Study on Forest Planning Decision Based on Carbon Sequestration Model

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Abstract. To mitigate the effects of climate change, this paper need to take effective action to reduce greenhouse gases in the atmosphere. From a global perspective, moderate harvesting is beneficial for carbon sequestration, but it is important for forest managers to consider the value of harvested forest products and the value of forest growth for carbon sequestration, and to consider other factors. A model for calculating forest carbon sinks was developed, setting carbon sinks of plants, soils, forest products, and the water environment as primary indicators, and dividing six secondary indicators downward. By quantifying the secondary indicators, the total amount of carbon sequestration is obtained. Second, a complete forest management plan is developed, taking into account other values of the forest. The forest management problem is transformed into a planning problem, and then a particle swarm algorithm is used to solve the forest management planning problem. Trees are not harvested when there are significant differences in biomass at different growth levels and when the value of the forest products exceeds the value of the sustained carbon sink of the trees. The value of forest products is weighed against the value of sustained forest growth to find the transition point, and specific forests and their location characteristics are used to determine the transition point.

Keywords: Forest carbon sequestration, forest management planning, decision models.

1. Introduction

In recent years, climate change has dramatically impacted the biosphere. The greenhouse effect is an important factor affecting climate, which can lead to global warming and further lead to glacial melting. Studies have shown that for every 0.5-degree rise in global temperature, the chances of mountain fires, food supply shortages, etc., increase significantly. With the progress of society and the improvement of human thinking, governments are paying more attention to environmental and climate issues. To reduce the impact of climate change on the environment as soon as possible, there is an urgent need to propose countermeasures to mitigate the greenhouse effect.

Mitigating the greenhouse effect can be achieved not only by reducing the number of greenhouse gases in the atmosphere but also by increasing the carbon sink of forests through proper tree cutting and storing carbon in plants. Therefore, a complete forest management strategy should be developed. In optimizing the forest management strategy, the age, geography, and topography of the trees should be considered to balance the value of cutting trees to produce forest products and the value of the forest carbon sink.

This paper will build a carbon sink model to calculate the carbon sink level of the forest and develop an appropriate forest management strategy. And build a decision model with which to determine an appropriate forest management plan that balances various values, including carbon sinks.

2. Model assumptions and notation

2.1. Assumptions

The data this paper collect from the online database is accurate and extensive.

One identical tree is planted for each tree harvested, and there is no significant change in forest structure.

Every tree harvested, an identical tree is planted.
Plants play a decisive role in biodiversity.

2.2. Notations

Important notations used in this paper are listed in Table 1.

Table 1. Notations

Symbol	Description
CST	Total Carbon Sequestration
CSF	Forest Carbon Sequestration
CSP	Carbon Sequestration in Forest Plants
SSC	Forest Soil Carbon Sequestration
WSC	Forest Water Storage Carbon Sequestration
PSC	Carbon Sequestration in Forest Products
WT	Gross Revenue from Forest Products
PCS	Potential Carbon Sequestration
CS	Coal Carbon Sequestration
OS	Petroleum Carbon Sequestration
GS	Natural Gas Carbon Sequestration
BID	Biodiversity
D	Simpson Biodiversity Index
H	Shannon Weiner Biodiversity Index
AMU	Recreational Use
TT	Forest Tertiary Industry
TN	The Number of Forest Tourists
TI	Forest Tourism Investment
CUL	Cultural Aspects
ECOC	Ecological Culture
TOUC	Tourism Culture
L	Total Value of Forest

3. Model construction and solving

3.1. Carbon Sequestration Model

Carbon sequestration includes forest carbon sequestration and carbon sequestration of forest products.

3.1.1 Forest carbon sequestration

According to the question, forest carbon sequestration includes plant carbon sequestration, soil carbon sequestration, and water environment carbon sequestration [1]. Carbon Sequestration Model is shown in Figure 1.

