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Artificial Logging or Natural Growth

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Abstract

Global climate change makes forestry carbon sequestration a hot issue. In order to improve the comprehensive benefits of forest management, this paper studies the carbon accounting problem, and uses the forest stock conversion factor method to create a carbon sequestration accounting model based on the reserve transformation method. Then, the HWP carbon sequestration accounting algorithm is obtained after the improvement of the reserve change method and the atmospheric flow method with the HWP half-life as a bridge. Based on the ecological and economic benefits, a multi-objective and multi-attribute decision-making model for forest management plan is constructed, and the optimal strategy of stand structure based on selective cutting is proposed. Finally, the entropy weight TOPSIS method is used to quantitatively analyze the comprehensive benefit value and provide suggestions for forestry departments. To verify the model, we chose the Greater Khingan Mountains forest region as the research site. Through successive iterations of CSAM, we calculate that the forest will absorb 534 million tons of live forest and forest products in 100 years. From the stand structure of the forest area, when the selected cutting intensity is 20% and the selected cutting cycle is 10.7 years, the comprehensive benefit value of the Greater Khingan Mountains is the highest.

Keywords

Forest Management Strategy, Selective Cutting Intensity, Selective Cutting Cycle, Optimal Decision Model, Entropy Weight TOPSIS Method

1. Introduction

1.1. Background

With the development of human society, how to deal with global climate change has gradually become an unavoidable topic. It is well known that global warming can lead to melting glaciers, a sharp decline in biodiversity and even natural disasters such as hurricanes and tsunamis. Thus it will cause irreparable damage to the planet on which we live. But do you know who is responsible for global warming? The answer is the Greenhouse Effect caused by an increase in greenhouse gases in the air. Forest can absorb carbon dioxide through photosynthesis and fix it in vegetation and soil in the form of biomass. As the main part of the terrestrial ecosystem, it has the function of carbon sequestration that cannot be underestimated. Therefore, the development of carbon sequestration forestry will contribute an irreplaceable role in improving the current global warming situation.

It is now known that in addition to the carbon sequestration functions, people can also make some trees into specific products, including furniture, plywood, and so on. Therefore, originally short-lived plants will have a longer life to absorb more carbon dioxide, gaining unexpected benefits. Therefore, we should consider adopting appropriate forest management strategies at the global level, finding a balance between the two carbon sequestration methods. At the same time, maximize the carbon sequestration function of forests as much as possible so as to protect the unique, beautiful planet in the universe.

1.2. Restatement of Problems

In order to help all parts of the world design their own forest management policies and coordinate the weight distribution of forest values, we should take into account the differences in geographical environment and human information of different regions. The main tasks are as follows:

- A model for determining the expected carbon sequestration of forests and their products, which involves time factors.
- Combined with social benefits, a decision-making model is developed to facilitate forest managers to find the best forest utilization plan.
- Apply the above decision model to practice, and carry out experiments on a forest to determine its best management plan. Calculate the total carbon sequestration of the forest in 100 years, and then discuss how to migrate from the old model to a new timeline with an interval of two harvests (10 years).

1.3. Innovation

♦ In this paper, the carbon sequestration accounting is divided into HWP carbon sequestration accounting and forest carbon storage two parts. For forest carbon storage, the forest stock conversion factor and atmospheric flow method are used to build the carbon accounting model based on the storage transformation method. For HWP carbon sequestration, we use the half-life to update the differential equation iteratively to build the HWP carbon sequestration accounting model.

♦ This article used the multiple attributes of the forest management decision model, using the method of entropy and TOPSIS is a more advanced analysis, get accurate forest comprehensive benefits value under the different management plan, and then sensitivity analysis carried out to verify its effectiveness so that the model is further promotion, the results of these models for the forestry sector has a larger reference.

- Through preliminary preparation, we determined the target of selective cutting intensity and cycle as the forest management plan. First, we qualitatively analyzed the forest stand structure and obtained the dominant indicators. A sigmoid function was used to calculate the selective cutting period based on different selective cutting intensities, and then the score of the dominant index was obtained according to the principal component quantitative analysis.

2. Assumptions and Justifications

1) Suppose that the area S_{ij} of type j forest in type i region is constant. (Problem 1(a))

It is considered that forest density is a more significant determining factor, so as to further simplify the model.

2) Ignore the effect of forest cutting on soil organic carbon. (Problem 1(b))

The decomposition of soil organic matter is mainly realized by unstable carbon, while stable carbon as the main component of soil organic matter changes little.

3) Suppose the forest we consider is a natural forest in a fixed area.

Because our planning and decision-making problem is to consider the allocation problem in the fixed area, in order to simplify the problem, the changes in the estimation of carbon stocks and social value caused by the problem of forest area are not taken into account.

4) It is assumed that all the trees in the forest after felling are used to produce forest products.

In order to simplify the problem, we only consider the benefits of using the felled trees for various kinds of work on forest products.

5) In terms of cultural tourism, it is assumed that only the positive effects of tourism on forests are considered.

In other words, only consider the benefits of cultural tourism, and do not consider the negative impact of environmental problems caused by tourism, such as forest destruction, environmental pollution, and so on.

3. Notations and Glossary

3.1. Notations

In order to enable readers to have a clear understanding of the symbols involved in the article and to simplify the content of the article, this paper explains the key symbols in the article, as shown in Table 1.

Table 1. Notations.

Symbol	Definition
s_k	Different selective cutting intensity
q_v	The growth rate of retained trees after logging
a	Selective cutting cycle
α_k	Different forest types

Continued

β_k	Forests of different ages
C_{LS}	Carbon storage of living forests
C_H	Carbon storage of forest products
HL	Half-life of HWP library
TR	Preserve the contribution of wood tribute after logging
S	Decision scheme set
Y, Z	Decision matrix, standardized decision matrix
E_k	information entropy
d_k	Proximity of decision-making scheme

3.2. Glossary

- ✧ **Carbon pool:** In the process of carbon cycle, forest ecosystems store the components of the carbon. It includes five parts: aboveground living plant biomass, underground living plant biomass, litter, dead wood and soil.
- ✧ **Natural forest:** A forest area that is generated naturally without man-made measures and managed the forest by selective cutting to achieve the specified purpose.

4. Modeling

4.1. Forest Carbon Sequestration Model

Forest is not only the link between the environment and society but also the key medium to realize their unity. As the most well-functioning resource pool and carbon storage in nature, the forest plays an important role in maintaining the global ecological balance. At the same time, it has the strategic significance of promoting sustainable development.

The scope of global forest research is too broad, so we consider using the stock-change approach to build a carbon inventory accounting system at the national level. Then estimate the carbon storage changes of forest carbon pool and consumer woody products carbon pool. As shown in **Figure 1**.

4.1.1. Carbon Sequestration Accounting of Living Forest

A living forest ecosystem (excluding HWP) stores carbon through a variety of organisms such as forest vegetation. According to the knowledge of biology, carbon sequestration can be realized because the photosynthesis of plants is stronger than other carbon exchanges such as respiration. To sum up, the carbon sequestration of the living forest system is determined by two indicators, namely, carbon storage and carbon sink.

