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Forest Management Plans for Carbon Sequestration

Boyao Li[1], Zimeng Zhang[1], Chenyuan Zhao[2] and Linsheng Huo[1,a]

[1]Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, China

[2]School of Mathematical Sciences, Dalian University of Technology, Dalian, China

[a]Corresponding author e-mail: lshuo@dlut.edu.cn

Abstract. Carbon sequestration in forest ecosystems has become an important issue in the discussion about abrupt climate change. Forestry sequestrates carbon from the atmosphere and stores it in living tree biomass, dead organic matter and wood-based products. However, it is difficult to estimate the stored carbon in a forest accurately. To address this issue, this study develops a series of models to calculate the carbon sequestration of the living tree and the additional part of the forestry carbon sequestration. The influences of four carbon sequestration pathways on total carbon sequestration are analyzed using the proposed model. The results show that the proposed model can predict future carbon dioxide and determine the cutting intensity. This study provides a feasible plan for forest management.

Keywords: carbon sequestration; entropy method; forest management

1. Introduction

Forests, the largest carbon reservoirs in terrestrial ecosystems, play a vital role in reducing the concentration of greenhouse gases in the atmosphere and slowing global climate change. Enhancing forest carbon stocks is well recognized in the scientific literature [1-4]. Adaptation actions may be needed to maintain forest carbon stocks [5]. Some previous syntheses of forest carbon-management strategies do not explicitly incorporate protecting biodiversity, providing economic and cultural value. However, there is thus a growing recognition that effective management of forests for carbon sequestration warrants consideration of future climate projections and expected impacts on ecosystems. Hence, when making forest management plans, it is often necessary to consider multiple values to make appropriate decisions [6,7].

It is still a challenge to quantify the stored carbon for a forest accurately. This paper proposes the carbon sequestration model and gives the weights for different objectives in four management schemes. The independent evaluation indicators are screened out, and the weights are determined by the entropy method. The forest management plan is optimized through the comprehensive evaluation value, where the deforestation and the deforestation rate are determined.

2. Carbon Sequestration Calculation

2.1 Carbon Sequestration Model

The model of calculating carbon sequestration is determined by consulting many historical documents [8]. The model consists of two parts: the total carbon sequestration of the forest and the carbon sequestration of wood. The formula is as follows

$$\mathrm{CF} = \sum (\mathrm{S_{ij}} \times \mathrm{C_{ij}}) + \alpha \sum (\mathrm{S_{ij}} \times \mathrm{C_{ij}}) + \beta \sum (\mathrm{S_{ij}} \times \mathrm{C_{ij}}) \tag{1}$$

$$\mathrm{CW} = \lambda \sum (\mathrm{S_{ij}} \times \mathrm{C_{ij}}) \times \rho \times \gamma \tag{2}$$

where CF is the sum of carbon sequestration from tree biomass, understory plant, and woodland; CW is the wood sequestration; $\mathrm{C_{ij}} = \mathrm{V_{ij}} \times \delta \times \rho \times \gamma$; $\mathrm{S_{ij}}$ is the area of category j forest type in category area i; $\mathrm{C_{ij}}$ is the biomass carbon density of forest type j in type area i; $\mathrm{V_{ij}}$ is the accumulation per unit area of forest type j in the category area i; α is the carbon conversion

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coefficient of understory plants; β is the forest land carbon conversion factor; λ is the wood carbon sequestration conversion factor; δ is the biomass expansion factor; ρ is the volume factor; γ is the carbon content.

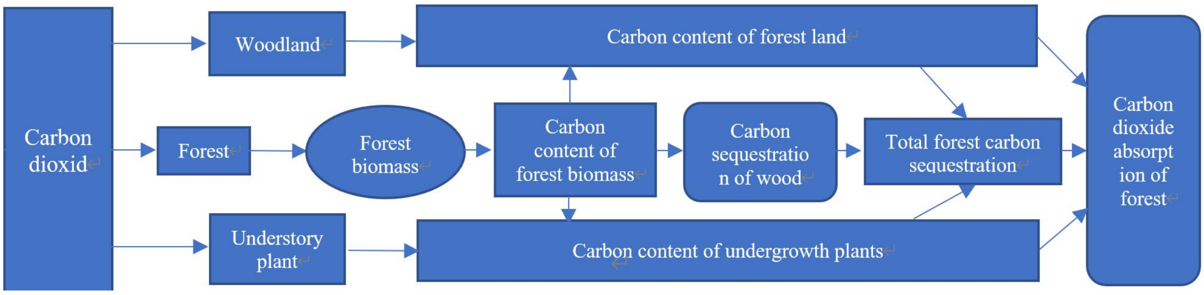

Figure 1. Schematic diagram of forest ecosystems.

