Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
E		2212087

Harvest Brings Values

Summary

In the past few decades, global development has prioritized the efficiency and profits and ignored the climatic degeneration. Despite the serious problem of global warming, we should not abandon development for the sake of protecting the environment. Forests play an indispensable role in mitigating climate change, but they also have economic and cultural values. Therefore, how to balance the multiple values of forest and what measures can be adopted to maximize the values of forests is a very crucial subject.

To solve this problem, a carbon sequestration model is proposed initially. We divided the forest into several equal areas, and the felling is carried out in one area each year. The carbon sequestration is then divided into two parts: the stock in wood products and the carbon sequestration in forest trees. Then the formula of the stock is obtained through the conversion relationship between biomass and carbon stock. Taking "Qinling Forest" and "Vietnamese Forest" as the research objects, we obtained the growth models of their tree species and the carbon sequestration volume, which is calculated to be 1.059×10^8 tons and 1.517×10^8 tons respectively.

To get management strategies that maximize the value of forests, value decision model is established. We divide forest values into carbon sequestration value and other values, propose the classification of subordinate values, and obtain the calculation formula of these values from the literature. In order to sum up the different values, weighting factors are set for some of them, and finally the maximum value is solved using the multi-objective optimization model. And we proposed forest management plans and transition points which are extracted from it.

After applying the second model to four selected forests, we found the model is the best fit for Qinling Forest. We modified the value decision model by considering the rest period. The related discussion is conducted and here came up with the following conclusions:

- Qinling Forest could sequester 1857.024×10^9 tons of carbon over 100 years.
- The forest management plans include allowing harvesting, expanding nature reserves and banning unauthorized felling.
- Strategy for transition: felling at 90.88 years of age with 10.3 ha per year and stopping deforestation after 74.07 years of felling.

Finally, the article will conclude with a short newspaper article designed to tell people about the importance and necessity of harvesting trees.

Key words: carbon sequestration, forest values, Multi-Objective Optimization

Contents

1.Introduction

1.1 Problem Background

Decades of resource exploitation and industry revolution have caused severe climate change, and the worsening climate poses a severe threat to our biosphere. For the purpose of alleviating the catastrophic consequences, we should take radical actions to expand our stocks of carbon dioxide sequestered out of the atmosphere.

In the process of carbon sequestration, forests play a vital role in stocking carbon dioxide, which makes them an essential part of our climate change alleviation effort. During all their lifespan, forests and the products made from them can sequester carbon dioxide from atmosphere. By wisely cut down some trees to make wood products and allow them to regrow, we can maximize carbon sequestration amount. Therefore, we should develop reasonable strategies to manage our forests.

However, the values of forests are not limited to carbon sequestration, but also in other aspects such as the economic and cultural benefits. As forest managers, we should take all the factors into consideration and make decisions that can reach a balance between the forest carbon sequestration and the other benefits of forests.

1.2 Restatement of Problem

Because the dominant species, natural conditions and degree of exploitation vary in different forests, building a model is far from sufficient. Having understood the problem, we are required to finish the following problems:

- Establish a carbon sequestration model to estimate the maximum amount of carbon dioxide sequestered by forests and wood products, and find out the most efficient management strategy.
- Establish a decision model to determine a management plan, different forest values should be taken into consideration.
- Find out the conditions that leave the forest being uncut.
- Find out transition points between different forests and use specific forest and location features to identify them.
- Estimate how much carbon dioxide will be absorbed over 100 years by different forests and their corresponding products.
- Set and explain the management plan for a certain forest.
- Look for ways to achieve a smooth transition from the existing logging timeline to the extended timeline.
- Write a newspaper report to explain the significance of harvesting forests properly.

2.Assumptions and Justifications

1. Extreme natural disasters are not expected.

Justification: Some unpredictable extreme natural disasters like wildfire and flood will cause severe damage to forest, making the area rapidly decline. In order to simplify the problem-solving process, we ignore their influence.

2. The market value of wood products remains stable.

Justification: We believe that the long-term supply and demand in the timber market is balanced and prices are at a stable level.

3. Only the predominant tree species in the forest are considered.

Justification: There is competition between different species of trees. Carbon sequestration in forests mainly comes from the photosynthesis of predominant tree species, while disadvantaged tree species have very low significance to carbon sequestration.

4. Forests species do not evolve spontaneously.

Justification: Community succession can lead to the change of the dominant species in forests. However, this process is quite slow. For the time period we studied, we ignore the effect of this factor.

5. Trees cannot be cut down repeatedly.

Justification: Trees are being cut down much faster than they can grow back so we think that newly grown trees have no value to be harvested again. But they still have value for carbon sequestration.

3.Symbol Descriptions

Symbols	*Definition*
S_0	Area deforested each year
x	Number of deforesting years
t_0	Age of the tree
σ	Timber yield ratio
r	Interest rate
N	Species richness
β	Carbon tax rate
C_V	Value in biodiversity
W_a	Value of carbon sequestration

4.Model 1: Carbon Sequestration Model

4.1 Basic Analysis

For the current model, we only consider how much carbon dioxide a forest and its products can sequester over time. We want to establish a model that can assess the amount of carbon sequestration. Additionally, we hope that this model can be optimized by mathematical method to an ideal state.

4.2 Dividing Areas

As trees regenerate far less than logging, this makes forestry operation areas different each year. The operation area for the forest is abstracted into several equal-scale plots, and the logging operation is only conducted in the small plot corresponding area. Based on this method, a significant thing to be figured out is what kind of trees in the plots can regenerate and be cut down.

According to the research of tree age group [2], the same species tree can be divided into the following five types: young forest, half-mature forest, near-mature forest, mature forest and over-mature forest. Among these age groups, only trees that prior to the mature age group can be felled and regenerate. Trees of different age groups are assumed to be evenly distributed within the operating area, thus ensuring that each logged area has regenerative capacity.

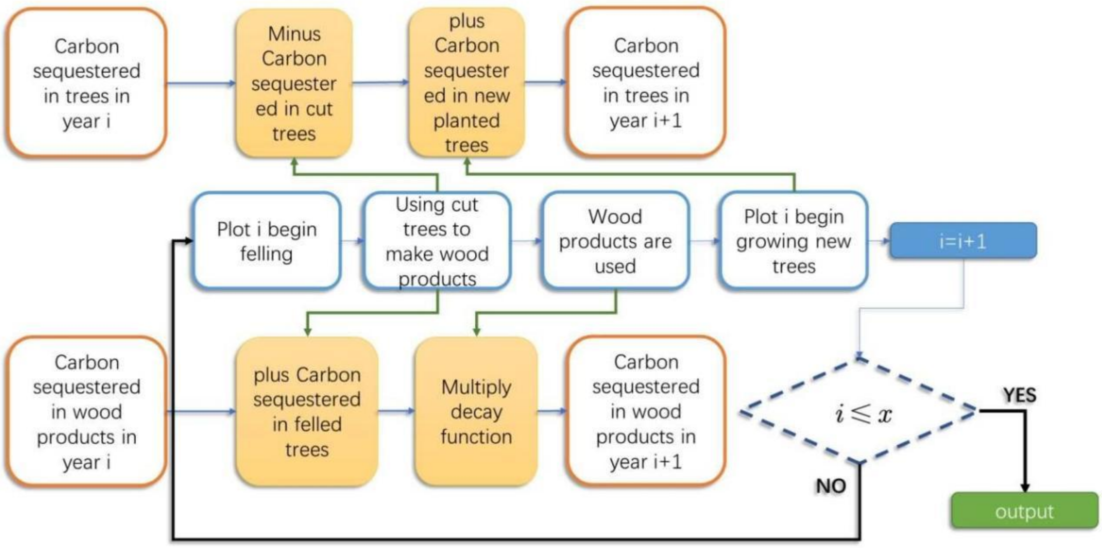


Figure 1: Variation of carbon

As shown in the figure above, the carbon stock in year *i* can be divided into carbon sequestration in trees and in wood products. From year *i* to year *i*+1, due to cutting and regrowth of trees, the year *i*'s carbon sequestration in trees will minus these in cutting stock volume and plus these in new grown trees, and after being multiplied by some factors, carbon sequestration in trees in year *i*+1 can be obtained.

