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Research Article

Study of Value Assessment Model of Forest Biodiversity Based on the Habitat Area in China

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Abstract: Forest biodiversity is an important part of biodiversity. There is an essential significance of studying forest biodiversity assessment for promoting the conservation of biodiversity and enhancing biodiversity management in China. This study collected forest biodiversity habitat area, output value of forestry and so on forest biodiversity assessment-related data from 2001 to 2010 in China and using optimal control methods in cybernetics to establish value assessment model of forest biodiversity based on the data of habitat area, as well as calculated the optimal price for forest biodiversity assessment. The result showed that forest biodiversity habitat assessment of the optimal price is 9,970 RMB Yuan/ha and there is a dynamic model for forest biodiversity assessment. Finally, the study suggested that studies of forest biodiversity assessment in China, in particular, studying of valuation of forest biodiversity should consider using shadow price and the social, economic and other factors should be taken into account.

Keywords: Biodiversity, forest, habitat assessment model, management

INTRODUCTION

The study of forest biodiversity assessment can be dated back to the study of environmental quality assessment and Finland forest resources accounting by the Organization for Economic Cooperation and Development (OECD) (Jeffrey and John, 1997).

The OECD has been studying the environmental quality assessment for decades. In 1993, the OECD developed a set of index system named Pressure-State-Response (PSR) indicator framework which mainly detects changes of a variety of environmental impacts. In this system, human activities cause some pressures on the environment and resources, which lead to changes in the quality of the environment and natural resources. The actual situation of the environmental influence changes is reflected in the status indicators. The community's response to the state of the environment is to develop some appropriate environmental policies in socio-economic activities. Therefore, response indicators can be used to reflect the community's response to environmental changes, which includes environmental protection expenditure, environmental monitoring, pollution control costs and citizens' viewpoints about the environment, etc. The framework focuses on four natural resources: water, forest, fishery resources and soil degradation. The recommended indicators for pressure of forest resources, especially for forest biodiversity include population growth and environmental protection expenditures, etc., in particular, the timber harvest volume and forest timber production capacity recommended to assess the pressure of forest biodiversity and forest area, species composition, forest age class distribution recommended to assess the status change and forest management methods as well as forest protection statistics of relevant indicators recommended to reflect the response to the status change of economic activities of human society. This index system can also be used for an assessment of forest ecosystem services change (World Resources Institute, 1999).

Finland's first study of the forest resources accounting was on the basis of above assessment indicators recommended by the OECD (Hoffren, 1997). The object of Finland's forest resources accounting is to carry out a different description of forest species diversity and forest ecosystems and to promote effective use of forest exploitation and utilization. Since forest resources accounting is a physical quantity which is limited as its quality cannot use statistical description and comparison of facts, it is impossible to form a health-related use of forest resources overall evaluation. The use of above impact assessment indicators can form an overall assessment of significant changes in forest resources and biodiversity. The early introduction of Finland forest resources accounting framework consists of four separate indicators and the general

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indicators. In these indicators, pressure indicators describe human-induced situation of forest ecosystem changes. Diversity index, species and ecosystem indicators describe how the state of forest ecosystems changes. From the perspective of social health development, using these general indicators can be able to analyze the development of forest changes, forest quantity, price and quality related statistics can also be incorporated into the accounting system.

Finland used the design of forest resources accounting quality assessment indicators calculated the changes of 1980-1996 forest quality general indexes. From the calculated results, with the 1980-1996 economic development in Finland, the pressure on forest biodiversity had changed, thus caused changes in the quality of the Finnish forest resources. These information has played an important role in Finland's forest resources management and biodiversity conservation, especially for the development of biodiversity protection policy making (Hoffren, 1997).

