

A Carbon Sequestration Model for Better Forest Management and Future Environmental Protection

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Abstract. In recent years, with the economic development, people's demand for forest resources has increased, thus leading to a large increase in tree cutting. Forest resources have both ecological and economic values, and this paper will propose an innovative forest management model that is based on a model of forest carbon sequestration. We take a forest in the Daxinganling Mountains as an example. First, we use python to build a forest growth model, which is related to many factors including forest growth rate, mortality rate, natural harvesting rate, and distribution of populations by age. Then, based on this model, we calculate the ecological value of the forest by the carbon sequestration of the forest, and the economic value that the forest can provide to people by the carbon content of harvested trees, which is our carbon sequestration model. Finally, we use the TOPSIS analysis algorithm to determine the weights of ecological and economic benefits according to regions and to maximize the combined benefits of the forest. The innovation of this paper is to fully consider the population distribution, birth rate, and death rate of the forest, and build a forest model with a good fit for reality. Therefore, it is also possible to calculate the influence of human factors on the comprehensive benefits of the forest by changing factors such as cutting rate, so as to obtain the optimal solution of the forest management model within a certain range.

Keywords: Carbon sequestration, Forest management, Future prediction.

1. Introduction

Climate change has become a serious environmental problem. Among them, the emission of large amounts of greenhouse gases is an important factor in triggering climate problems. Carbon dioxide is a greenhouse gas that absorbs heat from solar radiation in the atmosphere, creating a greenhouse effect, which in turn leads to atmospheric warming. Atmospheric warming can cause many serious harms to the global environment, such as causing sea level rise and triggering more natural disaster phenomena.

In the carbon cycle of the biosphere, forests play a role in converting carbon dioxide into carbon-containing organic matter. Forest is also a raw material for many wooden products., so it's facing a problem of over-harvesting. In order to balance the economic value and economic value of the forests, it's an urge for us to find out an innovative forest management model.

2. Preparation of the models

2.1 Assumptions

1). Trees in the forest can be classified into young, middle age, semi-mature, mature, and overripe according to their ages, and thus an age structure containing five ages is established for trees.

2). When calculating the forest carbon sequestration, only the carbon sequestration in trees is considered, and the carbon sequestration in shrubs and grasses is ignored.

According to the study, the existing stock of trees is 99.75% of the existing stock of forest stands , so the carbon content of trees can be used to approximate the overall carbon content of forests.

3). Trees cut each year will only be randomly selected in mature and over-mature forests.

4). The trees that die each year are produced only in the over-mature forest, with a fixed proportion each year.

5). wood products have different service lives.

There are different wood products, some of which have a very short life span, such as disposable chopsticks and napkins, while mahogany furniture and wooden artwork have a very long life span.

6). Wood products are gradually decomposed and their stored carbon is released as they reach their useful life.

2.2 Symbol table

Table 1. Notation

Notations	
Symbols	Descriptions
$time$	timeline
MAX_i	the maximum age of a certain age type
MIN_i	the minimum age of a certain age type
$C_{forest}(t)$	the total amount of carbon stored in a certain forests in year t
$M(t)$	the total amount of biomass for a certain forest in year t
f_c	carbon content of forest biomass
B_i	per unit area biomass of a certain type of forests
$S_i(t)$	the size of a certain forest in year t
$d_{forest}(t)$	the amount of carbon sequestration for forests in year t
$carbonForest(t)$	the ability of carbon sequestration for forests in year t
P_i	the proportion of a certain type of wooden product
$M_{harvest}(t)$	the biomass of the harvested trees in year t
$M_{total}(t)$	the total biomass of a certain forest
$C_{product}(t_0, t)$	the carbon stored on wooden products produced in year t0
$decay_i(t_0, t)$	the decay function of carbon storage in wooden products
$carbonProduct(t)$	the ability of carbon sequestration for a forest in year t
birth_rate	the proportion of annual new tree growth in overall forest
harvest_rate	the proportion of annual tree harvesting in overall forest
death_rate	the proportion of annual old tree death in overall forest
time_interval	the time interval between two big harvest

3. Carbon sequestration model

After the forest absorbs carbon dioxide, part of the carbon is stored in the tree trunks, while the other part of the trees is cut down and made into wood products. Therefore, the carbon sequestration in the forest and forest products includes these 2 parts. To study the forest carbon sequestration over time, we first study the forest growth model.

