A new forest carbon sequestration model and multi-faceted forest balanced management options

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ABSTRACT

The increase in greenhouse gases has an impact on climate change, and forests play a significant role in the process of carbon sequestration. To quantify the effectiveness of forests in carbon sequestration, this paper constructs carbon sequestration models for forests and is evaluated using the Daxing'an mountains. We randomly select 57 countries, and a comprehensive evaluation of the ecological and cultural value of forests is conducted using the Topsis model combined with the entropy weight method. The results show that the model can maximise the combined benefits of forests in terms of carbon sequestration, culture and ecology, and is conducive to the sustainable development of society.

Keywords: carbon sequestration, cluster analysis, comprehensive evaluation

1. INTRODUCTION

With the rapid development of industrialization, the concentration of greenhouse gases in the atmosphere affected by human activities is increasing, leading to global warming, which will seriously threaten the global environment on which human beings depend for survival[1]. At present, the international community's dependence on fossil fuels such as oil, coal and natural gas will not diminish soon, so it is urgent to find new ways to reduce greenhouse gas emissions in order to ensure sustainable development of society[2]. Forests are indispensable to change this situation. Carbon sequestration usually refers to the storage of carbon with the direct potential to become carbon dioxide gas, both naturally and as a result of anthropogenic activities. Forests achieve carbon dioxide sequestration through plants and forest products, thus maintaining ecological balance[3], and carbon storage in forest products has been included as a critical issue in UNFCCC negotiations and will be a major component of national greenhouse gas inventories[4].

Wang X Y et al. used the MIAMI model to quantitatively assess the forest carbon balance in Liaoning Province over the past 50 years using mean annual rainfall and mean air temperature. Cai L Q used the MIAMI model to study the impact of climate change on grassland production potential in the Yangtze River source area[5].Using this model in conjunction with the MIAMI model to analyse trends in forest vegetation productivity in the northern Daxing'an mountains, Zhao H Y et al. concluded that the climatic production potential of vegetation is extremely sensitive to changes in precipitation and mean annual temperature[6]. Xiao S H divided the forest benefits into social and ecological benefits, and obtained a model for predicting carbon sink stocks[7].

A sound forest management plan is needed to balance the value of harvested forest products with the value of sequestered carbon. In the early 20th century, Gifford Pinchot recognised the profitability of active public participation in sustainable forest management[8]. Xu Y M examines trends in global forest management and the impact on carbon stocks[9]. An effective forest management plan facilitates the development of the forest industry[10].

This paper constructs carbon sequestration models (CMSF and CMSP) for forests and is evaluated using the Daxing'an mountains. The results show that the model can maximise the combined benefits of forests in terms of carbon sequestration, culture, and ecology, and is conducive to the sustainable development of society.

2. CARBON SEQUESTRATION MODEL AND CARBON SEQUESTRATION QUANTITY PREDICTION MODEL

2.1 Carbon sequestration model

2.1.1 Foundations of the Model. The forest carbon sequestration model (CSMF) is based on the common carbon stock

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estimation method proposed by the IPCC, which uses the forest stock, wood density, biomass conversion factor and rootstock ratio as parameters to build a woody biomass model to guide countries in biomass and carbon stock estimation. Its essence is to multiply the biomass by the stand biomass carbon content green to get the stand carbon content, whose basic formula is

$$C_f = V \times BCF \times (1 + RSR) \times CF \tag{1}$$

where: C_f is the forest carbon sequestration (t); V is the forest stock (m3); BCF is the biomass conversion and expansion factor (t/m3) for converting the forest stock to above-ground biomass; RSR is the ratio of below-ground biomass to above-ground biomass; and CF is the carbon content rate of forest biomass. The above biomass parameters and carbon measurement parameters can be obtained from the Standing Wood Biomass Model and Carbon Measurement Parameters.

2.1.2 Improvement of the Model. In order to study the effect of forest management plans on carbon stocks of forests and their forest products, so as to obtain the most effective forest management plan in terms of sequestering carbon dioxide, forest management instruments are introduced based on the IPCC model to obtain our forest carbon sequestration model (CSMF).

Forest management tools mainly include logging and fire prevention. To facilitate quantification, it is assumed that forest managers only use logging to accomplish forest management. The means of logging include the lower layer of nurturing for young and middle-aged forests and the upper layer of harvesting for mature and over-mature forests.

·Lower tending: A technical measure for harvesting young and middle-aged forests to improve the growing environment, adjust stand density, and increase forest production by obtaining more growing space.

·Upper harvesting: Also known as forest harvesting, it is a technical measure to harvest mature forest stands, which plays a role in the renewal of the forest and the harvested trees are used for the processing of forest products.

