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Estimation of Carbon Sequestration Content Based on Computer Modeling Techniques

Minghao Cui[a,*], Yuntao Fu[b] and Shangyu Zeng[c]

School of Computer Science and Engineering, Northeastern University, Shenyang, Liaoning, China

[a]cmhstuedu@163.com, [b]1917615858@qq.com, [c]1917615858@qq.com

**corresponding author*

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Abstract: In today's world, the global warming trend continues, and forests are the main sites for capturing carbon dioxide to reduce greenhouse gas emissions. So it is necessary to improve forest carbon sequestration capacity through human intervention. In this paper, we collect information on carbon sequestration and calculate the total carbon sequestration into forest carbon sequestration and woody forest products carbon sequestration. We use multiple linear regression and biological inventory method to compare the carbon sequestration of planted forests and natural forests, then estimate the total carbon sequestration of forests themselves. We use the carbon sequestration formula of woody forest products to calculate the carbon sequestration of woody forest products. Then, according to the plant carbon stock estimation method and the biomass survey of forest ecosystem, the proportion of trees of different ages and the number of species in the forest are the influencing factors of total carbon sequestration. Combined with the set sustainable development model of tree cutting, it can be concluded that deforestation is one of the ways to regulate the carbon sequestration capacity of forest, and the development of cutting plan is also the transition point of forest management plan.

1. Introduction

The global warming problem has led to a series of ecological, economic and social problems of increasing severity, which has aroused the high attention of the international community. In addition to industrial CO2 reduction, forest carbon sequestration has become an important way to solve this problem. In this paper, we need to design a carbon sequestration model to quantify the amount of carbon dioxide sequestered by a forest and its products in a limited period of time, and use the results of the model to design an intervention measure on deforestation plan that can make the forest at that location absorb as much carbon dioxide as possible.

2. Phytolith Carbon Sequestration Analysis

2.1. Factors of Phytolith Carbon Sequestration

Phytolith is amorphous silica particulate matter precipitated intracellularly by transpiration from soluble monosilicicic acid in soil solutions absorbed by plant roots, in which the organic carbon encapsulated is called phyllosomal carbon, which can be preserved for a long enough time with plant apoptosis into the soil and is a long-term stable carbon sequestration mechanism. The phytolith content in gymnosperms in forests is lower than in angiosperms, and monocotyledonous grasses contain the highest amount of silica among angiosperms, i.e., the amount of carbon sequestered by the phytolith is related to the plant species [1].

Phytolith is formed mainly under the transpiration pull of plants, i.e., differences in the strength of transpiration affected the phytolith carbon content, where the closed carbon content within the vegetation of the subtropical horsetail pine forest growth area is high, i.e., temperature, and the degree of air humidity also affect the closed carbon content of phytolith. Phytolith carbon content is positively correlated with phytolith content and phytolith content is positively correlated with total organic carbon content, i.e., phytolith carbon content is positively correlated with the area of the Horsetail pine forest [1].

2.2. Factors of Carbon Sequestration in Horsetail Pine

The phytolith closed carbon content of above-ground organs of Pinus sylvestris, for example, also differed significantly ($P<0.05$), showing that stem > branch > leaf, and the difference between stem and leaf was significant, that is, the phytolith closed carbon content was different among the organs of Pinus sylvestris. The phytolith closed carbon content of P. equisetum also differed among different stand ages (Figure 1), showing that the phytolith closed carbon content of all organs did not differ significantly among different stand ages, but the phytolith closed carbon content in different organs of different stand ages differed significantly. Horsetail pine showed sensitivity to soil pH in the growing environment, i.e., it showed differences in the content of closed carbon in the body when it was in soils with different pH [2].

