A Forest Carbon Sequestration Model Used to Assess Carbon Storage

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Abstract. Forests play a crucial role in carbon sequestration. A comprehensive carbon sequestration model can accurately assess the amount of carbon sequestration in forests, which can determine how to plan forests to achieve maximum carbon sequestration benefits. However, traditional carbon sequestration models only focus on the carbon sequestration of trees themselves and forest products. This article innovates and modifies the traditional model by including more indicators, such as the carbon sequestration of new growth and the carbon emissions caused by the residual material from logging. All factors that affect carbon sequestration are classified and unified in a reasonable way, resulting in a more excellent and comprehensive carbon sequestration model. Finally, this article validates and discusses the model, which shows that the model is consistent with actual results, has accuracy and predictability, and has practical value.

Keywords: Forest Carbon Sequestration, Forest Harvesting, Regenerating Forests

1. Introduction

As climate change intensifies, the use of biological or other methods to sequester carbon should be a priority to reduce the amount of carbon dioxide in the atmosphere. Among these, forests play a crucial role in carbon sequestration. However, it does not mean that forests should not be harvested at all. In fact, forest products also have the ability to sequester carbon, and some can even absorb more carbon than the trees that produce them. In addition, the free space can be planted with new trees after the trees are moderately cut down and made into forest products. Therefore, if the deforestation and production of forest products, as well as the planting of new trees are combined, the carbon sequestration of the forest could be further increased.

In order to calculate the carbon sequestration of forests and plan forest harvesting, it is necessary to establish a complete carbon sequestration model. However, traditional models of carbon sequestration tend to focus on the amount of carbon sequestered by the forest itself and the amount of carbon sequestered by forest products, while ignoring other aspects. In this paper, on the basis of the traditional carbon sequestration model, the carbon sequestration of newborn wood and the carbon emissions caused by felling and fire are further considered, so as to obtain a more complete model.

2. The potential indicators and basic model

2.1. Determination of indicators

In the current domestic and international studies, there are three main methods to calculate the amount of carbon sequestered by forests and their products: forest carbon pool model, forest carbon sink and HWP (carbon sequestration of forest products). accounting methods. For the forest carbon pool model, the HWP carbon pool model can be used as carbon stock and carbon flow [1]. The stock volume method can reflect the objective dynamics of the forest carbon pool subsystem more comprehensively [2]. One paper used the stock change method included in HWP accounting method to deal with issues about HWP net importers [3].

However, there is a problem with these methods - they only calculate the carbon sequestration of a specific part of the forest, and each part has its own influencing factors and indicators. When it comes to calculating the total carbon sequestration of a forest, it is difficult to unify the indicators of each model and form a complete carbon sequestration model. Therefore, we have taken into account several influencing factors of carbon sequestration in each part of the forest and added multiple variables that are equivalently converted by these factors to the basic carbon sequestration calculation formula. Referring to the forest carbon sequestration calculation method proposed by Zhang Xufang et al. [4], we have developed a more unified carbon sequestration model that has consistent indicators for all parts of the forest[5]. These indicators include:

2.1.1 Tree species

The carbon sequestration capacity of different trees can be significantly different, so it is necessary to separately obtain various carbon sequestration indicators and calculate them.[6]

2.1.2 The amount of carbon stored per unit area

The calculation of the carbon content of a forest is based on the area of the forest. Considering the sparseness of the trees in the forest, the factor of storage per unit area is introduced. It is also influenced by the climate, topography, vegetation cover and the average diameter and age of the trees in the forest.

2.1.3 Volume coefficient

The amount of carbon stored per unit area is a two-dimensional influence, while forests are three-dimensional structure. As a result, volume coefficient is introduced to measure the amount of storage per unit space. The main factors affecting the volume coefficient are the climate of the forest site, as well as the average height and age of the trees. In addition, trees are a dynamic process of continuous growth, during which the volume coefficient changes.

