Research on Forest Operation Plan Based on Carbon Sequestration Model

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Abstract. Forest managers must find a balance between harvesting trees and not harvesting trees, taking into account ecological and economic factors and so on. We will develop a model to predict the carbon sequestration capacity of the forest and its products and establish a decision model to determine a management plan that maximizes the carbon sequestration capacity of the forest. Select a forest and apply the model to predict the amount of carbon dioxide absorbed by the forest and determine the best forest management plan. Use the model to solve the problem of the transition period in different rotation periods.

Keywords: Carbon Sequestration, AHP, BP Neural Network.

1. Introduction

With the continuous improvement of people's living standards, people's attention to ecological environmental deepened, especially to the greenhouse gas. The forest is the strongest biosphere of carbon dioxide isolation biological community, gradually appeared in public view. Therefore, this article will discuss ‘carbon sequestration’ ability of forest and its products and try to get a series of forest management plan to achieve the overall sustainable development. In particular, we give The Democratic Republic of the Congo a better forest management plan [1].

In this paper, we selected five forests from the five natural zones, found relevant data, and used the Time Series Prediction to predict the amount of "carbon sequestration" in the next 20 years. Then by using the AHP, we got the importance of six factors that influence carbon sequestration. Next, we use Comprehensive Indicator Scoring Method to evaluate the scores of six factors. Finally, the GA is used to solve the optimal solution and get the optimal forest management plan and get our decision model [2].

Besides, we used GIS to select the forest in Congo as the actual forest for the application of the model. Then, we use the same model and combine it with the neural network to make a step-by-step prediction of the amount of "carbon sequestration" in the next 100 years. We use the improved model to obtain a more suitable management plan of forests in Congo. In Congo, the best harvesting scale of young trees, middle-aged trees, and old trees are 1.48%, 4.12%, and 0.51%, and the best rotation period should be 14.1years. In the improved decision model, we make a strategy for the people in Congo to accept our new management plan within 10 years.

2. Model assumptions and notation

2.1. Assumptions

1) There are different types of trees in a forest. To simply the analysis, we only consider three major types of trees in a forest and these three types of trees are dominant tree species.

2) Different trees have different growth processes. We consider the main forest species and takes their average. The 5-10 years old trees are called young trees, the 10-20 years old trees are called middle-aged trees and more than 20 years old are called old trees.

3) We assumed that harvesting has no impact on biodiversity, because biodiversity depends on local climatic conditions and long-term growth of forests.

2.2. Notations

Important notations used in this paper are listed in Table 1.

Table 1. Notations

Symbol	Significance	Unit
x	The proportion of young trees that should be cut down in the whole forest	%
y	The proportion of middle-aged trees that should be cut down in the whole forest	%
z	The proportion of old trees that should be cut down in the whole forest	%

3. Carbon Sequestration Prediction Model and Decision Model

3.1. Develop a Carbon Sequestration Prediction Model

3.1.1 Choose Five Typical Forest Type

To get a global prediction model, we select 5 typical forest types: tropical rainforest, sub-tropical evergreen broad-leaved forest, temperate broad-leaved forests, sub-frigid mixed forest, and frigid conifer forest [3].

3.1.2 Use the Time Series Forecasting Model to Predict

In this part, we will use the Time Series Forecasting model to get the amount of carbon sequestration over 20 years

First, we collect the data of carbon sequestration and the area of the forest in that five typical forests for the past 20 years and calculate the unit carbon sequestration.

Then we use the Moving Average model to predict the future carbon sequestration over 20 years with formulas (1) and (2). The value of N is 9 and 10. We use formula (2) to reduce the error.

$$\hat{y}_{t+1} = M_t^{(1)} = \frac{1}{N}\left(y_t + y_{t-1} + \cdots + y_{t-N+1}\right), t = N, N+1 \tag{1}$$

$$S = \sqrt{\frac{\sum_{t=N+1}^{T}\left(\hat{y}_t - y_t\right)^2}{T-N}} \tag{2}$$

Comparison of data before and after prediction is shown in Figure 1 to Figure 5.

