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Analysis of Carbon Sequestration within Forest Management Practices by the CO_2FIX Model

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Abstract: *Climate problems are becoming more and more frequent. Without forests to regulate the climate, human race will not be able to survive. In this paper, a mathematical model was proposed to calculate various values of forests, classify forests, and determine how forests should be managed. In order to determine how forests should be managed, this paper uses the CO_2FIX model to calculate the amount of carbon dioxide that can be sequestered over time in the Greater Khingan Range of China forest by calculating the amount of carbon sequestered by organisms, soil, and wood products respectively. To study the effects of different management practices, this paper makes a comparison between anthropogenic management and natural growth of the forest and that the proposed model is most effective for CO_2 sequestration when used the upper layer thinning method.*

Keywords: *carbon sequestration, CO_2FIX model, anthropogenic management, upper layer thinning method*

1. Introduction

CO_2FIX is a carbon accounting model for forest ecosystems, consisting of six modules: biomass module, soil fill module, forest products module, biomass energy module, economic module and carbon accounting module, all of which are simulated and calculated on a hectare scale with a time step of 1 year. It is mainly used to simulate forest ecosystems including biomass, soil carbon stocks and carbon fluxes between them and forest products, and also to simulate expenditures and revenues in the forest management process, as well as carbon credits that can be earned under different carbon accounting methods. The model is highly adaptable and has a wide range of applications, and achieves good simulation results in different climates and stand types.

2. Data and Methods

2.1 Data Selection

In order to determine the amount of carbon dioxide a forest can fix in a given period of time, this paper selected the Greater Khingan Range of China as a target and applied the CO_2FIX model developed by a research group at Wageningen University in the Netherlands to calculate the amount of CO_2 sequestered by organisms, soil and wood products in the forest. Among other things, this paper obtained carbon stocks from Greater Khingan Region Resources Bureau. Annual Report on Forest Resources Statistics in the Greater Khingan Range Data[1] were collected from 2013-2017 for forests in the Greater Khingan Range of Heilongjiang through a series of indicators such as biomass, soil organic carbon, and wood products. The CO_2 sequestration of forest management plan was confirmed by comprehensive calculation.

2.2 CO_2FIX model

Considering the determination of the amount of carbon dioxide that the forest and its corresponding wood products can fix in a certain period of time, it is necessary to determine the way the forest fixes carbon dioxide, and by searching the literature, it was obtained that the forest fixes carbon dioxide between the organism, soil and wood products during the growth of the trees. Among them, carbon

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fixation in the organism is a way to maximize the value of fixing atmospheric carbon dioxide by using photosynthesis of plants to increase the carbon absorption and storage capacity in the ecosystem. Since trees absorb carbon, the more trees fix more carbon, and this paper applies woods for building cities so that more carbon can be absorbed and neutralized, hence making it possible to move the existing fixed carbon out of the forest and transfer it to people's life in the process of cutting down trees, and also make space for the forest to fix more carbon dioxide, so this paper use the amount of carbon fixed by wood products as one of the indicators. Soil carbon sequestration works through the roots of trees and their associated mycorrhizal fungi. Between 50% and 70% of the carbon bound in the soil comes from fungal growth in and around the roots, which transport carbon from plant photosynthesis directly into the soil and sequester it[2].

In order to determine the amount of CO_2 that a forest can fix in a given period of time. This paper applied the CO_2FIX model developed by a research group at Wageningen University in the Netherlands to calculate the amount of CO_2 sequestered by organisms, soils and wood products in the forest. CO_2FIX is a carbon accounting model for forest ecosystems, which is mainly used to simulate forest ecosystems, including biomass, soil carbon stocks and their carbon fluxes with forest products, as well as to simulate expenditures and revenues from forest management processes, and carbon credits that can be obtained under different carbon accounting methods. The model is highly adaptable, has a wide range of applications, and achieves good simulation results in different climates and stand types. The specific process is shown in Figure 1.