The lower nursery means, upper harvest and tree species compositionwase introduced into the IPCC model to obtain the CSMF model with the following equation:

$$C_f = \sum_{i=1} a_i \times (V - V_{i1} - V_{i2}) \times BCF_i \times (1 + RSR_i) \times CF_i \tag{2}$$

where: C_f is the forest carbon sequestration (t); i denotes the tree species ; V is the total forest stock (m^3); a_i is the ratio of the stock of species i to the total stock; V_{i_1} is the stock of species i in the forest subjected to primary harvesting; V_{i_2} is the stock of species i in the forest subjected to understory nurturing; the remaining symbols denote the biomass parameters and carbon measurement parameters in the IPCC model.

2.2 Carbon sequestration quantity prediction model

The method of estimating carbon stocks at different times in the future using carbon stock time series is called the time series method of predicting carbon stocks. Considering the existence of deforestation and regeneration, there is a periodicity in the change of accumulation of some forests, therefore, in this question we use time series analysis to predict the carbon sequestration of forests and their forest products.

The first step is to calculate the carbon sequestration series. The carbon sequestration time series is calculated using the carbon sequestration models for forests and their forest products constructed in 2.1. The collected historical forest stock V and the deforestation ratio are substituted into the equation, and the values of other parameters are obtained by consulting the information, and then the maximum carbon sequestration time series for forests and their forest products are calculated.

Then time series analysis was used to make predictions. Considering the different growth and development conditions of different forests, the carbon sequestration time series of different forests have different patterns. Therefore, an expert modeler is used to automatically analyse the carbon sequestration time series patterns, give the most suitable time series model and make predictions of carbon sequestration.

3. BALANCED MULTI-FACETED FOREST MANAGEMENT OPTIONS

3.1 Comprehensive evaluation and cluster analysis

The ecological and cultural values of forests are embodied in wind and sand prevention, biodiversity protection, scientific and recreational utilization, and carbon sequestration. In order to measure the ecological and cultural value of each forest, we divide the indicators into three categories: ecological function, socio-cultural function and geographical characteristics. The corresponding indicators are the proportion and biomass carbon density of forest land for soil and water conservation and biodiversity protection, the proportion of forest land for ecosystem services and spiritual culture, annual precipitation and annual average temperature. The framework diagram of the evaluation model is as follows in Figure 1.

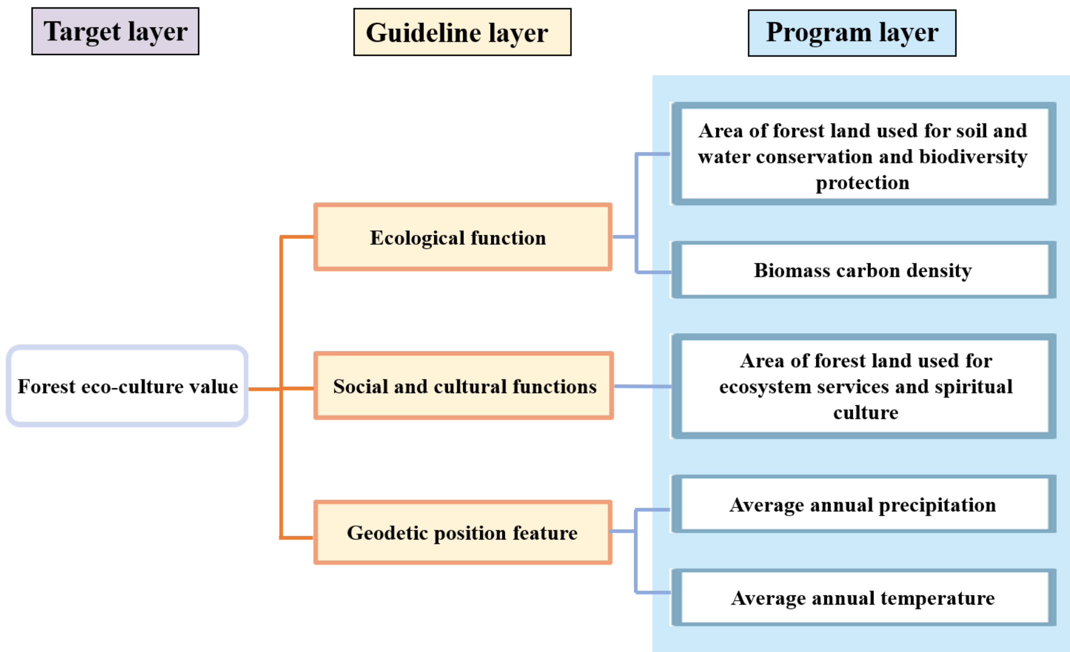

Figure 1. The framework diagram of the evaluation model.