4.3 Calculation Method of Carbon Sequestration

In order to calculate the amount of carbon sequestration, we must introduce three concepts first: growing stock volume, biomass, carbon stock. The three concepts are explained as follows:

Growing stock volume: the total amount of existing living wood in a certain area of forest, which takes the cubic meter per hectare as the calculation unit.

Biomass: it refers to the total amount of the organic substances including the weight of the food stored in the organism contained in a unit area at a certain time. The weight of the organic compound is the dry weight. The biomass of predominant tree species in the forest includes organic compound in above-ground tissue such as tree trunks, leaves, and organic compound in underground tissue such as roots, underground stems.

Carbon stock: the content of carbon elements in a carbon bank (such as forest, ocean). The carbon stock in the forest can directly reflect the carbon sequestration ability of the forest.

The relation of the three concepts can be reflected by the figure below:

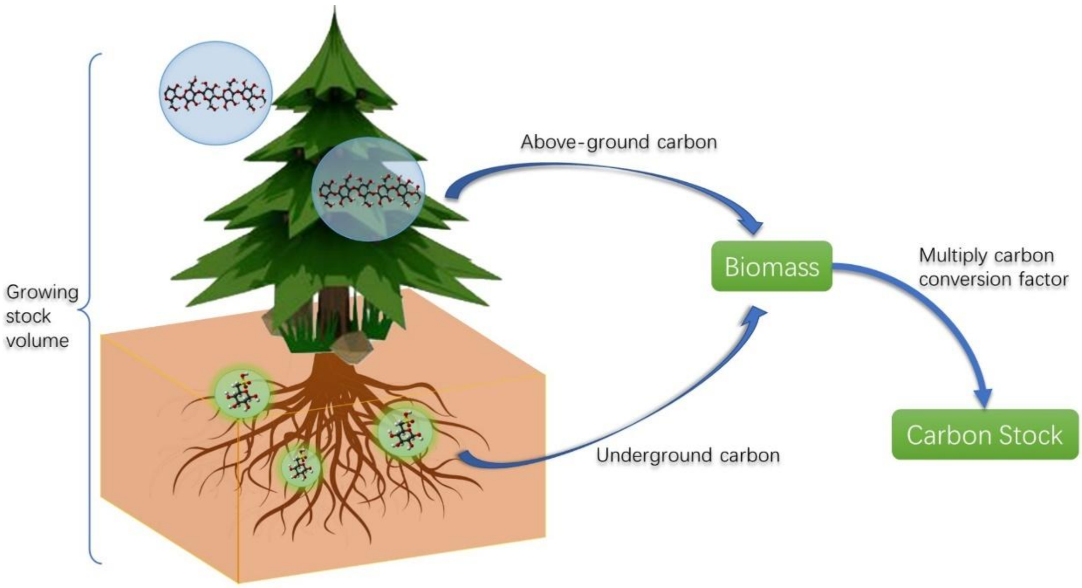


Figure 2: The relationship diagram of three concepts

This shows that the carbon sequestration amount can be obtained through the relationship demonstrated in the figure above. Through the growing stock volume of the forest, we can calculate its carbon sequestration.

Based on the former discussion, both trees in the forest and wood products have growing stock volume. And in order to evaluate carbon sequestration amount, we still need to obtain a computing mechanism of growing stock volume.

A number of techniques have been developed to tackle this problem. According to a previous study [4], the relationship between the age of the tree and its growing stock volume tends to obey a variety of functional models, which are listed below:

$$Logistic: \quad y = \frac{b_1 SI^{b_2}}{1 + be^{-kt}} \tag{1}$$

$$Gompertz: \quad y = b_1 SI^{b_2} e^{be^{-kt}} \tag{2}$$

$$Richards: \quad y = b_1 SI^{b_2} [1 - e^{-kt}]^{c} \tag{3}$$

$$Logarithmic\ linear: \quad y = b_1 SI^{b_2} e^{\left(a - \frac{b}{t}\right)} \tag{4}$$

With these models, we can now fit the functions to compute the growing stock volume of each tree species from collected data.

Chinese Qinling Forest and Vietnamese Forest are taken as the survey subjects to obtain the relationship between growing stock volume and time. The respective predominant species of the two forests are masson pine and cedar wood, so we can get abundant data to fit these two species' growing function.

Based on the statistics of their growth situation, we choose (4) and (3) to fit the growth of masson pine and cedar wood. Through MATLAB's curve fitting toolbox, we can obtain the following growth model graphs:

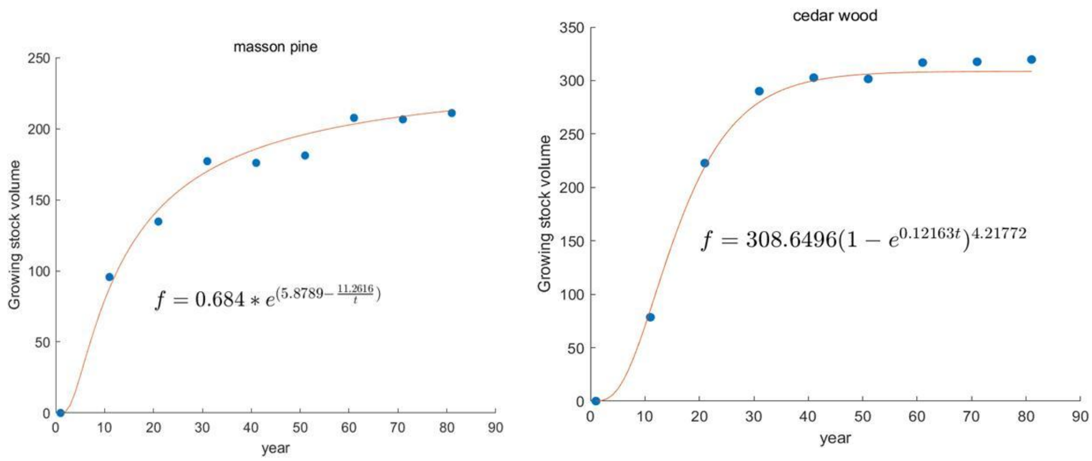


Figure 3: The growth model of masson pine and cedar wood

The relationship between growth situation and time was simulated and the respective growth models of masson pine and cedar wood are obtained.

