Carbon Sequestration Model Considering Forest Growth Cycle

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Abstract: According to the World Meteorological Organization, "record" greenhouse gas concentrations and heat accumulation have pushed the planet into uncharted territory, driving global warming. We need to figure out how to mitigate global warming by maximizing the overall benefits of forests based on the optimal deforestation period. This provides a basis for decision-making for forest managers. At the micro level, we only consider the carbon sequestration capacity of individual trees. AHP was used to determine the more important influencing factors. The S-curve model was fitted by single-factor and multi-factor analysis to obtain the carbon sequestration saturation point. It should be cut down at the saturation point of carbon sequestration. At the macro level, we consider the carbon sequestration capacity of forests. Therefore, from the economics perspective, we construct a carbon sequestration benefit model based on the optimal rotation period and deduce the optimal and maximum carbon sequestration benefits.

1. Introduction

On October 31, 2021, the World Meteorological Organization issued an interim report on the "State of the Global Climate in 2021". The World Meteorological Organization claims that "record" atmospheric greenhouse gas concentrations and heat accumulation have pushed the planet "into uncharted territory" and will have "profound implications" for present and future generations.[1]

According to the report statistics, the global average temperature (January to September) in 2021 will be about 1.09 degrees Celsius higher than that of 1850-1900 and is currently ranked by the World Meteorological Organization as the sixth or seventh warmest year on record globally. The deterioration of the climate situation has led to the frequent occurrence of extreme weather in many parts of the world, such as major forest fires, floods, and droughts. Extreme weather events, violent conflict, economic downturns, and pandemic shocks have created a "dangerous compound effect" that undermines decades of global progress in improving food security.

We must focus on addressing the climate issue to get to its roots. With the improvement of carbon sequestration measurement technology and the rapid development of related industries, forest carbon sequestration plays an irreplaceable role in adapting to and mitigating climate change.[2]

2. Construction of carbon sequestration model

Research points out that carbon sequestration is a process of capturing and storing carbon dioxide from the atmosphere. In this context, forest carbon sequestration is the fixation of greenhouse gases such as carbon dioxide in the atmosphere by forests in vegetation. The greenhouse gases referred to in the following text only consider carbon dioxide. Forests absorb carbon dioxide from the air through photosynthesis, store it in vegetation in organic matter, and release carbon dioxide through respiration, a natural property of forest ecosystems. When photosynthesis is greater than respiration, forests can reduce the concentration of greenhouse gases in the air. The process of carbon dioxide absorption and release accompanies the entire life process of the forest ecosystem and is affected by many factors, such as the age, type, geography, topography, and environment in which the tree is grown.

Many factors affect carbon sequestration capacity. Su Qian et al. studied the environmental factors during tree growth, including height, temperature, air humidity, light, etc. Based on the above, we select the following 7 influencing factors, forest area, air humidity, soil humidity, terrain, temperature, latitude, longitude, and light. The analytic hierarchy calculates the weights, and the more important factors are selected.

2.1. Getting the weight vector

Determine the judgment matrix. In AHP, the 1-9 method expresses the relative importance between criteria. To construct the judgment matrix $A=(a_{ij})_{n*n}$, each element

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must satisfy the following constraints: a_{ij}>0. Our hierarchical structure has only two layers, the factor layer and the indicator layer. The structure is shown in Table 1.

Table 1 Target factor layer

Goal	Influencing Factors
Index weight ranking	Forest Area
	Air Humidity
	Soil Moisture
	Terrain
	Temperature
	Longitude And Latitude
	Illumination

2.2. Applying consistency checking

$$CI = \frac{\lambda_{max}}{n-1}$$

We calculate the consistency ratio by $CR = \frac{CI}{RI}$. If $CR<$ 0.1, we consider the judgment matrix qualified, and the eigenvector with the largest eigenvalue can be used as the weight vector. Otherwise, the judgment matrix needs to be modified until the less-than condition is satisfied. Combining the above steps, the following analysis and results are obtained.

