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An Evaluation Management Model based on Forest Value

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Abstract

Forests play an irreplaceable role in mitigating climate change and promoting socio-economic development, and how to balance their various ecological values is a hot topic of current research. Considering the service values of forests at ecological and economic levels, 7 primary indicators and 11 secondary indicators were selected to establish a model for assessing the service values of forest ecosystems. Then, introducing the commercial value of timber, the R. Hartmann model was established to determine the functional relationship between the two, and the preconditions for deforestation were derived and three forest value management models were developed. Provide a sound basis for forest managers to make better forest management plans.

Keywords

Ecosystem Service Value; R. Hartmann Model; Forest Value; Forest Management.

1. Introduction

With the continuous growth of population and rapid socio-economic development, driven by economic interests, indiscriminate logging is repeatedly prohibited, resulting in serious damage to forest resources. The adverse effects of indiscriminate logging have led to a universal consensus among most people who do not log for a living that logging should be banned. The one-sided pursuit of the ecological benefits of forests and the restriction or ban on logging are tantamount to abandoning forest management. Trees and commercial timber stop growing and reach their highest commercial value after reaching a certain age.[1-3] How to regulate the balance between ecological, economic and social values of forest resources, and to develop reasonable forest management plans to maximize the benefits of forest resources is an urgent issue to be solved.

2. Ecosystem Service Value Model

2.1 Indicator Selection

The division of ecosystem services into provisioning service, regulating service, supporting service, and cultural service is done through the literature [4]. Based on the ecosystem classification criteria proposed by the literature[5] and a comprehensive analysis comparing other literatures[6-8] on the selection of forest ecosystem service evaluation indicators, this study proposes the theory of hunger, this study screened out quantifiable indicators based on the characteristics of forest ecosystems, and finally proposed an evaluation index system for forest ecosystem services, 7 first-level indicators (including air purification, water conservation, soil and water conservation, carbon fixation and oxygen release, organics production, maintenance biodiversity, and forest recreation) and 11 second-level indicators for values. The classification and integration of these indicators are shown in Figure 1 and Figure 2.

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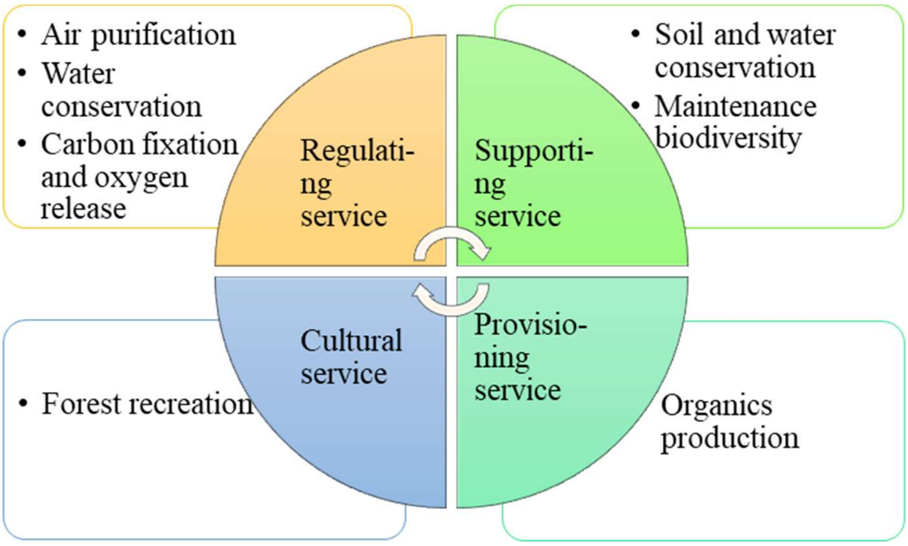

