Forest Management Plan Based on Comprehensive Benefit Model

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Abstract. Based on a well-documented analysis of influencing factors, this paper provides an effective and referenced forest management scheme to better balance deforestation and comprehensive benefits. First,construct a Carbon Sequestration Model by dividing it into two parts: forest carbon sequestration and forest-derived products carbon sequestration. For forest carbon sequestration, this paper take into account the Net Primary Productivity and estimate based on the Thornthwaite Memoral Model. For forest-derived products, this paper used K-means clustering to analyze the lifespan of wood and combined the conversion factor from wood volume to carbon tons to calculate. this paper analyzed the carbon sequestration model and fitted the relationship between the carbon sequestration per unit of existing forest area and the deforestation, and combined with the peak points to get the forest management plan: the peak point is the largest carbon sequestration per unit area, and you should prepare to cut down trees at this time. In order to prevent the carbon sequestration from becoming lower after the peak value; on the left side of the peak point, the tree needs to continue to grow; on the right side of the peak point, the tree needs to be cut down immediately. Second, based on the carbon sequestration model, this paper consider more factors and use the Entropy Weight Method to build a Comprehensive Benefit Model. this paper analyzed the comprehensive benefit model and fitted the relationship between the comprehensive benefit per unit of existing forest area and deforestation. this paper model is applicable to any forest situation including natural disasters subject to force majeure. when it is on the left side of the peak, it is not necessary to cut down the tree. Next,this paper combine the peak points, namely transition points, to arrive at the forest management plan. Third, this paper apply the comprehensive benefit model to various forests. this paper used a Markov Model to predict carbon sequestration after 100 years, and created a three-dimensional map of carbon sequestration in forests around the world. this paper combine the peak points to derive the forest management plan. this paper combine peak points with Pareto's law to optimize forest management plans

Keywords: Carbon Sequestration Model, K-means, the forest management plan, Entropy Weight Method, Comprehensive Benefit Model.

1. Introduction

Climate change is closely related to our lives, and the biggest cause of climate change is greenhouse gases. In addition to the need to reduce carbon dioxide emissions, it is more important to sequester carbon dioxide in the atmosphere. Forests are estimated to absorb around 30% of global carbon emissions each year, making them the largest and most important carbon sinks on our land. If combining this with the fact that deforestation accounts for around 12% of annual greenhouse gas emissions, the importance of forest conservation becomes even more apparent.

Forest is a natural resource that human beings depend on for survival. Human production and life are inseparable from forest resources. It occupies a very important position in the process of human survival and development. However, because of many factors in our country's forests, we often forget that forests protect our environment as natural buffers against extreme weather[1]. Therefore, we need to combine various factors to find a balance between forest growth and carbon sequestration[2].

2. Carbon Sequestration Model

2.1. Introduction

Our carbon sequestration model consists of two dimensions: the amount of carbon dioxide sequestered by forests and forest-derived products. As a key variable to characterize plant activities, net primary productivity is an important link in the study of material and energy operation in terrestrial ecosystems. It can adopt corresponding strategies and approaches for rational development and utilization of natural resources and the impact on global change. Provide scientific evidence. We obtain the amount of carbon sequestered in forests through a combination of net primary productivity and the Calvin cycle in photosynthesis. The carbon storage of forest-derived products is determined by its longevity and its carbon sink. We used the K-means clustering algorithm to analyze the longevity of wood, calculated by incorporating a conversion factor from wood volume to carbon tons.

2.2. Carbon Sequestration Model

2.2.1 Carbon sequestration of forests

For the carbon sequestration of forests, we consider the net primary productivity, which refers to the removal of the part consumed by its own respiration from the total energy that green plants can fix per unit time and unit area. We estimated the net primary productivity of vegetation based on the Thornthwaite Memorial Model[3]. Its model is as follows

$$\mathrm{NPP} = 3000(1 - e^{-0.0009695(\mathrm{E_r}-20)}) \tag{1}$$

$$\mathrm{E_r} = \frac{1.05\mathrm{P}}{\sqrt{1+(1+\frac{1.05\mathrm{P}}{\mathrm{E_i}})^2}} \tag{2}$$

$$\mathrm{E_i} = 3000 + 25\mathrm{t} + 0.05\mathrm{t}^3 \tag{3}$$

Vegetation can store carbon dioxide in the ecosystem through the Calvin cycle in photosynthesis, so we can estimate the amount of carbon dioxide sequestered through photosynthesis. Its chemical formula should be as follows:

$$6CO_2 + 6H_2O(\text{illuminatation,}$$
$$\text{enzymes,chloroplasts}) \longrightarrow (CH_2O)_n + 6O_2$$

