Study on Forest Management Plan Based on Forecast of the Carbon Sequestration and Comprehensive Value

Renyan Ling, Chuyi Xie, Congtong Qiu*

International College, Xiamen University, Xiamen, 361102, China

* Corresponding author Email: 32920192201092@stu.xmu.edu.cn

All Authors are co-first authors

Abstract. Carbon sequestration by the forest and its products can help to reduce carbon dioxide. However, when trees age, they will release the carbon accumulated in the body. So it raises the problem that how to make trees into products at the appropriate amount and time and make an effective forest management plan. Firstly, "DBH-Biomass-carbon sequestration" model is developed to calculate the amount of carbon sequestration of a tree at different ages. Then we predict the total carbon sequestration of a forest in the next 100 years, assuming that the age distribution of a forest obeys a normal distribution, and the best cutting time for a tree is when its marginal carbon sequestration is zero. Besides carbon sequestration, we introduce ecological, economic, and social dimensions to evaluate the comprehensive value of forests, and use the multi-objective planning model to obtain the optimized annual deforestation plan which take ecological, economic, and social dimensions into account. Finally, we select Tianshan Spruce Forest to apply the above models. The results show that the carbon sequestration of spruce began to decline after the age of 21. compare two management plans, one is to cut down spruce trees older than 21 years old every year and the other is to neither cut nor plant, we find that the forest carbon sequestration amount in 100 years for plan one and two is 4571t and 1728t, respectively.

Keywords: Carbon Sequestration, DBH Growth Model, GRA Model, Multi-Objective Planning Model, 3D Evaluation Model, AHP.

1. Introduction

Greenhouse gases have long been the most pressing global challenge. As the largest, most productive, and most structurally and functionally complex ecosystem on land, forests play an important role in regulating the global carbon balance and absorbing greenhouse gases. So, how can we keep forests healthy, and thus human health?

Sustainably managed forests are one of our most effective tools for tackling the greenhouse gas problem. A recently completed study shows that SFI-certified forests can absorb more than 20 billion tons of carbon and capture about 235 million tons of carbon each year, which is critical to reducing the impact of climate change.

Appropriate deforestation management strategies may be beneficial for carbon sequestration. Carbon sequestration means transferring atmospheric CO_2 into other long-standing global pools, including oceans, soils, biological and geological formations, to reduce the net growth rate of atmospheric CO_2. A growing body of research shows that trees take up carbon as they grow, but release the carbon they once took up by breaking down branches as they mature. Instead, wood products actually store carbon rather than emit it.

Arguably the best form of carbon sequestration is to cut down trees, restore our sustainable, managed forests, and use the resulting wood as a building material. Therefore, accurate forest assessment systems and effective forest management strategies are crucial for improving global ecosystems and making them most habitable for human habitation.

2. Related research

Over the years, many scholars studied the factors the level of forest carbon sequestration. Yin et al. [1] argue that natural conditions, urbanization rate; and degree of openness are fundamental factors.

Qiu's study [2] uses the method of carbon sink measurement of terrestrial forest. Wang and Liu [3] include above ground biomass, brightness index, wetness index, below ground biomass in their special model.

To study the economic value of forest, Elmi et al. [4] use contingent valuation method to determine the economic value of forest conserved by local community for carbon sequestration. The study also indicates the potential for sustainable forest management through community-based approach. The forest carbon sequestration efficiency can effectively measure the value of the forestry input and output. But the statuses and trends of the forest area changes in different regions are quite different (MacDonald and McKenney, 2020[5]). Guo and Yan study the forest management plan in Hubei Province to realize organic unity of economic, ecological and social benefits.

However, Cai et al. [6] indicate that new forestation from 2015 in the potential plantable lands would have little additional benefit. Therefore, how to find effective forest logging management methods is of great importance. Alongi [7] ponits out that a good management plan could promote the continuous optimization and upgrade of the structure of the forestry industry, and makes full use of forest resources

3. "DBH-Biomass-Carbon Sequestration" Model

Forest carbon sequestration is estimated by using timber volume information derived from field plots, where forest parameters like Diameter at breast height (DBH) are measured directly. Then the volume can be used to determine biomass of the tree. And by using the conversion coefficient BEF, we can estimate the carbon sequestration of a tree [2]. The observational data used in this paper were obtained from the China Flux Data Network (http://www.cnern.org.cn) and The Global Gridded Surfaces of Selected Soil Characteristics dataset released by IGBP-DIS. We then form a standardized dataset of ecosystem carbon and key meteorological elements, mainly including meteorological data and flux data on a monthly scale and an annual scale from 2000 to 2020. Based on this dataset, we built the "DBH-biomass-Carbon Sequestration" models in three steps and find the relationship between carbon sequestration and tree age.

3.1 DBH Growth Model

The change in diameter at breast height (DBH) of tree species$j$ in the next few years $\Delta Y_{t+\Delta t}^{(j)}$ is related to the growth environment of the tree $X_p^{(j)}$, growth acceleration b_j , and DBH in current year $Y_t^{(j)}$.

