Forest Carbon Storage Analysis and Comprehensive Forest Value Decision Model

Sifan Li[1, a, *, #], Yang Guo[1, b, #], Rizheng Zhang[1, c, #]

[1]Xi'an University of Architecture and Technology School of information and control engineering Xi'an City, Shaanxi Province, China

[a]1574101037@qq.com, [b]541461684@qq.com, [c]1002107768@qq.com

#These authors contributed equally

Abstract

Forests, as the lungs of the earth, are the perfect carbon storage boxes. But in the increasingly serious trend of environmental problems, we must ensure the maximization of forest. So, we integrate forest carbon sequestration and other major values to build a model for current forest management decisions. Firstly, we establish the Forest Carbon Sequestration Measurement System (FCMS) to quantify the carbon sequestration of a forest. We choose six indicators at three levels from two aspects. Then, they were integrated into forest carbon sequestration index (CSI) by entropy weight method (EWM) and coefficient of variation (CVM). Considering the time factor, we analyze the trend of CSI changes over time in various forests (vegetation zone division) Next, on the basis of carbon sequestration decisions, we consider other factors to obtain a more comprehensive and specific forest integrated value (IFV) management plan.

Keywords

Carbon sequestration, EWM, Integrated forest value, Forest management Plan.

1. INTRODUCTION

From melting glaciers to rising sea levels, from the frequency of natural disasters to the northward shift of climate zones and the migration of species. Carbon, the building block of all life, is increasingly threatening it. [1]Fortunately, humans are beginning to notice and reduce greenhouse gas emissions.But reducing greenhouse gas emissions alone is incomplete. Greenhouse gases come in and go out, and we should also focus on the process of greenhouse gas "coming in"[2], namely carbon sequestration. Forest is the principal part of carbon sequestration. In addition to carbon sequestration through photosynthesis, trees can also be processed into wood products to continue carbon sequestration[3].

Therefore, how to maximize the value of forests and carry out more reasonable forest management is particularly important[4]. To do this, based on carbon sequestration, we study a more balanced forest management decision model to try to mitigate the impact of greenhouse gases[5].

2. ANALYSIS OF FOREST CARBON SEQUESTRATION

In this section, to measure the relationship between carbon sequestration and forest management, we define the Vegetation Carbon sequestration Measurement System (FCMS) [6]. Firstly, we designed six indicators from two aspects, and integrated them into forest carbon sequestration index (CSI) by using entropy weight method (EWM) and coefficient of variation (CVM) [7].

First of all, we only consider the annual carbon sequestration of a forest. At this time, we can divide all the influencing factors into six indicators to quantitatively study the carbon sequestration of forest. Then, time factors are added, because time factors affect the life of living trees and the service life of forest products, and these factors affect the amount of carbon sequestration[8], so we take time as the independent variable and the amount of forest carbon sequestration for nearly 50 years as the dependent variable to plot and analyze, so as to determine the appropriate forest management plan[9].

2.1. Forest Carbon sequestration Measurement System

Based on a large number of relevant literature, we divided the forest carbon sequestration measurement system into two evaluation indexes: forest carbon sequestration and forest products carbon sequestration. The generally accepted classification results are summarized according to the existing research[10]. Based on the specific classification of forest products, the forest carbon sequestration measurement system is divided into three levels and six indicators.

2.1.1 Vegetation carbon sequestration VSI

Living trees carbon sequestration X1 (MtC). Carbon sequestration is the absorption and storage of elemental carbon. The most common example in nature is the process of photosynthesis in trees and plants. Forests, as prime sites for carbon sequestration, absorb and store large amounts of carbon. Among froests, living trees are the most important players, contributing most of the sequestration value. Therefore, for the carbon sequestration value of forests, we mainly consider the carbon sequestration of living trees and introduce this index.