The data in this study are derived from the forest of Daxinganling state-owned forest area in Heilongjiang Province of China [9], as shown in Figure 1.

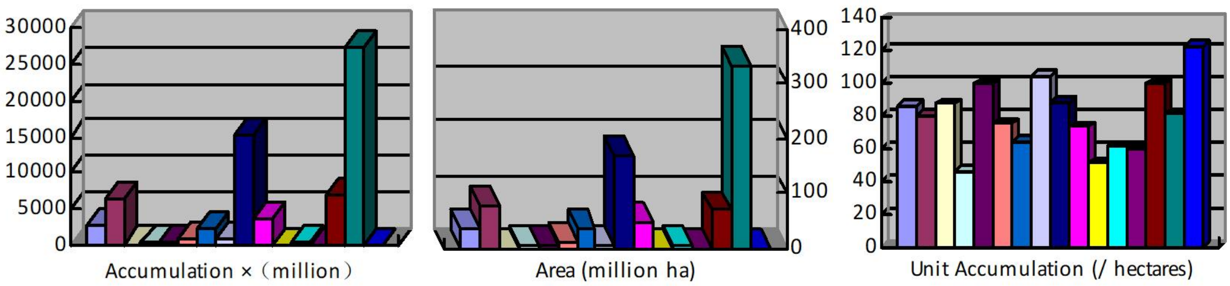

Figure 2. The area and accumulation of dominant tree species in the Daxinganling forest.

According to formulas (1) and (2), we can solve that CF=79351.8456 qCO2/(million ton), CW=2397.3900 qCO2/(million ton). The total carbon sequestration of the forest is the sum of CF&CW, and we end up with the carbon sequestration of 81749.2356 qCO2/(million ton).

2.2 Optimization of Forest Management Plans Based on Carbon Sequestration Models

Four different management schemes are designed. The weights of each scenario are listed in table 1 [10].

Table 1. The weight of different objectives of the four management schemes.

	Wood harvest	carbon sequestration	Water conservation	Conservation soil
Programme1	0.25	0.25	0.25	0.25
Programme2	0.4	0.2	0.2	0.2
Programme3	0.1429	0.2857	0.2857	0.2857
Programme4	0.1667	0.3333	0.3333	0.1667

According to formulas (1) and (2), we can find the value of the carbon sequestration. The calculation results are as follows:

C(Programme1) =30556.87597 qCO2/(million ton); C(Programme2) =26363.41278 qCO2/(million ton); C(Programme3) =34723.70409 qCO2/(million ton); C(Programme4) =33595.9214 qCO2/(million ton).

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Finally, after calculations and comparisons through the model, we found that management scheme 3, namely wood harvest, forest carbon sequestration, water conservation, and soil conservation weights of 0.1429, 0.2857, 0.2857, 0.2857, i.e., wood is slightly less important than the other three ecological objectives of the forest, and is most effective in absorbing carbon dioxide.

3. Optimization of Forest Management Plan Based on Comprehensive Evaluation Model

3.1 Data Sources

The data of the natural forest of the Eastern Red Forestry Bureau in eastern Heilongjiang Province of China [11] are selected to judge the relevance of various indicators and find appropriate weights.

3.2 Establishment of Evaluation Indicators

Carbon sequestration, biodiversity and economic value are selected to optimize the forest management plan, which is most beneficial to society. Among them, the Simpson index is used to evaluate biodiversity, the annual average carbon sequestration is used to evaluate the carbon sequestration, and the value of oxygen release is used to evaluate economic value.

We choose the entropy method [12] for a comprehensive evaluation of forest management plans, and in order to evaluate the model more comprehensively, the selected indicators should meet independent conditions.

3.3 The Establishment of Comprehensive Evaluation Mathematical Models

3.3.1. The entropy method

In information science, entropy is a measure of information uncertainty. In general, the larger the amount of information, the smaller the entropy value, and the greater the utility of the information. Conversely, the smaller the amount of information, the greater the entropy value, and the smaller the utility value of the information.

3.3.2. Preprocess the data

Since all three indicators considered are larger and better, that is, the larger the indicator, the more beneficial it is. There is no need for additional consistency.