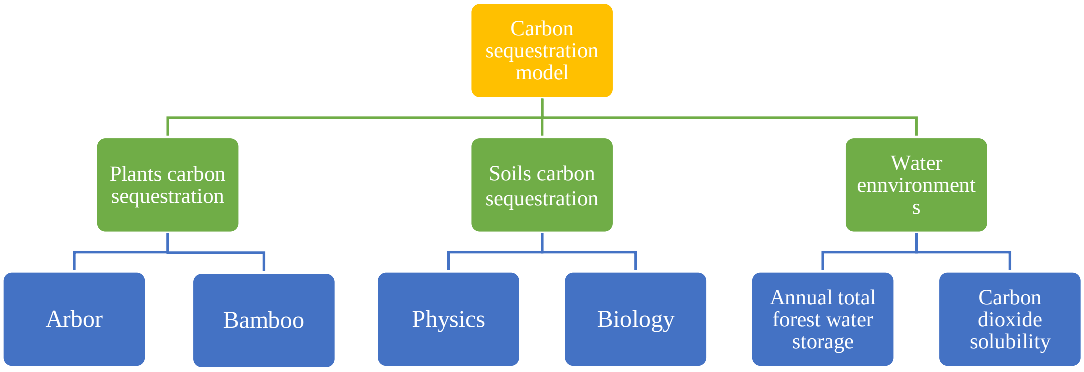

Figure 1. Carbon Sequestration Model

The intensity of photosynthesis is related to the type and age of plants. According to the National Forestry Network, the carbon sequestration capacity of forests depends mainly on tree and bamboo forests, while the carbon sequestration of shrubs and herbs is very low. Therefore, this paper divide the tree types into tree and bamboo types as plant carbon sequestration indicators and classify tree types into tree and bamboo types. To simplify the problem, the age structure is divided into young, middle-aged, and mature. Finally, this paper reviewed the relevant literature to obtain the corresponding calculation equations.

Based on the third hypothesis, the area occupied by each type of tree remains the same, and the forest can be divided into six regions with shrubs and herbs growing under the trees.

Taking bamboo as an example, this paper can get the biomass of young, middle-aged, and mature bamboo by reviewing the data in Table 2, which are recorded as $W_{X21}, W_{X22}, W_{X23}$ [2].

Table 2. Biomass calculation formula

Plant type	young forest	half-mature forest	mature forest
Cedarwood	$W_{11}=0.6170*H^{-0.1037}*D^{2.1153}$	$W_{12}=0.0971*L^{0.0346}*D^{1.7814}$	$W_{13}=0.0647*H^{0.8959}*D^{1.4880}$
Bamboo	$W_{21}=0.3710*H^{0.1357}*D^{0.9817}$	$W_{22}=0.2800*L^{0.2740}*D^{0.8357}$	$W_{23}=0.0398*H^{0.5779}*D^{1.8540}$

H is the plant height, D is the diameter breast height (cm), and L is the crown length (cm).

The following equation is obtained by combining all the above factors.

$$\begin{gathered} VCD_i^{(t)}=X_{i1}\times W_{Xi1}\times C_{Xi1}+X_{i2}\times W_{Xi2}\times C_{Xi2}+X_{i3}\times W_{Xi3}\times C_{Xi3} \\ PSC_i^{(t)}=VCD_i^{(t)}-VCD_i^{(t-1)} \\ PSC^{(t)}=\sum_{i=1}^{2}PSC_i^{(t)} \end{gathered} \tag{1}$$

Where W_{ij} is the average biomass of the jth growth state of the i-th class of plants, e.g., W_{11} denotes the biomass of seedling trees. C_i denotes the conversion factor for converting biomass to CO_2. The conversion coefficients are different for different growth states of different plants.

3.1.2 Soil carbon sequestration

There are many ways of soil carbon sequestration, after analysis, this paper calculates from **physical and biological** aspects. Intuitively, the sources of organic matter in forest soils are plant and animal remains such as fallen leaves and dead wood, and excreta. Our thesis focuses on forest carbon sequestration, so this paper consider the physical component of plant-soil carbon sequestration as plant remains. The biological component of the soil is the carbon dioxide sequestered by the microorganisms in it by multiplying the conversion factor to obtain the carbon dioxide sequestration. The calculation formula is as follows:

$$\begin{aligned} &SSCP_i^{(t)}=X_{i4}^{(t)}\times W_{Xi3}\times C_{Xi3} \\ &SSCP^{(t)}=\Sigma_{i=1}^{2}\ SSCP_i^{(t)} \\ &SSCB^{(t)}=\gamma_1\times(S1+S2) \\ &SSC^{(t)}=SSCP^{(t)}+SSCB^{(t)} \end{aligned} \tag{2}$$

Where, X_{i3} is the old trees, X_{i4} is the dead trees, γ_1 is the area factors, convert the area to the amount of CO_2, $SSCP$ is the physical component of soil carbon sequestration, $SSCB$ is the biological component, SSC is the amount of the soil carbon sequestration in the forest.