2.1.2 Forest products carbon sequestration PSI

a) Furniture of carbon sequestration X2 (MtC). Carbon dioxide can be sequestered in not only living plants but also products made from trees. These tree products will prevent internal carbon emissions during their lifetime, and when tree products outlive the life of the trees that produced them, carbon storage is extended in time compared to living tree sequestration. As a major part of forest products, furniture is indispensable in every home. Furniture carbon sequestration is in our life. Therefore, we introduce furniture carbon sequestration.

b) Wood carbon sequestration X3 (MtC). As another important component of forest products, wood also plays an important role in carbon sequestration. As one of the most important materials for infrastructure construction, wood is ubiquitous in every corner of society. As a building material, wood can be preserved for hundreds of years, making an indispensable contribution to carbon storage.

c) Plywood carbon sequestration X4 (MtC). Plywood is one of the commonly used furniture materials, one of the three wood-based panels, and also for aircraft, ships, trains, automobiles, construction and packaging materials. Turning trees into plywood for transport and construction also extends the time which some of the carbon is sequestrated in trees. The popularization of cars has greatly increased the utilization rate and carbon sequestration efficiency of plywood. Therefore, we consider the carbon sequestration factor of plywood in the carbon sequestration of forest products.

d) Paper carbon sequestration X5 (MtC). Paper, made from trees, also plays a role in carbon sequestration. The amount of carbon sequestration per sheet of paper is small, but a single tree can produce about 15,000 sheets of paper, and books made of paper can still be preserved for a long time. However, the use of paper is declining because of the growth of information networks. Paper carbon sequestration is facing a bottleneck.

e) Other products carbon sequestration X6 (MtC). Forest products include many by-products such as wood carvings and other decorations in addition to the aforementioned furniture, wood, plywood and paper. Carbon sequestration still lasts longer than the trees that produce them. These are integral parts that we introduce as other products carbon sequestration

2.2. Weight of indicators

2.2.1 Entropy weight method

In this section, we further determine the weight of these six indicators through the evaluation indicators defined above. We first use entropy weight method (EWM) to eliminate data incomparability caused by inconsistent data dimensions. According to the attribute type of the original index, standard 0-1 transformation and the given optimal interval method are used for non-dimensional and normalized processing. Therefore, it is convenient to judge the carbon sequestration capacity of forests directly from numerical values.

For several samples with 6 indexes, they are temporarily set as X_{ij}, which is the value of the jth index of the ith sample (j is 1-6). These indexes describe the factors affecting forest carbon sequestration. Forest carbon sequestration was proportional to all indexes. So we have

Positive indicators:

$$X_{ij} = \frac{x_{ij}-min\{x_{1j},\cdots,x_{nj}\}}{max\{x_{1j},\cdots,x_{nj}\}-min\{x_{1j},\cdots,x_{nj}\}} \tag{1}$$

Negative indicators:

$$X'_{ij} = \frac{max\{x_{1j},\cdots,x_{nj}\}-x_{ij}}{max\{x_{1j},\cdots,x_{nj}\}-min\{x_{1j},\cdots,x_{nj}\}} \tag{2}$$

Where Xij is the standardized value of each evaluation index, $max\ (Xij)$ and $min\ (Xij)$ are the maximum and minimum values of the evaluation index.

After normalizing the data, we can calculate the weight of the i th sample value under the jth indicator for that indicator:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \ , i = 1,\cdots,n, j = 1,\cdots,m \tag{3}$$

Based on the concepts of self-information and entropy in information theory, calculate the entropy value of the jth indicator:

$$e_j = -k\sum_{i=1}^{n} p_{ij}\ln(p_{ij}), j = 1,\cdots,m \tag{4}$$

Among them, $k = \frac{1}{\ln(n)} > 0$. satisfy $e_j \geq 0$;

Calculating information entropy redundancy:

$$d_j = 1 - e_j, j = 1,\cdots,m \tag{5}$$

Calculate the weights of each:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} , j = 1, \cdots , m \tag{6}$$

Up to this point, we calculate the weights of the 6 indicators, respectively w_1 to w_6.

In addition, vegetation sequestration and forest product sequestration are also obtained, which are abbreviated as TSI and PSI in this paper. According to the weights of these computed results, we have equations:

$$\begin{cases} TSI_j = w_1 X_{1j} \\ PSI_j = w_2 X_{2j} + w_3 X_{3j} + w_4 X_{4j} + w_5 X_{5j} + w_6 X_{6j} \end{cases} \tag{7}$$

Where, TSI_j and PSI_j represent the secondary indexes of the size of j, the weights of these indexes are determined by EVM method, and the expressions of these indexes are described at last.

2.2.2 Coefficient of variation method

After expressing the six indicators as two comprehensive variables, we need to further summarize the two indicators into one comprehensive indicator to directly obtain carbon sequestration, laying a foundation for further research on the change of carbon sequestration over time.