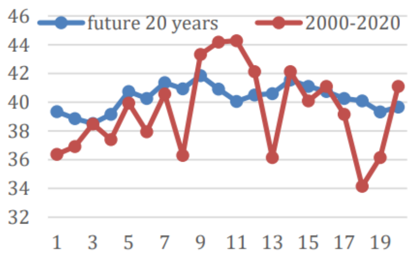

Figure 1. Predicted data of Frigid Zone (Million tons / million hectares)

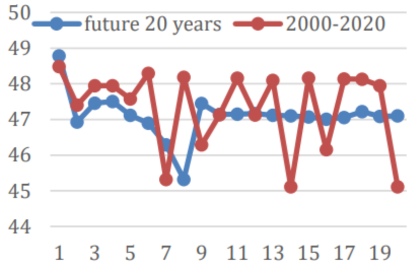

Figure 2. Predicted data of Sub-frigid (Million tons / million hectares)

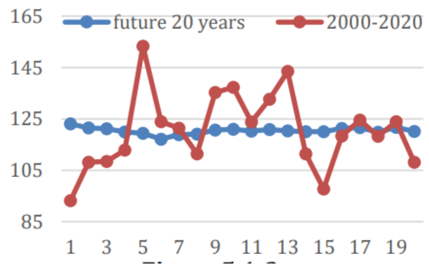

Figure 3. Predicted data of Temperate (Million tons / million hectares)

We collect the status of that six factors from the five typical forests. Then, with the help of BP Neural Network, we put the status and the predicted value we got in step 2 together and build our prediction model [4].

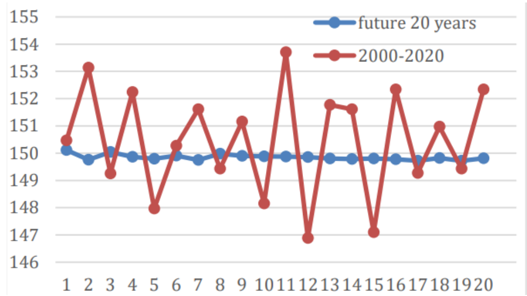

Figure 4. Predicted data of Sub-tropics (Million tons / million hectares)

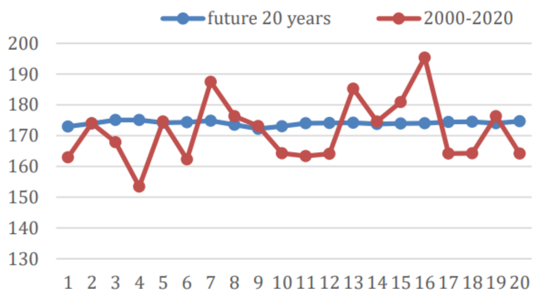

Figure 5. Predicted data of Tropics (Million tons / million hectares)

3.2. Develop a Decision Model

3.2.1 AHP Analysis to Get the Weight of 6 factors

Step1: Build the Hierarchy Model

The details are shown in Figure 6.

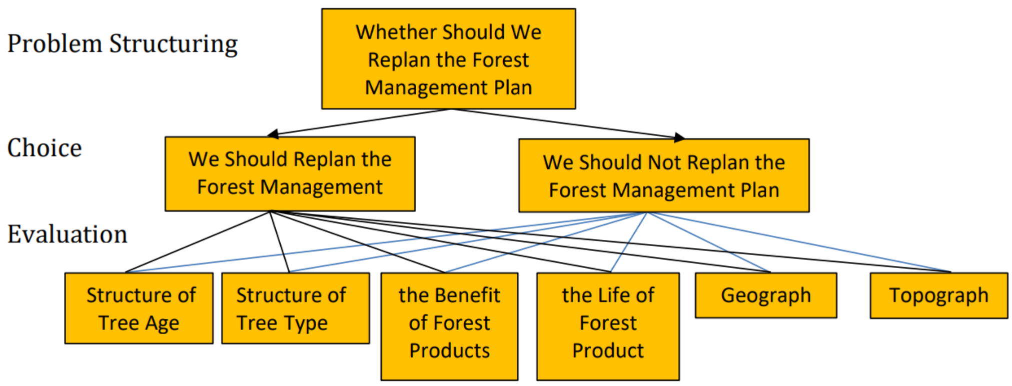

Figure 6. Hierarchy Model

Step2: Build Overall Preference Matrix

The standard way to make the pairwise comparison is to consult more than five professors and ten undergraduates who are majoring in ecology. The overall preference matrix is shown in Table 2.

Table 2. Overall Preference Matrix of 6 factors

	Structment of Tree Age	Structment of Tree Type	Geo-graph	Topo-graph	benefit of forest product	Life of forest product
Structment of Tree Age	1.00	3.00	3.00	7.00	2.00	6.00
Structment of Tree Type	0.33	1.00	2.00	5.00	1.00	5.00
Geo-graph	0.33	0.50	1.00	4.00	2.00	4.00
Topo-graph	0.14	0.20	0.25	1.00	0.33	2. 00
Benefit of forest product	0.50	1.00	0.50	3.00	1.00	5.00
Life of forest product forest product	0.17	0.20	0.25	0.50	0.20	1.00

Step3: Calculate the Weight

According to the matrix above, we can calculate the weight of each index. The answer is shown in the following table. The value of CR is 0.0433 which is less than 0.1, which means our answer passes the consistency test. The weight of each index is shown in Table 3.