We obtained the weights of the indicators using the entropy weight method, in which the weight of the average annual precipitation is 0.117, the proportion of forest land for soil and water conservation and biodiversity protection is 0.168, the proportion of forest land for ecosystem services and spiritual culture is 0.557, and the carbon density (ton/ha)) is weighted 0.084 and the annual mean temperature is weighted 0.073. After using the entropy weight method to determine the weight of each evaluation index, we evaluated the forests of 52 countries based on the TOPSIS method, and then clustered the comprehensive scores of the 57 countries as follows in Figures 2 and 3.

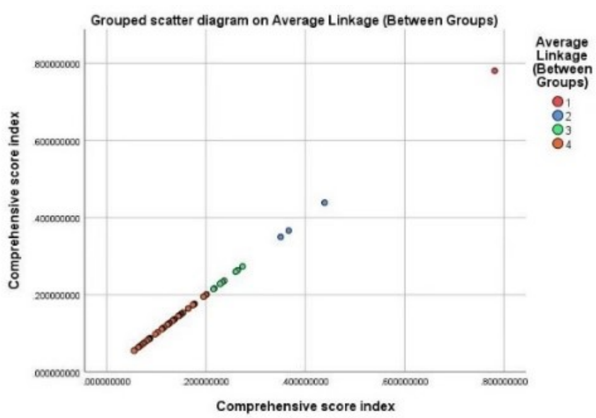

Figure 2. Grouped scatter diagram on average linkage.

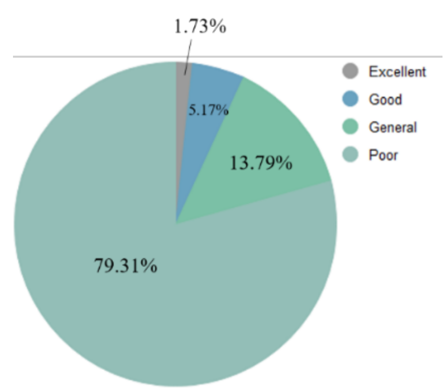

Figure 3. Category share chart.

From the line graph of the aggregation coefficient, it can be concluded that when the category K exceeds 4, the variation of the distortion degree is significantly reduced, so the category can be set to 4.

3.2 Forest management plan decision model

Forest management plans include over-harvesting, under-cultivation and woodland rehabilitation. The forest land is the forest with the main purpose of logging. The specific transformation measures of the forest land are: closing the forest and transforming it into a forest with ecological or cultural functions, etc., which is manifested in the reduction of the existing wood stock in the forest land and the reduction of the wood stock that can be harvested from the upper layers.

In order to synthesize forest economic benefits and carbon sequestration capacity, take carbon storage and stand output as objective functions, introduce constraints into forest management plan and timber forest transformation, and build a multi-objective nonlinear programming model. The objective function is as follows:

$$maxf(x) = C_f + C_p$$
$$maxP(x) = \frac{x_1 \cdot V_1 \cdot p}{V} \tag{3}$$

Among them:

$$C_f = (V - x_1 \cdot V_1 - V_2) \cdot BCF \cdot (1 - RSR) \cdot CF$$
$$C_p = \sum_{j=1} x_1 \cdot V_1 \cdot r_j \cdot \rho_1 \cdot I_j \cdot b_j \tag{4}$$

The following are constraints representing the reduction of timber forest stocking:

$$V_1 < V_{original} \cdot r$$
$$V_2 < V$$
$$V_2 + x_1 \cdot V < V$$
$$0 < x_1 < 1 \tag{5}$$

where, $V_1 X_1 V_2$ are unknown parameters, V_1 is the volume of woody forest after transformation, V_1 is the ratio between the volume of woody forest stock and the volume of woody forest stock obtained by upper layer harvesting, V_2 is the volume of upper layer nurturing stock, *P* is the value of wood production, i.e. the value of wood production obtained by upper layer harvesting, *p* is the weighted average price of wood in this forest, *BCF*, *RSR*, *CF* are the average parameter values weighted by species composition, *V* is the volume of stand stock in the whole forest area, V original is the volume of woody forest stock and initial woody forest stock, *r* is the category control coefficient.

Model interpretation: When the forest belongs to the "good" category, the category control factor is 1, which constrains the timber stand to be reduced; when the forest belongs to the "general" category, the category control factor is 0.95, which constrains the timber stand to be reduced by at least 5% of the initial When the forest belongs to "general", the category control factor is 0.95, which constrains the timber forest to reduce at least 5% of the initial stock; when the forest belongs to "poor", the category control factor is 0.9, which constrains the timber forest to reduce at least 10% of the initial stock, which is a different forest management plan for different categories of forests, reflecting the transition point in the forest management plan.

