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Research on Logging Strategy in Northeast China Forest Area Based on Evaluation Result-Oriented Decision Model

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Abstract. Forest farms in Northeast China play an important role in achieving carbon peaking and carbon neutrality in the region. Balancing the various values of forests is important to achieve sustainable development in the region. In this paper, a CO2FIX model for calculating forest carbon sequestration is first established. Then an evaluation result-oriented decision model (ERDM) is established. Evaluate the carbon sequestration value, economic value and ecological value of forests, and propose oriented policies for the values with lower scores. Then a multi-objective planning process is established with the goal of maximizing the sum of various forest values, and the oriented policy directly affects the constraints. The results of multi-objective planning provide quantitative indicators for forest management plans. After testing, the above decision-making scheme has achieved the benign development of forest farms in Northeast China in the process of simulated management.

Keywords. CO2FIX, ERDM, Forest farms in Northeast China.

1. Introduction

The impact of global climate change on world development is becoming more and more serious. The approach to carbon peaking and carbon neutrality involves not only reducing carbon emissions, but increasing carbon sequestration also plays an increasingly important role. Carbon sequestration can be achieved by increasing the amount of carbon dioxide sequestered in the biosphere. Components of the biosphere that can achieve carbon sequestration include trees, soil, and water. Forests and their wood products can play important roles in absorbing carbon dioxide due to their abundant carbon sequestration resources.

The exploitation of forest resources blindly pursuing economic benefits will break the carbon balance of the biosphere, and excessive forest protection will also be difficult to balance ecological value and social benefits. Therefore, a scientific and rational

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deforestation plan for forests can not only bring great economic value to society, but also increase the carbon sequestration of forests and their products. In this paper, forest farms in Northeast China are selected for the study.

Forest farms in Northeast China have a temperate monsoon climate, which is very suitable for forest restoration and growth. The region's economy is in a stage of continuous development and will not be able to get rid of its heavy dependence on natural resources for a long time to come. The once-overexploitation of forest resources has caused severe damage to forest farms in Northeast China. It is meaningful for the long-term development of the region to develop a scientific and effective forest management plan for the Northeast Forest Farm.

2. The Research Idea of this Paper

In order to balance the social benefits and the ecological benefits from carbon sequestration in forest farms in Northeast China. The formulation method of the forest management plan can be divided into two parts: the calculation process of forest carbon sequestration based on the CO_2FIX model and the evaluation result-oriented decision-making (ERDM) process. The results obtained based on the above two processes will provide quantitative guidance for forest management plans. The specific forest management plan formulation process is shown in figure 1.

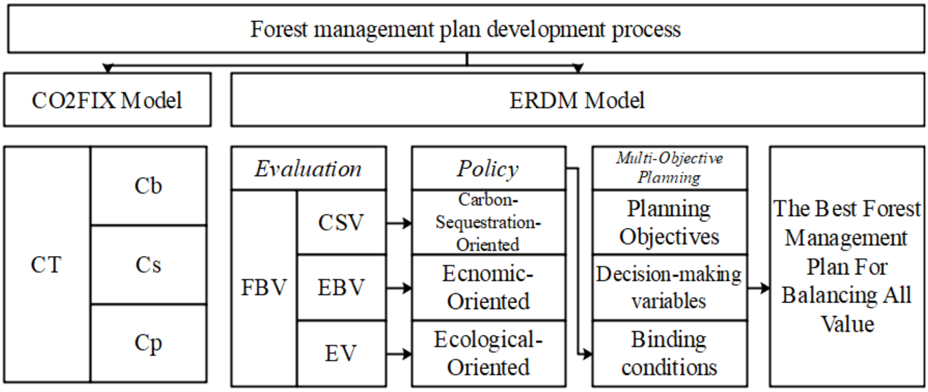


Figure 1. Forest Management Plan Development Process

Firstly, the carbon sequestration of forest can be obtained by substituting various carbon cycle parameters of forest into CO2FIX model[1]. Secondly, the evaluation system of the total forest value uses the quantitative value of carbon sequestration, economic value and ecological value as evaluation indicators. Guided forest management plans are proposed for lower-scoring indicators that affect the constraints of multi-objective planning. Finally, a multi-objective planning process is used to calculate the quantitative indicators of the forest management plan.