We combine all factors to build the DBH model:

$$\Delta Y_{t+\Delta t}^{(j)} = A_j \cdot (Y_t^{(j)})^2 e^{-b_j Y_t^{(j)}} \cdot X_p^{(j)} \tag{1}$$

$$X_p^{(j)} = \sum_{i=1}^{8} \lambda_i \cdot x_i \tag{2}$$

Where: $\Delta Y_{t+\Delta t}^{(j)}$: The expected changing amount of DBH of tree species j in Δt years; A_j : Growth rate coefficient of tree species j; b_j : Growth acceleration coefficient of tree species j; λ_i : Corresponding coefficients of factors such as temperature, altitude and longitude.

The growth environment factors $X_p^{(j)}$ include: annual average precipitation, soil thickness, air temperature, wind velocity, altitude, longitude, latitude and below ground biomass. Next we will explained these factors further

In the data obtained in this study, since we assumed that the environmental growth factors corresponding to each type of tree were the same, the data need to be normalized. The formula is as follows:

$$X_i = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{3}$$

In the process of tree growth, there will be many environmental factors that affect its diameter at breast height (DBH) growth. We summarize and categorize eight factors into three categories.

Figure 1. Growth Environment Factors

• Climate conditions

- Air temperature (x_1): Dead trees decompose faster in regions with warmer local temperatures, suggesting that as temperatures rise, climate change may increase wood decomposition in tropical or subtropical regions as long as moisture remains.

- Annual average precipitation (x_2): Precipitation can facilitate the decomposition of woody material, encouraging insect productivity. However, in boreal forests, precipitation slows decomposition. [9]

- Wind velocity (x_3): In the process of growth, forest trees rely on the wind to provide the nutrients needed for respiration, and at the same time blow away the wastes excreted by respiration. The shaking force of the wind to continuously tear the fiber bundles of the phloem, prompting the cells to speed up the division and increase its DBH.

- Soil thickness (x_4): Soil thickness affects the spatial range of soil nutrients, total water storage and phase distribution, so soil thickness is an important factor to determine forest productivity.[10]

• Geographical position

- Latitude (x_5): Affected by climate, forests form a zonal distribution from tropical rain forest to warm temperate deciduous broad-leaved forest and then to cold temperate coniferous forest. Therefore, the vegetation distribution has latitudinal zonality.

- Longitude (x_6): From the west inland to the east coast, there is a type change from desert to grassland and then to forest. Therefore, vegetation distribution also has longitude zonality.

- Altitude (x_7): With the gradual increase of the altitude, the solar radiation gradually increases, and the precipitation gradually decreases, and the vegetation presents the characteristics of zonal variation with the altitude (Li Bosheng, 2015). Therefore, the vegetation distribution also has vertical zonality. [11]

• Below ground biomass (x_8): Trees rely heavily on microbial symbionts. In soil, tree roots are most strongly affected, and these roots interact directly with root microbes to produce specific root exudates. [12]

3.2 Relationship between Tree DBH and Biomass

The most basic quantitative characteristic of the forest ecosystem is the forest biomass, which is the energy basis and the source of nutrients for the operation of the forest ecosystem. It not only indicates the management level of the forest, but also reflects the value of forest development and utilization. The relationship between tree biomass $\Delta W\ (j)\ t$ and tree DBH and tree height H is as follows:

$$\Delta W_t^{(j)} = \alpha + \beta \cdot (\Delta Y_t^{(j)})^2 \cdot H \tag{4}$$

According to the Tree Height Curve Model, there is a conversion formula between DBH and tree height:

$$H = \delta(\Delta Y_t)^b \tag{5}$$

3.3 Carbon Sequestration Model for a Tree

Based on the tree DBH growth model and relationship between DBH and biomass, we further build a tree carbon sequestration model. The amount of carbon sequestered by a tree is equal to the amount of carbon dioxide absorbed by a tree minus the amount of carbon dioxide released. The specific model of tree carbon sequestration is as follows:

$$\Delta C_t = \Delta input - \Delta output = BEF^j \cdot \Delta W^{(j)} - a \cdot e^{g-1} \cdot t \tag{6}$$

Where:

ΔC_t: Changes in the amount of carbon sequestration in a tree in year t; BEF^j: Conversion coefficient between tree biomass and carbon sequestration; g: Acceleration speed of a tree releasing carbon sequestration.

During the tree growth stage, the amount of carbon absorbed by the tree has a positive relationship with its DBH value. During this stage, the carbon released by the tree is mainly carbon dioxide released by the tree's respiration; in the stage of tree senescence to death, the tree absorbs less carbon dioxide than it emits, and the carbon dioxide stored in the tree also begins to be released to the outside world

According to the tree carbon sequestration model, we can draw the relationship between the annual carbon sequestration of trees and tree age. According to the annual carbon absorption rate of trees, the life of a tree is divided into four stages, namely:

- Accelerated growth period: Trees add more carbon sequestration each year.
- Stable growth period: The amount of carbon sequestration increase gently.
- Aging period: The rate of increase in carbon sequestration begins to slow down.
- Dead period: Carbon sequestration begins to decrease until zero.