Table 3. The weight of each index

Index	The Structment of Tree Age	The Structment of Tree Type	Geo-graph	Topo-graph	Benefit of forest product	Life of forest product
Weight	0.3822	0.2025	0.170	0.0504	0.1562	0.0388

3.2.2 Comprehensive Indicator Scoring Method

In this part, we assumed that the weight of the 6 indexes we got in 3.2.1 doesn't change.

So, to get a total evaluation value to quantitatively evaluate the performance of different forests under different forest management plans, we will calculate the evaluation value of each index under different forest management plans. Then, combined with the weight of indexes, we can get the total evaluation value of different forest management plans. The higher score, the forest management plan more appropriate [5, 6].

Calculations of each index:

Step 1: Calculate the evaluation value of the structure of tree age

Harvesting means more saplings will be planted, the average age of the trees in this forest will decrease and the amount of carbon sequestration will decline. To show this relationship between harvesting, tree ages, and the amount of carbon sequestration, we score the value of tree age with the formula below [7].

We know that when the proportion of harvesting is bigger than 10 percent, it will make irreversible damage to the forest. So, to maintain the sustainable development of the forest farm, we ensure that the forest belongs to the growth-oriented development model.

So x ranges from 0 to 3, y ranges from 0 to 6, and z ranges from 0 to 1.

$$TA = 100 - e^{-k_1 x^2} - e^{-k_2 y^2} - e^{-k_3 z^2} \quad x \in [0,3] \;\; y \in [0,6] \;\; z \in [0,1] \tag{3}$$

The value of k_i means the recovery coefficient of trees of different ages.

The value of TA means the evaluation value of the structure of tree age.

Step 2: Calculate the evaluation value of the structure of tree type

Forests in different temperature zones have different age structures that make carbon sequestration optimal, and trees of different ages have different effects on carbon sequestration.

To evaluate the structure of tree type, we use a, b and c to represent the proportion of middle-aged trees and old trees when carbon sequestration is optimal, and use A, B and C to represent the contribution of young trees, middle-age trees and old trees to carbon sequestration [8].

$$TT = \frac{x \cdot A + y \cdot B + z \cdot C}{a \cdot A + b \cdot B + c \cdot C} \tag{4}$$

The value of TT means the evaluation value of the structure of tree type.

Step 3: Calculate the evaluation value of Geograph and Topograph

Different forests require different forest management plans, and only after a particular forest has been identified can the appropriate forest management plan be discussed. So, when a particular forest is identified, its geography, and topography are fixed and do not change with harvesting. We scored the evaluation value of 'Geograph' about local hydrothermal conditions.

We evaluate the value of 'Topograph' based on the terrain types of forest. The scoring criteria are shown in Table 4 and Table 5.

Table 4. Scoring criteria for hydrothermal conditions ('Geograph')

Climate types	Tropics	Subtropics	Temperate	Sub-frigid	Frigid Zone
Evaluation Value (***G***)	90±10	75±10	60±10	45±10	30±10

Table 5. Scoring criteria for terrain types ('Topograph')

Terrain types	Steep slope	Gentle slope	Plain	Cliff
Evaluation Value (***T***)	60	50	45	30

To simplify the expression, we use ***G*** and T to represent the evaluation value of 'Geograph' and 'Topograph'.

Step 4: Calculate the evaluation value of the benefit of forest product

In this part, we consider the forest product will contribute to the economy and help sequestrate carbon dioxide. More harvesting means more production, accordingly, the benefit will improve. So, the larger proportion of harvesting, the higher score will be had. The harvesting intensity coefficient increases as s increases, the growth coefficient as decreases as s increases [9].

We use the formulas below to calculate the score:

$$s = x + y + z \tag{5}$$

$$BE = 5600 \cdot \frac{\exp\left[\frac{-(t-m)^2}{2 \cdot gr^2}\right]}{gr\sqrt{2\pi}} \tag{6}$$

The value of m means the harvesting intensity coefficient of different forests. The value of gr means the growth coefficient of different trees. The value of BE means the evaluation value of the benefit of forest product.

Step 5: Calculate the evaluation value of the life of forest product

We believe that as the expansion of harvesting scale, which means that the production of raw materials will increase, the quality of the forest products will improve, and, accordingly, the life will be extended to a certain extent. But it should not be ignored that the life of forest products has an upper limit. The formulas used here are:

$$s = x + y + z \tag{7}$$

$$L = 100 \times e^{-5+ns/0.2+\exp(-5+ns)} \tag{8}$$

The value of n shows the quality coefficient of different products. The value of L means the evaluation value of the life of forest product.