3. Establish CO_2FIX Model

A complete and effective carbon sequestration (CT) forest system should include: a community of organisms (Cb) that can sequester carbon dioxide and convert it into organic matter through photosynthesis; soil organic matter (Cs) that can sequester carbon dioxide and decompose biological remains into carbon dioxide and water, thus contributing to the carbon cycle; and wood that is made into different products (Cp) that can sequester carbon dioxide over different time horizons. In the carbon cycle, the burning of wood and wood waste that cannot be completely decomposed by the environment can have an impact on carbon sequestration. Calculating the carbon sequestration need to take these circumstances into account.

3.1 Carbon Stored in Living Biomass

Carbon sequestration stored in organisms in forests is the sum of various biological carbon sequestrations. In this paper, the hierarchical structure of organisms in the forest is divided into high-level trees and low-level mosses. Then the carbon sequestration stored in the living biomass[2] can be expressed as Equation 1:

$$Cb_t = \sum_{i=1}^{2} Cb_{it} \tag{1}$$

where Cbt represents the carbon stored in living biomass at time t, Cbit is the carbon stored in living biomass of cohort i at time t.

Furthermore, in order to calculate the carbon stored in living biomass at the next moment, more related factors should be considered. The input to the carbon sequestration of the living biomass is the growth of the organism and its outputs include branch and leaf shedding, senescence mortality, harvesting and logging mortality. The amount of carbon sequestered in the living biomass at the next moment can be obtained as shown in the Equation 2.

$$Cb_{it+1} = Cb_{it} + Gb_{it} - Ms_{it} - T_{it} - H_{it} - Ml_{it} \tag{2}$$

where Gbit represents the biomass growth of cohort i at time t, Msit is the senescence mortality of cohort i at time t, Tit means branches and leaves turnover of cohort i at time t, Hit expresses the harvest of cohort i at time t, Mlit represents the logging mortality of cohort i at time t.

3.2 Carbon Stored in Wood Products

Carbon sequestration stored in wood products is the sum of the carbon sequestration of various wood products. In this paper, wood products are divided into short-term products, medium-term products and long-term products according to their service life. Then the carbon sequestration of wood products can be calculated by Equation 3.

$$Cp_t = \sum_{m=1}^{3} Cp_{mt} \tag{3}$$

where Cp_t is the carbon stored in wood products at time *t*, Cp_{mt} means The carbon stored in product *m* at time *t*.

Changes in carbon sequestration in wood products include output process and input process. For the output process, carbon sequestration in wood products is gradually lost as the life of the wood products decreases; For the input process, the wood harvested each year is processed into wood products of different ages in different proportions. The iterative relation for carbon sequestration in wood products is Equation 4.

$$Cp_{mt+1} = Cp_{mt}\left(1 - \frac{1}{AG_m}\right) + P_{mt}\gamma\sum_{i=1}^{2}(H_{it} + Ml_{it}) \tag{4}$$

where P_{mt} represents production percentage of product *m* at time *t*, γ means proportion of wood not used to produce wood fuels, AG_m expresses the service life of product *m*.

3.3 Carbon Stored in Soil Organic Matter

In the carbon cycle of the biosphere, organic matter in soils plays an important role in carbon sequestration. The turnover of organic matter in soils is divided into input process and output process. For the input process, on the one hand, the carbon sequestered in the organism becomes part of the soil organic matter due to the shedding of leaves and branches and natural mortality. On the other hand, some of the carbon sequestered in wood products that have exceeded their useful life is released into the soil during the landfill process; For the output process, the carbon sequestered in the soil is released into the air due to the decomposition of microorganisms in the soil. Based on the above analysis, we can obtain an iterative relationship for carbon sequestration in soil organic matter, as shown in Equation 5.

$$Cs_{t+1} = Cs_t + \sum_{i=1}^{2}(T_{it} + Ms_{it}) + \theta\sum_{m=1}^{3}\frac{Cp_{mt}}{AG_m} - \alpha Cs_t \tag{5}$$

where Cst represents the carbon stored in soil organic matter at time t, α means soil decomposition rate, θ is the rate of obsolete wood products going to landfill.

3.4 Total Carbon Sequestration in the Forest

Based on the above analysis, the CO_2FIX model can calculate forest carbon sequestration as shown in Equation 6.

$$CT_t = Cb_t + Cs_t + Cp_t \tag{6}$$

where CTt represents total forest carbon sequestration at time t, Cbt means the carbon stored in living biomass at time t, Cst is the carbon stored in soil organic matter at time t, Cpt refers to the carbon stored in wood products at time t.