- **Carbon storage and carbon sink calculation model**

First of all, it is worth pointing out that based on *the guidelines for 2006 National greenhouse Gas inventories* (referred to as 2006 IPCC guidelines) prepared by the Intergovernmental Panel on Climate Change, there are many

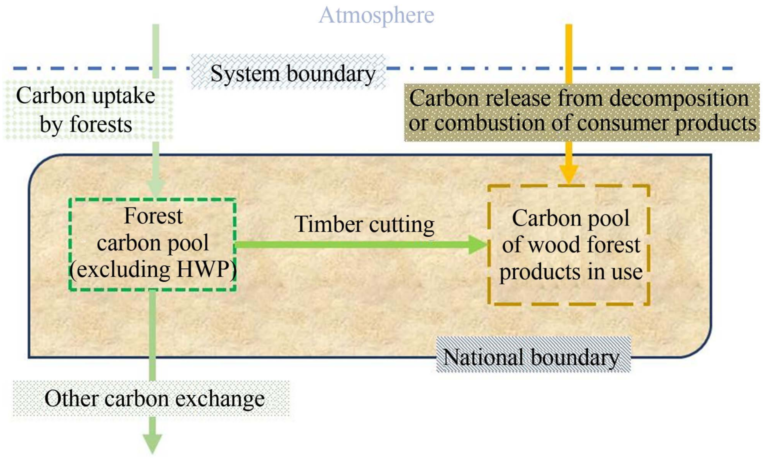

Figure 1. Graphic representation of stock-change approach.

methods for calculating forest carbon stocks. Some methods belong to on-the-spot investigation and scientific calculation. From the perspective of social science, we choose the **forest stock method** to estimate carbon stocks. This method has high credibility and the estimated data are generally consistent with the actual data. For example, the carbon storage of China's 7th and 8th forest resources are very close to the forest carbon storage data published by the National Forestry and Grassland Administration, with an accuracy of more than 90%.

We adjust the corresponding forest based on the **forest volume conversion factor method**, and calculate the required **carbon storage** of the specified forest. The expression is as follows:

$$C_{LS} = \sum_{i=n}^{j=n} \left(S_{ij} \times C_{ij}\right)\left(1+\alpha+\beta\right) \tag{1}$$

$$C_{ij} = V_{ij} \times \mu \times \nu \times \theta \tag{2}$$

where C_{LS} represents forest carbon storage, S_{ij} represents the area of category j forests in category i areas, V_{ij} represents the stock per unit area of type j forests in category i areas, α represents Carbon Conversion Coefficient of Understory Plants, β represents Carbon Conversion Coefficient of Forest Plants, μ represents Biomass amplification coefficient, ν represents volumetric coefficient, θ represents carbon content. It is known from the default universal value of IPCC that $\alpha = 0.195$, $\beta = 1.244$, $\mu = 1.9$, $\nu = 0.5$.

We believe that the increment of forest carbon sink is obtained by the difference of two adjacent carbon storage during the accounting period, while forest carbon sink means that forests absorb carbon dioxide from the atmosphere and fix it in trees or soil(regardless of their own carbon content) [1]. According to the established formula, the forest carbon density can be obtained by using the forest area in the past two years, and then the carbon storage and carbon sink can be obtained next.

- **Carbon storage accounting model of the living forest**

The volume per unit area at the stand level V (m^3/hm^2) is mainly related to two variables: the cross-sectional area G (m^2/hm^2) of the stand and the average height of the stand H (m). Its expression is given in [2].

$$V = a_0 G^{a_1} H^{a_2} + \varepsilon_V \tag{3}$$

where a_0, a_1, a_2 are model parameters, ε_V denotes error term (It is assumed that ε_V obeys the normal distribution with a mean of 0). Then the estimation formula is as follows

$$\hat{V} = a_0 G^{a_1} H^{a_2} \tag{4}$$

Then introduce dumb variables to represent different forest types, and a reserve model system based on the same explanatory variables and different forest type parameters is established.

$$\hat{V} = \left(\sum a_{0i} S_i\right) \cdot G^{\left(\Sigma a_{1i} S_i\right)} \cdot H^{\left(\Sigma a_{2i} S_i\right)} \tag{5}$$

where S_i represents dumb variables of different forest types($i \in N_+$), a_i represents parameters of different forest types.

Considering that the cross-sectional area and average height of the stand are important indicators to measure the growth status of the forest, and increase with the age of trees. We describe the law of biological growth through the growth equation, and use the growth characteristics of biological communities or individuals to construct a time change model, which is evaluated and discussed in the following models:

$$G = a e^{-\frac{b}{Age}} \left(\frac{S}{S_0}\right)^c \tag{6}$$

$$H = A\left(1 - e^{-B \cdot Age^C}\right) \tag{7}$$

where Age represents stand average age, S denotes stand density index, a, b, c, A, B, C are parameters to be estimated.

Based on the above analysis, the total model is

$$C_{LS} = \sum_{i=n}^{j=n} \left(S_{ij} \times a_0 \times \left(a e^{-\frac{b}{Age}} \left(\frac{S}{S_0}\right)^c \right)^{a_1} \times \left(A\left(1 - e^{-B \cdot Age^C}\right) \right)^{a_2} \times \mu \times \nu \times \theta \right) (1 + \alpha + \beta) \tag{8}$$

So we get the **carbon storage accounting model with time variable**.

4.1.2. Carbon Sequestration Accounting of Forest Products

Forests not only fix carbon through ecosystems, but also reduce carbon dioxide in the atmosphere in the form of forest products. The forest product HWP studied in this paper refers to all kinds of products processed with wood materials, including furniture, wood, plywood, paper and sawdust particles, etc.

Forest products have the substitution effect and lag effect of carbon emissions, which is an effective way to reduce greenhouse gas emissions. Therefore, the carbon sequestration of wood forest products has become an urgent problem to be studied. Take China as an example; as the largest carbon emitter, it will face the obligation to reduce emissions in future climate change negotiations. It can be seen that the accounting for carbon storage of woody forest products is particularly important. In addition, Finnish scholar Pingoud and other studies believe that the carbon storage of Finnish HWP is equal to 1.3% of Finnish fossil fuel carbon emissions in the same period. The total carbon storage of Finnish HWP is about 7% of that of the forest [3].

- **Current status of HWP carbon storage**

Stephen J. Colombo estimated the carbon storage of woody forest products in Ontario, Canada, from 2001 to 2100 by using the FOR forest CARB2 model of the national forest carbon budget of the United States. The results show that the carbon pool of forests and woody forest products in this region will increase by 465.3 million tons from 2001 to 2100, of which 417.4 million tons will come from the carbon sequestration growth of woody forest products. This fully affirms the contribution of wood forest products to the country's carbon storage.

- **Carbon Sequestration Accounting Model of Forest Products**

The wood after deforestation is produced into a variety of HWP, and the carbon is stored in the wood products over time. It will not be fully discharged in a short period of time, so the amount of carbon sequestration is related to its benefit and service life of it. On the other hand, all wood products have a life cycle. IPCC assumes that the life cycle of wood materials is expressed by half-life and attenuates according to the first-order exponential change [4].

At present, among the four HWP carbon accounting methods obtained by the Intergovernmental Panel on Climate Change (abbreviated as IPCC), apart from the IPCC default method which lacks certain scientific rationality and the production method which is easy to be confused in practical operation, atmospheric flow method and stock-change approach have become the common measurement methods to obtain the carbon storage of woody forest products at the present stage. Therefore, we only use the stock-change approach and atmospheric flow method to calculate the carbon sequestration of HWP.