3.1.3 Water environment carbon sequestration

The amount of carbon sequestration within the water environment of a forest is the unit of carbon dioxide dissolved in the water body multiplied by the annual forest water storage [3].

$$WSC=WS(t)\times S_{CO_2} \tag{3}$$

Where, $WS(t)$ is the total water storage in year t, S_{CO_2} is the amount of CO_2 dissolved in water, WSC is the carbon sequestration of forest water.

Sum the factors together and obtain the sum by the following equation:

$$CSF = (PSC + SSC + WSC) \times (1 + 1\%) \tag{4}$$

3.1.4 Carbon sequestration of forest products

Harvested trees can be used for furniture, lumber, glued paper, paper, wood pellets, and others [4], let the ratio of these five species be the mean life $\tau_1, \tau_2, \tau_3, \tau_4, \tau_5$. After the trees are made into forest products and put into use, due to the long service life of the products, this paper can ignore the CO_2 released in the process of use. It is believed that the CO_2 stored in it remains unchanged in the service life, that is, the biomass when it is cut. When the user stops using it, its mission as a carbon store is also ended, and the CO_2 corresponding to the biomass will be released. Therefore, its carbon storage can be expressed as an expression related to biomass and service life. Forest Products is shown in Table 3.

Table 3. Forest Products

Forest Products	Percentage	Mean Life	Average Profit
Furniture	λ_1	τ_1	P_1
Wood	λ_2	τ_2	P_2
Pasteboard	λ_3	τ_3	P_3
Paper	λ_4	τ_4	P_4
Wood pellets and others	λ_5	τ_5	P_5

Note that the total biomass harvested from the year (t-1) to year t is FPB:

$$FPB_i^{(t)} = X_{i5}^{(t)} \times W_{Xi3} \times C_{Xi3} \tag{5}$$

$$FPB^{(t)} = \sum_{i=1}^{2} FPB_i^{(t)} \tag{6}$$

$$CSP^{(t)} = \sum_{j=1}^{5} FPB^{(t)} \times \lambda_j \times (\tau_j - 1) \times \gamma_2 \tag{7}$$

Where CSP stands for carbon sequestration stock of forest products. γ_2 represents the losses in the production process.

So the total number harvested during the year is:

$$N^{(t)} = \sum_{i=1}^{2} N_i \tag{8}$$

The total forest carbon sequestration is:

$$CST^{(t)} = CSF^{(t)} + CSP^{(t)} \tag{9}$$

3.2. Forest management decision model

3.2.1 Value of forest products

Forest products are one of the significant indicators of forest value. Rational harvesting is conducive to the development of forests and ecological stability. In this paper, this paper calculate the value of forest products by the five factors in the previous section [5].

$$X_5^{(t)}=\sum_{i=1}^{2}X_{i5}^{(t)}$$
$$W_j^{(t)}=X_5^{(t)}\times\gamma_2\times\lambda_j\times P_j \tag{10}$$
$$WT^{(t)}=\sum_{j=1}^{5}W_j^{(t)}$$

Where, W_j is the profitability of each forest product, WT is the total forest product.

3.2.2 Potential carbon sequestration

In this paper, apart from the carbon sequestration method in the carbon sequestration model, this paper consider organic deposits also belong to carbon sequestration. Organic minerals are formed by plant and animal excreta and remain over long-term geological processes, so this paper choose three indicators to study potential carbon sequestration: Coal CS, Petroleum SS, and Gas GS.

$$CS=r_1\%\times 5$$
$$OS=r_2\%\times 5 \tag{11}$$
$$GS=r_3\%\times 5$$

3.2.3 Biodiversity

Biodiversity affects the ecological balance of a forest [6]. In the biological community, it seems that under normal circumstances, the greater the number of biotic populations, the ecosystem is more stable. This paper obtained biodiversity indexes by referring to the Simpson Diversity Index and the Shannon-Wiener Diversity Index [7].

This paper mainly studied the value of plants in the biosphere, so this paper did not consider the contribution of animals to biodiversity. Regarding the whole animal population, they cannot survive without plants as producers, so the above assumption is reasonable. So only the impact of plants on biodiversity changes needs to be considered.

According to the assumption to plant back a tree in time after harvesting it. To study the changes in biodiversity, this paper made a reasonable treatment by adding a coefficient of 0.5 for the contribution of seedlings to biodiversity, a coefficient of 0.75 for the middle age, and 1 for the mature ones.