The growth model of masson pine is:

$$V_t(t) = 0.6840e^{(5.8789 - 11.2616/t)}$$

And the growth model of cedar wood is:

$$V_t(t) = 308.64906(1 - e^{-0.12163t})^{4.2172}$$

Follow the same steps, we can also obtain the computing formulas for other species.

4.4 Model Calculation

Since now we have the computing formula of growing stock volume for different tree species, we can now build a model to stimulate the change of a forest's growing stock volume over time and thus calculate the forest's carbon sequestration.

We use $V_{t\bullet tree}$ to represent the growing stock volume per unit area of forest trees (including uncut trees and regenerated trees), and $V_{t\bullet cut}$ is used to represent the total growing stock volume of wood product. This representation is reasonable because the raw materials for these products are trees. The computing formula of $V_{t.tree}$ is shown below:

$$V_{t\bullet tree} = (S - xS_0)V_t(t_0 + x) + S_0 \sum_{i=1}^{x-1} V_t\,(i)$$

Where, S represents the total area of the studied forest, S_0 means the area of deforested area each time, x indicates the number of felling, t_0 represents the age of the tree. $V_t(t)$ reflects the growing stock volume per unit area of a specific tree species at a certain time.

The case for $V_{t.cut}$ is a bit different. As the logging operation proceeds, the wood products made from the trees that were felled earlier are constantly being used and worn out gradually. According to the microbiology-related studies[3], discarded wood products take three to five years to decompose completely. To simplify the model, we take four years as the average lifespan. The decay function of the wood product is indicated by $G(x)$, and the mathematical formula of $G(x)$ is as follows:

$$G(x) = \begin{cases} 0, x > \alpha + 4 \\ 1 - \frac{x-\alpha}{4}, \alpha < x \le \alpha + 4 \\ 1, \alpha \ge x > 0 \end{cases}$$

Among them, α represents the service time of wood products, whose unit is $year$, x represents the time interval from the raw materials were cut to the present time, whose unit is $year$. Therefore, the computing formula of $V_{t.tree}$ is as follows

$$V_{t\bullet cut} = S_0 \sum_{i=1}^{x} V_t\,(t_0 + i) \bullet G(x - i + 1)$$

So, where appropriate harvesting forests is feasible, it is necessary to know what management plan can be used to maximize the carbon sequestration of forests. To identify the carbon dioxide content of forest and forest products, the carbon sequestration model is proposed in this section.

However, despite the regenerative capacity of the trees before the mature forests, not all of the regenerated trees can survive as the living environment has been disturbed by forestry operations. To make the model more accurate, we set the survival ratio of the regenerated tree, which is represented by ε , and the corrected $V_{t\bullet tree}$ expression is as follows:

$$V_{t\bullet tree} = (S - xS_0)V_t(t_0 + x) + \varepsilon S_0 \sum_{i=1}^{x-1} V_t\,(i)$$

$$s.t \begin{cases} S - xS_0 > 0 \\ S_0 < 20 \end{cases}$$

According to **assumption 5**, each tree can be felled only once, so we set the constraint condition that $S - xS_0 > 0$. Additionally, according to the forestry law [3], the area of a single felling shall not exceed 20 hectares, so the constraint conditions are set.

After knowing the growing stock volume, we can calculate the carbon sequestration. The carbon stock can be calculated by the following formula:

$$S_{c,t} = F_{e,b}\rho(1 + R)C_c V_{t\bullet tree} + V_{t\bullet cut}\bullet\rho$$

Among them, $S_{c,t}$ represents the carbon stock amount of the tree at the age of t. $F_{e,b}$ means biomass extension factor, which is used to calculate the biomass. ρ represents the density of wood, R means the ratio of underground biomass to above-ground biomass, and C_c represents carbon content.

In order to convert the units of $S_{c,t}$ to US dollars, we define carbon tax rate β, whose numerical value is 151.5 dollars per ton, and use W_a to represent the value of carbon stock. The relationship among them is:

$$W_a = S_{c.t} \times \beta$$

The optimal solutions obtained by the algorithm are presented in the following table in order:

Table 1: Computed results of masson pine

Indicators	Value	Unit	Indicators	Value	Unit
$V_{t,cut}$	7.6×10^7	m^3	S_0	10.4734	$hectare$
$V_{t,tree}$	8.9×10^7	m^3	t_0	105.1630	$year$
x	71	$year$	$S_{c,t}$	1.059×10^8	ton

∗ The forest area is set at 10,000 hectares

Table 2: Computed results of cedar wood

Indicators	Value	Unit	Indicators	Value	Unit
$V_{t,cut}$	9.7×10^7	m^3	S_0	6.3472	$hectare$
$V_{t,tree}$	12.5×10^7	m^3	t_0	35.6217	$year$
x	29	$year$	$S_{c,t}$	1.517×10^8	ton

∗ The forest area is set at 10,000 hectares

For masson pine, when the tree is felled at 105 years old and the felled area is 10.4735 hectares, the carbon sequestration can reach the maximum of 1.059×10^8 tons in the 71st year after felling. For cedar wood, the maximum carbon sequestration reaches 1.517×10^8 tons in 29 years after the felling when the felled area is 6.3472 hectares and the felled age is 35.6 years.

The maximum carbon sequestration of the same forests can be obtained according to the calculated results. The carbon sequestration of other kinds of forests can also be obtained by figuring out the growth model of trees and using the carbon sequestration model to compute.

These forest management plans are extracted from the calculated results :

1. Setting logging areas

The calculated results show that the best felled area for masson pine is 10.4735 hectares, while 6.3472 hectares for cedar wood. The optimal area is the logging limit. When the felled area is lower than the optimal area, the carbon sequestration of forest and its wood products cannot achieve the best effect. However, when the felled area exceeds the optimal area, the carbon sequestration capacity decreases and even causes damage to the forest. Therefore, forest managers need to use carbon sequestration models to set felled areas.

2. Increasing the wood usage rate

This model uses the deforested area to replace the amount of cut timber, and believes that all the cut timber can be used to make woodwork. But in fact, it is impossible for the cut timber to be used entirely in the manufacture of woodwork, and during the cutting phase part of it would be selected. This requires managers to make full use of the cut timber and improve its utilization.

3. Determining the logging object

Based on the previous discussion, only trees that prior to the mature age group can be felled. But as time increases, the age of trees within regions also increases, which requires managers to monitor their age before logging to determine the deforested targets.

5.Model 2: Value Decision Model

The established carbon sequestration model enables maximum carbon sequestration for forest and wood products, which is beneficial to alleviate climate deterioration and also brings benefits to human society. However, forest values are also embodied in other aspects that we haven't considered yet, such as its potential for medical uses and cultural considerations. That means, it is far from enough to simply consider the values of forests in carbon sequestration and their commercial value for making wood products. In order to consider the multiple values of forests and to find a balance between these values, based on the previous model 1, we propose the value decision model in this section.