According to the existing HWP carbon pool annual change accounting model [5], we simplify it and define the carbon fixation accounting model for HWP. The expression is as follows:

$$C_H(t+1) = \mathrm{e}^{-\lambda} \cdot C_H(t) + \left[\frac{1-\mathrm{e}^{-\lambda}}{\lambda}\right] \cdot I_p(t) \tag{9}$$

$$\Delta C_H(t) = C_H(t+1) - C_H(t) \tag{10}$$

$$I_p = C_0 + C_{HIM} - C_{HEX} \tag{11}$$

where t denotes years, $C_H(t)$ is T-year HWP carbon storage, $C_H(1900) = 0$, $\lambda = \frac{\ln(2)}{HL}$ is annual first-order attenuation variable (HL is half-life of the HWP library, the half-life of specific forest products can be determined according to the 2006 National greenhouse Gas inventory Guide), $I_p(t)$ represents the amount of carbon entering the HWP carbon pool in the t year, $\Delta C_H(t)$

represent the change of carbon Storage in HWP Bank in the t year, C_0 denotes carbon content in annual production of forest products in China, C_{HIM} denotes the amount of carbon in imported forest products in China every year, C_{HEX} denotes carbon content in forest products exported by China every year.

So we can get the predicted value based on the carbon storage of forest products in previous years:

$$\begin{aligned} C_H(t+1) &= \mathrm{e}^{-\lambda} \cdot C_H(t) + \frac{1-\mathrm{e}^{-\lambda}}{\lambda} \cdot I_p(t) \\ &= \mathrm{e}^{-\lambda t} \cdot C_H(t) + \frac{1-\mathrm{e}^{-\lambda}}{\lambda} \sum_{k=1}^{t} \mathrm{e}^{-\lambda(t-k)} \cdot I_p(k) \end{aligned} \tag{12}$$

For example, according to the list of carbon storage of Finnish buildings provided, sawn timber increased by an average of 0.145 Tg per year from 1980 to 1990. The total carbon pool of wood products from the forest (excluding wood waste and paper products), taking into account the import and export of wood, we can calculate the carbon reserve in 1995 is 11.56 Tg by the above model. Through the actual investigation and verification, it is found that the data in 1995 is 11.5 Tg, which may reach 7% of the biomass [3]. To sum up, it is proved that the model is correct and can be used in the prediction of forest products.

4.2. Forest Management Plan

With the increasing production of greenhouse gases in the air, the global climate is getting worse and worse, and forests are an important component of the human carbon sequestration plan. Forest is important carbon storage in the terrestrial ecosystem, and woody forest products are the main components of this carbon pool [6]. Managers often need to consider how to make a reasonable forest management plan to achieve the goal of carbon sequestration. Forest cutting is the way to obtain woody forest products. Only when the cutting intensity is maintained within the self-recovery capacity of the ecosystem can its economic benefits be maximized [7]. Tang Mengping proposed structure determining function [8] in 2004, which overturned the mathematical modeling thinking of adaptation function in forest management and believed that the improvement of forest function could be realized by controlling stand structure. In this paper, the best forest structure was determined by the selective **cutting intensity** and **selective cutting cycle**, then the best forest management plan of carbon sequestration was realized.

Biolai, a French scholar, has put forward the idea of quantitatively describing the selective cutting volume of sustainable forests to determine the optimal ratio of volume to plant number according to diameter class in order to achieve the highest productivity [9]. In order to facilitate understanding, we use **Figure 2** and **Figure 3** below. In addition, on the basis of summarizing previous studies, some researchers put forward a balanced selective cutting forest structure. It is considered that the number of trees (each diameter class of different-age forest) decreases with the increase of diameter class, showing an inverted J curve [10].

Figure 2. Proportion of forest stock in different diameter classes.

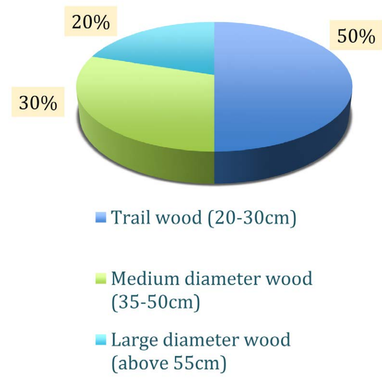

Figure 3. Proportion of tree number in different diameter classes.

The magnitude of the cutting intensity and the length of cutting cycle are the keys to forest management [11]. We choose **the elective cutting intensity** and **selective cutting cycle** as indicators to measure the carbon value obtained by cutting and living tree isolation, so as to determine the balance between the two values. The selective cutting intensity is controlled by the GMRWAL model, and the selective cutting cycle is obtained by the SCPVA algorithm formula. Thus the optimal forest management plan of forest managers is determined by both of them. In addition, we optimize the classification of selective felling trees, and we propose to **retain trees** and **select felling trees** in order to realize **the renewability of young forests.**

4.2.1. Design and Analysis of Ideas

1) Determination of selective cutting intensity

The selective cutting intensity cannot be determined arbitrarily, according to the law issued by the Ministry of Forestry: *selective felling shall be carried out in multi-layer non-aged forests with many young trees, and their intensity shall not be greater than 40% of the forest stock before felling.* Therefore, the upper limit of selective cutting intensity should be less than 40% and must be non-negative. In order to explore the regeneration of the young forest, the determination of selective cutting intensity is controlled by **tree growth rate**, and the formula is as follows:

$$s = 1 - \frac{1}{(1+q_v)^T} \tag{13}$$

where s represents selective cutting intensity under the control of tree growth rate, q_v denotes the growth rate of retained trees after logging, T denotes selective cutting cycle. Let the increment of time t be $G(t)$. Then the growth increment of the reserved wood after logging during the period from t to $\Delta t + t$ is

$$G(\Delta t + t) - G(t) = q_v G(t) \Delta t \tag{14}$$

equivalent to

$$G(t) = G_0 e^{q_v t} \tag{15}$$

From Equation (15), we can see that the model is an exponential model, so it is obvious that the retained trees will grow indefinitely after logging. The growth of trees should be based on the maximum environmental carrying capacity of the region where the trees are located, referred to as $ECC_{\max}$. However, it is difficult to measure the growth rate q_v of retained trees after logging. Because the growth rate will decline year by year with the passage of time, we think of analogy logistics population model to put forward the **growth model of retained wood after logging**, referred to as GMRWAL model. Define the following formula:

$$\begin{cases} G(t) = \dfrac{ECC_{\max}}{1+\lambda e^{-q_v t+5}} \\ q_r = q_v\left(1 - \dfrac{ECC_{\max}}{G}\right) \end{cases}, \quad ECC_{\max} > 0 \tag{16}$$

where q_r denotes relative growth rate. After substituting it into the calculation, $\lambda = \dfrac{ECC_{\max}}{G_0} - 1$ can be obtained. The picture of $G(t)$ is shown in Figure 4.