Next, the proportional transformation method is used to process the data in a dimensionless manner. The comprehensive evaluation question contains n evaluation objects and m indicators, and the corresponding indicator observations are respective. Each object has m evaluation indicators, and its observations are separate $a_{ij}(i=1,2,\cdots,n;j=1,2,\cdots m)$

Cause

$$b_{ij} = \frac{a_{ij}}{\max\limits_{1\le i\le n} a_{ij}} \quad \left(\max\limits_{1\le i\le n} a_{ij} \ne 0, 1 \le i \le n, 1 \le j \le m\right). \tag{3}$$

We get the normalized data.

3.3.3. Determine the comprehensive evaluation value.

Let the standardized data for the jth observation of the ith evaluation object $b_{ij} > 0(i = 1,2,\cdots,n; j = 1,2,\cdots,m)$.

Then the characteristic proportion of the ith evaluation object under the jth indicator is:

$$p_{ij} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}} \quad (i = 1,2,\cdots,n; j = 1,2,\cdots m). \tag{4}$$

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Calculates the entropy value of the jth indicator:

$$e_i = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (j = 1,2,\cdots m). \tag{5}$$

The larger the difference in observed values between the indicators, the smaller the entropy value; conversely, the greater the entropy value.

Calculate the coefficient of variance for the jth indicator:

$$g_{ij} = 1 - e_{ij} \quad (j = 1,2,\cdots m). \tag{6}$$

For indicators, the greater the difference in observations, the greater the coefficient of variance and the more important the indicator.

Determines the weight factor for the first metric j:

$$\omega_j = \frac{g_j}{\sum_{k=1}^{m} g_k} \quad (j = 1,2,\cdots m) \tag{7}$$

Calculate the overall evaluation value as:

$$f_i = \sum_{j=1}^{m} \omega_i p_{ij} . \tag{8}$$

The higher the rating value, the better.

3.3.4. Determine the weight

The weight values of the three aspects are listed in table 2

Table 2. The weight of three aspects.

Main role	Realization method	Weights
Carbon sequestration	Agriculture can increase production	0.41
Biodiversity	Species resource gene pool	0.23
Economic value	Ticket revenue	0.36

3.4 Logging or Not

We select the biodiversity, carbon sequestration and economic efficiency indicators of natural forests in Dongfanghong Forestry Bureau [13]. Two sets of data were obtained from relevant data, one recorded as Forest A without harvesting protocols and the other as Forest B with fostering harvesting protocols. The relevant data are listed in table 3.

Table 3. Indicators of the evaluation object.

	The Simpsons Index growth value	Average annual carbon sequestration	Economic value
Forest A	0.49	7.1	9980
Forest B	0.40	14.3	18596

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We substitute the above data into Formula (8) to get the comprehensive evaluation value of Forest A and Forest B. The following results are obtained.

$$f_A = 0.667, f_B = 0.833.$$

That is, for Forest A, it is more appropriate to include harvesting in the management plan.

3.5 Determine the Cutting Rate Using Comprehensive Evaluation Model.

Our goal is to calculate the scores under different harvesting rates through the comprehensive valuation model and to take the harvesting rate corresponding to the maximum value of the sum of the indicators as the optimal solution for the forest management scheme. It is known that the harvesting rate is quantitatively related to the rotation period:

$$P = \text{Forest stockpiles} / U \tag{9}$$

Therefore, the rotation period can be used as a basis for judging and generating indicators of the final management plan. We processed a large amount of data and finally determined the interval for obtaining the best values: that is, when the rotation period was between 5 and 25 years, the data were shown in Table 4.

Table 4. The relationship between indicators and rotation periods.

Indicators / U(year)	Carbon sequestration	Simpson Index Growth Value	Economic value
5	14.3	0.40	18596
10	15.0	0.43	14856
15	12.5	0.45	10782
20	7.1	0.49	9980
25	6.6	0.46	8675

We screened the best protocols through a python program and scored the highest during the ten-year rotation period. Therefore, we conclude that the best management plan for the forest is to set the crop rotation period to 10 years.

4. Conclusion

The forest management plan is optimized through the Carbon sequestration model. The optimal forest management plan is selected through the comprehensive evaluation value. The following conclusions were obtained:

(1) The carbon sequestration of wood can reach 1.4% of the total carbon sequestration of forests. Although the proportion is not high, the amount of carbon stored in wood cannot be ignored for such huge carbon storage as forests.

(2) After considering the carbon sequestration value, biodiversity value and economic value. The forest management is comprehensively evaluated, and the relative index values are given by calculation.

(3) The natural forest of the Forestry Bureau of Dongfanghong City as the object to research the optimization of the forest management plan. First, on the question of whether or not to cut, logging is a more rational management plan Secondly, when the rotation period is ten years, the best evaluation value can be obtained.

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