5.1 Values of Forests

To establish the value decision model, the value types of forests are required to be identified. Our thesis divides the forest value into two categories: value in carbon sequestration, and other value. Other value includes potential value in forests and economic benefits in the tree. To facilitate follow-up discussions, we divided and classified the forest values, which is shown in the following figure:

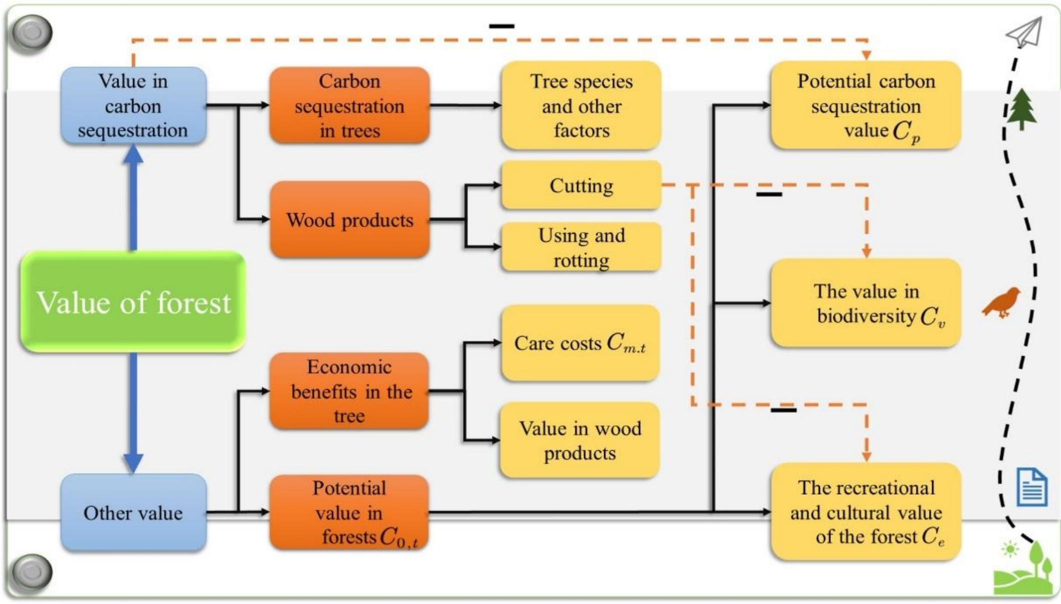


Figure 4: Values of Forests

The following content explains the glossaries in the figure and lists the computations:

In the figure, potential carbon sequestration refers to the difference value between optimal carbon sequestration amount and the actual carbon sequestration amount, which has certain economic benefits. According to the international carbon trading [5], the carbon amount in organic compound can be converted to the actual price by multiplying by the carbon sink ratio. The carbon tax rate is represented by β, whose numerical value is 151.5 dollars per ton. The potential carbon sequestration value can be calculated be the following formula:

$$C_p = (w_m S - W_a) \times \beta$$

Among them, w_m means the maximum carbon sequestration amount per unit area, which is a constant. And this parameter is multiplied by the area S to obtain the maximum value of the forest carbon sequestration amount. W_a means the actual carbon sequestration amount of forests and wood products.

The value of forests in biodiversity is mainly reflected in species diversity. According to the definition of species richness, species diversity can be represented by the number of species per unit area, namely species richness. We use N to represent species richness, whose numerical value can be obtained from surveys of each forest. Assuming the average value of living organisms per unit area be V_c , the value in biodiversity can be calculated by:

$$C_v = N \times V_c \times (S - xS_0)$$

In the computational expression above, $S - xS_0$ represents the remaining forest area after deforestation. So, C_v means the total biodiversity value of the remaining forest.

The cultural value is an important part of forest values. However, few previous studies have investigated the quantitative method of evaluating forest cultural value. Grounded on previous research that utilized man-forest symbiosis time as the core to evaluate the forest culture value [6], we made some further adjustment and propose our own assessment method. In our method, we introduced the economic concept of GDP per capita. And to be in consistent with other values, we choose USD as our unit to evaluate the cultural value. This is also in line with our common sense, for forest can be developed into scenic spots to boost tourism, which is where the recreational and cultural value of the forest lies. This value is represented by C_e , and is calculated by:

$$C_e = \left(\frac{nT \times GDP_P}{8760} + I\right) \times \frac{S - xS_0}{S}$$

Among them, I means total ticket revenue and n means total visit flow in a year. T means average travel time for visitors and GDP_p means real GDP per capita. Assuming the three parameters to be constant, the results can be calculated whenever the other parameter values are obtained.

Since the value of timber during tree cutting is more than just the commercial value of forest products. Due to the cutting of felled trees in the acquisition of timber, and indispensable labor and transportation costs in the transportation of timber, the value of forest products becomes even more complex. Besides, government will provide economic subsidies to forestry operations every year, and the amount of the subsidy is calculated according to the income of forest products multiplied by the interest rate [7]. Furthermore, under the action of subsidy interest rate, wood value increases exponentially over time. Therefore, the formula of value in wood products is modified to:

$$C_{b,t} = S_0 \sum_{t=t_0}^{t_0+x} [\delta(P_t - C_h)V_t(t) \times (1+r)^{-t}]$$

Among them, δ represents the timber yield ratio of the trees, P_t means timber price per stere. r means interest rate, which is set by government law. Under the Forestry Protection law issued by China, the value of the parameter is set 3.8%. And C_h represents the labor and transportation costs during timber transportation.

As human interventions such as forestry operations have caused damage to the forest ecosystem, even trees far from the logged areas are affected. In order to maintain the carbon sequestration and commercial value of forests, human care of forest trees is needed. To simplify the model and improve the practicability of the model, care cost is assumed to be constant.

The calculation of value of forest in carbon sequestration is based on the carbon sequestration model. Using the model to compute the actual carbon sequestration amount, which is multiplied by the conversion coefficient to get the actual price.

5.2 Model Optimization

After figuring out the values of the forest, the model calculation can be conducted. According to the value category diagram, potential carbon sequestration value, the value of biodiversity and recreational and cultural value are simply the subordinate indicators of other value. Due to their different levels, these value indicators cannot be directly applied to the calculation. In this part, system index analysis is applied to the calculation.

According to the principle of system index analysis [8], a planning problem has multiple goals, but decision makers can choose priorities when reaching these goals.

However, if we want to distinguish between the two targets with the same priority factor, we can respectively give them different weight coefficients w .

Based on this principle, computational expression for other values can be obtained as follow:

$$C_{o,t} = w_1 C_p + w_2 C_v + w_3 C_e$$

Among them, w_1, w_2, w_3 represent the weight coefficients of potential carbon sequestration value, the value of biodiversity and recreational and cultural value respectively.

