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Sustainable Development of Forest Management—Transition Point Analysis Based on Forest Value Assessment

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Abstract. Forest ecosystem management research is one of the hot spots and difficulties in forest sustainability development. Because of this, this paper constructs a framework of "integrated forest value assessment-transition point analysis-management strategy decision" from the perspective of integrated forest value assessment and its management strategy decision to maintain the integrity, continuity, and stability of forest ecosystem function. The model is universally applicable, and we obtain the transition periods of most countries in the world based on the model, and quantitatively analyze the forest status of George Jefferson Forest in the United States to obtain the optimal management plan, which verifies the accuracy and reliability of the model.

Keywords. Sustainable development, integrated forest value assessment, forest management

1. Introduction

Carbon sequestration is considered as an effective method to reduce emissions [1]. The rapid development of industry in the last hundred years has created an extremely rich material civilization, unprecedented scientific and technological achievements, and immortal artistic achievements for human society, but the price of blind industrial development is the destruction of the environment, global warming, and ecological degradation. We need an advanced, sustainable, and coordinated development model, namely the sustainable development model, to provide a way to transform society from industrial civilization to future civilization. As the growth time increases, the carbon density of the forest also increases and stabilizes at maturity [2]. According to the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC), carbon sequestration in forest ecosystems makes carbon management a promising solution to combat climate change [3].

The forest ecosystem is an important application of the sustainability model, which has the function of water conservation, wind and sand control, soil and water conservation, and carbon sequestration and release to increase biodiversity. The incredible thing is: reasonable deforestation is beneficial for carbon sequestration. In addition, forests have landscape patterns, ecological benefits, economic benefits, and social benefits. How to find a balance among the benefits is a key concern in the

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management strategies of forest managers. This paper gives appropriate management strategies for different stages of forests so that managers can make the most scientific, rational, and beneficial management decisions.

2. CFVE Model Building Process

Forests have a wide variety of values, and a combination of quantitative and qualitative analysis is used for comprehensive forest value evaluation.

We use the AHP (Analytic Hierarchy Process) method to establish a hierarchical structure model of indicators, and stratify and classify the complex model to make it a hierarchical and reasonably structured whole. In addition, the selection of evaluation indicators should fully reflect the characteristics of the forest and the overall level of the forest. Meanwhile, it follows the principles of scientificity, systematicity, independence and operability. Establish a hierarchical structure model of forest value evaluation indicators, and get the weight vector of each indicator. The specific indicator hierarchy chart is shown in Figure 1.

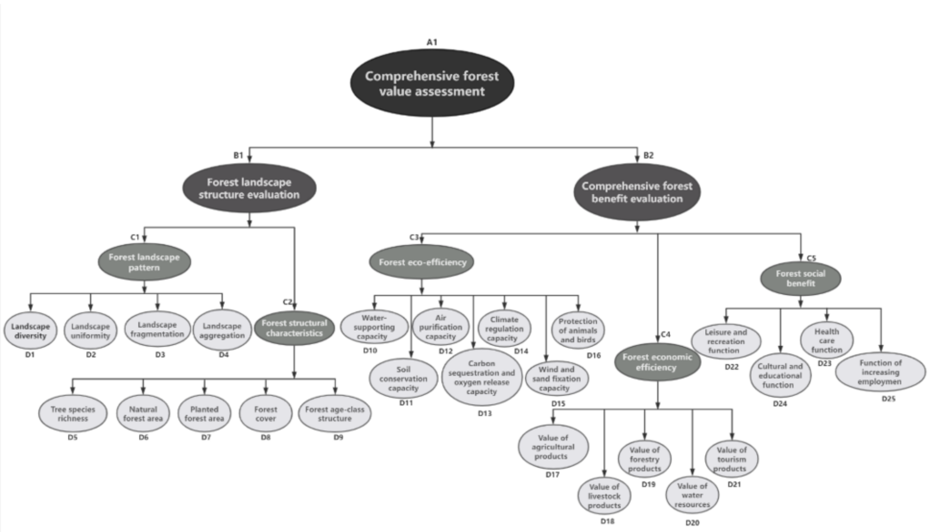

Figure 1. Indicator hierarchy chart [4].