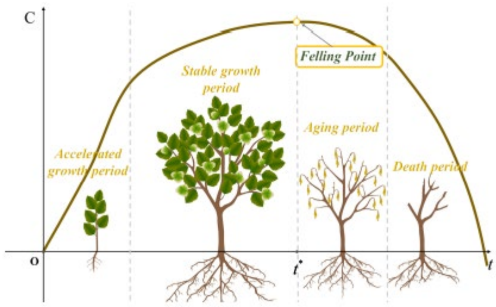

Figure 2. Amount of carbon sequestered by a tree during the growth cycle

4. Prediction of the Amount of Carbon Sequestered in a Forest and Products

4.1 Determine the Time and Proportion of Deforestation

According to the carbon sequestration model for a tree, we conclude that the marginal benefit of carbon sequestration is zero when the the tree is at t^* years old, that is, at the end of the stable growth period. After t^*, the tree enters the aging period, and the carbon sequestration amount shows a decreasing trend year by year. Therefore, to determine which type of trees and what proportion of trees to cut, we choose to cut down trees that are older than t^* and keep trees which are in the accelerated growth phase.

Next, because the age of the forest follows a normal distribution before the implementation of the forest management plan, the proportion of felling in first year t_0 is $p_0 = P(t \ge t^*) = 1 - \phi((t^* - \bar{t}) / \sqrt{\sigma})$, and the proportion of felling in the next year t_1 is the proportion of trees with an age of t^*-1 a year ago which is $P(t^*>t\geq t^*-1)$ and so on, the proportion of felled trees in year t^* is the proportion of trees with zero age t^* years before, which is $P(1>t\geq 0)$. Then starting from year t^*+1, since all the original trees in the forest have been cut down and made into wood products, the existing trees are newly planted after the first round od felling, and the the age of tree still obeys the original normal distribution. Therefore, the deforestation plan enters the second cycle, and the duration of a cycle is t^* years. The specific schematic diagram is as follows.

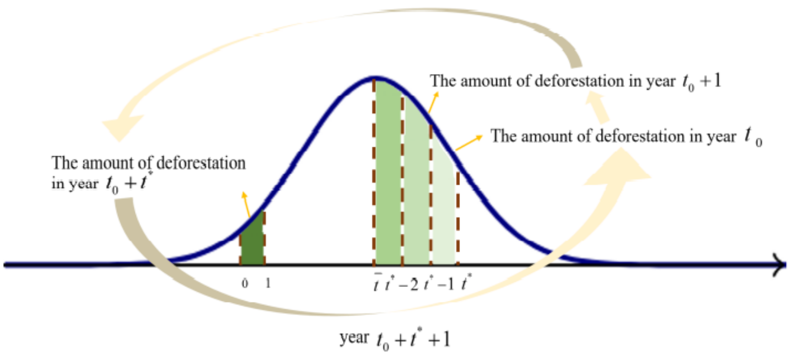

Figure 3. Periodic Chart of annual logging proportion

4.2 Calculate the Carbon Sequestration for Two Management Plan

The carbon sequestration of a forest consists of three forms: one is the carbon sequestration of existing trees, the second is the carbon sequestration of trees that are cut down and made into products, and the third is the carbon sequestration of newly planted seedlings. Based on these three forms of carbon sequestration, we construct the following model to calculate the total carbon sequestration of forests and their products.

$$CS_t = CS_{t-1} + CS_{new} + CS_{ori} - CS_{prod} \tag{7}$$

$$\begin{cases} CS_{ori} = q_{t-1}\cdot(1-p_t)\cdot\bar{c} \\ CS_{new} = q_{t-1}\cdot p_t\cdot c_0 \\ CS_{prod} = (q_{t-1}\cdot p_t\cdot c_1)/y_{prod} \end{cases} \tag{8}$$

where: CS_t: Total carbon sequestration of a forest and its products in year t; CS_{new}: Carbon sequestration of newly planted seedlings this year; CS_{ori}: Carbon sequestration of remaining trees after felling; CS_{prod}: The annual amount of carbon dioxide released by a forest product; q_{t-1}: The number of forest trees in year $t-1$; p_t: Annual percentage of tree felling which is derived from the cumulative normal distribution; t^*: The optimal logging age; $\bar{c}$: The average annual carbon sequestration of a tree; $c_{t=0}$: The carbon sequestration of a a seedling; $c_{t=1}$: The accumulated carbon sequestration of a tree before it was felled; y_{prod}: The useful life of the tree product.