The computational expression of the forest commercial value can be obtained after the application of the weight factors:

$$W_c = S_0 \sum_{t=t_0}^{t_0+x} [\delta(P_t - C_h)V_t(t) \times (1+r)^{-t}] + C_{o,t} - H$$

$$H = \sum_{t=0}^{t_0+x} \left[C_{m,t}(1+r)^{-t}\right]$$

The commercial value of the forest is the sum of timber proceeds, care costs, and other values. This is the part of the commercial value, and the forest also has the natural value of carbon sequestration, which has been discussed in model 1. Unlike Model 1, the amount of carbon sequestration considered in this part is the actual, rather than the maximum carbon sequestration. To distinguish between these two concepts, we denote the actual amount of carbon sequestration in $S_{c.t}$ .The natural value of the forest can be obtained by multiplying the actual carbon sequestration by the ratio β . Finally, we obtain two indicators (W_a ,W_c) that need to be optimized:

$$\max\ z_1 = W_a = S_{c.t} \times \beta$$

$$\text{Where } S_{c.t} = F_{e,b}\rho(1+R)C_e V_{t\bullet tree} + V_{t\bullet cut}\bullet\rho$$

$$\max z_2 = W_c = S_0 \sum_{t=t_0}^{t_0+x} [\delta(P_t - C_h)V_t(t) \times (1+r)^{-t}] + C_{o,t} - H$$

$$s.t \begin{cases} S - xS_0 \geqslant 0 \\ 0 < t_0 < 20 \\ x > 0 \end{cases}$$

The obtained computation of the forest value is the value decision model which can balance the various ways that forests are valued and figure out manage plans to maximize the forest values according to different requirements. The following content will discuss the model according to different requirements, and get the corresponding specific management plan through the calculation results. The optimal solution of the value decision model will be given below, and the management spectrum, transition points and other issues will be discussed.

- The spectrum of the management plan

Since the total value of forest is the linear superposition of other values and carbon sequestration value, the best case of total value of forest can be obtained by calculating the maximum of two parts. Artificially controllable forestry operation conditions include: annual felled area, felled tree age and felled time (the time between two large rest periods), these factors directly affect the carbon sequestration value and other values of forests. Using the multi-objective optimization model, the two parts are set as the investigation objectives, and the optimal solutions of these three factors are obtained through MATLAB calculation. Partial solutions are shown in the following table:

Table 3: Partial calculation results

Indicators	Felled area	Tree age	Felling time
Calculation results	18.024	61.464	55.164
	17.169	61.405	55.158
	12.513	61.477	55.156
	10.251	61.357	55.167
	9.380	61.382	55.183

The results can be used to obtain a rough range of felled area, tree age and time to extract management plans. Considering practical factors, we give the following management spectrum:

1. The felled area should be between 9 and 18 hectares per year.
2. Start logging when the tree is 61 years old.
3. Stop logging when the logging time reaches 55 years.

- Conditions to avoid felling

Based on the previous discussion, the value of forests includes carbon sequestration value and other values. Not cutting down trees will lead to a sharp decline in the amount of wood produced, which will plunge the economic value of forests. But these conditions make it possible to idealize the value of forests without felling:

Forests have a huge carbon sequestration value: a single poplar tree can absorb about 8,145 litres of carbon dioxide a day, according to research of poplar trees [9]. Poplars' carbon-absorbing capacity makes them highly valuable even when they are not cut down.

Forests have great other values: since there are no deforestation, the other values here refer to biodiversity and recreational and cultural values. Take Redwood National and State Parks as an example, V_c (the average value of living organisms per unit area) is so high that any logging here isn't worth the loss. In order to see what level of the average value can make logging worthless, the step size is set as 250 to change V_c ,and evaluate the S_0 value, The sensitivity analysis results are shown in Figure 5:

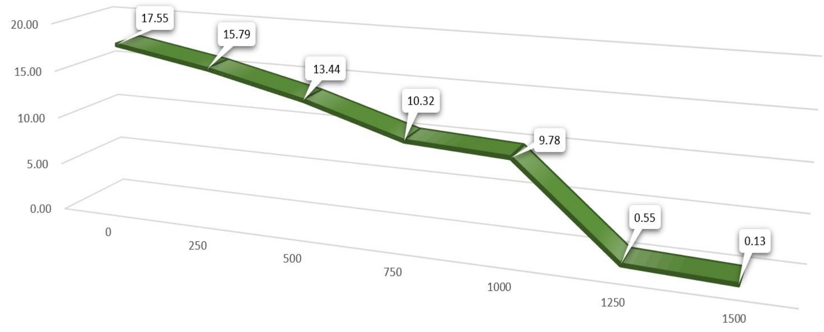


Figure 5: Sensitivity analysis results when changing V_c

- Transition points of the management plans

There are a series of transition points when applying management schemes to different forests because of the discrepancy in geographical environment, the dominant tree species and the degree of exploitation between them. Of course, these transition points should also keep forest values stay at a high level. The simulation results obtained by MATLAB are as follows:

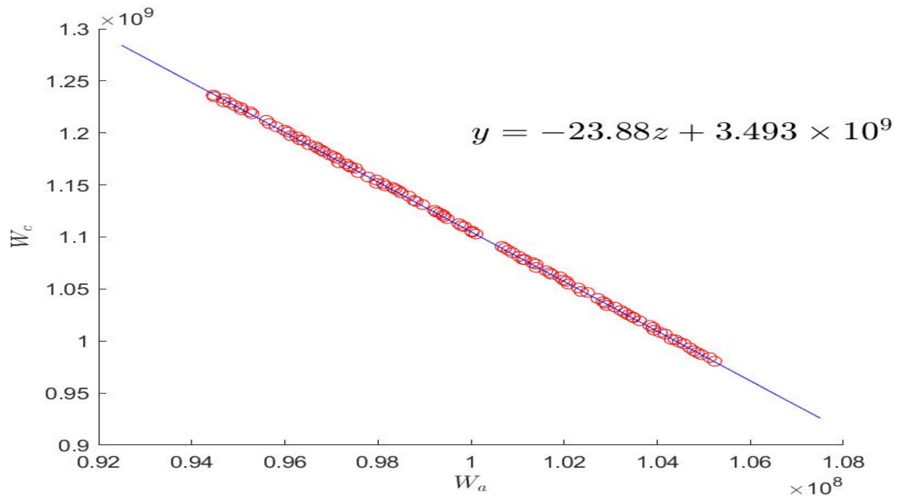


Figure 6: Simulation results

The point set in the figure corresponds to three coordinates, namely, the three key points of forest management: the area felled annually, the age of trees felled and the felled time. Different values are the transition scheme. These transition points enable managers to balance the different values of the forest when applying management plans to different forests. And these management plans can also be artificially modified.

Considering the different geographical location and the terrain of the trees in the forest, the growth of trees in the forest is different and the degree of crowdedness is different, so the felled area also needs to be adjusted constantly. But in order to make the forest value is not seriously affected, the scope of adjustment should be within the point set above.

6.Application of Model

Through the construction of value decision model, we can get the management measures to balance the forest values, so as to guide the forestry operation and forest exploitation. However, the forest targeted by the value decision model does not certainly exist, so it is necessary to apply the value decision model to multiple realistic forests, so as to find the most suitable object of the management scheme proposed by the value decision model.