Since the evaluation index system has different scales for each index, it is not appropriate to directly compare the degree of difference. In order to eliminate the influence of the different scales of each evaluation index, we use the coefficient of variation of each index to measure the degree of difference between the values of each index. The coefficient of variation of each index is as follows:

$$V_i = \frac{\sigma_i}{\bar{x}_i} \qquad (i = 1,2) \tag{8}$$

Note: V_i is the coefficient of variation of the ith indicator, σ_i is the standard deviation of the ith indicator, and $\bar{x}_i$ is the mean of the ith indicator.

The weights of each indicator are:

$$W_i = \frac{v_i}{\sum_{i=1}^{n} v} \qquad (i = 1,2) \tag{9}$$

After getting the weights of the 2 indicators, we can get the formula for the Forest carbon sequestration index (CSI):

$$CSI = (W_1 \times TSI + W_2 \times PSI) \times 100 \tag{10}$$

Table 1. Weight values of the indicators (FCMS)

Indicators(I)	Indicators(II)	Weights	Indicators(III)	Weights
Forest carbon sequestration	Vegetation	0.8909	Living trees	0.4547
	Forest products	0.1091	Furniture	0.1218
			Wood	0.2709
			Plywood	0.1117
			Paper	0.0236
			Other products	0.0121

As can be seen from the above table1, for the two secondary indicators, it is obvious that the carbon sequestration amount of living trees in the forest is greater than that of forest products. This indicates that although forest products have an impact on the total forest carbon sequestration to a certain extent, the total forest carbon sequestration mainly depends on the carbon sequestration of living trees, which is consistent with the reality. For the five third-level indicators under forest products, the proportion of carbon sequestration of other products is the smallest, while that of paper is slightly larger than that of other products. There is little difference between the weight of plywood carbon sequestration and furniture carbon sequestration, which is about 0.1. The weight of wood carbon sequestration is the largest, which is 0.2709.

2.3. Preliminary analysis of forest management

On the basis of the above model, time was taken as the independent variable and changes in carbon sequestration of various types of forests in the past 40 years were taken as the dependent variable, as shown in the figure1.

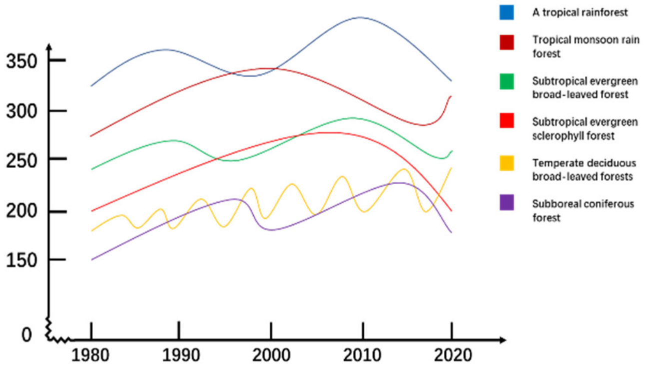

Figure 1. The carbon sequestration of each type of forest varies with time

According to the figure above:

No matter what type of forest, the total carbon sequestration as a whole showed a rising trend over time.

For each type of forest, there is an interval in which the growth continues to rise, and after reaching the peak, the growth will slow down or gradually decline, but eventually it will continue to rise.

Different types of forests have different ascending intervals. As can be seen from the figure, these intervals are about 3 years, 10 years, 15 years, 20 years and 25 years.

These findings are consistent with reality. First, as time goes on, the carbon sequestration of forests increases as long as they are not destroyed. Second, temperate deciduous broad-leaved forest of main trees for deciduous trees, mature period in the three years or so, tropical rain forests and subtropical evergreen broad-leaved forest of main trees for Chinese fir parashorea cathayensis and oil, in mature more than 10 years or so, mainly for Chinese fir trees of subtropical coniferous forest, the mature period of 15 years, mainly in tropical monsoon forest trees mature period of 20 years, The main trees in the subtropical evergreen sdurate forest are camphor trees, and the maturity period is as long as 25 years. These data are well consistent with the ascending interval in the figure, which verifies the reliability of our model.

According to the above model, in order to maximize carbon sequestration, the forest management plan is as follows:

Adjust the amount and use of logging according to the weight table: It is proposed to devote 10% of trees to forest products, increase wood and furniture manufacturing and reduce paper and other products.

Determine the interval years of logging according to the change of carbon sequestration with time: Different types of forest trees mature in different years. We try to determine the time of logging after a period of mature trees.

Protect the forest as far as possible, nurture and caress the forest. Add as many trees as possible to capture more carbon, but not more than the land can handle.