Based on AHP, the comparative matrix pairs are constructed. Then the regularized summation method is used to calculate the eigenvectors W and the maximum eigenvalue $\lambda_{\max}$.

Regularize each column vector of the matrix and perform vector regularization:

$$W_i = \frac{\sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}}{\sum_{i=1}^{n} V_i} (i, j = 1, 2, 3, \cdots . n) \tag{1}$$

The obtained vector $[w1, w2, \cdots, wn]T$ is the weight vector.

The maximum characteristic root $\lambda_{\max}$ of the judgment matrix is calculated:

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} (i, j = 1, 2, 3, \cdots, n) \tag{2}$$

In addition, we need to perform a consistency test on the constructed comparative matrix pairs to ensure that the pairwise comparison matrices converge, otherwise, the two comparisons will be repeated.

Next, we applied fuzzy integrated evaluation to establish the target subset U . Each sub-target U_i is influenced by each indicator $u_{i1}, u_{i2}, \cdots, u_{ik}$, the indicator set u_i is

$$u_1 = (u_{i1}, u_{i2}, \cdots, u_{ik})(i = 1, 2, \cdots, s) \tag{3}$$

Based on the multifaceted values of the forest, several evaluation sets are selected to form an evaluation set V

$$V = (V_1, V_2, \cdots, V_m) \tag{4}$$

Then several experts are asked to obtain the corresponding evaluation matrix by voting on each indicator, and summarized in the form of the weight of each rating of each indicator:

$$R = \begin{pmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{k1} & \cdots & r_{km} \end{pmatrix} \tag{5}$$

where r_{ij} denotes the frequency distribution of i^{th} factors u_i on j^{th} the rubric V_j , which usually satisfies $\sum r_{ij} = 1$. In addition, we assign a rank value to the comprehensive forest value assessment, which is specified as Table 1.

Table 1. Comprehensive forest value evaluation level assignment [5].

Evaluation level	V_1	V_2	V_3	V_4	V_5
Score	10	8	6	4	2

The final score is obtained by arithmetic:

$$Score = V(WR)^T \tag{6}$$

3. Transition Point

The composite value scores of forests are not set in stone, and we continue to analyze the trends of forests, the composite value scoring model reflects a ‘‘U-shaped curve’’: a process of moving from high to low to high scores. The curve is divided into six stages based on the value and slope of the change, as shown in Figure 2.

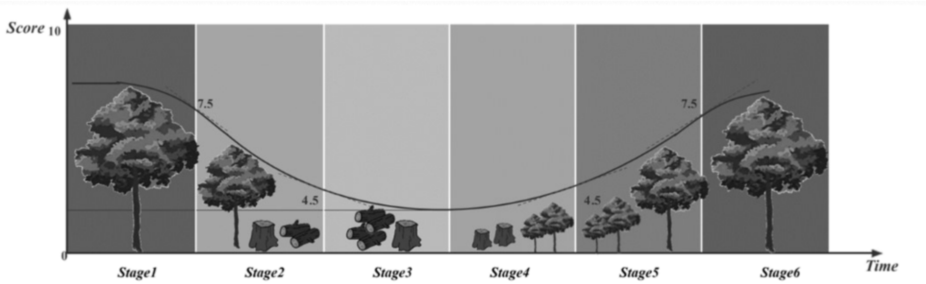

Figure 2. The universal law of world forest development.

- Stage 1: Pre-transition stage, with a score range of 8-10.
- Stage 2: Early transition stage, where the score decreases rapidly and at an increasing rate, with a score range of 5-7.
- Stage 3: Late transition stage, the score continues to decrease, but the speed is gradually slow, and finally reaches the lowest point of the score, the score range 0-4.
- Stages 4-6: The Post-Transition phase, the inverse of Stages 1-3. Forest cover increases through reforestation. The annual change is now positive.

Therefore, we define the association between transition points and forest value evaluation system scores as Table 2:

Table 2. The relationship between transition points and score.