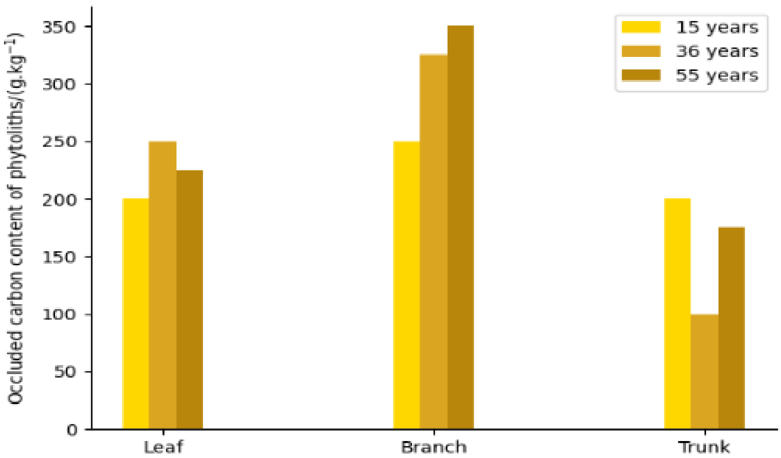

Figure 1: Phytolith occluded carbon (PhytOC) storage

3. Forest Carbon Sequestration Model

3.1. Calculation of Forest Carbon Sequestration

We estimated the actual and potential carbon stocks of forest ecosystems in China and the differences between them using the biomass- and stockpile-based plant carbon stock estimation method[3, 4], and combined the survey data collected from the research reports on forest biomass into young, middle-aged, near-mature, mature, and over-mature forests in order of age classes, and grouped them into 16 forest types, thus This model classifies forests into plantation forests, and the carbon stock of forest plants is calculated. In this model, forests are divided into planted forests and natural forests, and the corresponding carbon stocks are analyzed by multiple linear regression for their area and storage area, and the relationship functions are simulated.

Combining the analysis of the two figures, it can be obtained that each forest area and storage volume and the respective carbon stock are linearly related and well fitted, while the total carbon stock is the sum of these two forest sites, indicating that the size of the carbon stock is influenced by the size of the forest area and the size of the storage volume, so the forest area as well as the storage volume should be expanded in the forest management plan, and combined with the inventory of the recent forest resources surveys [5], it is found that the forest cover obtained from each survey is increasing, while the area and storage volume of both planted and natural forest sites are also increasing, i.e., the total carbon stock is increased.

Through the recent inventories of forest resources surveys [5], the increase rate of the area of the two types of woodlands can be derived, and assuming the size of the area and storage area of the two woodlands in the next survey period, the total carbon storage in the next survey period can be obtained by the existing linear regression analysis is about 9.29×10^{12}kg, and the value of the carbon storage in China in 2021 is close to the predicted value after the data survey, which means that the the linear regression estimation is valid.

The biomass is also a factor affecting the carbon stock, and the biomass is increasing every year, which means that the carbon stock in the biomass is also increasing every year, and the data surveyed by the Food and Agriculture Organization of the United Nations [6] can be obtained as Figure 2 and Figure 3 below.