4. Establish ERDM Model

The evaluation result-oriented decision-making model is divided into the evaluation process of various forest values and the multi-objective decision-making process. The two processes are discussed separately below.

4.1 Evaluation for the Forest Value

In order to balance the value of carbon sequestration in forests and other aspects, forest carbon sequestration is quantified as carbon sequestration value (CSV). On this basis, economic benefit value (EBV) and ecological value (EV) are introduced as part of the forest benefit value. The forest benefit value (FBV) can be calculated by adding CSV, EBV and FBV equally as Equation 7.

$$FBV = CSV + EBV + EV \tag{7}$$

- Carbon Sequestration Value

The value of forest carbon sequestration over a period can be calculated according to Equation 8.

$$CSV_t = Pc_t(CT_t - CT_{t-1}) \tag{8}$$

where Pct is the price of carbon over this time period.

For forests with low forest carbon sequestration value, a series of carbon sequestration-oriented policies are proposed:

1) Control forest carbon emissions below the country's highest carbon emissions standards set by the Paris Agreement[3], reducing carbon sequestration losses.
2) Improve the production ratio of various wood products, increase production of long-term products compared to the previous stage to minimize carbon sequestration losses.
3) Improve the energy mix in the region, reducing wood fuel use by 5%.
4) Enhance the recycling of wood products, implement garbage recycling pretreatment, and increase soil carbon sequestration by 10%.

- Economic Benefit Value

The economic benefit value can be divided into the benefits of making various wood products and the benefits of making wood fuel. Various wood products and fuels have different discount rates[4] when they are circulated as commodities. Therefore, the economic benefits of various wood products and wood fuels can be expressed as Equation 9:

$$\begin{aligned} NTV_m &= \sum_{t=1}^{T} \frac{P_{mt} Cp_{mt}}{(1+D_{mt})^{t-0.5TPL}} \\ NFV &= \sum_{t=1}^{T} \frac{(1-\gamma) Pf_t Cp_t}{\gamma (1+Df_t)^{t-0.5TPL}} \end{aligned} \tag{9}$$

where, Pmt represents the price of product m at time t, Pft represents the price of wood fuel at time t, Dmt is the discount rate of product m at time t, Dft is the discount rate of wood fuel at time t, NTVm means the economic benefits value of product m, NFV means the economic benefit value of wood fuel.

Then, the total economic benefits value can be written as:

$$EBV = \sum_{m=1}^{3} NTV_m + NFV \tag{10}$$

For forests with low economic benefit value, a series of economic-oriented policies are proposed:

1) Promote the development of the market economy, implement "replacement of plastic and steel with wood", increase the sales of long-term products, and reduce the discount rate of long-term products by 20%.
2) Improve the product structure, increase the output of short-term products, medium-term products, and wood fuel, and promote the rapid circulation of wood products.
3) Moderately increase felling, with a 4% increase in felling volume compared with the previous period, and expand the economic benefits brought by wood products.

◆ Ecological Value

Since water and oxygen are the basis for forests to maintain their biodiversity, the ecological value of forests can be quantified as Equation 11.

$$EV = \sum_{t=1}^{T} S\left(1 - \frac{Cp_t}{Cb_t}\right)(322.5Pw_t + 2.02Po_t) \tag{11}$$

where S is the forest land cover area, Pwt represents the price of water at time t, Pot means the price of oxygen at time t.

For forests with low ecological value, a series of ecological-oriented policies are proposed:

1) Afforestation, return farmland to forest, increase the growth speed of forest coverage area by 10% in the next stage to improve the protection effect of forest on the ecological environment.
2) Moderately reduce wood harvesting, increase the proportion of tree carbon sequestration in forest carbon sequestration, and make forests more ecologically active.