So, for every 1 g of NPP generated, 1.6 g of CO2 can be fixed. That is, =1.6.

After integrating the data, the carbon sequestration amount S1 of the forest can be obtained:

$$\mathrm{S_1} = 3000\,\mathrm{M_{CO_2}}\mathrm{S_t}(1 - e^{-0.0009695(\frac{1.05\mathrm{P}}{\sqrt{1+(1+\frac{1.05\mathrm{P}}{3000+25t+0.05t^3})^2}})}) \tag{4}$$

2.2.2 Carbon sequestration of forest-derived products

For forest-derived products, we analyzed the longevity of wood[4] by K-means clustering, combined with a conversion factor from wood volume to carbon tons[5]. The lifespan of wood is affected by fungal decay, beetles, and termite erosion. We collect the natural durability grades of wood decay fungi, beetles, and termites of different woods, and divide them into 5 comprehensive grades A-E through a clustering algorithm, as shown in Table 1 below.

Table 1: Wood Grade derived from Wood Lifespan

GRADE	WOOD LIFESPAN(L)
A	25
B	20
C	15
D	10
E	5

Table 2: Conversion Factor

CONVERSION FACTOR
1 m^3 wood=0.28 t carbon (Conifers and Poplars)
1 m^3 wood=0.30 t carbon (Broadleaf trees except poplars)
1 hm^2=3.4 t carbon (Broadleaf tree)
1 hm^2=9.6 t carbon (Broadleaf tree)

After combining the data in Table 2[6] above, the carbon sequestration amount S2 of forest-derived products can be obtained:

$$S2 = k_1 L V_w \tag{5}$$

So the expression for carbon sequestration S is:

$$S = S_1 + S_2 = 3000 M_{CO_2} S_t \left(1 - e^{-0.0009695\left(\frac{1.05P}{\sqrt{1+\left(1+\frac{1.05P}{3000+25t+0.05t^3}\right)^2}}\right)}\right) + k_1 L V_w \tag{6}$$

2.3. Analysis of the model

In the model, St is Existing forest area and Vw is the volume of the forest-derived product, so we can obviously get the following relationship:

① $V = \phi(S_t)$

② V_w increases as S_t decreases

To analyze the relationship between the amount of deforestation and the amount of carbon sequestration, we need to know the proportion of deforestation, that is, we need to find the proportion of existing forest area and the volume of forest-derived products($\frac{S_t}{V_w}$)。 By fitting data from different forest areas in the world, we can get an image of the sequestration per unit area and the proportion of carbon forest area and forest-derived products ($\frac{S}{S_t}$ - $\frac{S_t}{V_w}$), like Figure 1:

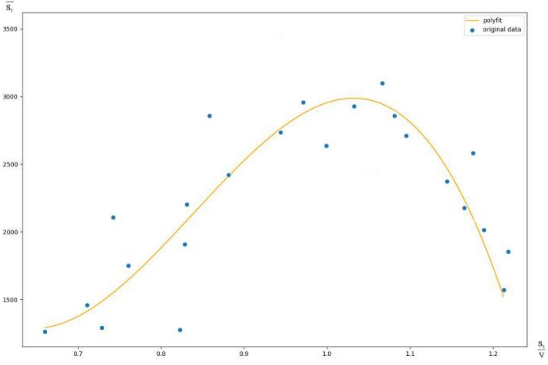

Figure 1: Fitting of Carbon Sequestration per unit Area and Logging

Table 3: Specific value of the Fitting (Figure 1)

implication	Numerical value
Coefficients	[-59307.52071919 149322.41705986 -118703.77117647 31642.83824642]
peak	(1.03209, 2987.32575)
Intersection with the x-axis	(1.279102234, 0)
singular_ values	[1.96054047e+00 3.94206318e-01 2.96835155e-02 1.16300646e-03]
rcond	1.7763568394002505e-15

When the number of forest-derived products rises, the Carbon sequestration per unit area will first rise and then fall. We therefore conclude that when the curve peaks, carbon can be sequestered more effectively and climate change mitigated.