As can be seen from Figure 4, the growth rate of reserved trees after logging will continue to decrease with the passage of time. According to the proportion

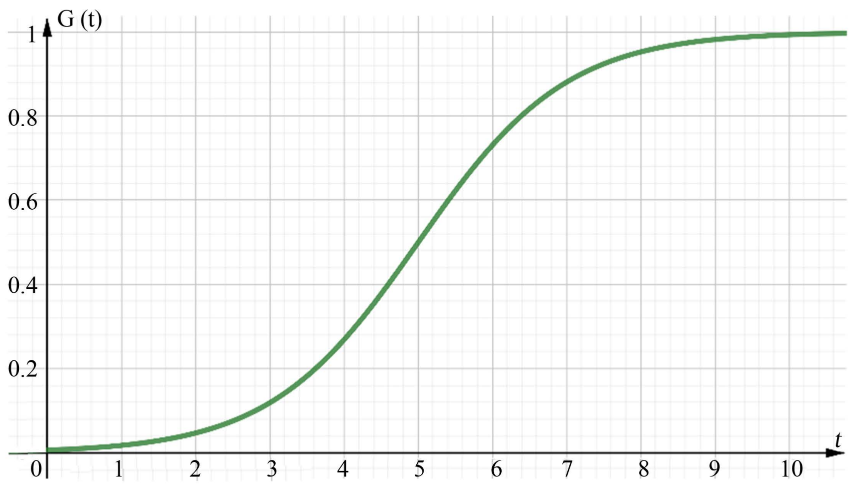

Figure 4. Growth model curve of retained wood after logging.

of trail wood: medium diameter wood: large diameter wood = 2:3:5 and the position of reserved trees except inverted J curve, the approximate cutting range can be determined. The selective cutting intensity under different stand structures is not similar. It should be noted that according to the above limitations, the intensity should not exceed 40%. We divided the selective cutting intensity into 20%, 30%, 40%, and selected 0% of the selective cutting intensity as the blank control group.

2) Determination of selective cutting cycle

We believe that unrestricted logging is a major obstacle to sustainable forest development. Therefore, in order to ensure the cultivation plan of the forest, we define the selective cutting cycle. With regard to the determination of the selective cutting cycle, the transfer matrix method and diameter class method can be selected according to different objectives. According to the follow-up measurement of this problem, we choose the volume method as our selective cutting cycle algorithm. **The selective cutting periodic volume algorithm**, referred to as SCPVA, is the algorithm in which the volume per unit area of reserved trees after selective cutting is restored to the level of reserved trees before selective cutting. In this algorithm, we still continue the control of selective cutting intensity. It is expressed by the following formula:

$$b_0 = b_1 \left(1 + q_v\right)^a \tag{17}$$

where b_0 represents stock level of reserved wood per unit area before selective cutting, b_1 represents stock level of reserved wood per unit area after selective cutting. After taking the logarithm, the formula of SCPVA algorithm can be obtained by calculation and arrangement. In addition, restrictions can be obtained according to the selective cutting intensity stipulated in the law of the Ministry of Forestry:

$$\begin{cases} a = \dfrac{\lg b_0 - \lg b_1}{\lg\left(1 + q_v\right)} \\ b_0 = \left(1 - s\right) b_1 \end{cases} \tag{18}$$

The SCPVA algorithm formula can be obtained by sorting out the above formula:

$$a = \frac{-\lg\left(1 - s\right)}{\lg\left(1 + q_v\right)} \tag{19}$$

where s denotes selective cutting intensity. The selective cutting cycle can be obtained when the selective cutting intensity and the growth rate are determined according to the stand structure.

4.2.2. Optimal Strategy of Stand Structure Based on Selective Cutting Rules

In order to measure what kind of selective cutting intensity and cycle makes the stand structure optimal, we put forward the optimal strategy of stand structure based on the selective cutting rule, referred to as SCR optimal strategy. Based on the amount of carbon sequestration, the following indicators are established for quantitative calculation. The optimal ranking of different indicators is obtained to determine what kind of selective cutting intensity and cycle can maximize the contribution value of dominant indicators, that is, the SCR optimal strategy. As shown in Figure 5.

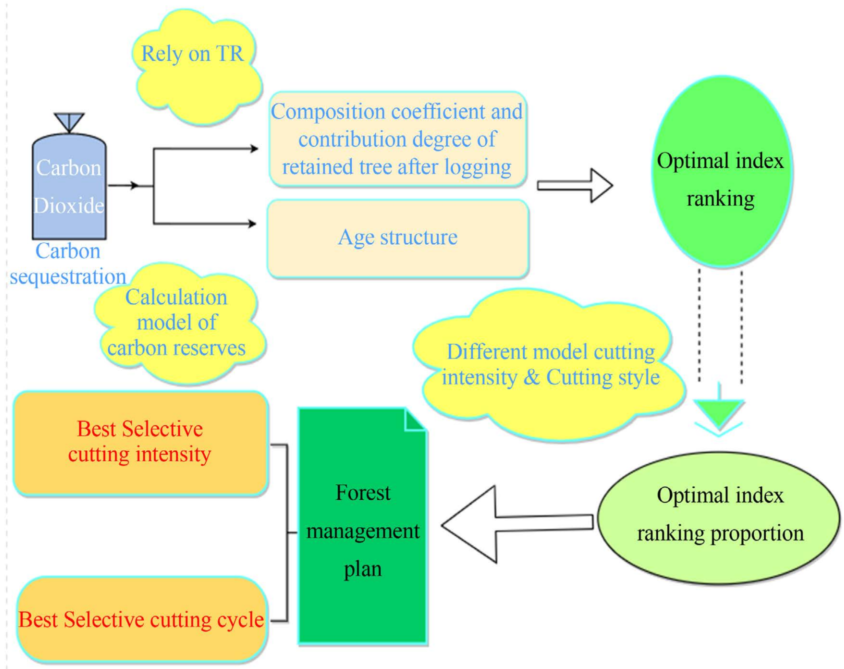

Figure 5. SCR optimal policy flow chart.

1) Analysis method based on stand non-spatial structure

- **Composition coefficient and contribution degree of retained tree after logging**

The model uses the tree species composition coefficient to represent the proportion of retained tree species of the forest after felling, which is based on the proportion of tree species carbon storage to the total carbon storage of the stand. Then analyze the changes of reserved tree species after 10a and 20a of cutting under different selective cutting intensities.

In addition, different tree species have different contribution values to total carbon storage. So timber retention contribution after logging is defined to show the contribution value of different tree species. The definition is as follows:

$$\begin{cases} TR = \left(R_n + R_f + C_a\right)/3 \\ R_n = \dfrac{N_i}{\sum N_i} \times 100\% \\ R_f = \dfrac{R_i}{\sum R_i} \times 100\% \\ C_a = \dfrac{C_i}{\sum C_i} \times 100\% \end{cases} \tag{20}$$

where TR denotes preserve the contribution of wood tribute after logging, R_n denotes relative quantity, N_i denotes the number of trees of class i tree species retained after logging, $\sum N_i$ denotes the number of trees of all tree species, R_f denotes relative frequency, R_i denotes frequency of class i tree species retained after logging, $\sum R_i$ denotes the frequency of all tree species, C_a denotes comparative advantage, C_i denotes the sum of the cross-sectional area of breast height of category i tree species after logging, $\sum C_i$ denotes the sum of the cross-sectional area of breast height of all tree species.

- **Retain the age structure of trees after logging**

According to the carbon storage accounting model, we get the actual and potential plant carbon storage in Daxing'an Mountains. Use Excel to clean the data, and eliminate similar and incomplete forest types. Finally, we get the following summary table. For convenience, assume the following variables to represent.

By summarizing the distribution law of carbon density in different age groups, we found that the average carbon density of over-mature forest was higher than that of other age groups, but there was no significant difference. Followed by mature forest and near-mature forest, the average carbon density of young forest was the lowest. The carbon reserves of each age group are as follows: Middle-aged forest > young forest > near-mature forest > mature forest > overmature forest. In addition, it can be clearly seen from the table that the carbon storage of larch is the highest. Followed by broad-leaved mixed forests, both of which are much higher than other groups, while the carbon storage of mixed coniferous forests is lower.