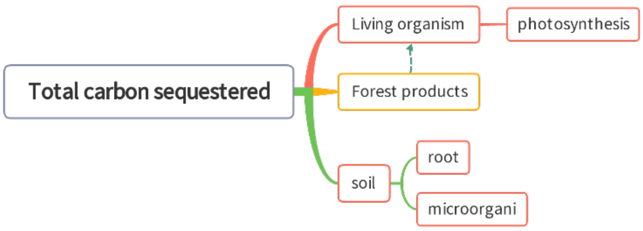

Figure 1: Schematic of CO_2FIX model

In our model, this paper defines CT_t as, at moment t, the total carbon stock in the forest with equation (1),

$$CT_t = Cb_t + Cs_t + Cp_t \tag{1}$$

where Cb_t denotes the total carbon sequestration in the organism at moment t, Cs_t denotes the total carbon sequestration in soil organic matter at moment t, and Cp_t denotes the total carbon sequestration in wood products at moment t.

2.2.1 Total carbon sequestration in organisms

This paper estimate carbon stocks and fluxes in living organisms using a "cohort model" method. Each cohort is defined as a group of individual trees or species, and these groups can be species in primary forests, mixed forests, or agroforestry systems.

The total carbon sequestered in living organisms at the moment of cluster t, Cb_t can be expressed as:

$$Cb_t = \sum Cb_{it} \tag{2}$$

where Cb_{it} denotes the amount of carbon sequestered in cluster *i*,

$$Cb_{it+1} = Cb_{it} + K_c[Gb_{it} - Ms_{it} - T_{it} - H_{it} - Ml_{it}] \tag{3}$$

Where Gb_{it} denotes biomass growth rate, Ms_{it} denotes tree mortality due to senescence, T_{it} denotes branch, limb and root turnover rate, H_{it} denotes tree rotation rate, Ms_{it} denotes tree mortality due to senescence, Ml_{it} denotes tree mortality due to rotation, and K_c denotes conversion factor for

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converting biomass to carbon stock.

2.2.2 Carbon sinks in wood products

The carbon stock of forest ecosystem carbon pool is obtained based on soil organic carbon density and stand area, Cs_t using equation (4):

$$Cs_t = B_d \times CF \times S \qquad (4)$$

Where S is the forest area, B_d denotes the average biomass per unit area of dead litter in the forest, and CF denotes the average carbon content of dead litter, where B_d and CF use the results of forest ecosystem carbon pool survey and measurement.

2.2.3 Sequestration of CO_2 volumes

The raw material is harvested from fading leaves and is divided into round wood, wood for pulp and paper, and shrubs. The shrubs are either left in place and thus degrade into the soil or are used to generate energy. The manufacturing process includes different types of production lines, such as sawn wood for sale, boards and building panels, pulp and paper, and wood fuel. During the manufacturing process, part of the raw material is processed into primary products (e.g. wood or furniture), part is processed into secondary products (e.g. cork board and pulp from wood chips), and part is used to produce wood fuel or simply discarded. Also, the products are divided into different use categories (long-term use, medium-term use, short-term use and wood fuel) according to their average life cycle. The specific relationship diagram is shown in Figure 2.