2.1.4 Biological expansion coefficient

An indicator of forest carbon sequestration is also related to the biological community living within it, therefore introducing this indicator expands the forest's accumulation to include biomass.

This indicator can more comprehensively evaluate the contribution of forests to carbon sequestration, as it considers the influence of the biological community within the forest. When evaluating the carbon sequestration capacity of a forest, only considering the forest's accumulation may overlook the role of biological organisms, as they also promote carbon sequestration by absorbing carbon dioxide and fixing it in their bodies.

2.1.5 Basic density, carbon rate and carbon factor

Forest products are calculated in terms of wood volume. In order to unify the caliber of products, we convert them into dry weight by the use of conversion factors, which vary by region and species.[7]The proportion of carbon is also an important factor affecting the amount of carbon sequestered by HWP(Carbon sequestration of forest products) . The carbon factor is obtained by multiplying the basic density and carbon content rate, which makes the amount of carbon sequestered by various HWPs uniformly comparable.

2.1.6 Half-life period of carbon fixation in wood products

The amount of carbon sequestered by forest products changes over time, so we introduce the half-life period of carbon fixation in wood products.

2.2. Derivation of model

Based on the discussion above, we can derive the models for each part based on the same indicators. The derivation of models for each part are as follows:

2.2.1 Soil carbon sequestration and forest carbon sequestration

Assuming that there are n tree species in a forest, they can be numbered from 1 to n, and each number i can represent one of the tree species. We can consider the accumulation area and unit area accumulation of each tree species separately. In addition, we also need to consider their volume coefficient and biological expansion coefficient.

2.2.2 Carbon sequestration by forest products

Different products made from trees have different amounts of carbon sequestration. Even for the same product, the amount of carbon sequestered is not constant, but decreases over time [8].So, we also need to know the half-life period of carbon fixation in wood products.

2.2.3 Carbon sequestration by regenerating forests

After a portion of the forest is cut down and made into wood products, new trees can be planted in the cleared area. These new trees will also bring benefits in terms of carbon sequestration, and this needs to be taken into account.

2.2.4 Additional carbon emissions from harvesting residues

After trees are harvested and made into HWP, the forest residues generated during the harvesting process will emit carbon through their branches and leaves, resulting in additional forest carbon emissions and a reduction in carbon sequestration. At the same time, forest fires can also lead to a surge in carbon emissions. Although this is an uncertain quantity, research surveys have shown that [9] forest fire-induced carbon emissions show a fluctuating trend and are generally linearly related to forest area, so it can also be included in the scope of consideration to make the model more accurate.

3. Results

3.1. Determination of the model

3.1.1 Soil carbon sequestration and forest carbon sequestration

$$C_1 = \sum S_i * T_i * \rho * \gamma \tag{1}$$

$$C_2 = \alpha * \sum S_i * T_i * \rho * \delta + \beta * \sum S_i * T_i * \rho * \gamma * \delta \tag{2}$$

Here, S_i represents the area occupied by the tree species numbered i in the forest, T_i represents the carbon sequestration per unit area of the tree species numbered i in the forest, ρ represents the volume coefficient, γ represents the proportion of carbon in trees, δ represents the biological expansion coefficient, α represents carbon conversion coefficient of understory plants, and β represents carbon conversion coefficient of forest plants.

3.1.2 Carbon sequestration by forest products

When the wood has just been made into a product, there is no need to calculate the reduction in carbon sequestration. As a result, we can easily calculate the carbon sequestration in first year.

$$C_3(1) = C_a(1) + C_b(1) = \sum M_j * a_j * V_j + \sum M_j * b_j * V_j \tag{3}$$

The carbon sequestration in year i is relative to year $i-1$. Due to the difference in the nature of hardwood products and softwood products, they have different half-lives.

$$C_a(i) = e^{-\frac{\ln(2)}{HL_a}} * C_a(i-1) \tag{4}$$

$$C_b(i) = e^{-\frac{\ln(2)}{HL_b}} * C_b(i-1) \tag{5}$$

Here, a_j and b_j represent the carbon content ratios of hardwood and softwood products respectively, and it can be seen concretely from Table 1. V_j represents the amount of wood used to make the *j-th* type of product, and M_j represents the loss ratio of wood during the production of the *j-th* type of product. HL represents the half-life period of carbon fixation in wood products.