3. Comprehensive Benefit Model

3.1. Introduction

Based on the first carbon sequestration model, we considered more factors and upgraded the model to a comprehensive benefit model. We analyze the strong independence of each element through correlation analysis, and the comprehensive benefit can be expressed linearly. We use the entropy weight method to calculate the weight of each factor to construct a comprehensive benefit model.

3.2. Comprehensive Benefit Model

3.2.1 Correlation analysis

The following variable data comes from forest areas in different countries:

①Total Carbon Sequestration(S)

The free carbon dioxide in the air is retained in a specific way, and the total mass of the fixed carbon dioxide is called 'Total Carbon Sequestration'[7].

②Biodiversity(N) [8]

'Biodiversity' is the ecological complex formed by organisms animals, plants, microorganisms and the environment and the sum total of various ecological processes related to it, including three levels of ecosystem, species and gene . Here we refer only to species diversity.

③GDP per capita(G)

Per capita GDP is often used as an indicator of economic development in development economics. It is one of the most important macroeconomic indicators and is a monetary measure of the market value of all final goods and services produced in a period.

④Average Value of Trees(T)

The economic value of each cubic meter of wood produced after trees are felled and made into wood.

⑤Population(R)

'Population' is the number of people in an area.

Table 4: KMO and Bartlett's Test

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.523
Bartlett's Test of Sphericity	Approx. Chi-Square	19.042
	df	10
	Sig.	.040

First, KMO test and Bartlett's Test were performed on the collected data. From Table 4, we get a KMO value of 0.523 greater than 0.5, which indicates that there is a certain correlation between the data; the Bartlett's Test obtained a significant coefficient of 0.040 less than 0.05, indicating that the data is spherically distributed, and each variable is independent of each other to a certain extent.

Considering that the KMO coefficient is only slightly greater than 0.5, we further performed a Pearson two-tailed test on the data, and the test results are shown in the figure. We found that only two groups of variables have significant correlations. We believe that the overall correlation of the samples is not strong and is not suitable for dimensionality reduction processing. Therefore, these five variables will directly affect the structure of the model.

Based on the above analysis, the comprehensive benefit model we constructed is:

$$B = w_1 S + w_2 N + w_3 G + w_4 T + w_5 R \tag{7}$$

Were,

$$S = 3000 M_{CO_2} S_t \left(1 - e^{-0.0009695\left(\frac{1.05P}{\sqrt{1+\left(1+\frac{1.05P}{3000+25t+0.05t^3}\right)^2}}\right)}\right) + k_1 L V_w \tag{8}$$

$T = \phi(V)$

3.2.2 EWM-IDM

After summarizing the data the entropy weight method is used to obtain the weight of each indicator.

① data normalization

Because the order of magnitude of each indicator is different, the data need to be converted into the same range and then compared. Assuming that the standardized data matrix element is rij:

$$r_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}} \tag{9}$$

Where,Xij is the original value of the jth indicator data of the ith unit.

② Calculate information entropy

After the above processing, we can form a data matrix R:

$$R = (r_{ij})_{m*n} \tag{10}$$

For each index rj, its information entropy is Ej:

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{11}$$

$$p_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \tag{12}$$

③ Calculate weights

We can calculate weights Wij from this:

$$w_{ij} = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \tag{13}$$

The result is shown in Figure 2 below.