Simpson Diversity Index:

$$D=5\times\left(1-\sum_{i=1}^{2}\sum_{j=1}^{3}p_{ij}\times a_j\right) \tag{12}$$

The Shannon-Wiener Diversity Index:

$$H=\sum_{i=1}^{2}\sum_{j=1}^{3}\left[-p_{ij}\times\ln\left(p_{ij}\right)\times a_j\right] \tag{13}$$

Denote by p_{ij} the proportion of the jth state (seedling, middle-aged, mature) in the ith category of trees:

$$p_{ij}=\frac{X_{ij}}{X_i} \tag{14}$$

a_j denotes the effect coefficient of seedling, middle age, and maturity on biodiversity: 0.5,0.75,1.

$$BID=\frac{(D+H)}{2} \tag{15}$$

Where BID is the biodiversity value of the forest.

3.2.4 Entertainment

The entertainment of the forest is mainly tourism, sightseeing forest park, and other uses, so this paper's recreational use selected these three indicators: the value of the forestry tertiary sector, the number of visitors, and investment in tourist sites [8].

$$
\begin{aligned}
TT^{(t)} &= e^{\left(\frac{Third^{(t)}}{Third^{(t-1)}}\right)} \\
TN^{(t)} &= e^{\left(\frac{Number^{(t)}}{Number^{(t-1)}}\right)} \\
TI^{(t)} &= e^{\left(\frac{Invest^{(t)}}{Invest^{(t-1)}}\right)}
\end{aligned} \tag{16}
$$

Considering that TT, TN, and TI have a long-term impact on the value of forest recreation, this paper used the weighted-average method:

$$
weight_i = \frac{(1-a)^{\,i}}{\sum_{i=1}^{5}(1-a)^{\,i}} \tag{17}
$$

a is a fixed constant, and this paper consider the effect of the last five years, the closer the distance, the greater the weight given. This paper take the processed TT, TN, and TI.

$$
AMU^{(t)} = \rho_1 \times TT^{(t)} + \rho_2 \times TN^{(t)} + \rho_3 \times TI^{(t)} \tag{18}
$$

3.2.5 Culture

After checking the information about forest culture in Wikipedia, this paper divided the forest culture into eco-culture and tourism culture. Eco-culture is mainly related to the ecotope of the forest and is expressed by the ratio of planted and natural forests; tourism culture is related to human society and is measured by the cultural creativity index of the forest location.

$$
\begin{gathered}
ECOC = (\xi_1 \times t_1 + \xi_2 \times t_2) \times 5 \\
TOUC = CulIndex \times 5 \\
CUL = \eta_1 \times ECOC + \eta_2 \times TOUC
\end{gathered} \tag{19}
$$

t_1 and t_2 denote the proportion of natural forest and humans in a forest, respectively.

η_1, η_2 will be given later.

Based on the data [9], this paper can calculate the value created by the forest in one year. As forestry managers, the woods can still grow regularly according to our assumptions. In addition, this paper should consider six aspects to determine the appropriate management plan to maximize the total value, and it should include what trees to cut and when to cut them. To develop a feasible management plan, this paper refer to the felling ratio of different types of trees.

3.2.6 Value of carbon sequestration

After analyzing the six main values for forest managers to consider, this paper get the total values:

$$
L = \theta_1 \times CST + \theta_2 \times WT + \theta_3 \times PCS + \theta_4 \times BID + \theta_5 \times AMU + \theta_6 \times CUL \tag{20}
$$

Where $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$ are carbon sequestration, forest product value, potential carbon sequestration, biodiversity, entertainment use, and cultural consideration, respectively. The weights of these 6 aspects will be given later.

3.2.7 Hierarchical analysis for weighting

Using hierarchical analysis (AHP) it can get θ, ϕ, ρ, ξ respectively as:

$$
\begin{aligned}
&\theta=[0.38060.19040.11480.20450.05060.0593] \\
&\phi=[0.1635 \ \ 0.5394 \ \ 0.2971] \\
&\rho=[0.5815 \ \ 0.3090 \ \ 0.1095] \\
&\eta=[0.7500 \ \ 0.2500]
\end{aligned} \tag{21}
$$

3.2.8 Forest management planning

Now calculate the value created by the forest in a year based on the data. As forestry managers, assume that the forest will still be healthy and growing. In addition, six aspects of value are considered to determine the appropriate management.

Plan to maximize the total value. The plan should include the target and the timing of the cut, and the percentage of different types of trees cut can be used to get a reasonable plan. Taking bamboo as an example, this paper can obtain the biomass of bamboo seedlings in young forests and mature forest by consulting the data, which are recorded as $W_{X21}, W_{X22}, W_{X23}$.