4.2 Multi-objective Programming

In order to obtain the management plan of the next stage of the forest, a multi-objective planning model is established based on the assessment of the CSV, EBV and EV of the previous stage of the forest. The model takes the maximization of the total forest value as the planning goal, and uses the age, area and amount of felled trees as decision variables, and generates constraints with oriented policies. The multi-objective programming model is shown in Equation 12.

$$\max_{Ml_{it}, Age_{ijt}, X_{ijt}} (CSV + EBV + EV)$$

$$s.t.\begin{cases} Age_{ijt} \geqslant Age_{\min} \quad \forall i,j & ① \\ A_i X_{ijt} + \sum_{k \epsilon U_i} \sum_{n=1}^{T} A_k X_{kjn} \leqslant U_{\max} & ② \\ X_{ijt} \epsilon \{0,1\} \quad \forall i,j & ③ \\ Orientation\ constraints \end{cases} \tag{12}$$

where Ageijt represents the age of the tree with coordinates (i, j) at time t, Agemin is the minimum age at which trees are allowed to be felled, Ai or Ak is a certain logging area of the corresponding area block, Xijt represents the area block whose coordinates are i, j in the target forest at time t, Umax means the maximum amount of harvest in an area to prevent over-harvesting, Ui refers to the surrounding area of the harvested area.

Constraints ① to ③ are common to all plans and are derived from the basic properties of the forest. Constraint ① represents a limit on tree age, where the trees to be harvested need to be higher than the minimum harvesting age. Constraint ② is a classic contiguous area constraint[5] to prevent possible over-harvesting during planning. Constraint ③, which means that each area can have two states of logging or no logging. When the tree age is insufficient or for the needs of environmental protection, logging may not be carried out.

And the orientation constraints are shown in table 1:

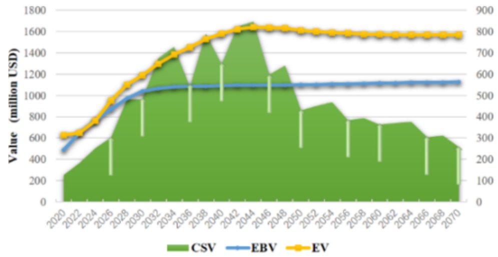
Table 1. Orientation Constraints

Carbon-sequestration-oriented		Economic-oriented		Ecological-oriented	
$CT_t - CT_{t-1} \leqslant CT_{\max}$	④	$D_{3t} = 80\% D_{3(t-1)}$	⑧	$\frac{\partial S}{\partial t}\|_{t=\tau} \geqslant 104\% \frac{\partial S}{\partial t}\|_{t=\tau-1}$	⑫
$P_{mt} \geqslant P_{3t}$	⑤	$\gamma_t \geqslant \gamma_{t-1}$	⑨	$\frac{\partial Cp_t}{\partial t} \leqslant \frac{\partial Cb_t}{\partial t}$	⑬
$\gamma_t \leqslant 95\% \gamma_{t-1}$	⑥	$P_{mt} \geqslant P_{m(t-1)} (m=1,2)$	⑩		
$Cs_t \geqslant 105\% Cs_{t-1}$	⑦	$\frac{\sum_{m=1}^{3} P_{mt}}{1-\gamma_t} \geqslant 104\% \frac{\sum_{m=1}^{3} P_{m(t-1)}}{1-\gamma_{(t-1)}}$	⑪		

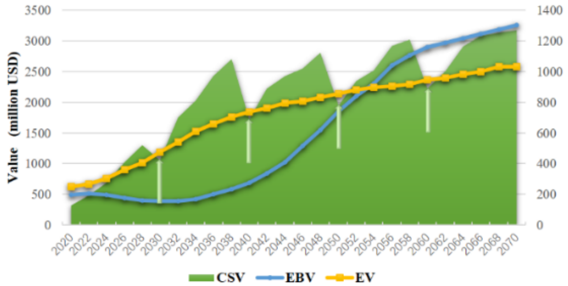
For the optimization decision of each time period, different orientated management plans correspond to different orientation constraints, in which constraints ④ to ⑦ is needed to add in when the period is carbon-sequestration-oriented, ⑧ to ⑪ for the economic-oriented plan and ⑫, ⑬ for the ecological-oriented plan. The decision variable values under the optimal results will be used as the basis for making the best forest management plan.