Transition point	Score
Between Stages 1 and 2, Stages 5 and 6	7.5
Between Stages 2 and 3, Stages 4 and 5	4.5

4. Decision-Making Recommendations

Three forest management decision recommendations can be summarized in Li’s study [6], corresponding to the division of the score bands of the comprehensive forest value evaluation model in 2, which is also appreciated for the transition stage. The decision model is shown in Table 3.

Eco-demand function-led business management model:

The model applies to ecologically fragile areas of forests and areas with serious deforestation, etc. to play a role in ecological conservation. Specific management measures are as follows:

(1) Protect and restore forest biodiversity, avoid non-nurture and renewal logging, and prohibit destructive production and construction activities.

Table 3. Decision model.

Evaluation score	Forest management decision recommendation
0-4	Eco-demand function-led business management model
5-7	Protection and production twin business management model
7-10	Integrated management model of conservation, development and production

(2) To carry out appropriate human management, reduce pests and prevent fires to guarantee the rate of natural ecological restoration.

(3) Deforestation should be stopped as much as possible in this stage and the required wood be obtained by import.

Protection and production twin business management model:

The model applies to forests with a good ecological environment, but the dominant function is ecological functional area. Specific management measures are as follows:

(1) Pay attention to the coordination within the forest ecosystem. Under the premise of not affecting the habitat environment, part of the ecological construction can be carried out.

(2) Implement classification management, so that the division of commercial forest and public welfare forest is consistent with ecology.

Integrated management model of conservation, development and production:

The model applies to forests with good forest ecology and comprehensive benefits. Specific management measures are as follows:

(1) The forests are divided into three major types of forest operations: soil and water conservation forests, human-forest symbiosis forests and resource recycling forests.

(2) Cultivate large diameter timber stands and mixed forests, and restore understory vegetation promptly.

(3) Increase timber production for intensive management. Promote inter-logging activities and implement long-logging operations.

5. Case: George Washington and Jefferson National Forests

Several studies have assessed the stage of national forests across the world [7]. The recent analysis to date was published by Florence Pendrill and colleagues which looked at each country's stage in the transition, the drivers of deforestation and also the role of international trade [8]. Based on the CFVE Model, we can delineate the transition stages that various forest areas in the world are currently in, as shown in Figure 3.

Figure 3. The current distribution of the world's forests in the transition phase.

Among the many forests in the world, we chose the George Washington and Jefferson National Forests in West Virginia, USA, to apply our model to the management process of this forest.

The indicator weights for this forest, as shown in Figure 4, are calculated by collecting a large amount of statistical data from the George Washington and Jefferson National Forests and applying the model.

Figure 4. Weight of each indicator.

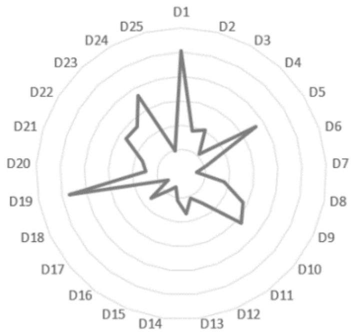

Figure 5. A score of each indicator.

This gives the George Washington and Jefferson National Forests an overall value score of 8.7 for the current phase. In addition, the specific scores for each indicator are shown in Figure 5.

According to the decision model, an integrated management model of conservation, development and production is decided for this forest. This forest management plan is compatible with the integrated values of the George Washington and Jefferson National Forests and can achieve an optimal balance of landscape pattern, structural characteristics, ecological, social, and economic benefits.

6. Conclusion

Based on the diversity of forest values, we construct a forest value evaluation model, which is based on a comprehensive evaluation of 25 indicators of forests, to obtain a more reasonable score and achieve a balance of multiple values of forests. In addition, we also conclude the general development pattern of the world's forests. We synthesize the comprehensive evaluation of forest values and forest development laws, find their intrinsic connections, and propose different forest management decisions for each transition process. In summary, we propose forest management plans that are better for society and facilitate forest managers to understand the best use of forests at present.

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