3.1 Forest growth model

The overall growth process of trees in a forest is influenced by several factors, including birth_rate, natural mortality, deforestation rate, and the natural growth process of trees.

birth_rate: the proportion of new growth in the forest each year, including both planted and natural growth.

harvest_rate: The proportion of trees cut per year in the forest, where trees cut are randomly selected from mature and over-mature forests.

death_rate: The percentage of trees that die each year in the forest, where the trees that die are only randomly selected from over-mature forests.

Growth process: Each year, a portion of trees in each age group will progress to the next stage, and this portion of the progression rate is represented by $rate_i$. For example, a portion of the young forest grows into a middle-aged forest, and the proportion of its progression is determined by the difference between the two age stages.

We mainly used data on Daxing'anling larch from the sixth inventory data of the China Forestry Administration as starting data to predict the growth of this forest in the future. We can see that Daxing'anling larch is divided into five age groups, and the table below shows the age of the trees corresponding to each of the five age groups.

Table 2. Five age groups of Daxing'anling larch

Young	Middle-aged	Semi-mature	Mature	Overripe
0-40	41-80	81-100	101-140	>140

3.2 Carbon sequestration model

We consider the carbon sequestration capacity of the forest as the sum of the carbon sequestration capacity of the forest and the carbon sequestration capacity of woody forest products:

$$carbonSequestration(t) = carbonForest(t) + carbonProduct(t)$$

3.2.1 Forest carbon sequestration

Forest biological carbon stocks

It is assumed that the relationship between the biological carbon stock of the forest and the change with year is represented by $C_{forest}(t)$, The relationship between forest biomass changes with year was determined by $M(t)$, The carbon content rate of forest organisms is expressed as f_c , The formula for calculating the forest biological carbon stock can be obtained:

$$C_{forest}(t) = M(t) \times f_c$$

Forest biomass

We divided the forest into five stages according to age, classified as young, middle-aged, semi-mature, mature, and overripe. because the biomass per unit area varies greatly in different age stages, it is not possible to generalize when calculating the biomass per unit area.

Assume tree area biomass per tree area of a single tree species forest is B . The forest area changes as a function of year as $S(t)$. So we can get the following equation:

$$M(t) = B_{young} \times S_{young}(t) + B_{middle} \times S_{middle}(t) + B_{semi} \times S_{semi}(t) + B_{matue} \times S_{mature}(t) + B_{overripe} \times S_{overripe}(t)$$

Biological carbon content rate

Internationally, a carbon content rate of 50% is often used for various tree species to measure the carbon stock of biomass, and most researchers at home and abroad also use 50% as the average carbon content rate of all tree species, while an average carbon content rate of 45% is usually used for non-woody parts of apomixis, herbs, etc. In the Xing'an Mountains. This model uses 47% which is close to the actual one.

$$f_c = 0.47$$

Forest biological carbon sequestration capacity

The model for calculating forest biological carbon storage has been given above, and we next propose a carbon storage model based on carbon storage. Assuming that the carbon sequestration capacity of the forest in a certain year t is $d(t)$:

$$d_{forest}(t) = C_{forest}(t) - C_{forest}(t - 1)$$

Then the carbon sequestration capacity of the forest can be expressed as:

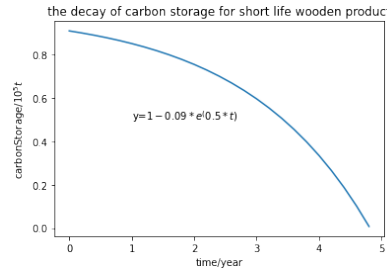
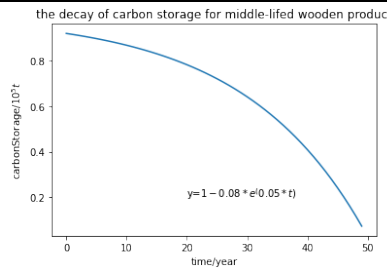
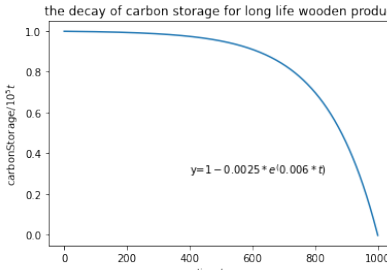
$$carbonForest(t) = \sum_{i=0}^t d_{forest}(i) = C_{forest}(t) - C_{forest}(0)$$

3.2.2 Carbon storage of woody forest products

First, we classify woody forest products into three types according to their life span, namely 1000 years, 50 years and 5 years life span, and use different exponential decay functions to describe the change curve of carbon storage of wood products with time. According to our observation, some of the wood products have a very short life span and are discarded by people after a very short period of

use, and the carbon in them is quickly decomposed into carbon dioxide, such items include, disposable chopsticks, napkins, etc.; while another part of wood products have a long life span, including books, mahogany furniture, tables, etc., and they can maintain carbon sequestration for decades or even millennia, so we believe that the carbon sequestration capacity of woody forest products decays with time.