2) Optimal solution of non-spatial structure of stand under different selective cutting intensity

- **Analysis of retained Tree species and dominant species after logging**

According to Table 1, we selected Daxing'an Mountains as the sample area for analysis, selected 12 sample plots, and used Formula (20) to process the data of previous years to obtain the composition of retained tree species and dominant species after logging for 10a and 20a, as shown in Figure 7 and Figure 8.

According to Figure 6, 10a after logging, the dominant species is still the larch obtained in Table 2. But with the continuous enhancement of selective cutting intensity, **the contribution value of larch reached the peak value of 57% when the selective cutting intensity was 30%**. At this time, the carbon sequestration ability of dominant species played the greatest role. When the selective cutting intensity is 40%, the composition of tree species and dominant species is almost similar to that of the control group. At the same time, it shows that the selective cutting intensity cannot exceed 40%. The range of the above upper limit is verified.

As can be seen from Figure 7, with the continuous increase of selective cutting intensity 20a after logging, the contribution value of dominant species larch is relatively large, accounting for 43% when the selective cutting intensity is 30%. At the same time, horizontal comparison showed that the contribution value of dominant species decreased after selective felling for 20a. This shows that in

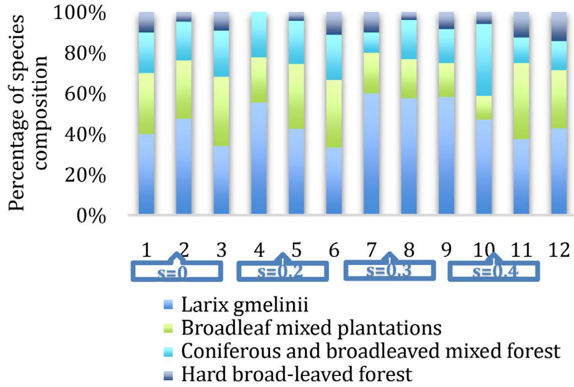

Figure 6. Percentage of retained and dominant species at different intensities after logging for 10a.

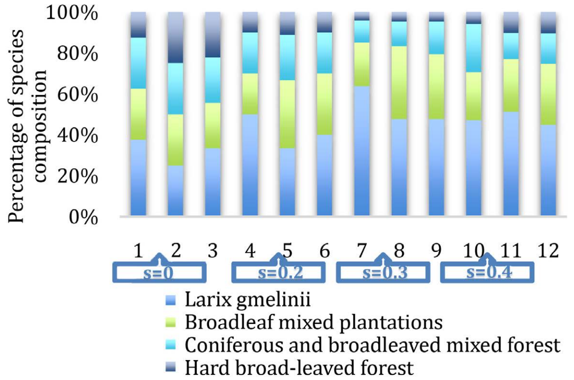

Figure 7. Percentage of retained and dominant species at different intensities after logging for 20a.

Table 2. Actual and potential plant carbon storage in Daxing'an Mountains ecosystem.

Forest type	Carbon storage density ($Mg \cdot ha^{-1}$)					Carbon storage (Tg)		Actual percentage of potential carbon storage %
	β_1	β_2	β_3	β_4	β_5	Actual	Potential	
α_1	28.59	37.86	73.57	66.36	80.86	4.50	7.71	58.33
α_2	3.18	9.78	18.53	15.57	31.36	6.36	24.40	25.46
α_3	17.56	33.54	46.48	98.88	131.94	2.98	3.23	31.04
α_4	13.55	46.49	58.00	86.89	116.47	7.66	16.65	46.41
α_5	18.34	50.54	67.03	80.55	118.74	19.29	56.95	34.11
α_6	5.06	19.47	29.79	47.13	84.48	9.41	30.35	31.26
α_7	17.13	36.84	46.57	50.17	79.65	4.29	9.53	45.45

where $\alpha_i\left(i=1,2,\cdots,7\right)$ stand for larch, Chinese fir wood, conifer mixed, needle-broad mixed, hard-broad mixed, soft-broad mixed, broad-leaved mixed respectively and $\beta_j\left(j=1,2,\cdots,5\right)$ stand for young forest, middle-aged forest, near-mature forest, mature forest, overmature forest respectively.

order to maximize the carbon sequestration capacity of larch, we should choose 30% selective cutting intensity. Through the above SCPVA algorithm, the selective cutting period is calculated to be 11.9 years.

- **Analysis on the age structure of retained trees after logging**

Summarizing the carbon stock distribution of different age groups in Table 2, we can get the following Figure 8.

Figure 8 shows that the carbon storage of the overmature forest at the bottom of the inverted pyramid is the smallest, and the carbon storage increases sequentially from the bottom to the top. In order to maximize the carbon storage of the living forest, the overmature forest should be classified as one of the priority felling in selective felling. Trees of specific species that are too old in accordance with the rules for *Forest Renewal* should be given priority to be selected for selective felling, and the diameter class of such trees is often too large. As a result, attention should be paid to the protection of other reserved forests within a certain radius with the overmature forest as the center. In order to realize the renewability of the forest management plan, the selective cutting strategy of trail wood: medium diameter wood: large diameter wood = 2:3:5 depicted in Figure 3 and Figure 4 should be followed.

4.3. Bayesian Updating Model Based on Distance Discrimination

Forest cutting should pay attention to comprehensive benefits, and it has become the consensus of human beings to combine economic benefits with ecological benefits organically. As a forest manager, from an overall point of view, we should not only consider the current problems of carbon sequestration and forest products, but also consider how to formulate a sustainable forest management plan from a social point of view. For this reason, this chapter considers solving the problem of multi-objective and multi-attribute decision-making and constructs a multi-objective and multi-attribute forest management planning decision-making model (MMF). In determining the attribute weight, it is no longer given in advance, but the entropy method is used to calculate the weight objectively. After getting the weight, we use TOPSIS method to analyze the

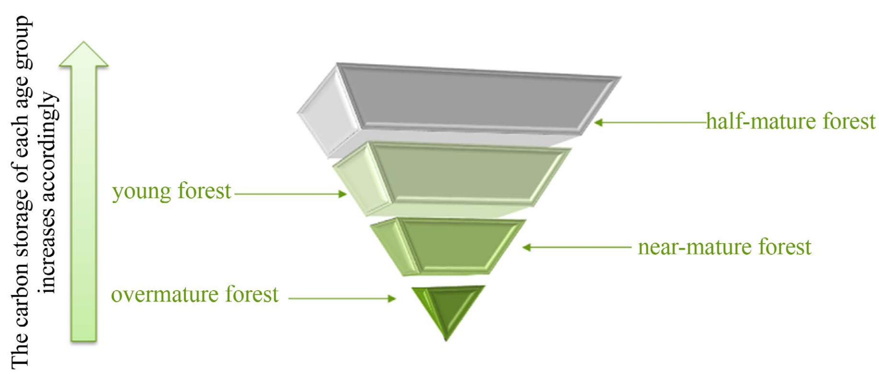

Figure 8. Inverted pyramid of carbon storage distribution in different age groups.

optimal forest management plan under different objectives. This chapter continues the selective cutting strategy made in the previous chapter and takes different selective cutting intensities and selective cutting cycle as the selective cutting index. We know from the previous chapter that the selective cutting cycle is determined by the selective cutting intensities. Therefore, in the choice of decision-making scheme, we study the impact of different selective cutting intensities on the two major benefits, and finally calculate the selective cutting cycle.