For the other plan, there are no new trees are cut down or planted every year, the aging trees will no longer absorb carbon dioxide, but will release the carbon dioxide originally stored in the body, then the carbon sequestration amount of this forest is calculated as follows:

$$CS'_t = CS'_{t-1} - q_{t-1}\cdot p_t\cdot c_1 - q_{t-1}\cdot(1-p_t)\cdot\bar{c} \tag{9}$$

5. EES Model: Identify and Evaluate a forest management plan that maximize the overall value of forests

5.1 Select forest value factors by GRA Model

There are many factors that affect the value of forests. In the selection of indicators, it is necessary to find indicators related to deforestation rate and planting rate. We adopted the grey relational analysis (GRA) model to judge the degree of association based on the similarity of the geometrical shapes of the sequence curves.

Select the reference sequence (deforestation rate in the past ten years) pt and the comparison sequence (various value indicators of forests in the past ten years) xt, carry out dimensionless processing on the reference sequence and the comparison sequence respectively, and standardize them. Compute the difference sequence and the maximum and minimum values:

$$\Delta i(t) = | x_0(t) - x_i(t) | \quad (10)$$

$$\Delta_{\max} = \max(i) \cdot \max(t) \cdot | x_0(t) - x_i(t) | \quad (11)$$

$$\Delta_{\min} = \min(i) \cdot \max(t) \cdot | x_0(t) - x_i(t) | \quad (12)$$

Calculation of grey correlation coefficient:

$$\zeta_{0i}(t) = (\Delta_{\sin} + k\Delta_{\max}) / (\Delta_{0i} + k\Delta_{\max}) \quad (13)$$

Among them, k is the resolution coefficient, and its value range is $k \in (0, 1)$. The smaller the value, the more the difference of the correlation coefficient can be improved, and the general value is $k = 0.5$. From this, we can further calculate the correlation:

$$\gamma_{0i} = \frac{1}{n} \sum_{i=1}^{n} \zeta_{0i}(t) \quad (14)$$

The index system was screened by the correlation between the deforestation rate and various value indicators, and the first 8 indicators with relatively large correlation were selected as the evaluation factors of the comprehensive forest value, and they were divided into three dimensions: ecology, economy and society.[9] The indicators identified and their correlation to deforestation rates are as Figure 4:

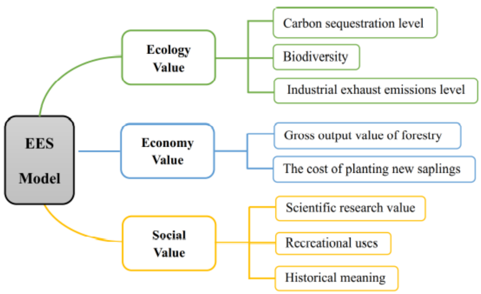

Figure 4. Three dimensions of ESE model

Table 1. Correlation of variables in ESE model

Ecology	Value	Economy	Value	Society	Value
Variable	Correlation	Variable	Correlation	Variable	Correlation
X1	1	X4	0.6889	X6	0.7932
X2	0.7434	X5	0.5463	X7	0.6692
X3	0.6403			X8	0.5318

5.2 Three Dimensions for Forest Value Assessment

We then explain the above three dimensions and eight forest factors in detail as follows:

a. Ecological value

• Carbon sequestration: The carbon sequestration of forests belongs to the ecological value of forests. The specific calculation formula is given in the previous section.

• Biodiversity: Forest organisms are closely related to trees. Cutting down trees will lead to regional climate changes. At the same time, organisms that originally parasitized the felled trees will also lose their habitats. Therefore, cutting down trees has a negative impact on species diversity. Therefore, species diversity indicators measure as follows:

$$Bio_t = q_1[-\alpha_1 \cdot p_t + \frac{\alpha_1 + \alpha_2}{2} \cdot (1 - p_t)] \tag{15}$$

Among them, α_1 is the biomass undertaken by mature trees, α_2 is the biomass undertaken by tree seedlings

• Industrial waste gas emissions: The deforestation of forests and the processing of wood products will lead to a certain degree of industrial waste gas emissions, posing a threat to the forest environment. From the following formula, the impact of felling trees on industrial exhaust emissions can be obtained.

$$Fac_t = q_t \cdot j \cdot p_t \tag{16}$$

Among them, j is the industrial exhaust emissions from felling a tree and making wood products.

b. Economic value

• Gross output value of forestry: Trees are cut down and made into wood products, which can be used for construction, vehicles, paper making, furniture manufacturing, etc., bringing economic income to the local area.

$$Inc = i \cdot q_t \cdot p_t \tag{17}$$

Among them, i is the profit from wood products produced per tree.

• The cost of planting new saplings: Planting new saplings requires a lot of labor, transportation, and management costs, which will bring economic burdens to the local area.

$$\text{Cos}t = f \cdot q_t \cdot p_t \tag{18}$$

Among them, f is the cost of planting a tree.

c. Social value

• Scientific research value: The scientific research value of forests is reflected in the protection value of rare tree species. At the same time, rare tree species are also the focus of research in some social sciences. However, tree felling has a negative impact on rare tree species. With the intensification of felling, the content of ancient trees in a forest will decrease.

$$Sci = (1 - p_t) \cdot q_t \cdot o \tag{19}$$

Among them, o is the proportion of rare tree species in the forest.