5. Forest Management Plan for Forest Regions in Northeast China

Based on the data of the forest area in Northeast China in the past decades, its parameters for the next 50 years were predicted using the SVR model, and there are many new parameter prediction methods, such as the multigrid method[6,7], the homotopy method[8,9]. Substituting the forest-related parameters of the next 50 years into the CO2FIX model and the ERDM model, the evaluation results of CSV, EBV and EV in each period can be obtained as shown in the figure 2a.



a-Before the implementation of forest management plan



b-After the implementation of forest management plan

Figure 2. Evaluation for Forestry Resources in Northeast China in the next 50 years

In the next 15 years, due to the rapid expansion of forest areas, the total environmental value and carbon sequestration value of Northeast China have increased steadily, and the number of trees used to produce short-term products and fuelwood has increased, while the forestry industry has contracted, but economic value has increased. In the next 15–30 years, the forest will gradually saturated, the forestry industry will further shrink, the growth rate of total environmental value and total carbon sequestration value will slow down to the highest point, and the growth rate of economic development will further improve. In the next 30–50 years, the total amount of forests exceeds the maximum environmental capacity, and most of them are mature forests with carbon balance. Therefore, the total environmental value shows a downward trend, and the total carbon sequestration value shows a lagging downward trend, and the total economic value decreases accordingly. It is worth noting that the change curves of economic value and ecological value are relatively smooth, while the carbon sequestration value has a periodic short-term decrease-increase change once every five years. That's due to the short-term reduction in carbon sequestration brought about by forest rotation.

Forest management plans are proposed for the region in response to this evaluation. Our plan is divided into four stages, and each stage implements different forest management plans according to different objectives:

- The first stage (2020-2030): to improve the total carbon sequestration value oriented.

  Recommended harvesting: 8.4 million ton, 10 years

  Recommended production of long-term products: 36.8%

  Product life (AG) and wood utilization rate (γ) should be increased, and the proportion of short-term product production (P1) should be reduced, so as to lay the foundation for high carbon sequestration of forest and its wood products at the expense of moderate economic development.

- The second stage (2030-2045): to improve the overall economic value oriented.
  Recommended harvesting: 14.9 million ton, 10 years
  Recommended production of long-term products: 27.4%
  Appropriately increasing cutting volume (H), improving wood utilization rate (γ), and slightly increasing the proportion of short-term product production (P1), H can be divided into two aspects: single cutting volume and rotation period. Wood products, especially short-term wood products, can easily improve the short-term economic growth rate and make up for the inhibition of the previous stage on the economy.
- The third stage (2045-2060): oriented towards improving overall environmental value.
  Recommended harvesting: 11.6 million ton, 15 years
  Recommended production of long-term products: 31.0%
  Appropriately reduce the amount of cutting (H), extend the time interval between the two cutting, delay the time when the total forest reaches the maximum environmental carrying capacity, restore and improve the beneficial impact of forest on the environment.
- The fourth stage (2060-2070): to improve the overall economic value oriented.
  Recommended harvesting: 17.2 million, 20 years
  Recommended production of long-term products: 33.3%
  Because the total amount of forest is close to the maximum environmental carrying capacity, the tree regeneration rate and the cutting rate reach a balance state. In this stage, we should pay attention to the direct economic returns brought by forest resources, moderate cutting, and win-win between man and nature.

The effectiveness of the proposed forest management plan is evaluated and the effects after the implementation of the plan are shown as figure 2b.

6. Conclusion

In this paper, in order to balance forest carbon sequestration with other values of forests, the CO2FIX model used to calculate forest carbon sequestration was first established. Then, it evaluates the value, economic value and ecological value of forest carbon sequestration, and proposes oriented policies for the values with lower scores. Then a multi-objective planning model is established with the goal of maximizing forest value, and the oriented policy will affect the constraints of the model. Finally, a forest management plan for a period of time is generated based on the optimization results.

After the implementation of the first phase of the plan, the value of forest carbon sinks has been well supported. Compared with before the implementation of the plan, the growth rate is faster, and the growth level of ecological value is basically the same as that before the implementation of the policy. The economic value of forests has actually declined due to a reduction in the proportion of short-term production. However, the economic value of the forest recovered quickly after the implementation of the second stage of the management plan. Although the growth of forest carbon sink value and ecological value has slowed down, it still maintains a certain growth rate. After the arrival of the third stage, the growth rates of the three aspects of the forest gradually stabilized, showing a common growth trend. Until the fourth stage, forests in Northeast

China can adopt longer rotation periods, and the production of long-term products can ensure both carbon sink value and economic benefits.

To sum up, the CO2FIX model can fully measure the carbon sequestration of forests in Northeast China, and the ERDM model can realize the benign development of forest farms in Northeast China.

Acknowledgments

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