Table 1. Default factors to convert form product units to carbon for HWP

	Industrial logs and related		**Charcoal**	**Board mean**	**Paper and related**
	Temperate species	Tropical species			
density	0.45	0.59	0.9	0.628	0.9
carbon content	0.5	0.5	0.85	0.468	0.5
carbon factor	0.225	0.295	0.765	0.294	0.45

3.1.3 Carbon sequestration by regenerating forests

$$C_4 = \sum S_i * T'_i * \rho * \gamma * \delta \tag{6}$$

Here, the carbon sequestration per unit area of newly grown trees is denoted as T', and the coefficient is denoted as γ.

3.1.4 Additional carbon emissions from harvesting residues

$$C_5 = \varepsilon * \sum S_i \tag{7}$$

Here, ε is a human-determined average coefficient.

3.1.5 total carbon sequestration

If we designate that the ratio of uncut trees to the total amount of forest wood is k, then the ratio of wood made into wood products to the total amount of forest wood is $1-k$. After part of the forest is cut and made into wood products, it can be planted with new trees, so this part of the space can be used again. The total formula is as follows.

$$C(i) = C_1 + k * C_2 + (1-k) * (C_3(i) + C_4 - C_5) \tag{8}$$

Substituting the derived formula above, the final formula is as follows.

$$\begin{aligned} C(i) = {} & \sum S_i * T_i * \rho * \gamma \\ & + k * \left(\alpha * \sum S_i * T_i * \rho * \delta + \beta * \sum S_i * T_i * \rho * \gamma * \delta\right) \\ & + (1-k) * (e^{-\frac{\ln(2)}{HL_a}} * C_a(i-1) + e^{-\frac{\ln(2)}{HL_b}} * C_b(i-1) \\ & + \sum S_i * T'_i * \rho * \gamma * \delta - \varepsilon * \sum S_i) \end{aligned} \tag{9}$$

3.2. Validation of the model

In order to guarantee the accuracy and reliability of the model, we conducted a thorough collation of forest carbon storage data spanning a period of two decades, from 1993 to 2013. This involved combining the latest five national forest inventories, which provided us with a comprehensive and robust dataset to work with. Using the model outlined above, we were able to calculate the forest carbon storage levels for each year in the time period in question. To validate these results and ensure their accuracy, we compared them with the actual results derived from on-the-ground surveys.The result is shown in Figure 1. The comparison revealed that the results calculated by the model were consistent with the trend of the actual results, indicating that the model was effective in accurately calculating forest carbon storage levels. Although there was a slight gap between the calculated and actual results, this was deemed to be reasonable and acceptable, and did not affect the overall validity of the model. As a result, we are confident that this model can be used as a reliable tool for calculating forest carbon storage levels in the future.