Figure 1. Classification of Ecological Service Types

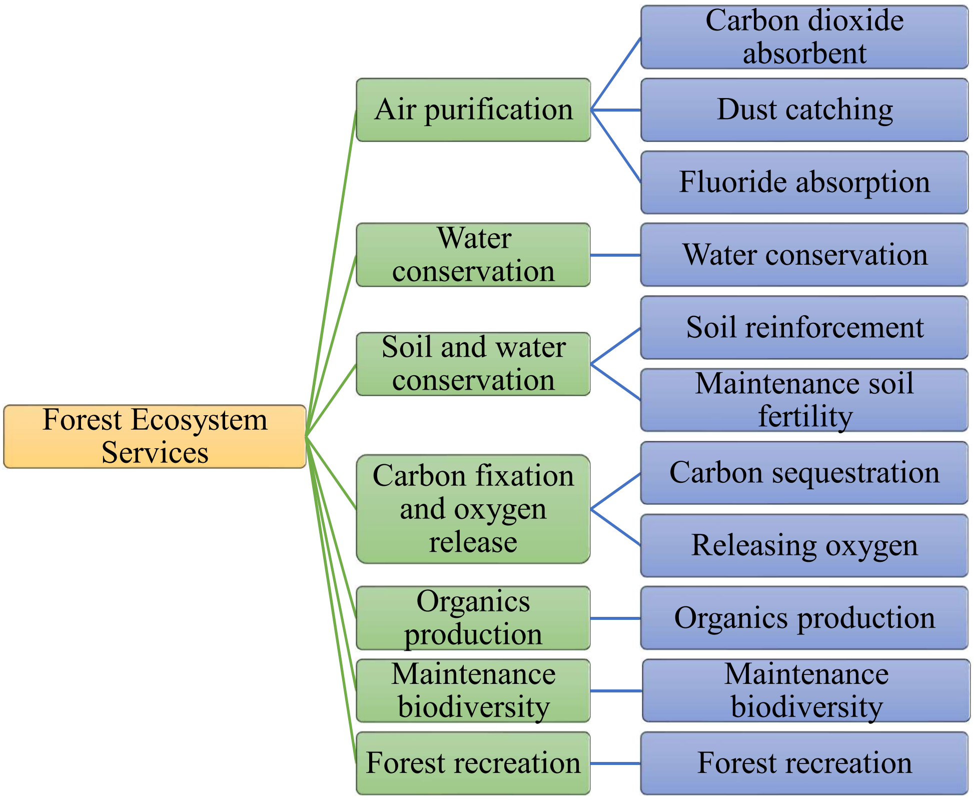

Figure 2. The Evaluation Index System of Forest Ecosystem Services

2.2 Value Assessment

Based on the various indicators of forest ecosystems, organics production was chosen to assess the service value of forest ecosystems at the economic level. And air purification, water conservation, soil and water conservation, and carbon fixation and oxygen release were chosen to measure the service value at the ecological level. And two indicators, maintenance biodiversity and forest recreation were chosen to assess the deeper value of the ecological perspective. The evaluation method of forest ecosystem service value in the study area and the calculation formulas of each index are shown in below.[9]

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Table 1. Calculation formulas for different evaluation indicators

Index	Calculation formulas	Parameter Description		
		symbol	definition	unit
Air purification	$G_g = \sum G_j = \sum A_i \times q_j$ $F_g = \sum (G_j \times P_j)$	G_j	Total physical quantity of SO_2, dust catching and fluoride absorbed by the ecosystem	kg
		A_i	Area of different forest stands	hm^2
		q_j	SO_2, dust catching and fluoride absorption capacity per unit area of forest	kg/hm^2
		F_g	The economic value of forest ecosystems purifying the atmosphere	yuan
		P_j	Pollution charge standards of SO_2, dust catching and fluoride	yuan/k
Water conservation	$G_w = 10 \times A_i \times (P - E)$ $F_w = G_w \times W \times T_W / T_C$	G_w	Total physical quantity of water conservation	m^3
		P	Annual precipitation	mm
		E	Forest evapotranspiration	mm
		F_w	The economic value of forest ecosystems for water conservation	yuan
		W	Gibbs free energy of water	J/m^3
		T_W	Transform of energy of groundwater	sej/J
		T_C	Currency ratio of the energy value	sej/yua
Soil and water conservation	$G_s = 10^6 \times A \times (X_2 - X_1)$ $F_s = G_s \times T_{loss} / T_C$ $G_f = \sum G_j = 10^6 \times \sum A \times (X_2 - X_1)(H_j / R_j)$ $F_f = \sum (G_j \times T_j / T_C)$	G_s	Physical quantity of forest soil conservation	g
		F_s	Economic value of forest ecosystem for soil conservation	yuan
		T_{loss}	Transform of energy of land loss	sej/g
		G_j	Physical quantities of N, P, and K are maintained in solid soils, respectively	g
		F_f	Economic value of forests ecosystem maintaining soil fertility	yuan
		H_j	The average content of N, P and K in the soil, respectively	-
		T_j	Transform of energy of nitrogen, phosphorus and potassium fertilizers	sej/g
Carbon fixation and oxygen release	$G_{CO_2} = 10^4 \times A \times \frac{11}{3} \times NPP$ $G_{O_2} = 10^4 \times A \times \frac{8}{3} \times NPP$ $F_{CO_2} = G_{CO_2} \times T_{CO_2} / T_C$ $F_{O_2} = G_{O_2} \times T_{O_2} / T_C$	G_{CO_2} G_{O_2}	Net fixation of CO_2 and net release of O_2 in physical quantity	g
		F_{CO_2} F_{O_2}	Economic value of net CO_2 fixation and net O_2 release	yuan
		NPP	Net primary productivity	gC/m^2
Organics production	$G_o = 10^4 \times A \times NPP$ $F_o = G_o \times Q_w \times T_w / T_C$	G_o	Physical quantity of net accumulated carbon	g
		F_o	Economic value of organics production in forest ecosystems	yuan
		Q_w	Calorific value of combustion of wood	J/g
Maintenance biodiversity	$F_b = Q_s \times T_s / T_C$	F_b	The economic value of habitats that maintain biodiversity	yuan
		Q_s	The number of species	-
		T_s	Transform of energy of a single species	-
Total value of forest ecosystem services	$F(t) = F_g + F_w + F_s + F_f + F_{CO_2} + F_{O_2} + F_o + F_b + F_r$	F_r	The value of forest recreation	yuan

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3. Establishment of the R. Hartmann Model

Forests have a long growth cycle and trees in a certain age range have no commercial value, therefore the age of the tree has a greater impact on the commercial value of the wood. Forest resources are often subject to multiple rotations, so we build the R. Hartmann model to determine the optimal rotation period to ensure maximum forest value.