6.1 Selection of Subjects

According to UN statistics [10], the forest area accounts for about 9.4 percent of the earth's total surface area, or about 4 billion hectares. These forests are distributed in Asia, America, Europe and many other places. Due to the topographic factors, human intervention and temperature and humidity differences in each region, the growth of major tree species and trees in these regions are different. For example, the forests in Europe are often mixed forests, while the forests in South America are rain forests. The map of the global forests is as follows:

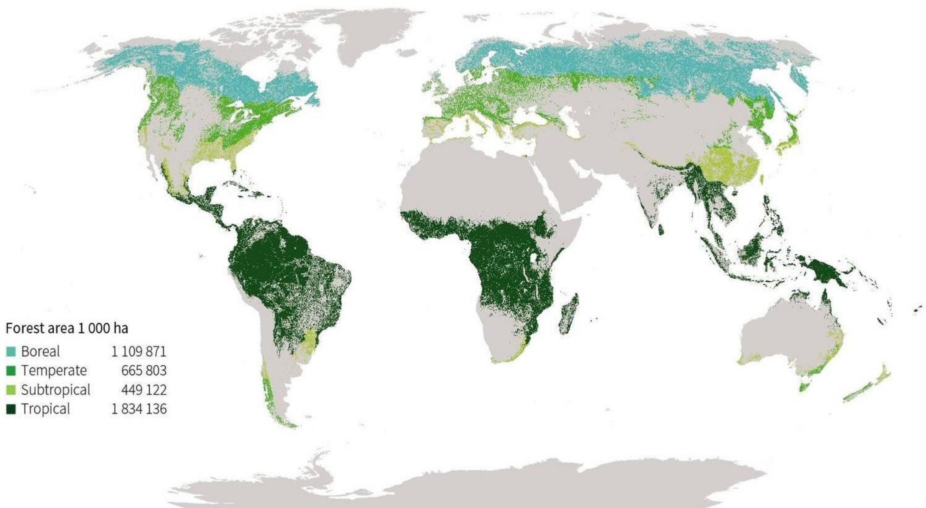


Figure 7: Global Forests Map

Some of these forests have been developed into nature reserves or scenic spots, and some are still in their original state. The undeveloped primeval forests have unknown potential value, so the selection of these forests as research objects to conduct the research is quite complicated, and even the results obtained are completely inconsistent with the reality. Therefore, the selected research objects should meet the following requirements:

- The forest has been developed and has recreational and cultural value.
- The forest is allowed to be cut down and has economic value.
- The forest has not suffered major damage at present and has the value of carbon sequestration.
- The forest has the common characteristics of similar forests.

To meet these requirements, Qinling Forest, Vietnamese Forest, Mark Twain National Forest and Nantahala National Forest are chosen as the research objects to find the most suitable forest for subsequent discussion.

6.2 The Most Suitable Forest

In order to apply the model to real forests, relevant data of multiple forests need to be known. The data and information of research objects are shown in the following table:

Table 4: Data and information of forests

Forests	Qinling Forest	Vietnamese Forest	Mark Twain National Forest	Nantahala National Forest
Dominate species	masson pine	cedar wood	ulmus pumila	pinus palustris mill
Area of woods	$5158400ha$	$13400000ha$	$607000ha$	$1246700ha$
Richness	250 per hectare	200 per hectare	250 per hectare	300 per hectare
Timber price	97.01	126.87	462.69	197.01
Density of wood	0.38	0.307	0.54	0.375

To facilitate the direct comparison of the model application results, the following assumptions need to be set:

I. The same timber yield rate for different tree species. This refers to the same volume of trees that are able to produce the same volume of wood.

II. The average species value per unit area is the same, which enables the biodiversity value of different forests to only depend on their respective species richness and area.

III. The average play time of people, the flow of tourists, and the total ticket income of different forests are the same. This assumption can make recreational and cultural value only depend on forest area.

Based on these assumptions, the data of each forest is brought into the value decision model, and the value statistical graph of each forest is obtained as follows:

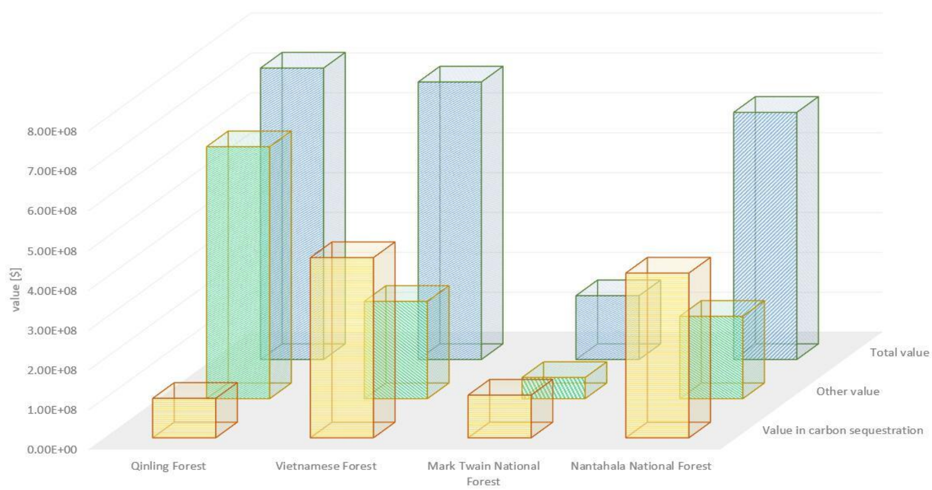


Figure 8: Value statistical graph

This statistical graph result shows that Qinling Forest has the greatest value while Mark Twain National Forest has the lowest value among the objects, indicating that Qinling Forest is the most applicable object of the value decision model considering the forest harvest. This forest will be discussed later as the study subject.

6.3 Question Discussion

Since trees regenerate very slowly, the rest time is used to regenerate the trees that have been cut down. This section discusses the consideration of rest time based on the value decision model.

Assuming that the deforestation needs to stop after x_1 years and rest for T years, and this break is followed by x_2 years of forestry operations, the total felling time is $x_1 + x_2$ years. Grounded on this assumption, the modified formula of growing stock volume is:

$$V'_{t.tree} = [S - (x_1 + x_2) S_0] V_t (t_0 + x_1 + x_2 + T) + \epsilon S_0 \left[\sum_{i=1}^{x_1 - 1} V_t (i + T + x_2) + \sum_{j=1}^{x_2 - 1} V_t (j) \right]$$

Besides, there is also growing stock volume in forest products with the following equation:

$$V'_{t.cut} = S_0 \sum_{i=1}^{x_1} V_t (t_0 + i) G (x_1 - i + 1 + T + x_2) + S_0 \sum_{j=1}^{x_2} V_t (t_0 + j + T) G (x_2 - j + 1)$$

And the modified formula of value in carbon stock and the other values are listed below respectively:

$$W'_a = \beta S'_{c.t} = [F_{e.b} \rho (1 + R) C_c V'_{t.tree} + V'_{t.cut} \rho] \times \beta$$

$$W'_C = S_0 \sum_{t=t_0}^{t_0 + x_1} [\sigma (P_t - C_h) V_t (t) (1 + r)^{-t}] + S_0 \sum_{t = t_0 + x_1 + T}^{t_0 + T + x_1 + x_2} [\sigma (P_t - C_h) V_t (t) (1 + r)^{-t}] - \sum_{k = t_0}^{t_0 + x_1 + x_2 + T} [C_{m.t} (1 + r)^{-t}] + C_{0.t}$$

Due to the total felling time has been changed, the value of biodiversity should be modified as well:

$$C_V = NV_C \left(S - \frac{x_1 + x_2}{T} S_0 \right)$$

$$C_e = \left(\frac{n\bar{T} \times GDP_P}{8760} + I\right) \times \frac{S - \frac{x_1 + x_2}{T} S_0}{S}$$

※The meanings of unspecified variables are the same as those in the previous value decision model. The modified value decision model can be applied to conduct the subsequent discussion.