α_1 is the growth rate of bamboo [10], α_2 is the aging rate of bamboo, and α_3 is the natural mortality rate of bamboo i. β_1 is the harvest rate of bamboo. According to the assumption that the cut bamboo is to be replanted, then the planting rate is $\beta_2 = \beta_1$. Checking the relevant literature, this paper know that the formula for α_1 is:

$$\alpha_1 = A_j \times \sqrt{X_1 \times X_2} \tag{22}$$

Where, A_j is the coefficient of the model, X1 is the growth pattern index of bamboo and X2 is the growth structure index.

According to the age structure of bamboo, it can be obtained because the bamboo population is to grow normally, and the proportion of mature years is the largest. The average lifespan of bamboo is T_2, and it can be considered that there is a death of $\frac{1}{T_2}$ bamboo within a year. Then $\alpha_2 = \gamma_3 \times \alpha_1$, $\alpha_{23} = \frac{1}{T_2}$.

Also considering the influence of geographical topographic factors, this paper choose the factors of latitude and longitude, slope, and rainfall for this paper. According to the references, the following equations are available.

$$
\begin{gathered}
\ln X_1 = \lambda_L \times X_L + \lambda_B \times X_B + \lambda_H \times X_H + \lambda_T \times X_T + \lambda_R \times X_R \\
\ln X_2 = \lambda_a \times X_a + \lambda_b \times X_b + \lambda_c \times X_c + \lambda_h \times X_h
\end{gathered} \tag{23}
$$

Where L is longitude, B is latitude, H is elevation, T is temperature, R is rainfall, α is sthe lope, β is slope direction, γ is slope position, h is soil thickness, and X corresponds to the corresponding parameters. λ is the scale factor of the corresponding factor.

This paper selects China's domestic forest resources data to fit the proportion coefficient as follows Table 4:

Table 4. China's domestic forest resources data and the proportion coefficient

scale factor	value
longitude	-0.777
latitude	0.411
elevation	-0.561
temperature	-0.443
rainfall	0.801
slope	-0.423
slope direction	0.008
slope position	-0.097
soil thickness	-0.154

The proportion coefficient of slope direction and slope position is less than 0.15, which has little effect on the whole. To simplify the calculation, this paper do not consider the slope direction and slope position.

Combining the above factors yields the following equation:

$$VCD_i^{(t)} = X_{i1} \times W_{Xi1} \times C_{Xi1} + X_{i2} \times W_{Xi2} \times C_{Xi2} + X_{i3} \times W_{Xi3} \times C_{Xi3}$$
$$PSC_i^{(t)} = VCD_i^{(t)} - VCD_i^{(t-1)} \tag{24}$$
$$PSC^{(t)} = \sum_{i=1}^{5} PSC_i^{(t)}$$

This paper set β_{11}, β_{21} the proportion of Cedar-wood and Bamboo cut down each year, taking bamboo as an example, this paper can get the following equation.

$$\begin{cases} \dfrac{\Delta X_{21}}{\Delta t} = -\alpha_{21} \times X_{21} + \alpha_{24} \times X_{23} + \beta_{22} \times X_{23} \\ \dfrac{\Delta X_{22}}{\Delta t} = \alpha_{21} \times X_{21} - \alpha_{22} \times X_{22} \\ \dfrac{\Delta X_{23}}{\Delta t} = \alpha_{22} \times X_{22} - \alpha_{23} \times X_{23} - \beta_{21} \times X_{23} \\ X_{24} = \alpha_{23} \times X_{23} \quad , X_{25} = \beta_{21} \times X_{23} \\ X_2 = X_{21} + X_{22} + X_{23} \\ \alpha_{23} = \alpha_{24} ; \beta_{21} = \beta_{22} \end{cases} \tag{25}$$

From this, the growth coefficient per bamboo can be obtained.

When trees and bamboo are cut according to the forest manager's management plan, the average cut rate can be used as the cut rate if only the following year is considered.