For the scope of the forest management plan, we choose the selective cutting intensity as the decision set. When the selective cutting intensity is 0%, it means that there is no logging action in the forest at this time. Because of its vacuum, we estimate the comprehensive benefit value at this time through low intensity, so as to analyze the benefit when the forest is not cut down. In addition, when the selective cutting intensity takes different values, the calculated comprehensive benefit value reaches the same value. At this time, we think that a variety of decision-making schemes can be transformed into each other, and different decision-making schemes can be selected according to different stand structures.

4.3.1. Target Benefit Analysis

It is worth noting that the ultimate goal of forest management plans is not necessary to achieve the best results in terms of carbon sequestration. Considering the different types of forest value, the forest management plan we have developed above is not necessarily the most beneficial to society. Among them, forest value benefits include economic benefits such as entertainment and cultural benefits of forest products, as well as ecological benefits such as biodiversity and carbon sequestration.

Therefore, we need to carry out a comprehensive evaluation and analysis. In order to quantitatively measure the relevant economic and ecological benefits, we have selected each benefit index respectively, and the specific indicators are as Figure 9.

1) Economic Benefits

- **Forest product benefit**

Figure 9. Schematic diagram of target benefit index.

For natural forests, the cost of afforestation is almost zero [12]. The income obtained from forest products is used as the economic benefit index of selective felling, because for natural non-aged forests, selective felling can only be used. At the same time, it can be known that the profit of selective cutting comes from the amount of selective cutting. More precisely, it comes from selective cutting intensity and selective cutting cycle. Therefore, the income value of forest products is selected as one of the attributes. The income of forest products includes the conversion of the short-term benefits of the previous harvesting to the present value and the current value of forest stocks on the mountain [12]. Among them, we need to meet the literature requirements of the unified quota of forestry production in different places. The production cost is converted into the present value, and the standing wood value of the mountain stock is calculated according to the forest price [13].

- **Entertainment and cultural benefit**

With regard to the cultural benefits of entertainment, we assume through reasonable assumptions that the benefits of entertainment culture are only related to the benefits of tourism. The amount of tourism revenue depends on the number of living forests that have not been cut down. Similarly, the tourism income is different under different selective cutting intensities; for example, with the increase of selective cutting intensity, tourism income may decrease in a certain range.

2) Ecological benefit

The forest ecosystem not only produces economic benefits directly through forest products, but also indirectly produces ecological benefits. The results show that the ecological benefits of forest ecosystem mainly come from carbon storage, species diversity and water resources. Therefore, we believe that the ecological benefit indicators include water conservation benefits, soil fixation & fertilizer conservation benefits, biodiversity benefits and carbon sequestration & oxygen release benefits. These ecological benefit values may constantly be changing due to social factors such as national policies, people's awareness of environmental protection, the level of social economic development, and so on.

In order to achieve the purpose of making the best use of the forest, we make a quantitative analysis of these benefits through the indicators. From a reasonable and scientific point of view, we take money as the measurement scale to select a series of indicators to unify the variables of forest ecological benefits.

4.3.2. Define the Scope of the Forest Management Plan

According to the new forestry theory, forest resources are a complete system. In operation and management, we should not only emphasize the economic benefits, but also pay attention to the ecological benefits of the forest, such as the protection of biodiversity, potential carbon sequestration and so on. In the process of selective cutting, some events will lead to the change of biological chain in varying degrees. For example, the damage to the surrounding ecosystem during selective cutting, the influence of soil along the bad chain and so on [14].

Therefore, the appropriate selective cutting rules play a balancing role between ecological benefits and economic benefits. Through the analysis of Section 5.1, we believe that the optimal forest management plan is inseparable from selective cutting rules, and selective cutting intensity and selective cutting cycle are the two major factors that determine the comprehensive benefit index. After the optimal selective cutting intensity is determined, the selective cutting cycle can be obtained by the calculation of Formula (19). To sum up, we think that the decision-making scheme of the model is selective cutting intensity.

4.3.3. Multi-Objective and Multi-Attribute Forest Management Decision Model

1) Determining Index weight by Entropy method

- **Constructing homogenized decision matrix**

The decision-making model is a multi-attribute problem, and the ecological and economic benefits contain a total of eight indicators. Therefore, we need to classify the indicators to determine whether they all play a positive role in the comprehensive benefit indicators, and if not, linear transformation is needed. We roughly divide attributes into three categories, as shown in Figure 10.

For the problem of attribute homogenization, the attribute is generally treated positively.

The cost attribute in Figure 10 shows that the smaller the attribute value is, the more favorable it is for the comprehensive index. So the reciprocal is taken; the benefit attribute is the larger the attribute value is, the better; the interval attribute value is the best in an interval. Based on the formula [15] proposed by Zhang Tian *et al.*, we summarize the above results. Where $[h, g]$ is the interval in which the attribute is the most stable, $[a^*, b^*]$ is the maximum tolerance range. According to the above treatment, the homogenized decision matrix can be obtained. $Y = (y_{ij})_{n\times m}\ (i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m)$, which is represented as

$$Y = \begin{bmatrix} y_{11} & \cdots & y_{1m} \\ \vdots & \ddots & \vdots \\ y_{n1} & \cdots & y_{nm} \end{bmatrix}$$

- **Construction of standardized decision Matrix based on range method**

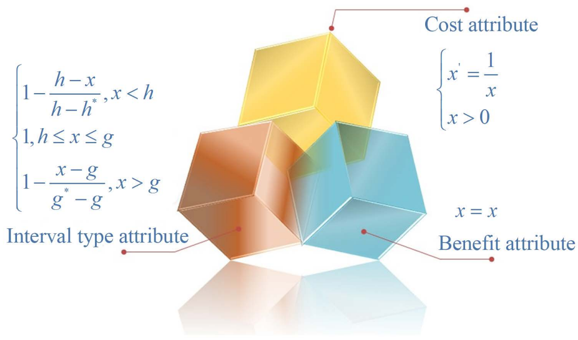

Figure 10. Three kinds of classification diagram of multi-attribute of homogeneous decision matrix.

Multi-attribute problems often have different dimensions. Therefore, in order to realize the unity of dimensions, we use the range method to standardize the homogenized decision matrix. The treatment is as follows:

$$Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \left(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m\right)$$

After the matrix Y is processed by the range method, the standardized decision matrix is obtained: $Z = \left(z_{ij}\right)_{n \times m} \left(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m\right)$.