Besides that, Pukkala and Kangas (1993) conducted an assessment study of forest biodiversity, mainly from the perspective of species, in which forest biodiversity was decomposed into a single measure of stand and the stand's appearance rate of sporadic, considered threatened and endangered species as a key assessment factor (Hanley *et al*., 1995). Puumalainen *et al*. (2003) considered forest composition, structure and function as the key factors of forest biodiversity and determinants of the quality of biodiversity assessment and used these three elements and national level statistics, etc. to assess forest biodiversity in Europe (Ji *et al*., 2000). In Ericsson, study on Sweden's woodland key habitat's forest biodiversity, they emphasized on the species and structural elements (Xu, 2000). The author thinks that forest biodiversity assessment has uncertainty which is a typical "black box" system in Cybernetics. Therefore, using the "black box" theory, this study proposes a forest biodiversity assessment method on the basis of PSR and the results of evaluation of 1973-1998 China's forest biodiversity changes try to find some useful conclusions (Zhang, 2002).

THE DEFINITION AND METHODS

The definition of forest biodiversity: The Convention on Biological Diversity (CBD) (1992) defined biodiversity as “ the variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. In other words, biodiversity includes diversity within species population (genetic variation); the number of species and the diversity of ecosystems (TEEB, 2010).

Species diversity is the richness of animal, plant and microbial species, they are the basis of human survival and development. Species diversity is the simple measure of biodiversity, only counts the number of different species in a given region. Species diversity is an objective indicator of the richness measure for biological resources in a certain area. In the actual biodiversity measurement, people often simply use species diversity to reflect the size of the biodiversity (State Environmental Protection Administration, 1998).

Besides latitude, altitude, the size of the habitat of the species also has a direct relationship with the richness of species diversity, especially the distribution area and the type of the species under a certain latitude, altitude area are strongly related to it. Therefore, often using the size of the biodiversity habitat area established for the protection of biodiversity under a certain latitude, altitude simply to reflect of the richness of species diversity. Biodiversity habitat (Nature Reserve) includes not only "hotspots" areas established for the protection of certain species, also critical areas established in order to protect certain community diversity or ecological diversity, the size of the area can be simply to reflect the richness of biodiversity (Jean-Christophe *et al*., 2010).

Forest biodiversity also includes above three levels, it has a great significance and value for maintaining the stability and diversity of the ecosystem. Measure on forest biodiversity mainly measures the changes of species diversity and ecosystem diversity and commonly uses diversity index method, sometimes simple use of the biodiversity habitat or conservation area (biological communities or biomes) to reflect the size of the forest ecosystems diversity (Myers, 1988).

Methods and assessment model: As mentioned above, species diversity assessment is considered to be the center of the evaluation of biodiversity, however, accurate statistics of the number of species in a certain area is very difficult, therefore the size of the habitat area of the protected species is often used to simply assess the change of biodiversity. In order to straightforward evaluation of the size of forest biodiversity, we simply use the size of forest biodiversity habitat area to assess changes of forest biodiversity habitat area to assess changes of forest biodiversity and study of forest biodiversity assessment model (State Environmental Protection Administration, 1998).

According to the characteristics of forest biodiversity assessment and the economic system of discrete-time equations (Zeng, 1995), the method of minimum principle in cybernetics we used, forest biodiversity assessment formula can be simply abstracted as the following model:

$$B(k+1) = B(k) + I(k) - D(k)$$

$$B(k_0) = B_0 \quad (1)$$

Table 1: Forest biodiversity assessment data

Year	GDP (10^8 RMB)	Output value of forestry (10^4 RMB)	Forestry fundamental construction investment (10^4 ha)	Habitat areas (10^4 ha)	Number of habitat areas	Habitat area income (output) (10^4 RMB)	Increased area of habitat (10^4 ha)	Decreased area of habitat (10^4 ha)	National accounting proportion of habitat areas (%)
1990	18667.8	330.3	184990						
1991	21781.5	367.9	211998						
1992	26923.5	422.6	258160						
1993	35333.9	494.0	304549						
1994	48197.9	611.1	363461						
1995	60793.7	709.9	415463						
1996	71176.6	778.0	482531						
1997	78973.0	817.8	600392	7697.9	926				7.64
1998	84402.3	851.3	770243						
1999	89677.1	886.3	995294	8815.2	1146				8.80
2000	99214.6	936.5	1569255	9820.8	1227		1005.6	0	9.85
2001	109655.2	938.8	1977253	12989.0	1551	8043.53	3168.2	0	12.90
2002	120332.7	1033.5	3062404	13294.5	1757	14528.09	305.5	0	13.20
2003	135822.8	1239.9	3951904	14398.1	1999	18704.11	1103.6	0	14.40
2004	159878.3	1327.1	4040486	14822.8	2194	21038.64	424.7	0	14.80
2005	184937.4	1425.5	4467520	14994.9	2349	29060.65	172.1	0	15.00
2006	216314.4	1610.8	4789929	15153.5	2395	34911.56	158.6	0	15.80
2007	265810.3	1861.6	6297242	15188.2	2531	41840.40	34.7	0	15.19
2008	314045.4	2152.9	9522903	14894.3	2538	38600.67	0	293.9	15.10
2009	340902.8	2193.0	12881763	14894.3	2538	44800.27	0	0	15.10
2010	401202.0	2595.5	14491880	14944.1	2588		49.8	0	14.90

