Assessment of the Potential Capacity of Carbon Sequestration of forest

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Abstract. Climate change poses a great threat to human survival, and therefore strong actions are needed to reduce the amount of greenhouse gases in the atmosphere in order to mitigate the effects of climate change, and forests play an important role in the process of greenhouse gas sequestration. To assess the carbon sequestration capacity of forests, this paper develops a carbon sequestration model to measure the amount of carbon sequestered in forests: first, an overview of the carbon sequestration content of forest vegetation is given, and various influencing factors affecting this content are listed. Then, the entropy weight method and the topsis integrated evaluation method were used to determine the effects of vegetation type, age and geography of the forest on the amount of carbon sequestered in the forest. After that, the changes of CO2 sequestration in the forest over time were further explored using Volterra class. In addition, the benefits and longevity of forest products are then integrated to determine how much CO2 can be sequestered by the forest and its products over time.

Keywords: carbon sequestration model, multi-objective model, Integrated evaluation method, Forest Products.

1. Introduction

In recent years, a series of environmental problems have emerged, such as the greenhouse effect, the melting of the Antarctic ice cap, rising sea levels, threats to marine life, the destruction of ecological balance, and the repeated occurrence of extreme weather, frequent typhoons and hurricanes, high temperatures, droughts, heavy rains, mudslides and other natural disasters. These phenomena have been highly valued around the world. Excessive CO2 emissions are an important cause. Human activities have a significant impact, and the consumption of fossil energy such as coal, oil and natural gas generates large amounts of greenhouse gases.

Many initiatives have been taken around the world to address world climate change effectively, control greenhouse gas emissions and achieve sustainable development. The development of alternative energy sources is a way to control global climate change. However, economic and technological requirements have not yet been met, insufficient costs or some technical shortcomings have not been resolved, the demand for energy continues to rise, alternative energy sources still cannot become the main source of energy for human survival and development for the time being. The International Energy Agency also expects that in the coming decades, as the world economy continues to develop, energy supply will still be dominated by fossil energy [1]. Moreover, it is not enough to reduce carbon emissions, but it is equally significant to sequester the emitted carbon [2].

Therefore, it is crucial to search for more practical and efficient ways to regulate climate change, such as carbon sequestration. Through photosynthesis, plants can convert carbon dioxide in the air into carbohydrates. As a result, carbon can be fixed in the form of organic carbon in plants, soil and the water environment, which is also known as biological carbon sequestration [3-4]. Not only forests but also forest products can be used for carbon sequestration.

We need to establish a model to determine the carbon sequestration of forests and their products over time. Some scholars have studied forest management planning decision model based on carbon storage prediction, the forest is divided into artificial forest and natural forest in their paper. The AR(P) model predict the two forest types respectively, and the final carbon sink reserve prediction model is obtained. They score the forests by TOPSIS method in various provinces[5].To address these questions, we prepare to provide an overview of the carbon sequestration content of forest vegetation and list the various influencing factors that affect that content. We then need to develop a model to determine the effect of different forest vegetation types as well as geography on the amount of carbon sequestered by the forest. In addition, the benefits and longevity of forest products are then integrated to determine how much CO2 can be sequestered by the forest and its products over time.

2. Model Theory of the Carbon Sequestration

2.1. Determining the Effects of Different Forest Vegetation Types and Geography on the Amount of Carbon Sequestered by Forests

Trees grow through the stages of young, middle-aged, near-mature, mature, and over-mature forests, and their carbon stocks are inextricably linked to their age. The carbon stock of forest organisms can be calculated by multiplying the biomass of the forest with the carbon content of the biomass[6]. Taking the Greater Khingan Range forest area as an example, the carbon stock of middle-aged trees is calculated to be the largest and the carbon stock of young trees is the smallest, which seems to be in line with our conventional knowledge. And the carbon stocks of other age-stage woods are, in descending order, mature, near-mature, and over-mature forests.

"The carbon density of forests varies greatly among different age groups, which is also an important factor *in determining their carbon stocks. The magnitude of carbon density in Chinese forests is in the order of:*

Over-mature *forest > mature forest > near-mature forest > middle-aged forest > young forest and the* older *the forest age the higher the carbon density.[7]"*

In addition, the carbon stock varies according to the type of trees. We can see from the table that the highest carbon stock is in mature forest of *pinus sylvestris var. mongolica forests* and the lowest carbon stock is in young forest of *quercus mongolica forests*. We conjecture that under the condition that the structural diversity of the forest does not decrease, the overall carbon sequestration capacity will be enhanced if more trees with high carbon stocks are planted. The more complex the structure of the forest and the greater the biodiversity, the higher the overall carbon sequestration capacity of the forest should be. We used BP Neural Network to perform a comprehensive analysis to verify the correctness of our conjecture. We classify the age and type of vegetation into five classes o_1, o_2, o_3, o_4, o_5 (representing the stages of young, middle-aged, near-mature, mature, and over-mature forests respectively) and q_1, q_2, q_3, q_4, q_5 (vegetation carbon content rating from high to low), let them be 0.31, 1, 0.72, 0.85, 0.69 and 1, 0.8, 0.6, 0.4, 0.2.