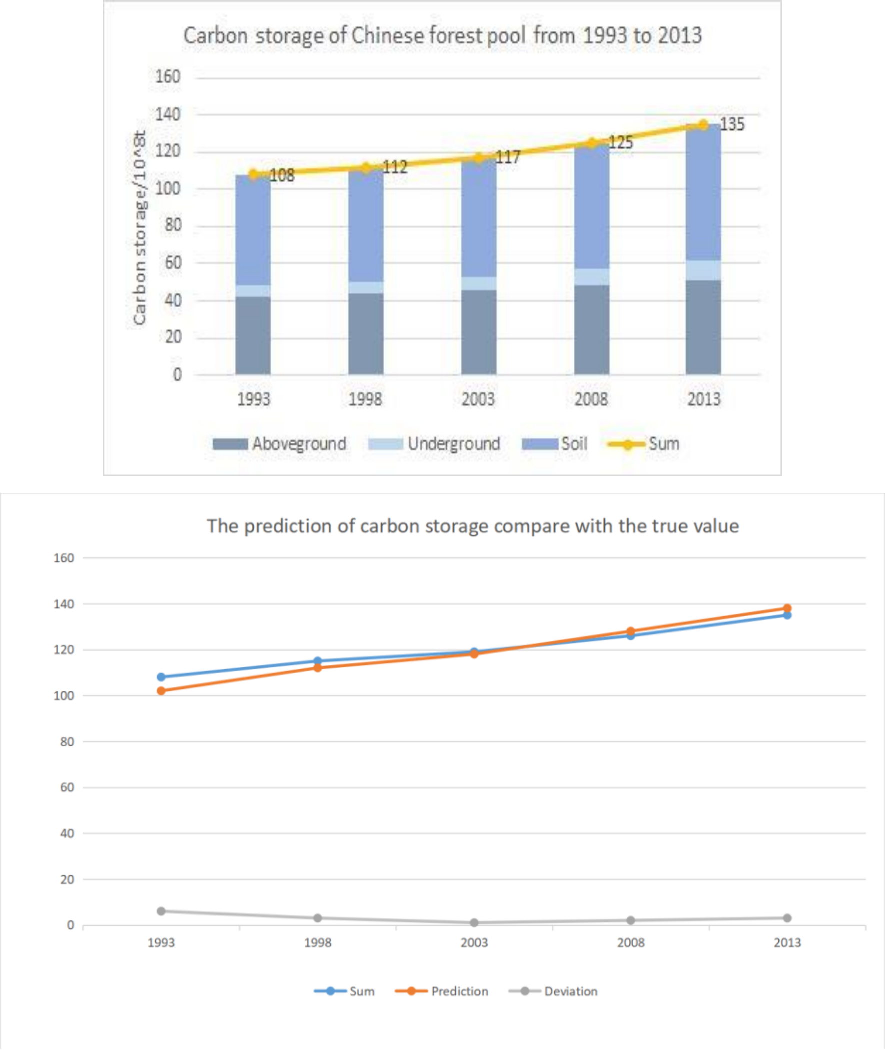

Figure 1. Comparison chart of carbon sequestration data

4. Discussion

Compared to traditional carbon sequestration models, our model has visible advantages. We comprehensively considered factors that may affect forest carbon sequestration (different half-life periods for different forestry products, expanding forest carbon sequestration to biological carbon sequestration, and considering the impact of harvesting residues and forest fires on carbon sequestration), and reasonably classified them. Some difficult-to-determine factors were considered as secondary impact factors, and their effects were converted to the main impact factors that are easy to measure for modeling and calculation purposes.

However, our model also has some limitations and drawbacks. It is difficult to obtain accurate results from our carbon sequestration model through predictions, so some parameters need to be assumed to remain constant in calculations. In addition, determining the carbon sequestration of newly grown trees and the carbon emissions from harvesting residues involve setting some parameters[10], but some of these are based on experience and have not been thoroughly studied for their impact on results.

5. Conclusion

To better utilize the carbon sequestration function of forests, forest management should consider various factors when deciding on harvesting methods. Proper harvesting can increase the total carbon sequestration of forests and forest products. Therefore, it is necessary to establish an accurate and comprehensive carbon sequestration model for forests. Traditional carbon sequestration models often only focus on the carbon sequestration of trees and forest products, neglecting other aspects. This article developed an innovative model based on traditional models that considers the carbon sequestration of newly grown trees and the additional carbon emissions that may occur. This article also reasonably classified and transformed all factors that affect carbon sequestration to build a new carbon sequestration model. The experimental results show that the model is relatively consistent with the actual results, demonstrating accuracy and predictability, and possessing certain practical application value.

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