Xiao (2005), State Forestry Administration (2011)

$$B(k) \geq 0,\ D(k) \geq 0,\ 0 \leq I(K) \leq I(k)_{\max}$$

where,

- $B(k)$ = Forest biodiversity habitat area in time k, ha
- $I(k)$ = Increased area of forest biodiversity habitat in time k, ha
- $D(k)$ = Reduced area of forest biodiversity habitat in time k, ha
- k = Year

In the above model, $I(k)$ is the control variable, other variables are state variables. Assessment of forest biodiversity is under the constraints of Eq. (1) to calculate the minimum loss of value of forest biodiversity habitat. That is:

$$\min_{(D(k))_1^{k-1}} J_k = \varnothing\left[B(N), N + \sum_{k=1}^{k-1} F\left[B(k), I(k), k\right]\right] \tag{2}$$

In the Eq. (2), $\varnothing[B(N), N]$ is the terminal constraints of the value of forest biodiversity habitat.

Data collection: The main data of forest biodiversity are from National Forest Resource Statistics (Department of Forest Resources Management, 2000), China Forest Resource Inventory (Xiao, 2005), China Forestry Statistical Yearbook (State Forestry Administration, 2007), China Statistical Abstract (State Statistic Bureau of China, 2008) and some related research reports (Zhang *et al*., 2008). Specifically, the forest biodiversity habitat area, forestry output data are from the National Forest Resource Statistics. Forest biodiversity habitat areas' annual increase, decreasing area, GDP, investment and income in forest biodiversity habitat areas are from the China Statistical Yearbook and China Forestry Statistical Yearbook. In addition, due to lack of statistics of forest biodiversity habitat area over the years, we use the statistics of the forest biodiversity reserve area in China instead of forest biodiversity habitat area and part of data are from some related study reports.

As a result, basic data of forest biodiversity assessment collected are showed in Table 1.

RESULTS

Equation of state: According to the data of Table 1 for forest biodiversity assessment, stepwise regression method can be used to estimate the model. Since the data of annual decreased area of forest biodiversity habitat area $D(k)$ is insufficient, there are only annual increased habitat area $I(k)$ and habitat area $B(k)$ in the regression equation, the regression results of state equation are shown in Table 2 to 4.

From Table 2 we can see that the goodness-of-fit R^2 of the regression model is 1.000, adjusted R^2 is 1.000, which has a high goodness-of-fit. In Table 3, F value of the model is 134,174.40, Sig. Value is 0.00, indicating that the model pass the statistical test and has a statistical significant, namely, the independent variables $B(k)$, $I(k)$ in regression model can significantly explain the dependent variable $B(k+1)$.

Thus, according to the regression coefficients in Table 4, the assessment model of forest biodiversity is:

$$B(k+1) = 0.997B(k) + 1.015I(k) \tag{3}$$

In the above assessment model, $D(k)$ is not included.