Through the economic analysis of economic management of forest resources[2], the value of forests consists of two major parts, one is the value of ecosystem services provided by forests and the other is the commercial value of timber.

Assuming that the tree is cut down at age T and the other trees that are not cut down are of age t, there is the following formula.

$$PV = \int_0^T F(t)dt + e^{-r} \ M(T) \tag{1}$$

where $F(t)$ is the value of ecosystem services provided by uncut forest in that year at age t, in yuan. $M(T)$ is the commercial value of cut timber, in yuan. r is the discount rate.

The condition for maximizing the total value of the forest is expressed by the following formula.

$$PV' = e^{-rT}[F(t) + M'(T) - rM(T)] = 0 \tag{2}$$

$$\text{That is} \quad F(t) + M'(T) = rM(T) \tag{3}$$

$$\text{or} \quad \frac{M'(T)}{M(T)} = r - \frac{F(T)}{M(T)} \tag{4}$$

The left-hand part of Formula (3) is the commercial value of forest ecosystem services and timber growth, and the right-hand side is the marginal cost of delayed logging. Analysis of the above model yields the following results.

When the value of forest ecosystem services does not exist, the natural growth rate of the forest is equal to the discount rate, at which point deforestation is required. And when the value of forest ecosystem services is large enough that $PV'(t) > 0$ always holds, it means that it can never be cut. And if the value of forest ecosystem service function exists as long as making $\frac{F(T)}{M(T)} > 0$ always holds, the forest can be deforested under the condition that the natural growth rate is equal to the discount rate, and the deforestation period is appropriately delayed. Considering the effect of rotation, we improved Formula (1) to derive a new formula for total forest value as follows.

$$\begin{aligned} PV = M(T)\left[e^{(-rT)} + e^{(-2rT)} + e^{(-3rT)} + \cdots\right] + \\ \int_0^T e^{(-rT)} F(t)dt \left[e^{(-rT)} + e^{(-2rT)} + e^{(-3rT)} + \cdots\right] \end{aligned} \tag{5}$$

The total forest value is maximized when there is:

$$F(T) + M'(T) = rM(T) + \left[\frac{e^{(-rT)}M(T) + \int_0^T e^{(-rT)} F(t)dt}{(1 - e^{(-rT)})}\right] \tag{6}$$

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Formula (6) shows that the marginal cost of deferring deforestation, taking into account the rotation factor, includes not only interest income from the commercial value of the timber, but also from the value of future forest ecosystem services.

4. Model Analysis

By analyzing the above model, we can classify the forest value management plan into three modes based on the different values of forest ecosystem services.

Mode I

Ignoring the ecosystem service value of forests, which are valued only for their commercial value of providing timber, this model is applicable to specific forests. If agreed by the forestry management department, the property owner of the forest land can make the decision to build a forest land with specific commercial functions, such as a fuel forest, etc.

Mode II

If agreed by the forestry management department, the property owner of the forest land can decide to build a forest land with specific commercial functions, such as a fuel forest, etc.

Mode III

When forests have a certain ecosystem service value, but not enough to keep them from being cut forever, both the ecological service value of the forest and the commercial value of the cut trees need to be considered. Since forest conservation and development requires certain costs and the value of forest ecosystem services does not provide benefits to forest owners, it is important to cut moderately and determine the optimal rotation years based on $\frac{M^{'}(T)}{M(T^{'})} = r$.

5. Summarized and Prospected

Different estimation methods are used to calculate different functional values by dividing forest ecosystem service types and the second-order division of its service functions, and the forest ecosystem service value is comprehensively assessed. The R. Hartman model determines different forest value management models through mathematical analysis of ecosystem service value and timber commercial value, and obtains a more intuitive and effective decision-making model for forest value management.

Harvesting overripe forest trees in the optimal rotation period as a cycle, so that the forest always remains vigorous, the forest growth is large, and the economic value is high, then its ecological value is bound to increase with the economic value. Such healthy forests provide abundant forest products to society and maintain their good ecological condition, maximizing the value of the forest. During the optimal rotation period, harvesting balances the commercial exploitation value of forest ecological functions with the value of logging, allowing the interests of loggers and the public to be balanced while achieving enhanced forest benefits.

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