, nature reserve has an important influence to forestry ecological sustainability.

Forecast of sustainable development level: Through the gray prediction based on the gray system theory, we worked out the comprehensive evaluation index predictive values from 2014 to 2020, which are shown in Fig. 2. Figure 2 shows that the overall gray forecasting outcomes fit the model very well and the sustainability of forest ecosystem could continue to be improved in the future and is expected to reach a critical sustainable level in 2019.

DISCUSSION AND CONCLUSION

The level of sustainable development of forest ecosystem in China has been undergoing a large fluctuation during 2005 to 2013 and from 2005 to 2008, there is a lower level of sustainable development, forest ecosystem has been in an unsustainable level. Facing in the increasing severe pressure, forestry system response is very small, resulting in unsustainable forest ecosystem. Beginning in 2009, the government recognized the importance of forest in response to the ecological pressures and thus increased the forestry investment and had introduced a series of policies just like quota system for logging, forest ecological compensation system and so on. Therefore, from 2009 to 2013, forest ecosystem stay in unsustainable level.

From the analysis of the various subsystems, we can find that the system pressure value is smaller, indicating that pressure that the forest ecosystem undertaken is bigger and the demand for social and economic development of eco-forestry is growing. State value of the system is improving and becoming flatter, which makes the state system constantly close to saturation, but there is still room for improvement. The rise of response value in 2013 is larger, which is nearly three times than that of 2005, improved from 0.0931 to 0.2424, but in face of increasing pressure, the value of response is not enough and the weight of response system of sustainable forest ecosystem development comprehensive evaluation is only 0.521, therefore, we need to focus on the response system. The comprehensive evaluation value increased steadily from 2006 to 2013, through gray prediction, we can figure out that the level of sustainable development of forest ecosystem will continue to increase in the future.

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