2) Determining the order of selective cutting intensity by TOPSIS method

- **Determine the optimal scheme and the worst scheme**

The determination of the optimal scheme is actually based on the optimal solution composed of the maximum value of each column of elements, while the determination of the worst scheme is based on the optimal solution composed of the minimum value of each column of elements. The optimal set Z^+ and the worst set Z^- are as follows:

$$\begin{aligned} Z^+ &= \left(\max\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \max\left\{z_{12}, z_{22}, \cdots, z_{n2}\right\}, \cdots, \max\left\{z_{n1}, z_{n2}, \cdots, z_{nm}\right\}\right) \\ &= \left(Z_1^+, Z_2^+, \cdots, Z_m^+\right) \end{aligned}$$

$$\begin{aligned} Z^- &= \left(\min\left\{z_{11}, z_{21}, \cdots, z_{n1}\right\}, \min\left\{z_{12}, z_{22}, \cdots, z_{n2}\right\}, \cdots, \min\left\{z_{n1}, z_{n2}, \cdots, z_{nm}\right\}\right) \\ &= \left(Z_1^-, Z_2^-, \cdots, Z_m^-\right) \end{aligned}$$

- **Calculate multi-attribute weights**

First of all, the information entropy is introduced, which is usually used for the qualitative analysis of the amount of information. To put it simply, the greater the amount of information on an attribute value, the higher the degree of confusion of the model, and the smaller the role of this attribute value in the decision set. The information entropy E_j of the attribute *j* is as follows:

$$\begin{cases} p_{ij} = \dfrac{z_{ij}}{\sum_{i=1}^{n} z_{ij}}, j = 1, 2, \cdots, m \\ E_j = -\dfrac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \end{cases}$$

Secondly, the attribute contribution of multiple attributes is calculated. The contribution of attribute j is as follows:

$$w_j = \frac{D_j}{\sum_{j=1}^{m} D_j}$$

- **Calculate the weighted Euclidean distance between each scheme and maximum scheme**

$$\begin{cases} d_i^+ = \left[\sum_{j=0}^{m} \left(\left(Z_j^+ - z_{ij}\right) w_j\right)^2\right]^{\frac{1}{2}}, \left(i = 1, 2, \cdots, n\right) \\ d_i^- = \left[\sum_{j=0}^{m} \left(\left(Z_j^- - z_{ij}\right) w_j\right)^2\right]^{\frac{1}{2}}, \left(i = 1, 2, \cdots, n\right) \end{cases}$$

- **Calculate the proximity between each scheme and the maximum scheme**

We judge whether the result of the decision-making scheme is satisfactory or not according to the proximity of each scheme to the optimal scheme and the worst scheme. The proximity d_i of option *i* is as follows:

$$d_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, \cdots, n$$

The closer the value of the proximity degree is to 1, the better the scheme is. Based on this, we can give *n* decision-making schemes to rank, and get the optimal decision-making scheme for the forest management plan.

4.3.4. Extreme Value and Transition Point Problem

1) The extreme value problem of the decision-making Model of Forest Management Plan

In the decision scheme set $S = \{S_1, S_2, \cdots, S_n\}$, continue the blank control group selected in Section 5.1, which is the selective cutting intensity. This means that there will be no logging in the part of the forest and the forest will not be cut down. This is a vacuum, because in real life, except for the logging actions allowed by forest managers, there will always be deforestation. Therefore, we assume that logging operations are carried out only with the permission of forest managers. In other words, logging can be completely controlled by man. However, looking at the current situation of forest management, except for a very small number of national forest reserves that do not allow logging, most forests will have felling actions. Therefore, in the data collection, we take the attribute value obtained under the selective cutting intensity as the estimation of the selective cutting intensity of 0.

2) The transition Point of Forest Management Plan decision-making Model

The forest management plan determines the selective cutting cycle and selective cutting intensity, and the selective cutting cycle is calculated from the selective cutting intensity according to (19). Therefore, in the management plan which is suitable for all forests, we think that the comprehensive benefit value calculated according to the MMF decision model under different selective cutting intensities is the same; thus the solution to the transition point problem is given. This means that the two decision-making schemes can be converted into each other. At this time, a variety of decision-making schemes can be selected according to the benefit needs of different forests, so as to solve the problem of transition points of management plans in all forests. As shown in Figure 11.

5. Results and Discussion

5.1. Result of Instance Data

We select the Daxing'anling forest region as the sample for the application of the model. Four samples with selective cutting intensity of a, b, c and d were selected as different decision-making schemes. Among them, the sample land with the selective cutting intensity e is the blank control group, but there is no forest area without cutting at all in the Daxing'anling forest area. Therefore, we select the forest area with selective cutting intensity f to estimate. According to the treatment of the seven attribute values in the previous chapter, the value change with currency as the unified scale can be obtained. After normalization, the canonical matrix is obtained. Finally, the comprehensive benefits under different strengths are obtained according to the entropy weight TOPSIS method. The results are shown in **Tables 3-5**.

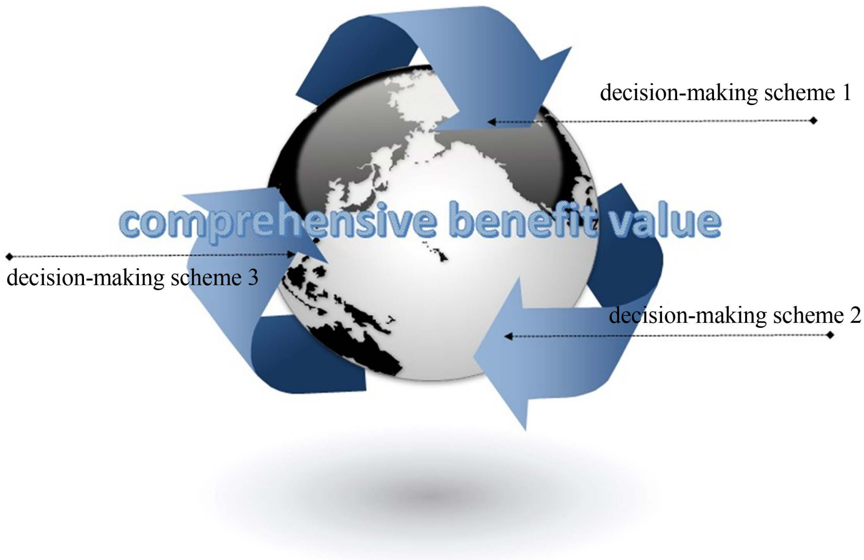

Figure 11. Schematic diagram of decision alternatives applied to all forest transitions.

Table 3. Benefit value under four kinds of selective cutting intensity.

Selective cutting intensity	f_1	f_2	f_3	f_4	f_5	f_6	f_7
s_1	17,584	87.0	−2.5	−184.3	−91.4	32.3	112.9
s_2	54,675	29.1	−2.6	−823.4	−117.4	87.4	302.3
s_3	67,556	−29.5	−4.1	−2756.5	−145.3	37.5	133.2
s_4	123,325	−67.8	−6.5	−2987.0	−234.7	−132.0	−423.2

Where $f_j\left(j=1,2,\cdots,7\right)$ stands for economic benefits, change of soil water retention, change of water holding capacity of decomposer, change of water conservation, benefit of soil consolidation and fertilizer conservation, benefits of carbon sequestration and oxygen release, respectively (They are all in yuan/hm^2 unit). $s_i\left(i=1,2,3,4\right)$ stands for the selective cutting intensity is 0%, 20%, 30% and 40%, respectively.

Table 4. The weight coefficient of seven benefit indicators.

Weight	f_1	f_2	f_3	f_4	f_5	f_6	f_7
$w_i\left(i=1,2,3,4\right)$	0.300	0.083	0.113	0.102	0.131	0.121	0.150

Table 5. Comprehensive benefits under different selective cutting intensities.