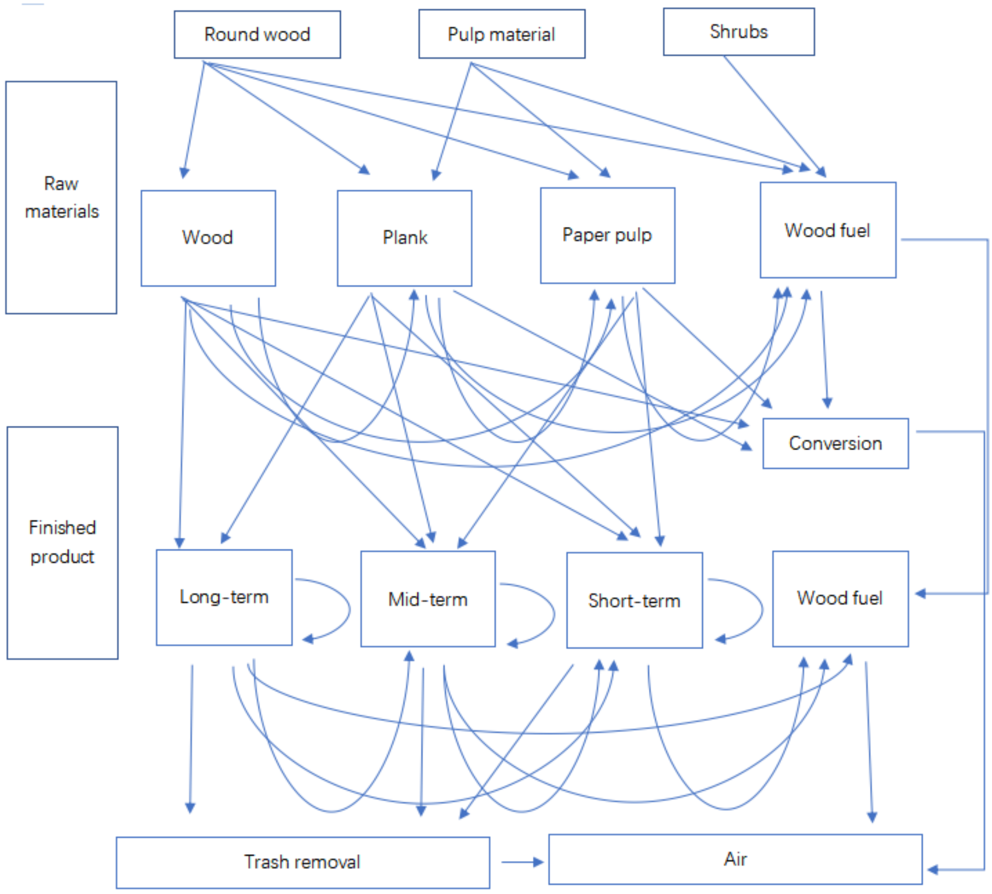

Figure 2: Wood products process

The total carbon sequestration in the wood product at time t, Cp_t can be expressed as:

$$Cp_t = \sum Cp_{it} \qquad (5)$$

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$$Cp_{mt+1} = Cp_{mt} \times (1 - a_m)(tCha^{-1}) \qquad (6)$$

Where Cp_m denotes the carbon stock of class *m* wood products at moment *t* and a_m denotes the annual decomposition share of class *m* wood products.

3. Solution and Result

This paper searched for various management practices and for information on the amount of wood corresponding to the relevant management practices, as this determines the carbon content of forest wood products. The highest wood volumes were obtained from the literature for the upper thinning method and the lower thinning method, as shown in Table 1.

Table 1: Table of timber volume of forest trees by grade [3]

Grade	≤17.9cm		18.0~23.9cm		≥23.9cm	
	volume of wood		volume of wood		volume of wood	
	cm^3/hm^2	%	cm^3/hm^2	%	cm^3/hm^2	%
A	201.9	50.1	200.9	49.9	0	0
B	101	29.8	277.1	66.9	11.1	3.3
C	94.4	25.7	203	55.3	69.6	19
D	135.6	44.2	140.4	45.8	30.8	10
E	126.5	34.4	217.1	59	24.2	6.6
A	145.5	25.4	305	53.2	122.6	21.4
B	93.3	17.4	319.8	56.7	146.3	25.9
C	45.2	7.4	249	40.9	314.7	51.7
D	90.3	18.8	263.6	54.8	126.9	26.4
E	115.4	23.3	349.5	70.6	30.2	6.1

This paper therefore searched for information on a total of three different management practices that favor forest carbon sinks: no human intervention, upper layer thinning, and lower layer thinning [4].

The upper layer thinning method, also known as French thinning method. It is a method of cutting trees in the upper and middle layers of the forest canopy that compete with the good trees in the upper layers, as well as dying and dead trees in the lower layers of the forest canopy. When cutting wood, trees are divided into three categories: good wood, beneficial wood (or auxiliary wood), and harmful wood. Trees with good stem shape, normal canopy development and vigorous growth are good timber and are cultivated; trees conducive to the growth of good timber are beneficial timber and are preserved; as upper thinning mainly cuts the middle and upper layers of the forest, it actively interferes with the natural selection process of the forest and can provide better growth conditions for the preserved trees.