4. EXPERIMENT AND RESULTS

In order to illustrate our model more intuitively, we choose the Daxing'an mountains forest area in Heilongjiang, China as a case study.

The values of the Daxing'an mountains parameters that need to be used in the model were firstly obtained by reviewing the data, as shown in Table 1 below:

Table 1. Default factors to convert from product units to carbon.

	Proportion	*BCF* (t/m^3)	*RSR*	*CF*
Larch	0.64	0.6938	0.3333	0.4306
Birch	0.25	0.7738	0.3076	0.4872

4.1 Prediction results of forest carbon sequestration

The carbon sequestration of forests and their woodlands from 07 to 20 years was calculated by substituting the deforestation rate into the carbon sequestration model. The carbon sequestration data from 07-16 years were used as the test group to predict the carbon sequestration data from 17-20 years using the method of time series analysis, and the average relative error between the recommendations of the expert modeler and the true value of the predicted values was combined, and the damped trend model in the exponential smoothing method (MA) was selected for the prediction, and the results are shown in the following Figure 4.

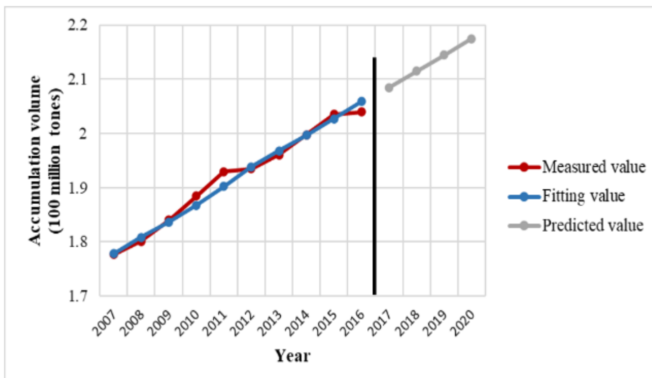

Figure 4. Time series prediction chart.

The following formula was used to calculate the average relative error between the measured and predicted values for 2017-2020, which was calculated as 15.67%, which is less than 20% considered that the model fit results to the original data meet certain requirements.

$$\varepsilon_r(k) = \frac{|x^{(0)}(k) - \hat{x}^{(0)}(k)|}{x^{(0)}(k)} \times 100\%, k = 2, 3 \dots, n \tag{6}$$

$$\bar{\varepsilon}_r = \frac{1}{n-1} \sum_{k=2}^{n} |\varepsilon_r(k)| \tag{7}$$

4.2 Balancing multifaceted forest management plan outcomes

In order to maintain the role of the Daxing'an Mountains in carbon sequestration, taking into account its ecological, economic and social benefits, a decision-making model was used to find the optimal forest management plan, including the upper harvesting stock, the lower cultivated stock and the timber forest to the ecological Lin's transformation.

In order to determine the forest types of Daxing'an Mountains, we collected the evaluation index data of Daxing'an Mountains in Heilongjiang, calculated the weight and the comprehensive score of forest ecological and cultural value according to the decision-making model, and the score was 0.245, and determined the category of ecological and cultural value as "general". ". Select the multi-objective nonlinear programming model in the "general" category, take the category control coefficient r=0.95, and obtain the optimal solution by substituting the relevant parameter values and stand volume V=620 million cubic meters, as follows:

$$x_1 = 0.22 \;\; V_1 = 4.03 \;\; V_2 = 0.744$$

They represent a forest management plan to reduce the timber forest stock to 403 million cubic meters, 22% of the timber forest overstory harvested, and the undergrowth stock to 0.744.

According to this forest management plan, the maximum value of the objective function is:

$$maxf(x) = C_f + C_p = 1.83 \; maxP(x) = 664.95$$

This means that the maximum carbon sequestration of forests and their forest products is 183 million cubic meters, and the maximum forest output value is 66.495 billion yuan, maximizing the comprehensive benefits of forests in economic, social, cultural and ecological aspects.

5. CONCLUSION

By analysing its collection data, a model has been developed that can predict the stock of carbon sinks for the next few years. Meanwhile, based on the time series prediction model, we randomly selected 57 countries, and a comprehensive evaluation of the ecological and cultural value of forests is conducted using the Topsis model combined with the entropy weight method. The results show that the model can help managers to better manage and use forests and provide advice to relevant practitioners on forest development to maximise the overall benefits of forests.

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