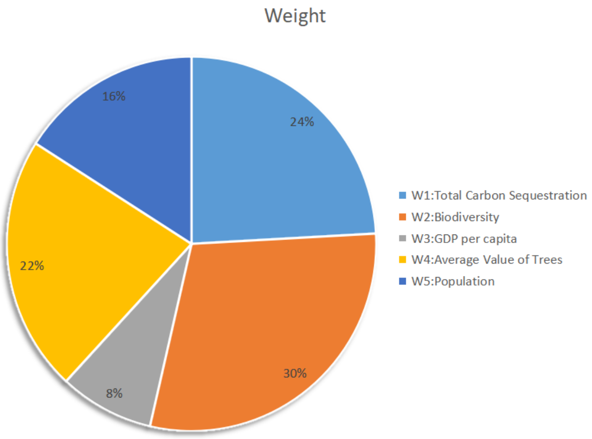

Figure 2: Results of the Entropy Weight Method

In order to analyze the relationship between the amount of deforestation and the comprehensive benefit, we need to know the proportion of deforestation, namely we need to find the proportion of existing forest area and the amount of forest-derived products ($\frac{S_t}{V_w}$). By fitting data from different forest regions in the world, we can get the overall benefit per unit area and the proportion of forest area and forest derivatives ($\frac{B}{S_t}-\frac{S_t}{V_w}$), shown in Figure 3.

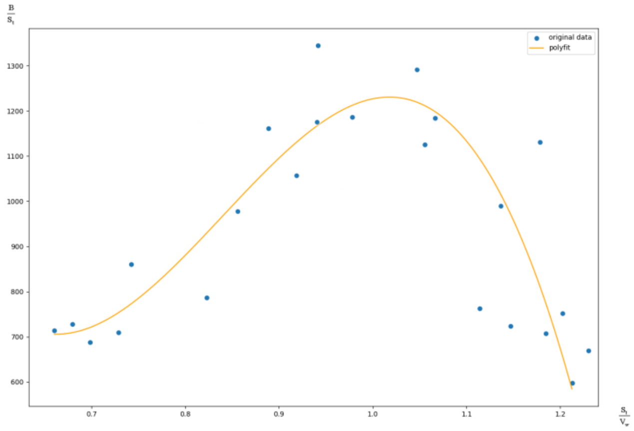

Figure 3: Fitting of Comprehensive Benefits per unit Area and Logging Conditions

Table 5: Specific value of the Fitting (Figure 3)

implication	Numerical value
Coefficients	[-23475.29302164 59187.81654225 -47525.74804351 13039.81736038]
peak	(1.0178999999999998,1230.4471180761102)
Intersection with the x-axis	(1.27545988,0)
singular_ values	[1.96054047e+00 3.94206318e-01 2.96835155e-02 1.16300646e-03]
rcond	1.7763568394002505e-15

4. Application of the model

4.1. Introduction

In order to better apply our model to future development [9], we combine the comprehensive benefit model with the Markov model. We divided different logging situations into 100 intervals, and constructed a transition probability matrix combining normal distribution and management plan. Through data collection on most of the world's forests, a three-dimensional map of carbon sequestration in forests around the world was built. Finally, we combine the Pareto principle [10] to optimize the forest management plan.

4.2. Markov model

According to our assumption, any plan of forest is beneficial to social development, so the comprehensive benefit is positive. We take the interval $\frac{B}{S_t}>0$ from $\frac{B}{S_t}-\frac{S_t}{V_w}$,namely [0,1.28] 。We quantify this interval and divide it into 100 small intervals, then all situations exist in the interval.

The Markov model considers that each state only depends on the previous state, then we can get:

$$\begin{aligned}&P(Xn+1 \mid X1 = x1, X2 = x2,...,\\&Xn = xn) = P(Xn+1 = x \mid Xn = xn)\end{aligned} \tag{14}$$

The intervals transfer process satisfies the above conditions, so the Markov model can be used. By combining our forest management plan and the normal distribution, , we can get the transition probability matrix P:

$$P=\begin{bmatrix} p_{1,1} & p_{1,2} & \cdots & \cdots & p_{1,100}\\ p_{2,1} & p_{2,2} & \cdots & \cdots & p_{2,100}\\ \vdots & \vdots & \ddots & & \vdots\\ \vdots & \vdots & & \ddots & \vdots\\ p_{100,1} & p_{232,2} & \cdots & \cdots & p_{100,100}\end{bmatrix} \tag{15}$$