The lower layer thinning method, also known as German thinning method, is mainly used to cut down the pressed wood, dying wood and dead wood that live in the lower layer of the forest canopy and are of small diameter, and also to cut down individual thick and poorly formed dry wood. This method is mainly used for pure coniferous forests such as pine, fir and larch. It improves forest health and stability, and promotes the growth of retained wood. Since only the understory wood that will be eliminated in natural selection is cut without changing the trend of natural selection, the forest still maintains a good horizontal depression. The result of thinning, mostly wood of smaller diameter class, is less economically effective.

The parameters as shown in Table 2 are from the survey report of the Greater Khingan Range and data provided by some forestry bureaus.

Table 2: Some basic parameters

H	ML	T	Ms	B	CF	am
0.3	0.001	0.02,0.02\0.33	0.04,0.01	12.4385	0.37	1/40,1/15

- Where Ms mortality rate was divided into 0.04 for the first 15 years and 0.01 after sixteen years, T turnover rate in branches, roots, leaves, am annual decomposition share was divided into long-term and medium-term.

With the data and parameters obtained above, and using CO_2FIX V.3[5,6] programming to bring in our CO_2FIX model, this paper conclude the following.

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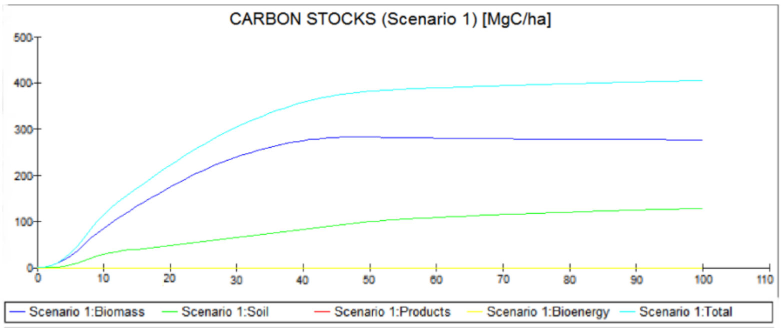

Figure 3: No artificial interference

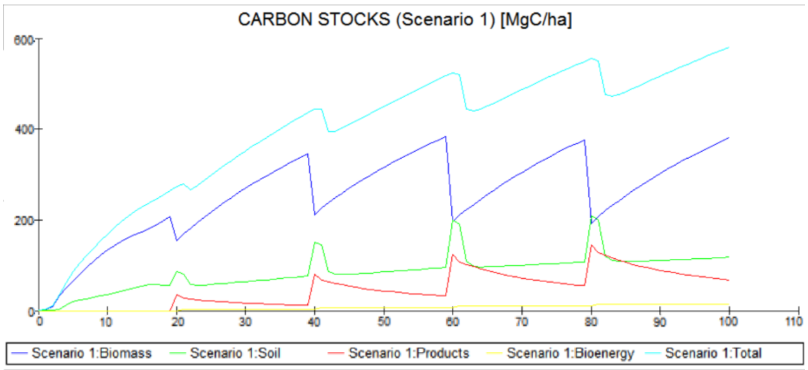

Figure 4: Upper thinning method

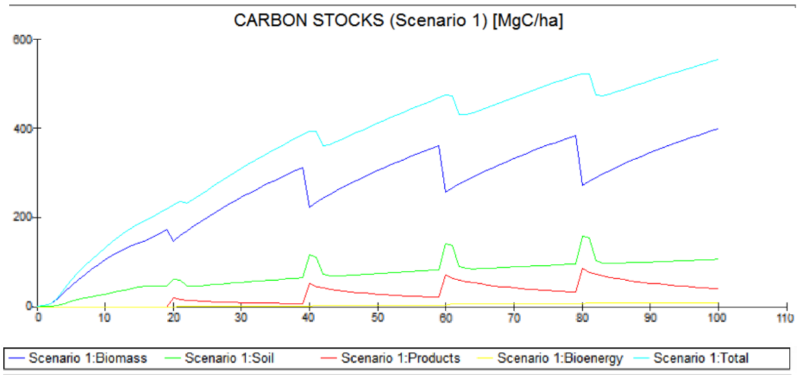

Figure 5: Lower thinning method

Figures 3, 4 and 5 above show the forest carbon sink curves of the three forest management methods, because there is a way to do no interference, so there will be no red curve of wood products, through the calculation, in order to be close to the real, this paper only take the sum of 50-100 years of carbon sink as 50 years of accumulated carbon sink, the results obtained are no interference $\overline{C_p}$: 201.6674 $/t \cdot hm^{-2} \cdot a^{-1}$, upper thinning method $\overline{C_p}$: 257.6596 $/t \cdot hm^{-2} \cdot a^{-1}$, lower thinning method $\overline{C_p}$: 246.0057 $/t \cdot hm^{-2} \cdot a^{-1}$, is the carbon sink per square kilometer, and the total carbon sink C_p is obtained by equation (7).