• Entertainment: Forests provide recreational value for human beings, and a variety of forest tourism and vacation activities can be carried out, but felling trees, manufacturing wood products and planting new trees will reduce the recreational value of forests.

$$\text{Re}cre = (1 - 2p_t) \cdot r \tag{20}$$

Among them, r is the average annual output value of local tourism.

• Historical value: The ancient trees have historical significance and ornamental value, and will also bring more opportunities to the local tourism industry.

$$His = (1 - p_t) \cdot q_t \cdot h \tag{21}$$

Among them, h is the proportion of old trees in the forest.

5.3 The Maximum Carbon Sequestration Amount under Multi-Objective Planning Model

We use a multi-objective (social, biodiversity and economic dimension) planning model to determine optimal forest management practices. Then, look for the best forest management approach that maximizes carbon sequestration and considers multiple value dimensions. We use a linear weighted sum method to solve a multi-objective programming model. First, we assign appropriate non-negative weight coefficients to the four targets in the multi-target model according to their importance: $w1$, $w2$, $w3$, ($\sum_{i=1}^{3} w_i = 1$), and normalize the value range of each dimension in (0, 1) between. Then, use the target function $V_{total} = w_1 \cdot V_{economy} + w_2 \cdot V_{eco\log y} + w_3 \cdot V_{society}$ as a function of being an evaluation (target) function to solve the single target programming problem:

$$\max V_{total}$$
$$s.t. \begin{cases} V_{eco\log y} \geq V_1^{(j)} \\ V_{economy} \geq V_2^{(j)} \\ V_{society} \geq V_3^{(j)} \end{cases} \tag{22}$$

Where: $V_1^{(j)}$: the lowest biomass of forest j in the past ten years; $V_2^{(j)}$: the economic development level of the area where the forest j is located; $V_3^{(j)}$: the lower limit of education and tourism development in the area where forest *j* is located. At the same time, we use the Analytic Hierarchy Process to find the weight coefficients required in the planning model.

Table 2. Weight coefficients for model variables

Dimension	Forest value factor	Weight	Total weight
Ecology	Carbon sequestration level	0.1407	
	biodiversity	0.1346	
	Industrial exhaust emissions level	0.135	0.4103
Economy	Gross output value of forestry	0.1922	0.3198
	Cost of planting new saplings	0.1276	
Society	Scientific research value	0.1433	
	Recreational uses	0.0473	0.27
	Historical meaning	0.0794	

5.4 Evaluation of Forest Management Methods

According to the above planning model, we can draw a forest management method that pays attention to various values of forests. Next, we will establish an evaluation model to evaluate these two plans of forest management.

Firstly, we calculate the average value of the three dimensions in the next 100 years, and establish a threedimensional evaluation model on the three-dimensional coordinate axis:

$$\overrightarrow{V_{total}} = (w_1 \cdot V_{economy}, w_2 \cdot V_{eco\log y}, w_3 \cdot V_{society}) \tag{23}$$

We set standard vector as: $\overrightarrow{(w_1, w_2, w_3)} \cdot |V_{total}|$ represents the size of the comprehensive value of the forest. The cosine distance $D = 1 - \cos\left\langle \overrightarrow{V_{total}}, \overrightarrow{(w_1, w_2, w_3)} \right\rangle$ between $\overrightarrow{V_{total}}$ and the standard vector indicates the degree of value balance of the forest. The smaller *D* is, the more uniform the value distribution of the forest in the three dimensions of ecology, economy and society is, which indicates that the overall system operation of the forest is more coordinated and sustainable and the ability to develop is stronger

6. Applying Our Models

6.1 Calculation of carbon sequestration for different types of tree species

We first divide the forest into four categories: arbor forest, economic forest, bamboo forest, and shrub forest. [6] Then we apply the relationship between the carbon sequestration amount of a single tree and its tree age calculated by "DBH-Biomass-Carbon Sequestration" Model to these four kinds of forest, and the results are as follows:

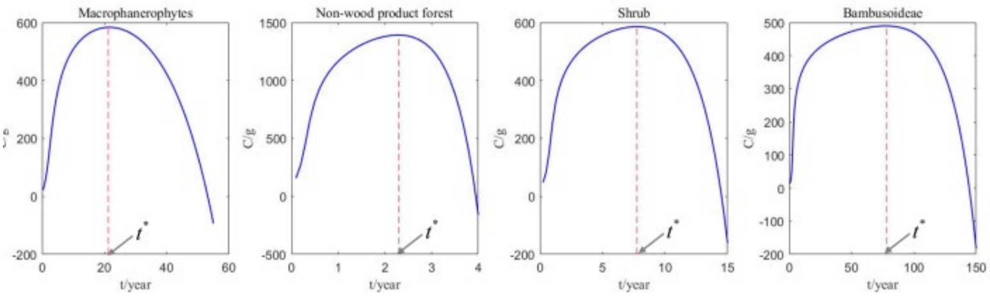

Figure 5. Relationship between carbon sequestration and tree age of different tree species

It can be seen that different types of tree species have different degrees of carbon sequestration ability as they age, but for all of them, in the middle and late stages of the life cycle, their carbon sequestration ability begin to decrease year by year. Therefore, according to the conclusion of the model, the trees will be cut down after reaching the age $t*$.