Since the transition probability is positive and the interval will definitely stay in the original interval or move to another interval in the next period, the matrix has the following properties:

① $p_{i,j}>0, i, j=1,2,\ldots,100$

② $\sum p_{i,j}=1, i=1,2,\ldots,100$

According to the existing stock of different forests and the volume of forest derivatives , we can get the initial state matrix Mk and matrix M0 :

$$M_k=\begin{bmatrix} n_1\\ n_2\\ \vdots\\ n_{100}\end{bmatrix} \qquad M_0=\begin{bmatrix} y_1\\ y_2\\ \vdots\\ y_{100}\end{bmatrix} \tag{16}$$

Here,ni (i=1,2,…,100)=0 or 1. yi (i=1,2,…,100) is the correspondence between intervals and carbon sequestration per unit area.

Define the rule of notation $\otimes$ is that

$$\begin{bmatrix} A_1 & A_2\\ A_3 & A_4\end{bmatrix}\otimes\begin{bmatrix} B_1 & B_2\\ B_3 & B_4\end{bmatrix}=\begin{bmatrix} A_1*B_1 & A_2*B_2\\ A_3*B_3 & A_4*B_4\end{bmatrix} \tag{17}$$

From this, we can get the carbon sequestration amount per unit area of forest in the y-th year:

$$N^y = M_0 \otimes (M_k^T * P^y)^T \tag{18}$$

The total amount of carbon sequestered from now to y-year only needs to be summed over the years, graphs as shown in Figure 4 to 9.