Calculations of total score:

Using the method above and combine with the weight of each index, we can calculate different total scores for a specific forest of different forest management plans.

This is our decision model to determine the forest management plan. The formula is in the following:

$$CS = 0.3822 \times TA + 0.2025 \times TT + 0.1700 \times G + 0.0504 \times T + 0.1562 \times B + 0.0388 \times L \quad (9)$$

The value of CS quantitatively describe the contribution of a forest to carbon sequestration.

Our decision model for different forests can be streamlined in formula (9).

3.2.3 Use Genetic Algorithm to Apply Our Decision Model

We apply our decision model to the five typical forests and get their most appropriate management plan [10].

Step 1: Collect the value of relevant coefficients in these five forests.

Relevant coefficients are shown in Table 6 to Table 8.

Table 6. The Value of Coefficient in Different Climate Type

Coefficient Names	Tropics	Subtropics	Temperate	Sub-frigid	Frigid Zone
a (optimal proportion of young trees) (%)	40	39	38	40	30
b (optimal proportion of middle-aged trees) (%)	38	36	35	30	30
c (optimal proportion of old trees) (%)	22	25	27	30	40
A (the contribution of young trees)	40	1	1	1	1
B (the contribution of middle-aged trees)	5	10	10	15	7
C (the contribution of old trees)	30	30	20	25	35

Table 7. Relevant coefficients of the benefit of forest product

Coefficient Names	Tropics	Subtropics	Temperate	Sub-frigid	Frigid Zone
m (harvesting intensity)	7	15	15	17	20
gr (growth coefficient)	30	25	20	17	13

Table 8. Relevant coefficients of the life of forest product

Coefficient Names	Tropics	Subtropics	Temperate	Sub-frigid	Frigid Zone
n (quality)	0.85	0.80	0.75	0.70	0.65

Step 2: Use Genetic Algorithm to determine a management plan

Plug the relevant value of coefficients into the model to get the highest scores of CS for these five forests. Accordingly, we can solve for the exact values of x, y, z and get the best forest management plan for carbon sequestration in 5 different forests.

The results are shown in Figure 7 and Figure 8.

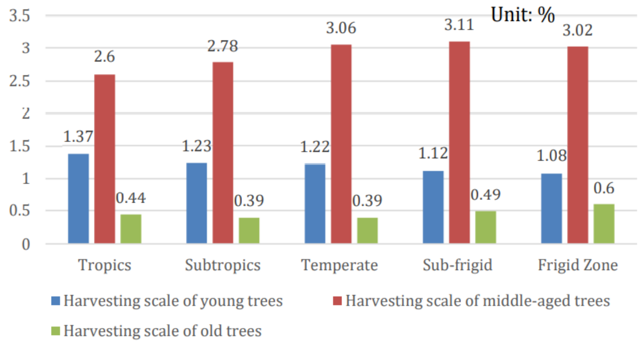

Figure 7. Detail management plan in 5 forests

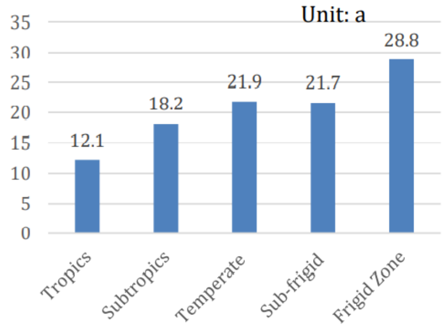

Figure 8. Rotation period in 5 forests

4. Forest Forecast Assessment

4.1. Apply and Extend Prediction Model to 100 Years' prediction

Step 1: Predict the amount of carbon sequestration in 5 typical forests.

Appling our prediction model in Task 1 and using Time Series Forecasting Model, we can get the predicted amount of carbon sequestration in those 5 typical forest types. The prediction data are shown in Figure 9.

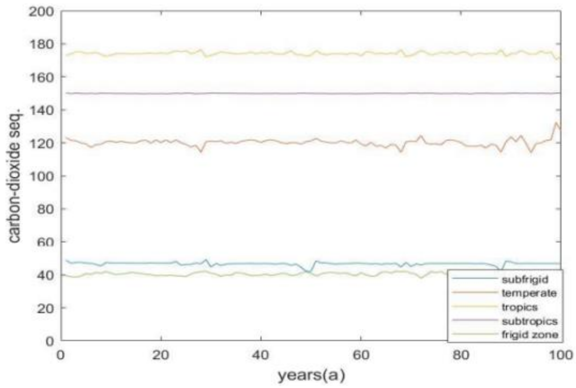

Figure 9. The prediction amount of carbon sequestration 5 typical forests

Step 2: Use BP Neural Network to predict the amount in Congo.