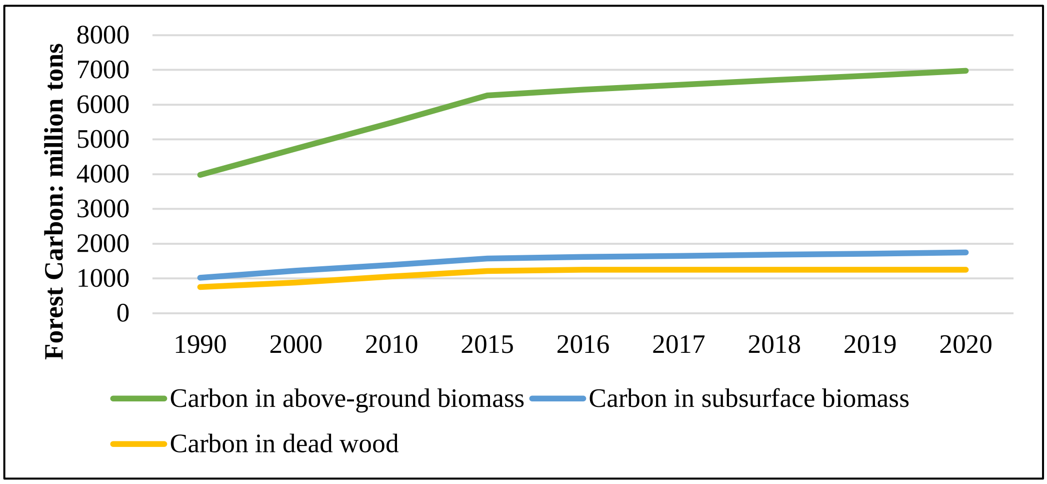

Figure 2: Biomass statistics of various types of forests in China, 1990-2020

(Data source: Food and Agriculture Organization of the United Nations).

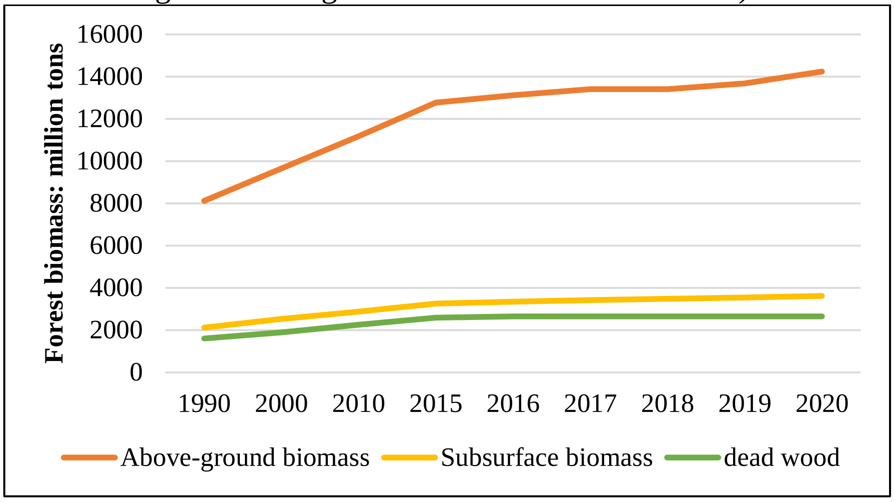

Figure 3: China's forest carbon volume by type, 1990-2020

(Data source: Food and Agriculture Organization of the United Nations).

Combined with the biomass survey of forest ecosystems by Luo Yunjian [7], the proportion of biomass of each forest age to the total tree layer and the proportion of tree layer to group biomass can be derived. The equation for estimating the carbon stock of forests by Xiaoke Wang[3, 4] can estimate the forest carbon stock of each type and each province and city in China as 9268469 Tg, and also the proportion of the total carbon stock of each forest age group can be derived as shown in Fig 4 .

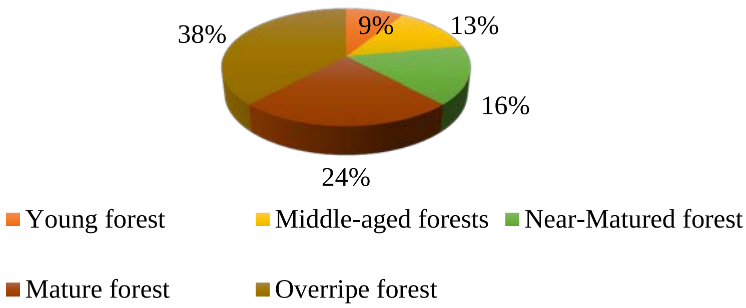

Figure 4: Comparison of forest carbon stocks by age group

In fact, the size of carbon stock estimated by the two calculation methods is similar and close, and the carbon stock of China's forests in 2021 is also close to these two data according to the information, which indicates that the model data estimation is reasonable.

According to the estimation method of plant carbon stock and data analysis, we can know that the plant carbon stock of different forest types varies greatly, and the main influencing factors are the characteristics of the trees in the forest itself on the one hand, and the proportion of trees of different forest ages in the forest on the other hand.