2.4. Validation of Forest Management Optimization (for Qinling Mountains)

We applied the model to The Qinling Mountains to obtain a more specific quantitative analysis. The change curve of carbon sequestration of Qinling forests in recent 40 years was obtained by querying the data, as shown in Figure 3 below.

According to the above model, we make the following optimization, and analyze the main tree composition in Qinling Mountains as follows:

Table 2. Composition of trees in Qinling Mountains

Main tree species in Qinling Mountains	Proportion	Maturity date
masson pine	36%	20 years
Chinese pine	31%	15 years
hemlock	28%	10 years

The optimisation is as follows: 10 per cent hemlock every 10 years, 10 per cent Chinese pine every 15 years and 10 per cent masson pine every 20 years.

The comparison of carbon sequestration amount after optimization is as follows:

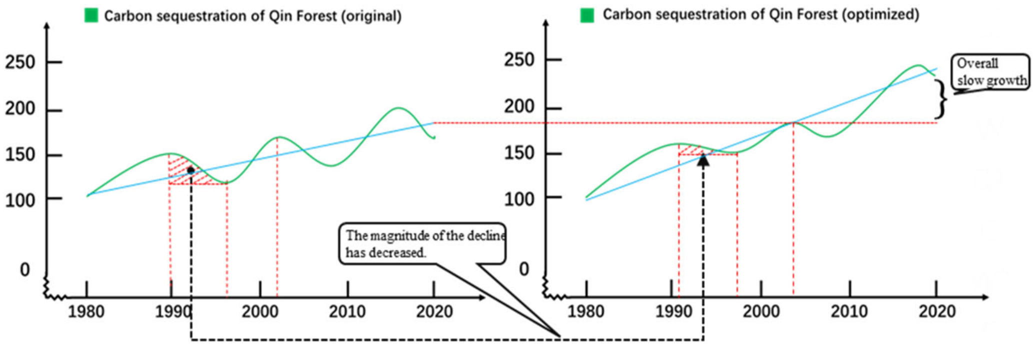

Figure 2. Variation of Carbon sequestration over time in Qinling Mountains (left) and variation of Carbon sequestration over time in Qinling Mountains after optimization (right)

It can be seen that after the adjustment and optimization of alternate felling, carbon sequestration did not decline significantly, but showed a slow growth trend. It is clear that this model is reliable.

3. INTEGRATED FOREST VALUE DECISION MODEL (IFVM)

On the basis of carbon sequestration, we use principal component analysis to introduce social value, including economic value, cultural value and recreational value, to comprehensively evaluate the forest value. Establish a decision-making model of forest integrated value, and propose the scope of management plan to determine the best way to use the forest. Then, the proportion of forest products is adjusted to 0, while the economic indicators are also 0, and the proportion of other indicators is adjusted to observe the changes in the overall value of the forest and judge whether there are conditions that will lead to the forest not felling. We implement management plans in different types of forests and analyze whether there are transition points between these plans. After that the management plan was applied to Shennongjia National Forest Park and the transition point of the management plan was determined according to its location characteristics.

3.1. Integrated forest value

First of all, we determined five indicators, namely, carbon sequestration of vegetation, carbon sequestration of forest products, cultural value, economic value and recreation value. There is mutual influence among these indicators, so we use principal component analysis (PCA) to synthesize these indicators into two indicators, forest carbon sequestration (CSI) and social value (SVI), and finally determine the forest comprehensive value (IFVI).

We have 6 samples, each sample has 5 indicators, the corresponding original data matrix is $Y = (y_{ij})_{6\times 5}$. After standardizing the original data, the correlation coefficient matrix of variables was established: $R = (r_{ij})_{5\times 5}$, as follows:

Find the corresponding unit feature vector of the characteristic root of R and obtain the coefficient formula of forest integrated value (IFV):

$$a_1 = \begin{bmatrix} a_{11} \\ a_{21} \\ \vdots \\ a_{51} \end{bmatrix}, a_2 = \begin{bmatrix} a_{12} \\ a_{22} \\ \vdots \\ a_{52} \end{bmatrix} \cdots\ a_5 = \begin{bmatrix} a_{15} \\ a_{25} \\ \vdots \\ a_{55} \end{bmatrix}, \tag{11}$$

$$IFV = a_1 Y_1 + a_{21} Y_2 + \cdots\ a_{51} Y_5 \quad i = 1, \cdots, 5 \tag{12}$$