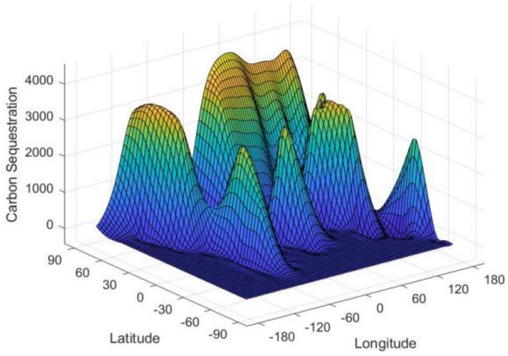

Figure 4: Carbon Sequestration in 2022

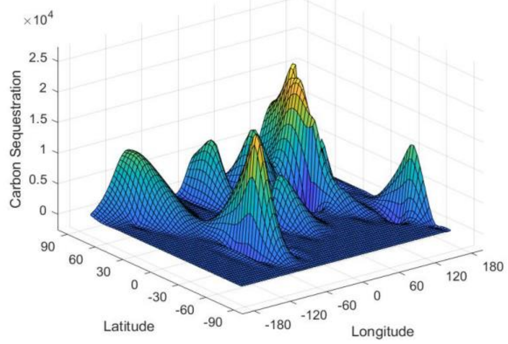

Figure 5: Carbon Sequestration in 2042

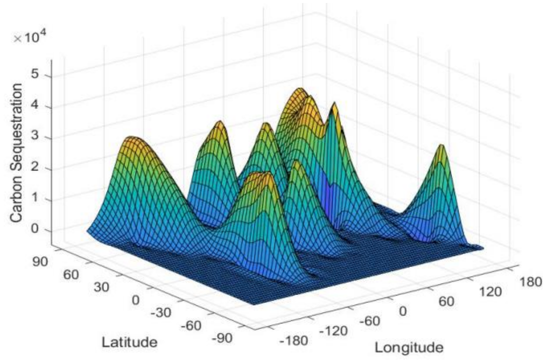

Figure 6: Carbon Sequestration in 2062

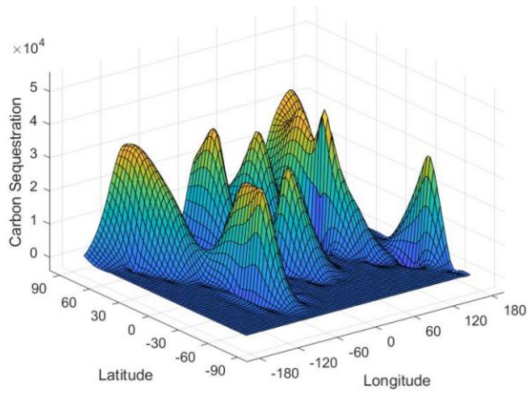

Figure 7: Carbon Sequestration in 2082

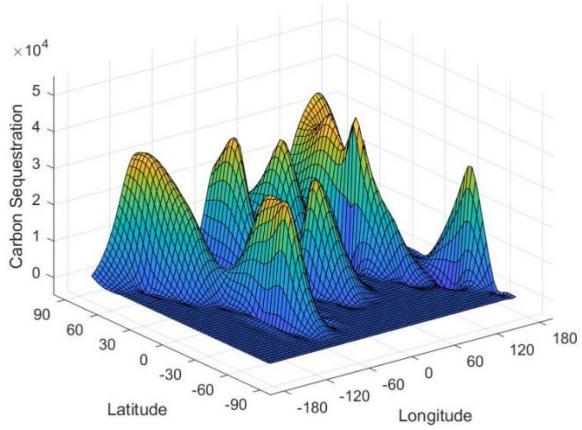

Figure 8: Carbon Sequestration in 2102

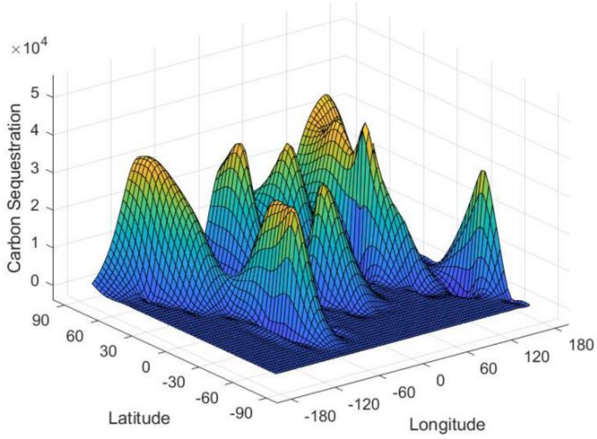

Figure 9: Carbon Sequestration in 2122

5. Conclusion

This paper consider that there are two ways for forest carbon fixation: one is that the plants themselves fix carbon dioxide in the air through the Calvin cycle and respiration, and the other is that products are made after trees are cut down, and then the carbon in the wood is retained in the product. We calculated the amount of carbon sequestered by trees through NPP and the corresponding chemical equation.

Next, this paper classified and estimated the service life of the corresponding wood products according to the natural durability coefficient of various types of wood, and then multiplied by the carbon sequestration conversion factor, and finally obtained the carbon sequestration amount of the wood products. We combined the two together and got a Carbon Sequestration Model.

And through data fitting, a curve is obtained. The extreme point of the curve represents the optimal amount of tree felling, the left side of the pole represents the felling of fewer trees, and the right side of the pole represents the felling of too many trees

In this model we take into account several factors including carbon sequestration. After collecting the relevant data, the data analysis is carried out, and it is found that there is a weak correlation between the factors, but a strong independence. Therefore, we consider the impact of these five factors on the forest area value separately. The sum of the five expressions obtained after calculation and analysis is enough to form a comprehensive evaluation model, which involves multiple dimensions and can comprehensively evaluate the overall value of a forest area.

This paper model is suitable for most situations including excessive deforestation or some force majeure factors (such as earthquakes, forest fires, landslides, etc.). As a forest farm manager, according to our model, they need to prohibit or open up logging in forest areas in a timely manner.

After logging, they should also pay attention to whether the forest needs people to plant trees to help its restoration.

Some existing forests have a small area, and the continued growth of forests can increase its comprehensive benefits. In this case, the forest farm manager should prohibit logging and allow it to grow naturally so that it can give full play to its value.

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