In order to further practice our Models built above, we will focus on analyzing one specific forest. We choose the Tianshan Spruce Forest in China as our analysis object, and calculate the carbon sequestration of this spruce forest in the next 100 years. Then we use EEM Model to find the best management method for this forest in the next 100 years. This management method is different from the management method of Model 1 because it incorporates biodiversity value, economic value and social value into the forest comprehensive value evaluation system rather than just maximizing its carbon sequestration.

6.2 Estimating Carbon Sequestration Level in Spruce Forests Over the Next 100 Years

Tianshan Spruce Forest is the dominant species of mountain forest in Tianshan Mountain, and it is also an unique tree species in the mountains of central Asia. It is a kind of arbor forest and plays an important role in biodiversity protection, soil and water conservation and climate regulation.

i. Calculate the BDH value and biomass of a spruce tree

According to the collected data of Tianshan Spruce Forest, after normalization, we can get the result: Aj = 0.0049, $b\ j$ = 0.11.We calculate the coefficients of the eight factors of the growth environment. At the same time, we perform a significance test on the regression coefficients, and the results are as follows:

Table 3. Significance test results

Tree species	Aj	**Significance**	$b\ j$	**Significance**	R^2
Tianshan spruce forest	0.0084	0	0.015	0	0.550

Table 4. Coefficient and Significance of Factors

Factors	**Coefficient**	**Sigificance**
Latitude	-0.567	0
Longgitude	0.203	0
Altitude	-0.488	0
Annual average precipitation	0.928	0
Soil thickness	-0.133	0.001
Air temperature	0.244	0
Wind velocity	0.008	0.011
Below ground biomass	0.467	0

After calculation, we found that Xp = 0.41, and according to the data, the DBH value of spruce seedlings $Y_{t=0} = 50mm$, so the DBH growth model of Tianshan Spruce Forest is as follows:

$$\Delta Y_{t+\Delta t} = 0.0049 \cdot (Y_t)^2 \cdot e^{-0.0011 \cdot Y_t} \cdot 0.41 \tag{24}$$

Then, substitute the DBH value into this the formula of calculating biomass, and finally, iterate the above formula to predict the biomass of the tree throughout its life cycle.

ii. Calculation of the Relationship Between Spruce Carbon Sequestration and Tree Age

According to the data, the biomass conversion coefficient BEF of the spruce forest is 56%. According to the tree carbon sequestration model, the relationship between the carbon sequestration of a single Tianshan spruce and the tree age can be obtained as follows:

$$\Delta C = \Delta input - \Delta output = 0.56\Delta W_t^{(j)} - 35e^{0.06t} \quad (25)$$

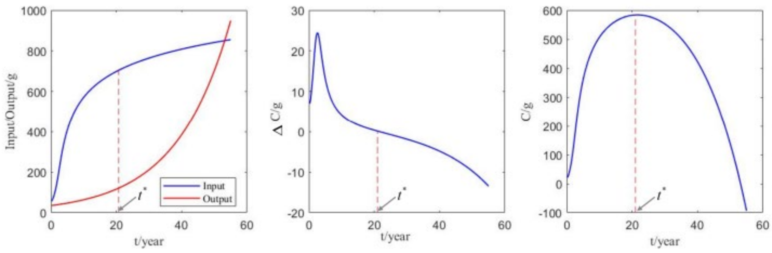

Figure 6. Net effect of Carbon input and output

Therefore, the optimal cutting age is $t^* = 21$

iii. Forest Management Practices Maximizing Carbon Sequestration in Spruce Forests

According to literatures and data, the current average age $\bar{t}$ of Tianshan Spruce Forest is 13, so the distribution of tree age of Tianshan spruce forest is $t \sim N(13, 5^2)$, the probability density function is $f(x) = e^{-(x-13)^2/50} / \sqrt{10\pi}$. In order to achieve the best carbon sequestration effect of Tianshan Spruce Forest in the next 100 years, our forest 13 management method is to cut down spruce forests at a ratio of p every year, $\begin{Bmatrix} P_{t=0} = P_{t\geq 21} = 5.72\% \\ P_{t=1} = P_{20\leq t<21} = 2.26\% \\ P_{t=2} = P_{19\leq t<21} = 3.1\% \end{Bmatrix}$ and so forth.