At the same time, the geography also has an impact on the carbon stock of the forest. The average elevation of Greater Khingan Range is 1100-1400m, and the east side is mostly plain and the west side is mostly plateau.By random sampling and typical sampling method, 100 plots of the same type of vegetation such as birch forest in different topographic conditions of the Greater Khingan Range were taken, each plot was 20 m × 20 m, and the age of trees in them was measured and counted[8]. We determined slope, slope direction and elevation as our independent variables, and divided several levels with the aim of detecting the carbon storage of trees under different topographic conditions[9]. For example, the slope is divided into three levels, 1-10°, 11-20°, and 21-30°. Here we used the SNK method (Student-Newman-Keuls), which takes the difference between two sample means, divides by the standard error, and finally compares them to obtain a more reasonable division of carbon stocks, 1-15° and 15-30°. We recorded the slope direction of the mountain as two levels: sunny side and shady side (set as a and b respectively). The altitude was divided into 1100-1250m and 1250-1400m. Next, the product of carbon content rate and biomass was used to calculate the carbon content. Carbon density is the rate of carbon stock to biomass area or obtained directly by multiplying the carbon content rate and biomass density. The carbon content rate can be obtained by sampling betula platyphylla forests and then measuring and weighting them. The soils of the Greater Khingan Range region are fertile and have high carbon stocks. We can also calculate the carbon stock and carbon density by using the equation (1) and equation (2).

$$P=BK \tag{1}$$

$$SOP= \sum_{i=1}^{n} p_i c_i d_i S_i \times 10^{-3} \tag{2}$$

Note that the variables used in the equation above are shown in Table.1:

Table 1. Variable name

Abbreviation	Abbreviation Description
C	Total carbon content (t)
P	Carbon density (t/hm^2)
K	Carbon content rate
B	Biomass density (t/hm^2)
SOP	Soil organic carbon density (t/hm^2)
S	Forest stand unit area (1 hm^2)
p_i	Density of the i-th layer of soil (g/cm^3)
c_i	Organic carbon content of the i-th layer of soil (g/kg)
d_i	Thickness of the i-th layer of soil (cm)

We can also get the total carbon stock by summing up the tree carbon stock and soil carbon stock.

First we analyze these three factors separately.Carbon content of different slopes and altitudes are shown in Figure.1.

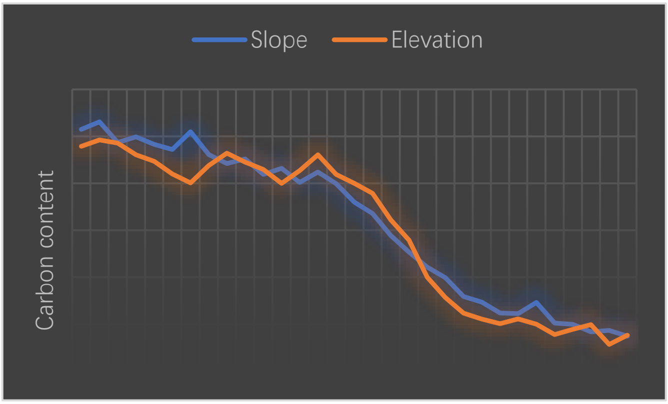

Figure 1. Carbon content of different slopes and altitudes

Further fitting gives,as shown in Figure.2:

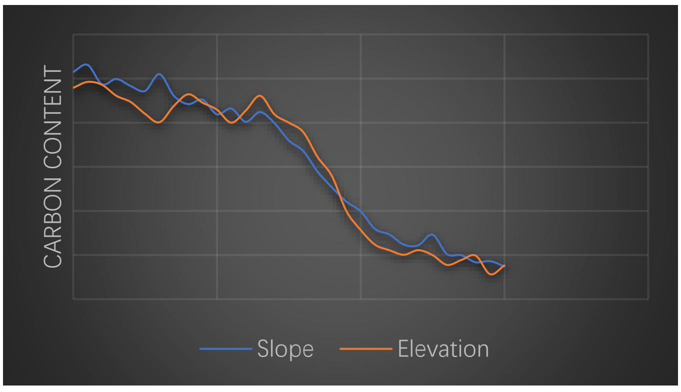

Figure 2. Fitted graphs of carbon content for different slopes and elevations

We analyzed this data using the integrated evaluation method and fitted the mathematical model equation as shown in equation (3) and (4).

$$C_x = \frac{189.49}{1+\left(\frac{x}{4.76}\right)^{6.38}} + 367.91 \tag{3}$$

$$C_z = 539.87 - \frac{586.32}{1+e^{-0.026\times(z-1518.39)}} \tag{4}$$

Note that the variables used in the equation above are shown in Table 2:

Table 2. Variable name

Abbreviation	Abbreviation Description
C_x	Carbon content with slope as the independent variable
C_z	Carbon content with elevation as the independent variable
x	Slope
y	Elevation

We calculated the average value of carbon stock for the two upward slope samples and plotted the following histogram in Figure 3.