2.3. Analyzing results

Determine the judgment matrix.

$$A = \begin{bmatrix} 1 & 1/3 & 2 & 1/5 & 1/8 & 1/2 & 1/9 \\ 3 & 1 & 3 & 1/2 & 1/6 & 1/2 & 1/7 \\ 1/2 & 1/2 & 1 & 1/5 & 1/7 & 1/3 & 1/7 \\ 5 & 2 & 5 & 1 & 1 & 3 & 1 \\ 8 & 6 & 7 & 1 & 1 & 2 & 1 \\ 2 & 2 & 3 & 1/3 & 1/2 & 1 & 1/3 \\ 9 & 7 & 7 & 1 & 1 & 3 & 1 \end{bmatrix}$$

Calculation results

Compliance check: CR=0.0365<0.1

u = (**0.384**, 0.0711, **0.312**, 0.2114, **0.2614**, 0.0969, **0.2897**)

According to the weight, the top four influencing factors are forest area, soil moisture, light, and season.

3. Construction of forest carbon sequestration capacity model based on the S-curve model

3.1. Single factor analysis

- Forest area

The carbon sequestration capacity of a forest must be positively correlated with its area. At the same time, the forest is also releasing carbon dioxide at a certain rate, so there is a theoretical equilibrium limit. The S-curve model satisfies the characteristics of increment and has an upper bound approximation, and is widely used in plant growth and development. For example, Dai Hongfen et al. fit the S-curve growth curve equation to realize the nonlinear regression between longan fruit's growth and development time.[3]

- Light intensity

According to the reaction formula of photosynthesis, with the increase of light intensity, photosynthesis gradually increases and then decreases slowly after reaching a maximum value. However, in real life, the light intensity conditions that can significantly reduce the photosynthetic intensity are often difficult to achieve. At the same time, carbon sequestration can be characterized as the carbon sequestration rate in a certain period, that is, the accumulation of photosynthetic rate.

- Dry and humidity

Water plays the role of dissolution and transportation in organisms' metabolic process, and trees' way of obtaining water mainly depends on the absorption of roots. That is to say, soil dryness and humidity considerably determine the metabolic rate of trees, thereby affecting the rate of carbon sequestration. In the case of too little or too much water, the water absorption rate of trees will be limited by the water absorption per unit area and the soil oxygen concentration, which will delay the carbon sequestration rate, while when the soil water content is moderate, the carbon sequestration rate will be limited. Rather, it is relatively fast. [4]

Through the above analysis, it is inferred that the forest area, light intensity, dry humidity, and forest carbon sequestration can be fitted by the S-curve model. We counted the forest carbon storage (Tg), forest area (hm^2), annual average soil moisture (%), and light intensity (Lux) of the six continents in the world (except Antarctica) in 2020. The S-curve model fits light intensity and forest carbon storage, and the fitting results are shown in the figure:

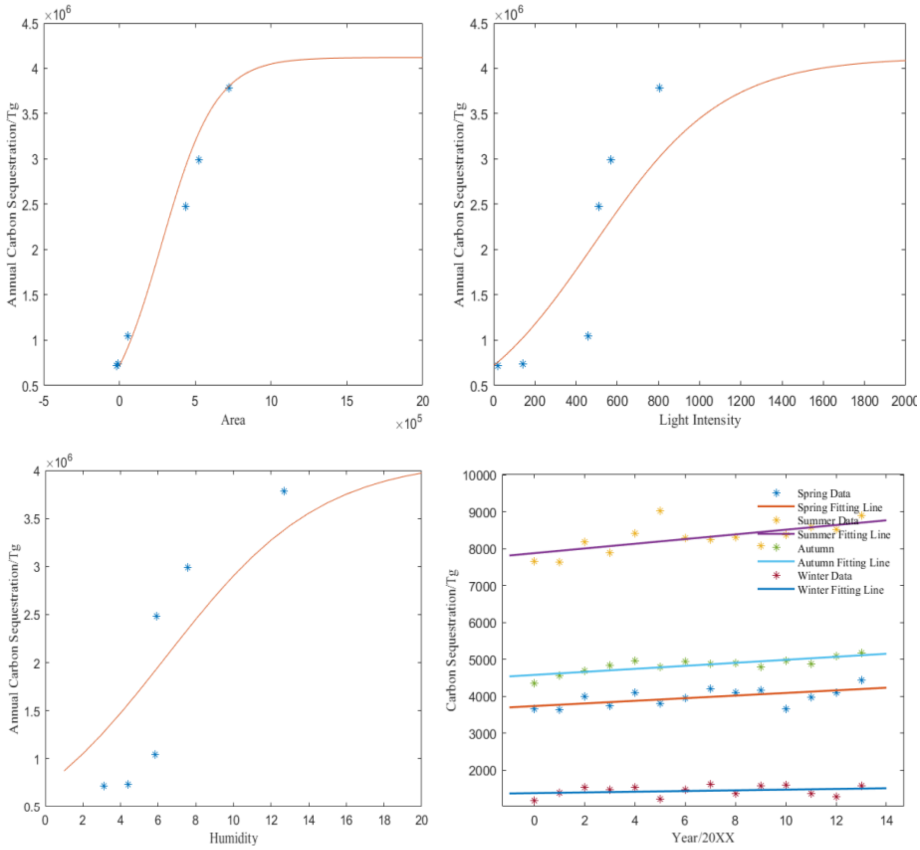

Figure 1 Single factor fitting curve group (forest area, light intensity, dry humidity, season)

We can see that the forest area and carbon sequestration conform to the S-curve. It is rare for a single forest to grow to the point where it can achieve its carbon balance. With no human overexploitation and major natural disasters, the world can maintain its carbon balance. That is to say, the forest area corresponding to the equilibrium point should be between the forest with the largest area and the total forest area in the world. However, there were obvious deviations in the fitting of light intensity, annual average soil moisture, and forest carbon sequestration. This shows that the average annual light intensity and soil moisture may be a certain influencing factor, but other factors play a leading role. In addition, the influence of a single factor is often more one-sided. Even if better-fitting results are obtained, conclusions cannot be drawn rashly. In this case, several factors should be taken into consideration.[5]

3.2. Model construction of forest carbon sequestration benefits based on the optimal rotation period

- According to Faustmann's rotation model, the following assumptions are made for multiple rotations: Markets are free to compete.
- The forest farm operator can operate forever, expecting to maximize the net present value.
- The trees are planted in the same period, and all the trees are in the same growth period.
- The value of wood is obtained after deforestation, and the forest has carbon sequestration benefits when it is not deforestation and will continue to be planted after deforestation.

The net present value of the rotation period after multiple rotation periods is the net present value of carbon sequestration benefits and wood value.

$$V_1 = V_s + V_c$$

where V_s represents the net present value of the discounted wood value.

$$V_S = [p_1 Q(t) - c]/[e^{rT} - 1]$$

where V_c stands for carbon sequestration benefit.

$$V_c = [\int_0^T e^{-rt} p_2\, aQ(t)dt]/[e^{rT} - 1]$$

Among them, $Q(t)$ represents the forest stock volume at time t, which is generally expressed as $Q(t)=at+bt^2-dt^3$; C is the cost of planting trees; p is the carbon price, which can be determined according to the carbon tax method, the afforestation cost method, and the willingness to pay method; e^{-rT} is the discount factor (discounting future economic benefits to the present); r is the social discount rate; T is the rotation period.[6]

When we maximize the net present value V_1, and derive V_1 so that the derivative function is equal to 0, we get:

$$V_1 = \frac{p_1 Q(t) - c}{e^{rT} - 1} + \frac{\int_0^T e^{-rt} p_2\, aQ(t)dt}{e^{rT} - 1}$$

4. Result analysis and conclusion

According to the S-curve model fitting performed above, only considering the carbon sequestration benefit, the carbon sequestration benefit of trees remains almost unchanged after reaching the carbon sequestration saturation point, so it can be understood that the carbon sequestration benefit remains unchanged whether or not cutting is selected. However, due to the particularity of forest trees, it is selected to be felled and produced as forest products. After the forest products reach their lifespan, they can be recycled or degraded to achieve carbon sequestration. Therefore, the carbon sequestration benefits of forest products hardly need to be considered. The above formula shows that the T value of multiple rotation periods is only related to $Q(t)$.[7]

According to the S curve, the carbon sequestration saturation point was obtained, and the rotation period of the forest was calculated to be 5-8 years. When considering carbon sequestration benefits, the lengths of their rotation periods were extended by 3-4 years, respectively. If only the standing value of the wood is considered, the operators tend to cut down the trees earlier to shorter the rotation period. Suppose the carbon sequestration benefits of forests are considered, the rotation period will be extended, and people will tend to cut down trees later, improving the carbon sequestration benefits of forests.

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