Take $t^* = 21$ years as a cycle, we can find the proportion of Tianshan Spruce Forest that will be cut down and turned into wood products each year for the next 100 years, that is, the logging schedule. The specific results are as Figure7:

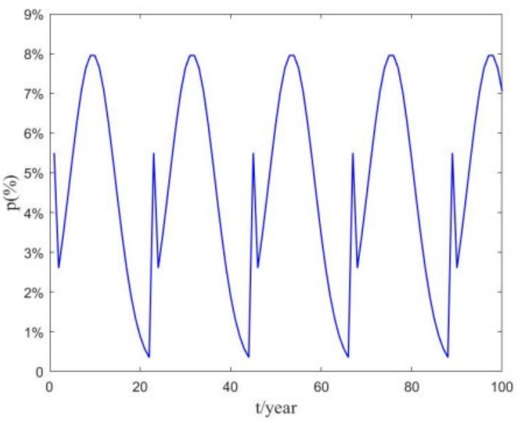

Figure 7. Timeline of the proportion of deforestation in Tianshan Spruce Forest over the next 100 years

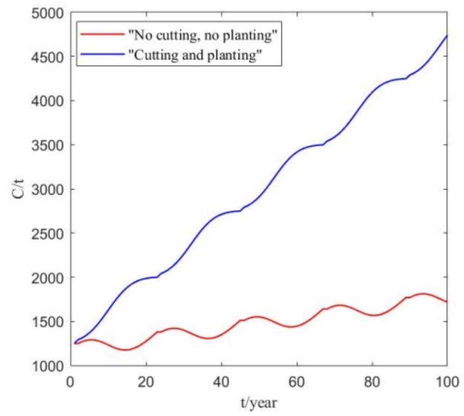

Figure 8. Comparison of two felling plans

Further, we can get the carbon sink of the spruce forest for the next 100 years. If the forest is allowed to grow on its own without human intervention, the carbon sequestration of this spruce forest over the next 100 years is shown in Figure 7. Compared with the planning scheme, the carbon sink growth rate of the "no cutting, no planting" scheme has slowed down. A comparison of the two schemes is shown in Figure 8.

6.3 The Best Forest Management Method for Tianshan Spruce forest

According to the collected data, the annual growth rate of Tianshan spruce forest in the future can be obtained by using the above planning model, which can be obtained for 100 years. The number of deforestation, the specific results are shown in Figure 9:

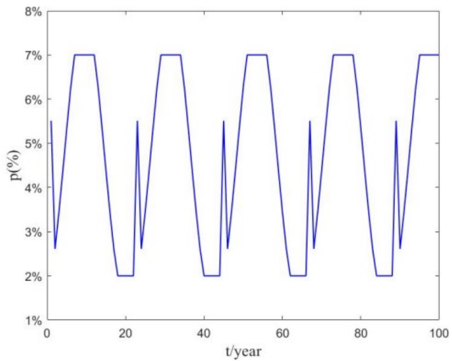

Figure 9. Optimized deforestation plan for the next 100 years

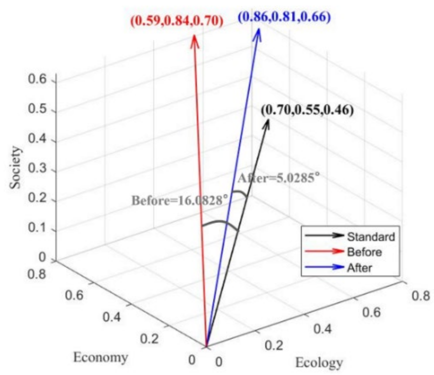

Figure 10. Comprehensive value comparison before and after optimization

The results show that the proportion p of trees cut down each year can neither exceed 7% nor be lower than 2%, because when p exceeds this range, the value of economic, cultural and ecological dimensions will exceed the critical point.

In order to verify the optimality of this forest management scheme, we use the evaluation model above to evaluate the management methods before and after optimization.

Calculate the comprehensive value before optimization $\overrightarrow{Val_{(1)}^{total}}=(0.59,0.84,0.7)$ and the value after optimization is $\overrightarrow{Val_{(2)}^{total}}=(0.86,0.81,0.6)$. The representation on the three-dimensional coordinate axiss as figure 10.

It can be seen that the cosine distance of the comprehensive forest value after considering other value dimensions is smaller than the cosine distance of the comprehensive forest value considering only carbon sequestration.

6.4 Sensitivity Analysis

When calculating the total carbon sequestration CS_t of forests and their products in year t, there are multiple parameters in the model we use. When applied to different situations, changes in parameters may have certain impacts on the model results. In this regard, considering that there are certain differences in the service life of different types of wood products produced by different tree species, we select the parameter y_{prod} , set $y_{prod}=15$, and analyze its sensitivity by adjusting the parameter value of y_{prod}.

Let y_{prod} = 13, 14, 15, 16, 17, and keep other parameters unchanged, the analysis result is shown in the figure11:

It can be seen from the figure that the total carbon sequestration CS_t of forests and their products each year shows the same trend when we use the different value of y_{prod}. In the same way, this processing method for other parameters can also get similar results, indicating that small changes in parameters will not have obvious effects, which proves the stability of the model.