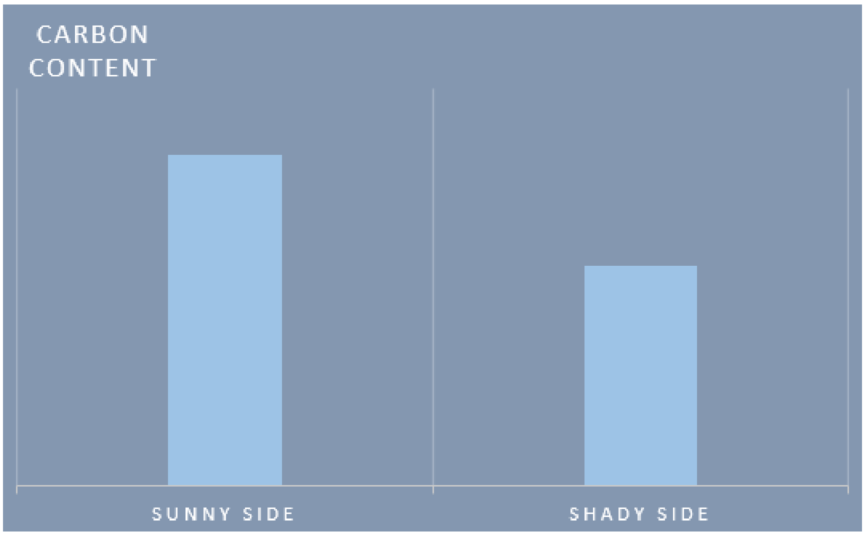

Figure 3. Carbon content of different slope directions

The DPS data analysis system was used to analyze the data, and a multi-factor model was developed using topsis comprehensive evaluation method at the same time. Then we further analyzed the three correlations to obtain in Table.3:

Table 3. Correlation analysis of slope, slope direction, elevation and carbon stock

	M	x_1	x_2	y_1	y_2	z_1	z_2
M	1						
x_1	0.938	1					
x_2	0.752	0.007	1				
y_1	0.986	0.429	0.394	1			
y_2	0.673	0.405	0.336	0.029	1		
z_1	0.892	0.392	0.401	0.773	0.76	1	
z_2	0.75	0.463	0.627	0.797	0.74	0.03	1

Note that the variables used above are shown in Table 4:

Table 4. Variable name

Abbreviation	Abbreviation Description
M	Carbon content rate
x_1	Slope 1-15°
x_2	Slope 15-30°
y_1	Slope to the sunrise side
y_2	Slope towards the shaded side
z_1	Elevation 1100-1250m
z_2	Elevation 1250-1400m

We put the slope, slope direction and elevation into the same model. And we use the entropy method to obtain an expression for the total carbon stock. The carbon content affected by slope, orientation and altitude is C_1. The following equation(5) was obtained:

$$C_1 = 0.192C_x + 0.204C_{y1} + 0.136C_{y2} + 0.468C_z \tag{5}$$

If it is sunny side, then C_{y1} equals to 1, C_{y2} equals to 0.

If it is the shady side, then C_{y1} equals to 0, C_{y2} equals to 1.

And it was found to be basically consistent with our calculated values.

An important part of the geographical environment is climate, water resources and soil conditions[10]. The climate of Greater Khingan Range is colder and the water system is more abundant. We went to find the climate, water resources and soil conditions of forests in other places, and classified them into four classes m1, m2, m3, m4, four classes n1, n2, n3, n4 and u1, u2, u3, u4, respectively by SNK method. Moreover, we let m1, m2, m3, m4 be 1, 0.89, 0.62, 0.54, and n1, n2, n3, n4 be 1, 0.97, 0.90, 0.72, 0.43, and u1, u2, u3, u4 be 1, 0.76, 0.54, 0.23, respectively.

This model is based on the forest itself, with variables such as age and type of trees, as well as a combination of geographic and topographic considerations. The carbon content influenced by the forest itself and the environment is C2.

We analyze the data to obtain equation(6):

$$C_2 = m_i\, n_j\, u_k\, o_h^3 q_l^2 C_1 \tag{6}$$

Among them, i=1,2,3,4; j=1,2,3,4; k=1,2,3,4; h=1,2,3,4,5; l=1,2,3,4,5.