- **Carbon sequestration in 100 years**

Based on the value decision model, a massive shutdown is required after continuous logging for x years, which is about 55 years. During the stop felling phase, trees that have been cut down begin to grow again. Since the value can be maximized when trees are felled at about 61 years old, the sum of these two periods exceeds 100 years, so the operation situation in 100 years is: felling 55 years, and let trees regenerate in the rest time. Taking this condition into the modified value decision model yields the relevant results: the Qinling Forest can absorb 1857.024×10^9 tons of carbon dioxide over one hundred years.

- **Optimal management plans**

The decrease of resources and the deterioration of environment are the inevitable results of human exploitation of nature and industry. However, we should not abandon the economy for the sake of protecting the environment, so we need to find a balance between protecting the environment and developing the economy, namely implementing the strategy of sustainable development. According to the value decision model, Qinling Forest has the greatest value, and in order to maximize the forest value, these management plans need to be implemented:

A. Harvesting forests is allowed, but it needs to be limited and targeted. The value decision model shows that the Qinling forests are still of great value when harvest forests are taken into account. So, harvesting forests is possible, but harvesting needs to be met: no more than A hectares per year, and only B years old trees.

B. Expand nature reserves. Some nature reserves have been established in the Qinling Mountains, which can protect the forest from destruction and preserve the DNA of rare species in the area, preserving the biodiversity value of the forest. But the current nature reserves in this area are incomplete and parts of the area cannot be protected. So, we need to expand the scope of nature reserves to increase species richness and biodiversity value.

C. Felling without authorization should be prohibited. Individual deforestation is unscientific, affecting carbon sequestration capacity of forests and even destroy biodiversity value. Therefore, regulators need to introduce policies to strictly prohibit individual logging, strengthen supervision, and severely punish loggers without authorization.

- **Longer time-out between harvests**

Grounded on the value decision model, the forestry operation need to stop after x_1 years and rest for T years. Rest period is used for the regeneration of felled trees, but the actual rest period is far from sufficient due to the extremely slow regeneration of trees. And directly extending the rest period by 10 years will lead to a longer gap in forest products, thus making the forest less valuable in economic terms. Therefore, it is necessary to propose a feasible management plan to achieve a smooth transition after extending the rest period.

Using the modified value decision model, the corresponding results are obtained, and from that comes a plan for managing the forest: Felling at 90.88 years of age with 10.3 ha per year and stopping after 74.07 years of felling can meet the needs of managers for forest values.

7.Sensitive Analysis

In order to test the stability of the model, we choose two relatively sensitive parameters: V_c and P_t, analyze how the direct output W_a and W_c change when other variables are kept unchanged. Selecting a step of 125 and 37.5 to change the two parameters respectively, the analysis results are shown in figures below:

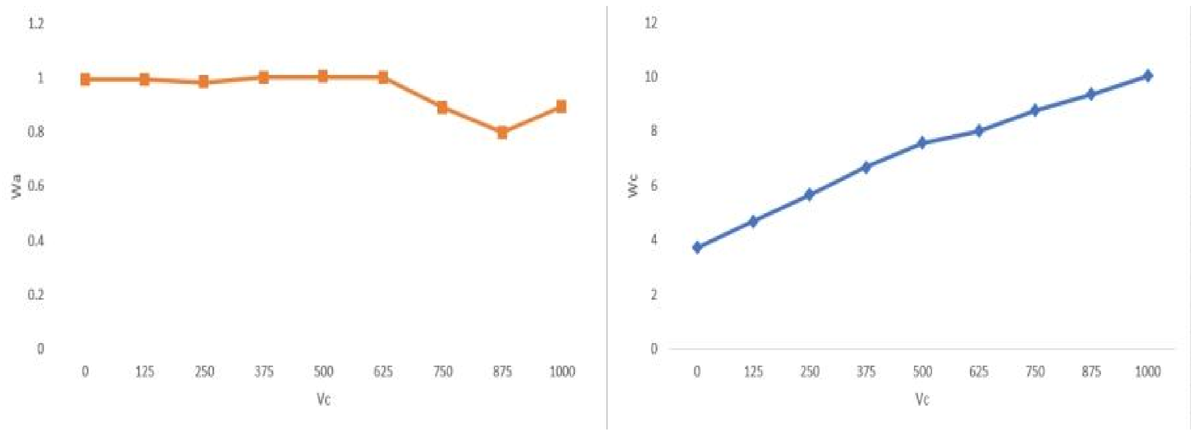


Figure 9: Sensitive analysis of V_c

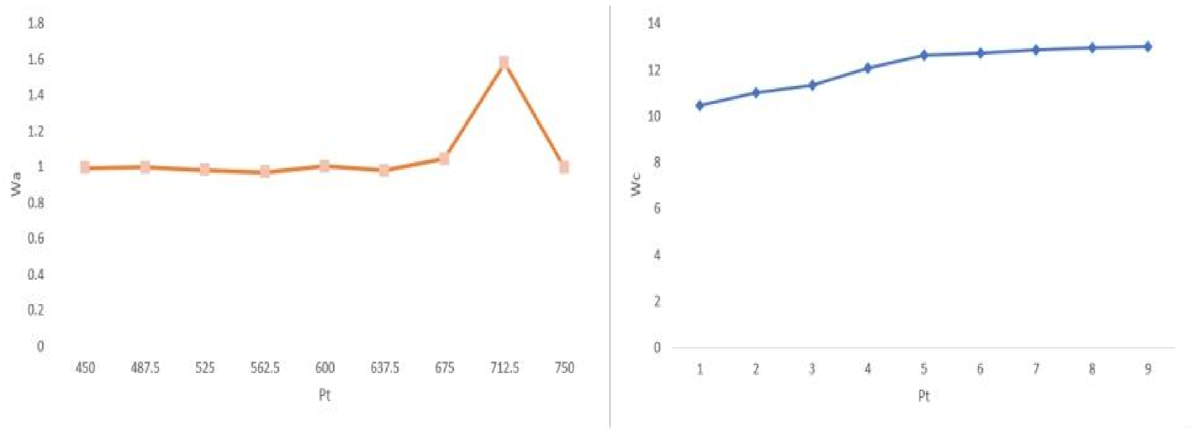


Figure 10: Sensitive analysis of P_t

As shown in Figure 9, the quantitative value of W_a is relatively insensitive to the change of V_c, while output W_c is the opposite. It is obvious that the value of W_c sensitively varies with V_c, because when V_c increases, the potential value of the forest increases as well, thus leading to the sharp increase of W_c.