Selective cutting intensity	Economic performance	Ecological benefit	Comprehensive benefit
s_1	0.029	0.560	0.589
s_2	0.171	0.645	0.816
s_3	0.145	0.454	0.599
s_4	0.229	0.314	0.543

5.2. Result Analysis

According to the analysis in Table 3, when the selective cutting intensity is 20%, the calculated comprehensive benefit value is the highest, which is 0.816. When the selective cutting intensity is 30% and 5%, the comprehensive benefit values are similar, 0.589 and 0.599 respectively. When the selective cutting intensity is 5%, the total number of forests in the forest area is very small, and the ecological benefit value should be the maximum of the four intensities.

However, by analyzing the data in the table, we can find that the ecological benefit value is not as high as when the selective cutting intensity is 20%. Except for the errors in the data, we think that there is a competitive relationship in the ecosystem, which leads to the decrease of a certain amount of change. When the selective cutting intensity is 40%, the comprehensive benefit value is the lowest, and the ecological benefit value is also the lowest.

Therefore, when formulating the forest management plan, we should pay attention to the reasonable selection of selective cutting intensity. Try to choose low and medium selective cutting intensity, and the selective cutting intensity should not exceed 40%. Only by finding the optimal forest management plan can a forest region achieve its sustainable development and create more ecological and economic benefits. As forest managers, we should not only focus on ecological benefits, such as blindly pursuing high carbon sequestration, nor should we ignore the ecological environment for the sake of economic benefits. The social value should be comprehensively considered after analyzing the stand structure and biodiversity of the forest area. Then, based on a certain target benefit, formulate the optimal forest strategy in line with their own needs.

6. Evaluation of the Model

6.1. Sensitivity Analysis of Selective Cutting Cycle

In this paper, all of our selective cutting cycles are determined by Equation (19). In fact, there are not only the SCPVA method, but also many methods to calculate the selective cutting cycle. Here we use the diameter class method to determine the selective cutting cycle, and based on this algorithm we calculate the final allocation of different attributes. As shown in Figure 12.

The attribute distribution of different new and old selective cutting cycles is different. In the selection, the algorithm is mainly based on the decision-making

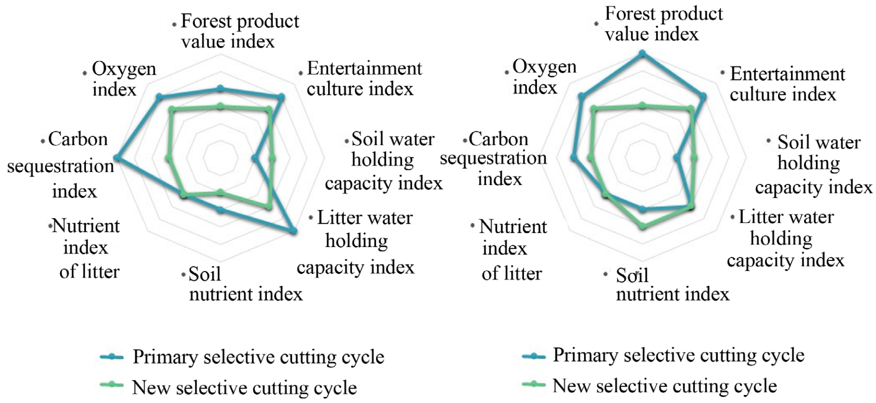

Figure 12. Old and new selective cutting cycle radar charts.

objectives to determine the selective cutting cycle. For example, according to Figure 12, we can see that when using the selective cutting cycle SCPVA algorithm in this paper, it is optimal for the Litter water holding capacity index at this time, and the model is relatively stable. At present, the algorithm is better than the diameter class method. For the Soil nutrient index, the diameter class method is better than the SCPVA algorithm.

6.2. Advantages and Disadvantages of the Model

- In this paper, the data in the official documents are used for modeling, so that the model has high credibility. The factors we choose in the modeling process are objective; Some subjective interference is eliminated, so it has good accuracy.
- The model does not study the correlation of forest indicators; it is possible to have multiple collinearities and cannot achieve the desired results. In this paper, the model is only applied to one region for verification, so the appropriate matching of other areas is unknown.

7. Conclusions

Nature gives us precious wealth-forests, which play an indispensable role in our industry and life. In addition, with the continuous progress of society, people hope to achieve a higher level of efficiency in the use of forests. In order to maximize the benefit of forest use, it is necessary to manage the forest artificially, in which cutting must be included in the management strategy. That is because people can obtain wood and forest products through forest cutting to achieve forest economic benefits.

The analysis of a mathematical modeling group and a large number of experimental data show that the comprehensive benefits of the forest achieved by not cutting down any trees are not very good. Next, we will explain why the forest management plan should include logging from the following aspects:

- **First, from the perspective of human needs.**

Considering the economic benefits of forest resources, taking forestry products as an example, the value of forestry products has a very high contribution rate to the value of the whole agricultural products. The total price index of Guangxi in the first half of the year is 118.16, of which the total price index of forestry products is 105.07. It is undeniable that we live without wood products as powerless as fish without water. Therefore, I think the act of not cutting down any trees is extremely undesirable.

- **Second, starting from the comprehensive value brought by the forest ecosystem. Comprehensive value, to be more precise, is to get different comprehensive values according to the different weight ratios of economic value and ecological benefit value produced by the forest ecosystem.**

The forest products obtained from forest felling can make human beings obtain economic benefits by directly flowing into the market. Although the main source of economic benefits of forest ecology is obtained through all kinds of forest products and forest by-products, the forest can properly develop tourism through artificial cutting management. Apart from the compensation value caused by some very small parts that may destroy forest vegetation and deforestation, forest resources are still charged a great deal for recreational and cultural purposes such as tourism. Taking the annual tourism income of Daxing'anling forest in China as an example, the study shows that the forest area of Daxing'anling is 84,600 square kilometers, and the annual tourism income is 5.4 billion yuan. From this, we can see that the forest ecosystem can obtain high economic benefits. But if we don't cut down any trees, we can't manage the forest. Then we must not be able to obtain economic benefits from forest products, nor can we organize and manage the construction of scenic spots and gain benefits from tourism and entertainment. To sum up, it is very likely that the forest cannot be used reasonably in order to achieve the optimization of economic benefits.

In addition, due to the early failure to realize the importance of the ecological benefits of the forest, the benefits of sustainable development of the forest, the protection of biodiversity and the carbon sequestration and oxygen release of the forest have not been brought into full play. Among them, it must be emphasized that the above ecological benefits do not simply decrease with the increase of cutting intensity. Under the selection of appropriate selective cutting intensity, the internal structure of the forest changed, the soil nutrients increased; at the same time, excluding the interference of tall trees to sunlight, there were seedlings that could thrive and biodiversity increased. Finally, the ecological benefits of the forest were increased.

From the results of the mathematical model group analysis, the comprehensive benefit under the condition of cutting intensity of 0 is lower than that of medium intensity. It further shows that not cutting down the forest may not necessarily reach the desired value.

- **Third, consider the impact of felling skills on the comprehensive bene-**

fits. The felling skills include the cutting methods and techniques, the continuous improvement of forest planting and the regeneration plan after felling.

What we call forest management by logging does not mean that we do not consider the species attributes of the trees to be cut down. For example, for natural wild mixed forests, we will cut down some tall trees to make the spatial form of the forest different, so that they can get enough light time. In addition, advanced logging tools can be used to improve work efficiency and reduce the degree of damage to forest ecological benefits.

To sum up, without any deforestation, it is impossible to optimize the comprehensive benefits under the constraints of various technologies and local policies under the development of the times. Therefore, we need to work out the appropriate selective cutting intensity and cycle according to different needs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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