2.2. Assessing the Benefits and Longevity of Forest Products

We plan to develop an appropriate model to maximize the carbon stock by properly harvesting the forest under certain conditions. We measured the carbon stock during the growth of trees roughly as such a curve with an upward and then downward trend, while the carbon density is increasing with the growth of trees. The higher the carbon density of the trees, the higher the carbon density of the forest products, and the higher the carbon stock of the same product with the same specifications. Through calculation, we found that cutting down trees during the over-maturity period and planting some new trees at the same time to increase the proportion of middle-aged forests. we can get the carbon fixing supplement from new trees while the forest products fix more carbon, and the sum of these two carbon fixing amounts obtains the maximum at this time. The carbon content of the forest over time (age) is denoted as C_3.

The following equation (7) is obtained:

$$C_3 = C_2 \sum_{h=1}^{5} \left(\log_{1.6} \frac{t}{o_h} \right) \tag{7}$$

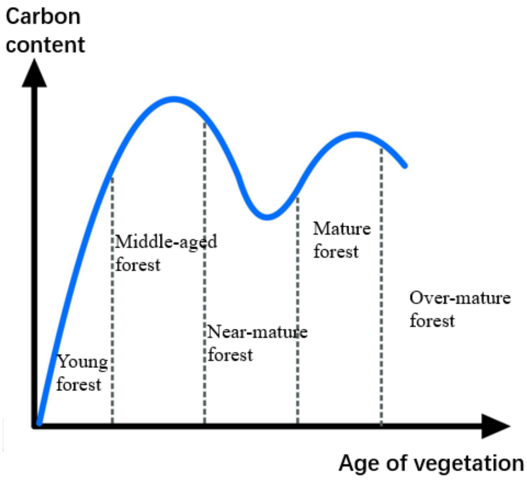

Figure 4. Fitting curve of carbon content with the age of vegetation

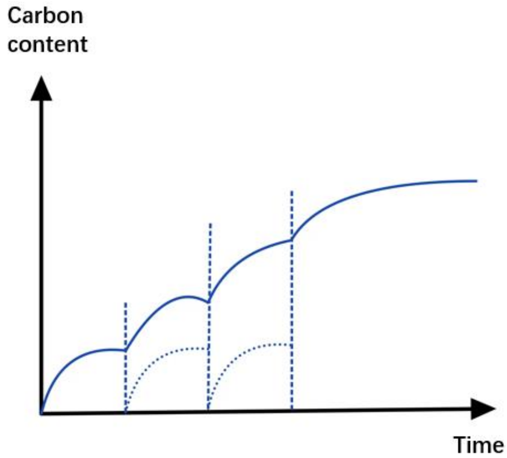

Figure 5. Fitting curve of carbon content with time

It is important to note that we also have to set a fixed harvesting cycle and fixed planting cycle . This is a combination of the amount of human demand for forest products that can be interpreted as the benefits of the forest products, and the life span of the forest products. Paper and some other wood products emit carbon by burning and decaying, and the life span of forest products certainly varies from one forest product to another. Eventually the total carbon stock is close to the equilibrium level and hardly ever changes again. Using time, benefits of forest products (W) and lifetime (T) as variables, we build model B to consider the carbon dioxide storage of forests and forest products over time as shown in Figure.4 and Figure 5.

The carbon content of the forest and its products over time is denoted as C .Combining the above models, we arrive at the equation (8)

$$C = -ae^{-kt} + m[\ln(T+t)]W - \frac{39.28}{1+\left(\frac{\mathrm{t}}{62.87}\right)^{2.86}} + C_3, t \le mT, m \in N \tag{8}$$

3. Conclusion

Climate change poses a huge threat to life. To mitigate the effects of climate change, we need to take powerful action to reduce the amount of greenhouse gases in the atmosphere, and how to cut down forests becomes the important issue of the moment. In order to develop deforestation guidelines for forest managers around the world, our group developed a carbon sequestration model to measure the amount of carbon sequestered in a forest.

We developed a multi-objective model based on vegetation type, age, and geography, and used the Student-Newman-Keuls (SNK) method to classify the classes, and used the Back Propagation Neural Network and DPS data analysis system to analyze the data. The effects of vegetation type, age, and geography of the forest on the amount of carbon sequestered by the forest were determined using entropy weight method and topsis integrated evaluation method. After that, the changes of carbon dioxide sequestration by the forest over time were further explored using the Volterra class. Besides, we investigate forest products, integrating the analysis of both benefits and longevity of forest products to determine the maximum effective value of carbon sequestration by determining forest products over time and calculating the amount of carbon sequestered by new trees after deforestation for forest products.

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