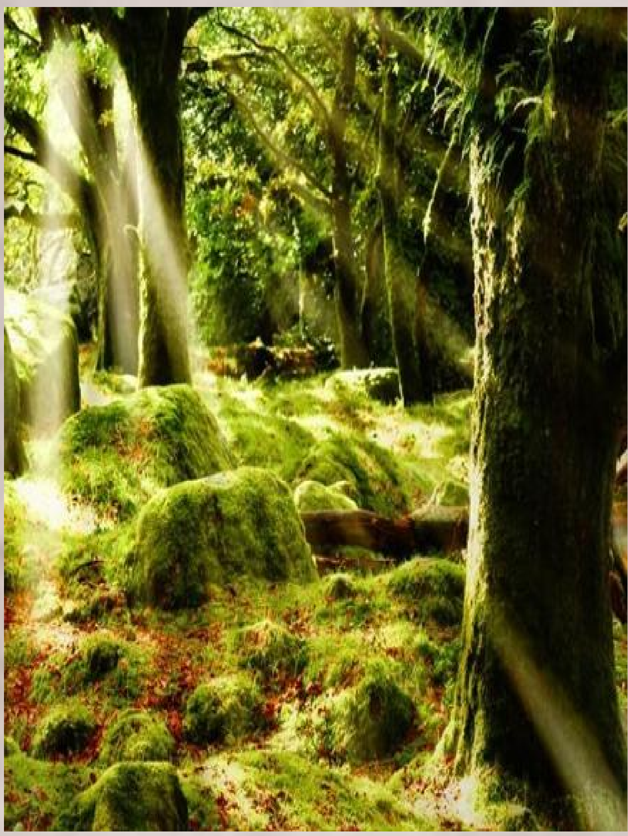
As shown in Figure 10, both W_a and W_c are not sensitive to P_t . This result is quite consistent with reality, because the value of forests in terms of carbon sequestration does not change with the price of wood. In addition, even if the price of wood increases significantly, the economic value of the forest will not be greatly affected due to the great demand for some wood products (e.g., paper).

The analysis outcome shows that our model is a relatively stable system.

Harvesting or Leaving the Trees Untouched?

——A question that must be considered in the present age

As the continuous exploitation of nature, environmental problems are constantly going bad. Global warming, in particular, has become the focus of all countries and non-governmental organizations. The growing global warming has caused severe problems such as rising sea level and reduced vegetation which are threatening life in the biosphere, including ourselves. We definitely don't want to go through the global snow disaster in "The Day After Tomorrow" or the interstellar migration in "Interstellar", so alleviating warming is a top priority for our human beings. Thankfully, states, cities, and even communities are taking a series of measures to ease the greenhouse effect. For example, in addition to the forest protection laws and regulations introduced in almost all autonomous states, many communities have also organized tree-planting activities. All of these measures seem to be focused on protecting or growing trees, but today, in today's weekly newspaper, we propose an almost unconventional solution: harvesting forests. It may seem ridiculous, but guys, we'll tell you the reasons of that.



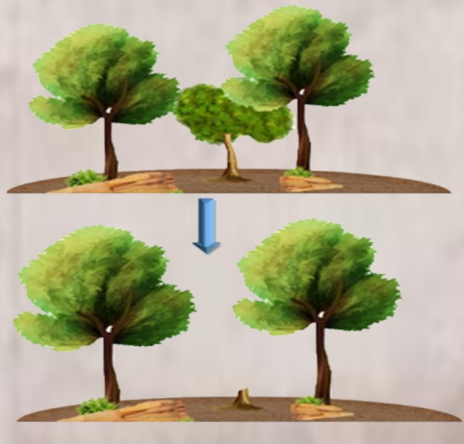
To explain the benefits of harvesting forests, we first need to understand carbon sequestration. Carbon cycle is a process in which inorganic carbon in the environment is transformed into organic carbon in organisms by plants, and then discharged into the environment again in the form of inorganic carbon through biological physiological activities. In theory, the amount of inorganic carbon absorbed should be the same as the amount emitted, but human activities have upset this balance, leading to the greenhouse effect. Therefore, it is necessary to increase the amount of inorganic carbon absorbed by plants, the process known as carbon sequestration. Therefore, accelerating the carbon sequestration and reducing carbon emissions is the primary measure to ease the greenhouse effect.

Harvesting forests can properly accelerate carbon sequestration. Why is that? First, the organic carbon produced by plants is transferred to other parts of the plants, which are often unable to synthesize organic carbon, but increase the emission of inorganic carbon. And not all trees are conducting carbon sequestration. Some dwarf trees in dense forests are at a disadvantage in the competition for sunlight and water, which makes these trees often in a carbon neutral state that absorbs and emits the same amount of carbon, or even emit far more than they absorb. Properly harvested trees can speed up carbon sequestration by cutting down trees that interfere with the process. In addition, the cells in wood products such as furniture are inactivated, allowing the sequestration of carbon in wood products to remain for a period of time, during which time the harvested trees can grow again and sequestration continues.

Besides, although the main photosynthetic tree species in a forest have a considerable competitive advantage, the carbon sequestration of these trees is also affected when the population density is too high. Especially for rare species like metasequoia and birch, we want them to grow big and tall. So, harvesting forests properly to reduce population density is good for the growth of these trees, thus accelerating carbon sequestration, which is consistent with the principle of fruit thinning.

As the world's population continues to soar, we need more land to feed people in order to solve the growing food shortage problem. As many countries are growing cash crops, people in some less developed countries are suffering from hunger. Changing the structure of food production in a short time does not seem realistic, so some nutrient-rich forest land needs to be developed to grow high-yield food. Of course, to compensate for the harm brought by this measure, we need to increase the area of plantation.

Well, that's the point we're illustrating, and don't be surprised if you see similar arguments next time, after all, cutting down trees properly could promote carbon sequestration. Wish you a nice weekend and see you next time!



References

[1] Liang Shichu,Jiang Xiaoxiao,Li Feng. A study on the age structure of the mangrove plant Indelum in Guangxi[J]. Oceanographic Research,2008,26(04):35-40.
[2] Jin Yimin. Observation of submicronic structure of wood decay[J]. Forestry Science and Technology,1982(01):61-64+16.
[3] Forestry Law of the People's Republic of China[J]. Zhejiang Forestry, 2020(07):4-9.
[4] Zhu Yahan,Huang Qingfeng. Compilation of harvest tables for Fir plantations based on forest resources type II survey data[J]. Journal of Anhui Agricultural University,2012,39(02): 239-242.DOI: 10.13610/j.cnki.1672-352x.2012.02.025.
[5] Wei Yali. Research on accounting treatment of forestry carbon sink[D]. Lanzhou University of Finance and Economics,2020.DOI:10.27732/d.cnki.gnzsx.2020.000196.
[6] Fan Baomin,Li Zhiyong,Zhang Decheng,Wei Lingling,Xie Hesheng. Value assessment of forest culture based on human-forest symbiosis time[J]. Acta Ecologica Sinica,2019,39(02):692-699.
[7] Xue Beibei,Tian Guoshuang. Costing model of carbon sequestration in plantations including opportunity costs and its influencing factors[J]. Journal of Northeast Forestry University,2021,49(06): 84-89.DOI: 10.13759/j.cnki.dlxb.2021.06.017.
[8] Li Xianghua. Economic evaluation of commercial real estate projects based on system dynamics[D]. Jiangxi University of Science and Technology,2011.
[9] Zhang Hongjing,Song Yuhua,Zhi Enbo,Zhang Chunshu,Cheng Junhong. Birch seedling and afforestation technology[J]. Hebei Forestry Science and Technology,2007(02): 71.DOI: 10.16449/j.cnki.issn1002-3356.2007.02.045.
[10] Food and Agriculture Organization of the United Nations: https://www.fao.org/faostat/zh/#data