Through the hypothesis proposed by Wanze Zhu [8], it can be known that even though the proportion of over-mature forest is the largest in all forests, some trees will reach the carbon balance phenomenon even if their carbon stock increases with the age of the forest, but their trees in over-mature forest will die after the age of the forest grows, so the amount of carbon sequestered in the forest may be reduced, and the trees in over-mature forest must be utilized for the sustainable development of the whole forest.

3.2. Carbon Storage of Wood Forest Products

Forest carbon stocks include not only the carbon stored in the forest itself, but also the amount of carbon stored in the forest itself after it is converted into wood products.

Based on the information from Jianxin Geng [9] a model can be constructed to calculate the change in the amount of carbon in wood forest products produced from domestic consumption and harvested wood.

$$C(i+1) = e^{-k} \cdot C(i) + \left[\frac{(1-e^{-k})}{k}\right] \cdot \mathrm{Inflow}(i) \quad (1)$$

$$\Delta C(i) = C(i+1) - C(i) \quad (2)$$

$$\mathrm{Inflow}_{DC} = P + SFP_{IM} - SFP_{EX} \quad (3)$$

$$\mathrm{Inflow}_{DH} = P \cdot \left[\frac{IRW_H}{IRW_H + IRW_{IM} - IRW_{EX} + WCH_{IM} - WCH_{EX} + WR_{IM} - WR_{EX}}\right] \quad (4)$$

$$V_t = V_{1961} \cdot e^{[U \cdot (t-1961)]} \quad (5)$$

Based on the data [6] collected from 1961-2011, calculations were performed to derive the amount of wood forest products and wood production needed to consume hardwood and paper products in China from 1961-2011, and the results are shown in the Figure 5 following graph.

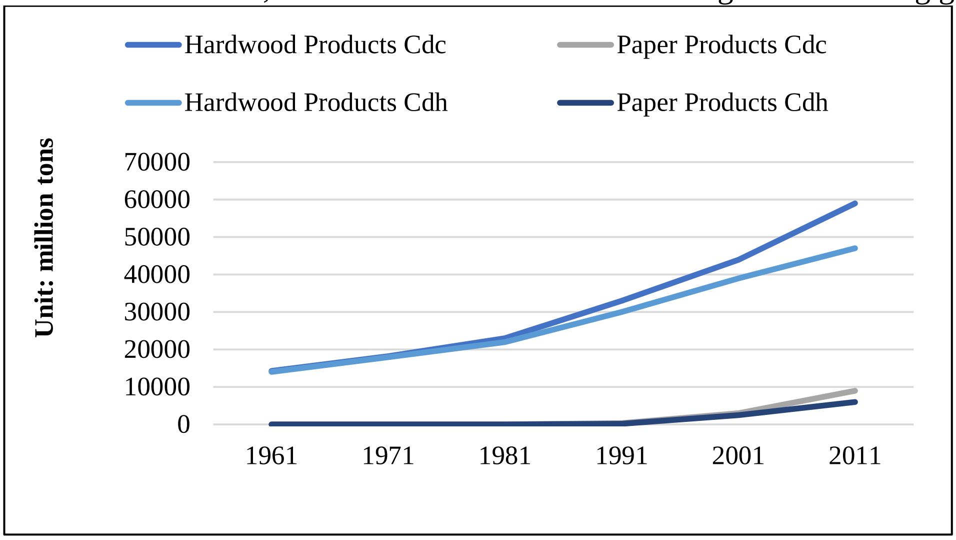

Figure 5: Hardwood Products Cdc, Cdh and Paper Products Cdc, Cdh

(Data source: Food and Agriculture Organization of the United Nations)

The carbon stocks of hardwood products (sawn wood, planks, other industrial roundwood) and paper products (paper and paperboard) are on the increase, so as forest managers, try to convert felled trees into these products. Also, they may optimize the way we handle wood raw materials and reduce carbon emissions during processing and increase marketing efforts for hardwood products and paper products to drive conversion of felled trees to hardwood products and paper products through demand relationships. Otherwise, they should increase the durability and longevity of wood forest products.