Then, we calculate the contribution rate and cumulative contribution rate of each index and obtain that the principal components are vegetation carbon sequestration amount and economic value (Contribution rate: 89.4%). Therefore, we have reasons to believe that the carbon sequestration value of forest vegetation can greatly represent the total carbon sequestration value of forest. And for social value, the economic value of forest can greatly represent it

Contribution rate: $\frac{\lambda_i}{\sum_{k=1}^{5} \lambda_k}$ $(i = 1,2, \cdots, 5)$

Cumulative contribution rate: $\frac{\sum_{k=1}^{i} \lambda_k}{\sum_{k=1}^{5} \lambda_k}$ $(i = 1,2, \cdots, 5)$

Through coefficient score matrix and normalization processing, quantified weight formula of forest comprehensive value (IFV), forest carbon sequestration (CSI takes vegetation carbon sequestration) and social value (SVI takes economic value) can be obtained:

$$IFV=0.7846\times CSI+0.2153\times SVI \tag{13}$$

3.2. Scope of management and felling conditions

Through principal component analysis, we can know that the carbon sequestration of forest products is negatively correlated with the carbon sequestration of vegetation, and positively correlated with economic value, economic value is positively correlated with recreation value, and vegetation carbon sequestration value is positively correlated with cultural value and recreation value. Combined with the principal component of the integrated value of forests that we identified, we decided to propose management plans in the two areas of vegetation carbon sequestration and recreational use. Specifically, the integrated value of forest can be increased by adjusting the proportion of forest products, increasing vegetation and trees, and building recreation places.

Then we adjust the proportion of forest products to 0, so that the economic index is also 0, adjust the proportion of other indicators to observe the changes in the overall value of forest, and get the following figure 3.

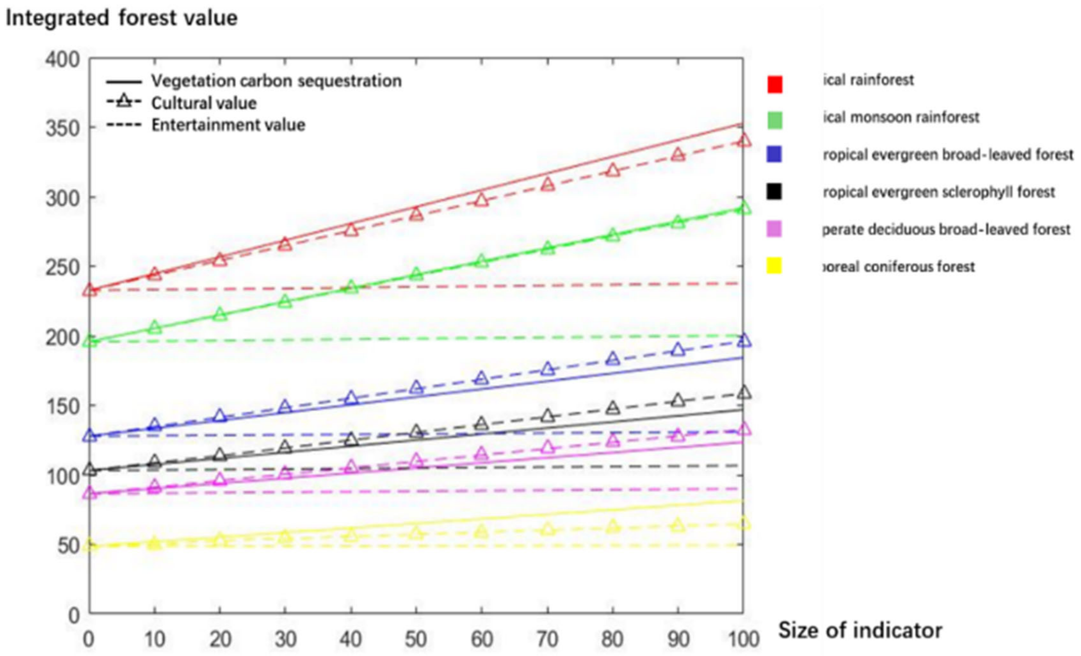

Figure 3. Change of forest value with impact index

It can be judged from the figure above: Change the proportion of different index, the change of forest value also presents different change trends. Changing the proportion of recreation value does not make the forest value back to its original level, but all types of forests has been obviously affected by the change of vegetation and the proportion of cultural, which can make the forest value back to the optimal level. So, when the proportion of vegetation or cultural value accounts for larger proportion, forests don't need to be cut down.