The predicted data of Congo are shown in the Figure 10.

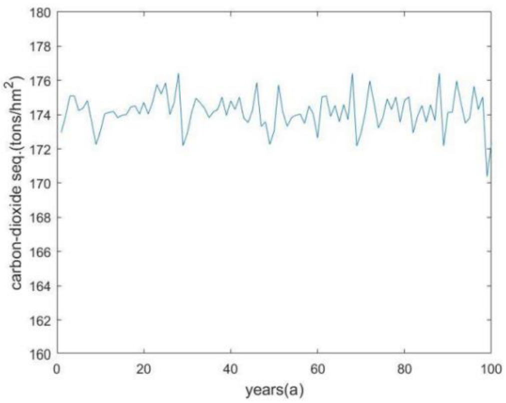

Figure 10. The prediction amount of carbon sequestration in Congo

4.2. Strategy for Transitioning From Different Rotation Period

Using our decision model and the Genetic Algorithm, we can solve the transition period of different rotation period accurately. According to basis data, the optimal rotation period of the forest in Congo should be 14.1 years. So it is assumed that the current rotation period is 4 years.

To find out a strategy for Transitioning from 4 years to 14 years, we only need to set the value of rotation period in the decision model as 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 respectively, then we can get the appropriate harvesting scale during the transition decade. The detail of the annual management plans are shown in Figure 11.

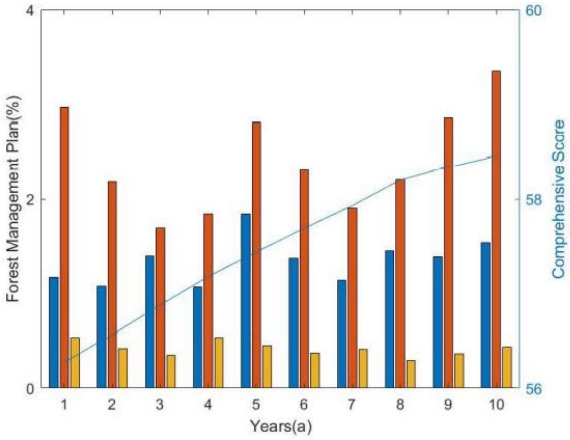

Figure 11. The detail management of Congo in 10 years

5. Conclusion

To determine the carbon sequestration index, a comprehensive analysis of several indicators is used. Genetic algorithm has been applied in all topics, and BP neural network algorithm and time series prediction are combined to enhance the connection of data processing in various parts and improve the accuracy of data. By using genetic algorithm, the local optimal situation is avoided effectively, and the selection of optimal value is applicable to all cases. However, the amount of data used by BP neural network algorithm is not very much, so the predicted results may not be very accurate.

References

[1] Earth Observatory Tracking Amazon Deforestation from Above

[2] Earth Observatory Deforestation in the Democratic Republic of the Congo

[3] Jet Propulsion Laboratory California Institute of Technology Study Examine Forest Vulnerability to Climate Change

[4] Gu S K. Design and implementation of urban forest ecological benefit evaluation system based on WebGIS [D]. Beijing Forestry University, 2012.

[5] ZHANG Y Q. Comparative study on carbon sequestration potential of masson pine phytoliths from different provenances [D]. Zhejiang forestry university, 2019.

[6] Qi, Lingxiu. (2021). The current situation of forest resources and resource protection measures in state-owned forest farms of Aohan Banner (Master's thesis, Inner Mongolia Agricultural University).

[7] Li Yanfang, Wang Jiajing & Xu Danni. (2012). Evaluation of biodiversity in Heilongjiang Province. Environmental Science and Management (12), 153-157.

[8] Ma Chen-Ya. (2021). An analysis of the current situation and measures of forest resource management in state-owned forest farms. Seed Science and Technology (04), 133-134.

[9] Ding, Xianglei, Zhao, W. T. & Huang, Jing. 2011 A new species of the genus Phyllostachys (Hymenoptera, Braconidae) from China. (2021). Optimization strategies for forest resource management and conservation in grassroots state-owned forest farms. Southern Agriculture (35), 54-56.

[10] Galinato, Gregmar I., Olanie, Aaron et al. Long-Term Versus Temporary Certified Emission Reductions in Forest Carbon Sequestration Programs (October 2011). Australian Journal of Agricultural and Resource Economics, Vol. 55, Issue 4, pp. 537-559