Table 2: Model summary

Model	R	R^2	Adjusted R^2	Estimated S.E.	Durbin-Watson
Estimation	1.000	1.000	1.000	90.9758	2.360

S.E.: Standard error

Table 3: Model ANOVA

Model	Variance S.S.	Degrees of freedom	The M.S.	F	Sig.
Regression	2221015635.229	2	1110507817.615	134174.396	0.000
Residuals	74489.401	9	8276.600		
Total	2221090124.630	11			

M.S.: Mean square; S.S.: Sum of square

Table 4: Model coefficients of analysis

	Un-standard coefficients		Standardized coefficients		
Model	B	S.E.	Beta	t	Sig.
B (k)	0.997	0.002	0.964	448.819	0.0000
I (k)	1.015	0.029	0.076	35.588	0.0000

The performance indicators: As we know, there is a definite relationship between growth of forest biodiversity habitat area and economic development, in particular, there is a quadratic curve relationship between the annual increased area of forest biodiversity habitat and habitat income (State Forestry Administration, 2011). According to the data in Table 1, the specific equation between them calculated by SPSS software is as follows:

$$I(k) = -10.301B(k) - 0.001B^2(k) \tag{4}$$

-2.912 (0.023) 3.469 (0.010)

where R = 0.976, R^2 = 0.952, F value of the equation is 69.256, Sig is 0.000.

According to the statistics of State Forestry Administration (2010), in 2010, China's forestry output value was 2277.902 billion RMB Yuan, of which forest cultivation and planting industry were 856.498 billion Yuan, forestry tourism and recreation services were 131.037 billion Yuan (Liu and Lin, 2008). According to the data in Table 1, from 2001 to 2010, the average annual income growth rate of China's forest biodiversity habitat is 23.95%, forest biodiversity habitat area will be 240,722,900 ha in 2020, accounting for 25% of the forest land area in China, the annual income of forest biodiversity habitat will reach about 475.506 billion Yuan (State Forestry Administration, 2007) in 2020. Therefore, in accordance with the biggest target in 2020, if 1990 is the beginning year, in 2020, yearly revenue of the forest biodiversity habitat in China will be about 475.506 billion Yuan. At this point, according to the equation of state, terminal constraints is $0.997B(k) + 1.015I(k) = 24072.29$. Therefore, the performance indicator becomes:

$$\min_{(I(k))_1^{k-1}} J_{19} = 0.997B(k) + 1.015I(k) - 24072.29 + \sum_{k=1}^{19}(-10.301B(k) - 0.001B^2(k)) \tag{5}$$

The specific meaning of above equation is: in the constraints of Eq. (3) and (4), in time (1, k-1), calculate k control variables like $I(1)$, $I(2)$, ..., $I(k-1)$ causes the change of beginning state $B(1)$ transformed to terminate state $B(k)$ and make the performance indicators of (5) be minimum, that is, in time (1, k-1), have the minimal value loss of forest biodiversity habitat.

Calculation of optimal price of forest biodiversity habitat assessment: According to statistics of Table 1, in 2020, China's forest biodiversity habitat area will be 240,722,900 ha, the maximum increased area of forest biodiversity habitat will be about 240,722,900 ha. Therefore, the equation of state of forest biodiversity habitat area is:

$$B(k+1) = 0.997B(k) + 1.015I(k)$$
$$B(k_{1997}) = 7697.90 \tag{6}$$
$$B(k) \geq 0,\ 0 \leq I(K) \leq I(k)_{max} = 24072.29$$

The Hamiltonian function $H(k)$ is:

$$\begin{aligned} H(k) &= H(B(k), I(k), \lambda(k+1), k) \\ &= 0.997B(k) + 1.015I(k) - 24072.29 - 10.301B(k) - 0.001B^2(k) + \lambda^T(k+1).\ [0.997B(k) + 1.015I(k)] \\ &= -24072.29 - 9.304B(k) + 1.015I(k) - 0.001B^2(k) + 0.997\lambda^T(k+1)B(k) + 1.015\lambda^T(k+1)I(k) \end{aligned} \tag{7}$$

With the adjoint equation $\lambda(k) = \frac{\partial H^*(k)}{\partial B^*(k)}$ can get:

$$\lambda(k) = \frac{\partial H^*(k)}{\partial B^*(k)} = 0.997\lambda(k+1) - 0.002B(k) - 9.304 \tag{8}$$