It can be seen from the above model that there are universal forest management plans for most forests, that is, to adjust the proportion of forest products, increase vegetation and trees, and build ecological protection areas or tourist attractions to enhance forest value according to the specific situation of forests. But when the model is applied to a particular forest, where the variation in indicators can be very large, it requires human intervention to adjust the forest management plan. For example, if our model is applied to the forest without tourist landscape, its cultural value will be greatly reduced. At this time, it is necessary to construct tourist landscape by human intervention, increase the proportion of forest products to enhance social value, or plant vegetation to increase carbon sequestration, so as to enhance the overall value of the forest. These interventions require a transition period, so there may be transition points between management plans that apply to all forests.

We applied the model to Shennongjia National Forest Park to identify transition points between management plans. Shennongjia National Forest Park is located in the northwest of China's Hubei Province and has a subtropical monsoon climate. Its forestland accounts for more than 85%, crop variety is various and have better economic value. As a nature reserve, there are a number of natural scenic spots and rare animals, with recreational and cultural values. There are many albino species which is attractive and valuable to researchers. The social value of the forest is increasing. Therefore, when we apply the management plan applicable to all forests to Shennongjia National Forest, the weight should transition from carbon sequestration to social value. We constantly increase the proportion of social value and observe the change of forest value, as shown in Figure 4.

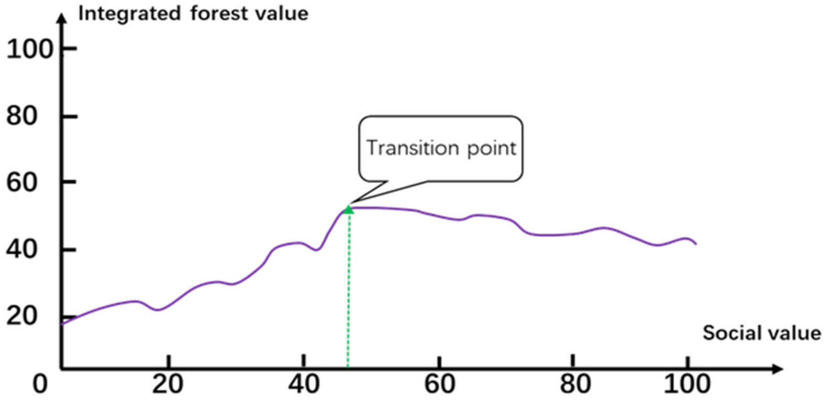

Figure 4. The Transition of social values

As can be seen from the figure, a peak value will appear in the process of constant change of specific gravity. This peak value is the transition point we need. Before the transition point, the forest value increases with the increasing proportion of social value. After the transition point, the improvement of social value cannot improve the forest value, so the transition point should be determined according to the specific situation of the forest

4. CONCLUSION

To sum up, for the forest carbon sequestration (*CSI*), the most efficient way of sequestration of carbon dioxide in forests is to harvest trees during their overmaturity and harvest no more than 10% of the total. To verify the correctness of our model, we applied the model to the Qinling Forest. Through specific analysis, we found that its carbon sequestration capacity increased by about 17%.

For the integrated value of the forest (IFV), we identified the scope of the forest management plan for vegetation carbon sequestration (VSI) and recreational use (RVI) according to the model. We then adjusted the indicators for forest products and determined that increasing the vegetation carbon sequestration (VSI) and cultural value (CVI) of vegetation would result in forests not needing to be cut down. We then apply management plans to different types of forests and judge that there is a transition point (saturation point of social value) between different plans. Finally, the model was applied to Shennongjia National Forest Park to determine the specific transition point. Its corresponding social value accounted for 47 %.

To get more concrete conclusions, we apply the decision model to different types of forests. We conducted further research on the Komi primeval forest that was allowed to be felled. The carbon sequestration model is used to predict the carbon sequestration amount of Komi virgin forest in 100 years, and the total is 20547.07MtC. Then, we used dynamic programming to determine the optimal management plan for the forest: 10% of pine is cut every 15 years and Korean pine every 25 years. An annual harvest is implemented for fruit trees, and nature reserves should be established to protect rare animals. Finally, we made a transition plan from the old strategy to the new strategy under the assumption that alternating felling time would increase by 10 years. The program meets the needs of forest managers and users.

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