4. Deforestation Management Plan Based on Carbon Sequestration Model

4.1. Deforestation Management Model

Forest managers need to cut down dying forests and use them to produce woody forest products on the one hand, and plant young trees on the other hand to ensure a stable number of trees in the forest. Therefore, they need to know how to cut trees reasonably in order to keep the carbon sequestration capacity of the whole forest stable. To further calculate the effect of the magnitude of carbon sequestration by trees of different forest ages on the proposed interventions, a sustainability model of tree cutting is proposed, before which the number of species in the forest ecosystem is ensured likewise the carbon sequestration capacity of the forest.

The model is set to replant a sapling in the same place for every large tree cut down, so that the total number of trees in this forest remains unchanged. The trees in the forest are considered as the same kind of trees, and the trees in the forest have different age distribution at the initial moment, and the age of the trees increase in different degrees during a generation period. At the same time, the model ensures that the felling remains continuous and stable and the number of trees remains constant. The growth of trees in the forest is represented by the age degree of trees a_i, and the economic value of trees is set as p_i. Let the period between cuts be the forest growing season, and within each growing season, the age degree of the trees changes. Denote by g the proportion of trees in level i that become level $i+1$ after one year.

$$f_i = 1 - g_i \tag{6}$$

Constructing tree growth matrix and seedling distribution matrix.

$$G = \begin{bmatrix} f_1 & \cdots & \cdots & \cdots & \cdots \\ g_1 & f_2 & \ddots & \vdots & \vdots \\ \vdots & g_2 & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ddots & f_{n-1} & \vdots \\ \cdots & \cdots & \cdots & g_{n-1} & 1 \end{bmatrix} \quad R = \begin{bmatrix} 1 & 1 & 1 & \cdots & \cdots & 1 \\ 0 & 0 & 0 & \cdots & \cdots & 0 \\ 0 & 0 & 0 & \cdots & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & \cdots & 0 \end{bmatrix} \tag{7}$$

The age degree distribution of the forest is expressed as:

$$G_x = [f_1x_1, f_2x_2 + g_1x_1, \cdots, f_{n-1}x_{n-1} + g_{n-2}x_{n-2}, g_{n-1}x_{n-1} + x_n] \tag{8}$$

The assumption of stable harvesting has a corresponding formula, while let $y_1 = 0$, the total number of trees in the forest is s, x_i denotes the number of trees left in level i after each cutting, and y_i denotes the number of trees in level i harvested after each cutting. The following equation can be obtained. Also, express the maximum economic return per year as E.

$$(I - R)y = (G - I)x \tag{9}$$

$$E = \sum_{i=2}^{n}(p_i - p_1)\, y_i \tag{10}$$

The constraint is a gradual increase in the proportion of age. According to the model, the economic benefit of cutting any of the young, middle-aged, near-mature, mature and over-mature forests can be calculated as E_k.

$$E_k = (p_k - p_1)s \div \sum_{i=1}^{k-1} \frac{1}{g_i} \quad (11)$$

5. Summary of Deforestation Management Plan

Since the carbon sequestration capacity of trees of different ages differs, and over-mature forests have the least potential for carbon sequestration due to the highest probability of death, it is necessary to cut down the oldest over-mature forests and convert them into woody forest products, and replenish the vacancies by young forests. Since the capacity of forest carbon sequestration is closely related to the growth condition of trees [10], it is important to pay close attention to the growth of trees when managing forests to ensure their normal growth, minimize the disease condition of trees, and check them regularly.

6. Conclusions

This paper constructs a forest carbon sequestration model from several sub-models, and estimates the forest carbon sequestration by comparing multiple linear regression and biological inventory method, the carbon sequestration estimates calculated by the two methods are similar, and the forest products carbon sequestration is analyzed by using the forest quality products estimation formula. The regression analysis is limited in some cases because of the unpredictability of some factors, and the relationship between the number of species and forest carbon stock can only be calculated when there are enough data to support it, and there are more factors involved, so the analysis of the prediction results may have more errors. So we introduce a harvesting model and this behavior is included in the consideration of forest management plan. This will enable the development of appropriate forest management plans for forest managers.

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