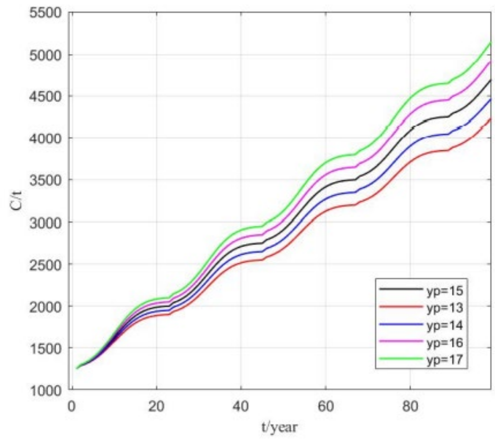

Figure 11. Forest and forest products carbon Cycle

7. Conclusion

Our study demonstrates that tree diameter at breast height (DBH) is related to climate conditions, geographical location and below ground biomass, and through DBH, we can estimate the biomass and carbon sequestration. We found that as it ages, a tree's carbon sequestration rises first and then declines, and the optimal cutting age is when its marginal carbon sequestration is zero. Take the Tianshan spruce as an example and based on the hypothsis of Normal distribution of forest age, we compared two forest management plans and found, if the "no-cutting" policy is implemented from 2022, the forest carbon sequestration after 100 years will be 1728t. But if we cut down a certain percentage of trees every year and plant the same amount of new saplings, the forest carbon sequestration after 100 years is 4571t. Our research has also provided the optimized deforestation plan when taking ecological, economic, and social dimensions into account. Using the multi-objective programming model, the optimized deforestation plan for Tianshan spruce is that the annual deforestation ratio cannot exceed 7.05% nor lower than 2.03%. In the three-dimensional coordinate axis, it can be seen that the cosine distance of the optimized scheme is smaller than unoptimized scheme.

References

[1] Shiwen Yin, Zhiwen Gong, Li Gu, Yuanjie Deng, Yujia Niu, Driving forces of the efficiency of forest carbon sequestration production: Spatial panel data from the national forest inventory in China, Journal of Cleaner Production, Vol.330, 2022, 129776, ISSN 0959-6526.

[2] Qiu Z X, Study on the method and application of carbon sink measurement of terrestrial forest vegetation in China, Beijing forestry university, 2019. DOI: 10.26949 /, dc nki. Gblyu.

[3] Wang Xiaoke, Liu Weiwei. The influencing factors of forest carbon sequestration. Journal of forestry and ecology, 2021, pp.40-41. DOI: 10.13552 / j.carol carroll nki lyyst.

[4] Elmi Nure Negewo, Zeleke Ewnetu, Yemiru Tesfaye, Economic Valuation of Forest Conserved by Local Community for Carbon Sequestration: The Case of Humbo Community Assisted Natural Regeneration Afforestation/Reforestation (A/R) Carbon Sequestration Project; SNNPRS, Ethiopia[J], Environmental Technology, 2016, 7(2):88-105.

[5] H. MacDonald, D. McKenney, Envisioning a global forest transition: status, role, and implications, Land Use Policy, 99 (2020), p. 104808.

[6] Weixiang Cai, Nianpeng He, Mingxu Li, Li Xu, Longzhu Wang, Jianhua Zhu, Nan Zeng, Pu Yan, Guoxin Si, Xiaoquan Zhang, Xiaoyu Cen, Guirui Yu, Osbert Jianxin Sun,Carbon sequestration of Chinese forests from 2010 to 2060: spatiotemporal dynamics and its regulatory strategies, Science Bulletin,2021, ,ISSN 2095-9273,https://doi.org/10.1016/j.scib.

[7] Shiyu Guo, Ni Zhou, Han Yan, Returning Farmland to Forest, Forest Management and Permanent Forest : Thinking on High-quality Development of Returning Farmland to Forest[J], 2020, pp:82-84.

[8] Alongi D M. Carbon sequestration in mangrove forests [J]. Carbon management, 2012, 3(3): 313-322.

[9] Chaiyo, Carbon storage in Above-Ground Biomass of Tropical Deciduous Forest in Ratchaburi Province, Thailand; World Academy of Science, Engineering and Technology, 2011, pp58. DOI:10.13140/2.1.3011.0723.

[10] R. Lal, Forest soils and carbon sequestration, Forest Ecology and Management, Volume 220, Issues 1–3, 2005, pp.242-258. DOI: https://doi.org/10.1016/j.foreco.

[11] Doraiswamy P C, McCarty G W, Hunt Jr E R, Modeling soil carbon sequestration in agricultural lands of Mali, Agricultural Systems, 2007, 94(1), pp.63-74. DOI: 10.1016/j.agsy.

[12] Alongi D M. Carbon sequestration in mangrove forests. Carbon management, 2014, 3(3), pp.313-322. DOI: 10.4155/cmt.12.20.