By the coupled equation $\frac{\partial H^*(k)}{\partial B^*(k)} = 0$ can get:

$$0.997\lambda(k+1) - 0.002B(k) - 9.304 = 0 \tag{9}$$

Equation (9) be substituted into Eq. (5), we can get:

$$\lambda_1^*(k) = 0 \tag{10}$$

By the control equation $\frac{\partial H^*(k)}{\partial B^*(k)} = 0$, we can get:

$$1.015I(k) + 1.015\,\lambda^T(k+1) = 0 \tag{11}$$

similarly, by the transversality condition $\frac{\partial \emptyset^*(k)}{\partial \emptyset^*(k)} = \lambda^*(k)$ we can get:

$$\lambda_2^*(k) = 0.997 \tag{12}$$

Equation (12) is taken into Eq. (11), we can get:

$$I^*(k) = -0.997 \tag{13}$$

Since $I(k) \geq 0$, so,

$$I^*(k) = 0 \tag{14}$$

Here, the calculated $\lambda^*(k)$ = 9,970 Yuan/ha which is the accounting of shadow price of forest biodiversity habitat per hectare.

Therefore, the specific meaning of the above calculation result is that the optimal price of China's forest biodiversity habitat is 9,970 Yuan/ha, also it is the expected compensation price of forest biodiversity protection in China.

CONCLUSION

Through study of the change of China's forest biodiversity habitat from 1990 to 2010, we can get:

- China's forest biodiversity assessment model based on habitat area is:

  $$B(k+1) = 0.997B(k) + 1.015I(k)$$

  $$B(k_{1997}) = 7697.90$$

  $$B(k) \geq 0,\ 0 \leq I(K) \leq I(k)_{max} = 24072.29$$

  $$\min_{(I(k))_1^{k-1}} J_{19} = 0.997B(k) + 1.015I(k) - 24072.29 + \sum_{k=1}^{19}(-10.301B(k) - 0.001B^2(k))$$

  Here, the goodness-of-fit of state equation for forest biodiversity habitat area is R^2 = 1.000, adjusted R^2 = 1.000, value F of the model is 134174.40, Sig. is 0.00, shows that the established model has a statistical significance. The performance indicator, that is objective function also indicates in 2020 annually incomes of China's forest biodiversity habitat will be about 475,506 billion RMB Yuan and the terminal constraints are $0.997B(k) + 1.015I(k) = 24072.29$, which indicator that there is a value assessment model of forest biodiversity based on the habitat area in China.
- Forest biodiversity assessment is inseparable from the biodiversity price measurement. According to our study, the shadow price (optimal price) of forest biodiversity habitat at national level can be calculated. This means that under a certain conditions we might be able to calculate the price of forest biodiversity and the price is close to the one of free market transactions. Therefore, in China, since market economy is encouraged nowadays, forest biodiversity value assessment should use shadow biodiversity price, not part of the cost price, which is neither in accordance with the economic norms nor the evaluation requirement of shadow price.
- Forest biodiversity assessment should consider incorporating the social and economical factors. Biology, ecology assessment pays more attention to the impact of biological and ecological factors, such as measurement of forest biodiversity scales, types, etc. In biological speaking, those factors are mainly affected by climate change etc., nature factors. Besides this, the change of forest biodiversity is also influenced by investment and habitat management level etc., of social and economic factors. Therefore, biodiversity assessment should take these factors into consideration. These elements are the key factors in policy making.
- According to different purposes, forest biodiversity assessment at different levels should be distinguished. Forest biodiversity assessment at national or provincial level is principally used for the biodiversity management or decision making, it requires understanding of the long-term trends and the influencing factors of biodiversity. Specific biodiversity assessment or biodiversity assessment in a small area is mainly used for research or comparative analysis. Since biodiversity will not change much in a relatively long period of time, forest biodiversity resources management will not have a big impact, but will have greater impact on biodiversity in a small area. Therefore, with different purposes, assessment formula and content are unique as well, so assessment and comparison without an object are not proper. Otherwise, forest biodiversity assessment is not scientific.

In short, this study adopts the difference equation and the optimal control method to study forest biodiversity changes based on habitat area and utilizes shadow price of resources, environmental economics to account for its price. We hope this study could promote the development of China's forest biodiversity management and have some reference for it.

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