$$C_p = \overline{C_p} \times S \qquad (7)$$

The highest amount of carbon sequestration was obtained in the Greater Khingan Range of China forest using the best upper layer thinning method as a management method, which was 42281317.52 tons of CO_2.

4. Sensitivity analysis

In this section, this paper tested the sensitivity of the two models related in our work through changing parameters and comparing the difference between the original results and changed results.

In the CO_2FIX model, this paper analyze the sensitivity of the model by varying the rotation period in the model.

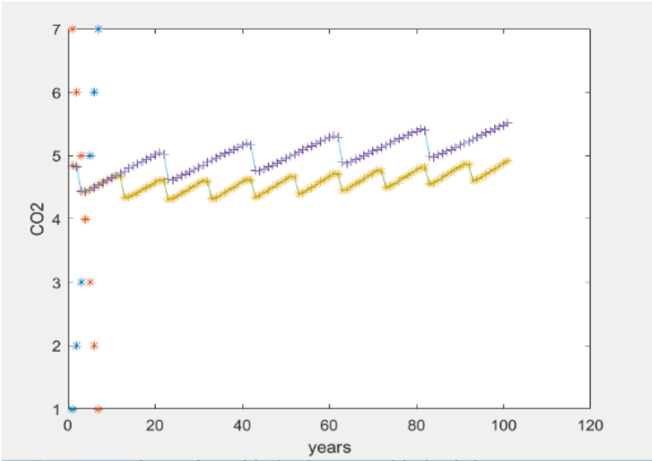

Figure 6: Sensitivity analysis: CO_2FIX model

Figure 6 corresponds to the first model and it can be seen: The blue curve in the graph shows a rotation period of 20 years, while the yellow curve shows a rotation period of 10 years. It can be clearly seen that changing the rotation period has little effect on CO_2 fixation. Moreover, the change of carbon fixation curve is smooth, which can indicate that our model is stable.

5. Conclusion

By our calculations, annual carbon sequestration is 11% less when the forest is unmanaged than when it is managed by people. Human management, thinning and cutting of dying and dead wood in the lower canopy. This actively interferes with the natural selection process of the forest and provides better growing conditions for the retained wood. It not only effectively increases the economic effect, but also increases carbon sequestration. Therefore, a reasonable artificial thinning of the forest in the Greater Khingan Range is the best decision for this forest. And in the comparison of different artificial thinning methods, its upper thinning method has the highest amount of carbon sequestration.

References

[1] Daxinganling Regional Resource Bureau. Annual Report on Forest Resources Statistics in Daxinganling [R]. 2013

[2] Tang W. G. Research on the optimal decision of converting agricultural land to carbon sink forestry based on real options [D]. Tianjin University of Finance and Economics, 2016.

[3] Qin Jianhua, Jiang Zhilin, Ye Jingzhong. Effects of different thinning methods on the growth and yield of fir forests [J]. Journal of Nanjing Forestry University, 1995(02):29-33.

[4] Ma Chengwu, Ying Liqing, Jia Shuangzhu, Gu Jiancai. Effects of ecological thinning on stand structure and biodiversity of larch in northern China [J]. Hebei Forest and Fruit Research, 2016, 31(03): 235-238. DOI: 10.13320/j.cnki.hjfor.2016.0046.

[5] Alivernini A, Barbati A, Merlini P, et al. New forests and Kyoto Protocol carbon accounting: A case study in central Italy[J]. Agriculture Ecosystems & Environment, 2016, 218:58-65.

[6] Cseh V, Kiss M, E Tanács. Carbon sequestration of floodplain forests: a case study from Hungary, Maros river valley[J]. Tiscia 40, 3-10, 2014.