Using bamboo as an example again, substitute $\Delta t = 1, \alpha_{21}, \beta_{21}$ into the system of equations, and get:

$$\begin{cases} \Delta X_{21} = -\alpha_{21} \times X_{21} + \alpha_{24} \times X_{24} + \beta_{22} \times X_{23} \\ \Delta X_{22} = \alpha_{21} \times X_{21} - \alpha_{22} \times X_{22} \\ \Delta X_{23} = \alpha_{22} \times X_{22} - \alpha_{23} \times X_{23} - \beta_{21} \times X_{23} \\ X_{24} = \alpha_{23} \times X_{23} \\ X_{25} = \beta_{21} \times X_{23} \\ X_2 = X_{21} + X_{22} + X_{23} \end{cases} \tag{26}$$

According to the above analysis, it can get the number of individual bamboo ages in the next year:

$$\begin{cases} X_{21}^{(t+1)} = X_{21}^{(t)} + \Delta X_{21} \\ X_{22}^{(t+1)} = X_{22}^{(t)} + \Delta X_{22} \\ X_{23}^{(t+1)} = X_{23}^{(t)} + \Delta X_{23} \\ \quad X_{24} = \alpha_{23} \times X_{23} \\ \quad X_{25} = \beta_{21} \times X_{23} \end{cases} \tag{27}$$

Similarly, the number of trees for the following year can be found.

Thus, this paper can find the total value of the forest for the following year $L^{(t+1)}$.

For forestry managers, first of all, the value of forestry in the following year must not be reduced, that is, the total value of the two years should at least meet: $\Delta L = L^{(t+1)} - L^{(t)} \geqslant 0$

Make it as large as possible.

Using the total forest value in the following year as the dependent variable, this paper obtain a function with the deforestation rate as the independent variable.

Choose the appropriate cutting rate that maximizes the total value. This is a planning problem, and by using the Cutting ratio as the cutting rate, this paper can determine the range from 0 to 1. Obtain the following planning equation.

$$\max L^{(t+1)} = \theta_1 \times CST^{(t+1)} + \theta_2 \times WT^{(t+1)} + \theta_3 \times PCS^{(t+1)} + \theta_4 \times BID^{(t+1)} + \theta_5 \times AMU^{(t+1)} + \theta_6 \times CUL^{(t+1)}$$

$$\text{s.t.} \begin{cases} 0 \leqslant \beta_{11} \leqslant 1 \\ 0 \leqslant \beta_{21} \leqslant 1 \\ CST^{(t+1)} \geqslant CST^{(t)} \\ PCS^{(t+1)} = PCS^{(t)} \\ AMU^{(t+1)} = AMU^{(t)} \\ CUL^{(t+1)} = CUL^{(t)} \\ L^{(t+1)} \geqslant L^{(t)} \end{cases} \tag{28}$$

Forest management plans are developed in an integrated manner, taking into account other values of the forest. This paper developed a decision model with a range of six primary indicators including carbon sequestration, forest products, potential carbon sequestration, biodiversity, recreational use, and cultural aspects, and 18 secondary indicators.

When the value of the forest products is less than the value generated by the continued growth of the forest, this paper think the forest should not be harvested.

In the field of fluid dynamics, the transition point refers to the point where the boundary layer changes from laminar flow to turbulent flow. The location and mode of this transition depend on a series of physical factors such as Reynolds number and pressure gradient. The essence of its movement is that the same substance in two different states increases resistance due to friction on the contact surface, making the transition point move. The main factors involved here are laminar flow, turbulence, and friction. The transition point is a point that exists in a balanced manner at different stages [11]. Apply to this problem, various forest management plans correspond to whether the fluid is turbulent or turbulent, and the forest location is compared to the frictional resistance to control the movement of the transition point.

In this case, this paper calculate the transition point between the two forest management plans based on the carbon sequestration model and decision model already developed in the previous section, with the first forest management plan focusing on carbon sequestration values and the second forest management plan focusing more on overall economic benefits. This paper use climate zones to classify the locations: tropical, temperate, and boreal, and the impact of the location parameters varies according to the climate zone characteristics. Finally, the point at which the two plans reach equilibrium is defined as the transition point.

4. Conclusion

In a word, this paper establishes a carbon sequestration model to solve the calculation problem of forest carbon sequestration, and answers the appropriate cutting to maximize forest carbon sequestration. Secondly, this paper establishes the forest management decision-making model, and uses the normalization method, particle swarm optimization algorithm and analytic hierarchy process to deal with the indicators. Then, this paper gives the optimal forest management plan by comprehensively considering various indicators. After applying it to multiple forests, this paper analyzes that the transition point is related to the cutting value and value balance generated by the continuous growth of trees, and adjusts the movement of the transition point according to geographical factors. In the prediction model, this paper analyzed the data of the Natural secondary forest of Liaodong Building in the loess Hilly region, Gansu, China, and predicted that the total carbon storage after 100 years should be $5.0946 \times 10^6 kgs$.

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