Table 3. we simulate the decay of carbon content of woody forest products with time for different life spans using an exponential function.

Items	Formula
Short life product	
Middle-aged product	
Long life product	

It is assumed that the percentage of logs used in the manufacture of each of the three products is p_{short} , p_{middle} , p_{long} . After reviewing the information, we believe that the following settings should be available.

$$p_{short} = 0.25 \quad p_{middle} = 0.5 \quad p_{long} = 0.25$$

Assuming that the annual forest biomass cut down $M_{harvest}(t)$ related by the trees cut down in that year:

Since some of the initial wood under felling is called scrap in the process of making it into products, there is a certain amount of wood loss in this process, and we consider the usage rate to be $f_{use}=0.7$, the initial carbon stock of woody forest products can be obtained from the forest biogenic carbon stock equation:

$$C_{product}(t_0, t_0) = M_{harvest}(t_0) \times f_c \times f_{use}$$

According to the above decay function of carbon sequestration capacity of woody forest products with time, it can be obtained that for products made in year t_0 , the carbon content at year t is as follows:

$$C_{product}(t_0, t) = C_{product}(0) \times p_{short} \times decay_{short}(t_0, t) + C_{product}(0) \times p_{middle} \times decay_{middle}(t_0, t) + C_{product}(0) \times p_{long} \times decay_{long}(t_0, t)$$

Carbon sequestration capacity of wood forest products:

We use the carbon content in all wood products produced from the starting year as the carbon sequestration capacity of woody forest products. Since the carbon storage of woody forest products decays every year after the manufacturing is completed, the decay needs to be considered when calculating the carbon sequestration capacity of woody forest products after t years.

In summary, the carbon sequestration capacity of woody forest products can be described by the following equation:

$$\mathit{carbonProduct}(t) = \sum_{i=0}^t C_{\mathit{product}}(i, t)$$

4. Decision model: balance forest values based on the TOPSIS integrated evaluation method

Forests can improve people's lives in many ways, so they can be considered to have multiple values, including ecological and economic values. Therefore, when deciding on a management model for a forest, we need to consider all the various values and adopt the model that has the greatest overall benefit for management.

4.1 Multiple Values of Forests

4.1.1 Ecological value

Forests play a variety of roles in environmental improvement, including but not limited to the following:

Water retention. Forests trap natural precipitation, thus giving them a flow-regulating effect, i.e., they store water during floods and release it during dry periods; they also reduce soil erosion

Protects wildlife. Forests provide natural habitats for many rare wildlife species.

Research shows that, forest carbon sequestration is an important part of its ecological value. So we use carbon sequestration of forest to describe the ability of forests' ecological.

4.1.2 Economic Value

Carbon sequestration in wood products can be used to calculate the value of forest products so we can use it to calculate the economic value of the forest.

4.2 TOPSIS comprehensive evaluation method

TOPSIS is a method of ranking a finite number of evaluation objects according to their proximity to an idealized target and is an evaluation of the relative merits among the existing objects. By calculating the distance of each case from the ideal solution and ranking it, we can obtain the item closest to the ideal solution. We have used the TOPSIS method in the integrated evaluation of ecological and economic values of forests.

4.3 Integrated calculation of ecological and economic values of forests using the TOPSIS integrated evaluation method

To facilitate the calculation through the model, we used the forest area after 100 years under different harvesting rates as a measure of the ecological benefits of the forest; and the carbon content in wood products produced through the forest in 100 years as a measure of the economic benefits of the forest.

We use a flow chart to describe this process, using these two sets of data as the original data set, and first, we set both weights (w_1, w_2) to 0.5. Then we normalize these two sets of data and filter out the optimal values that each of the two sets of data has and combine them as the ideal optimal solution. The ranking is determined by comparing the distance between each set of data and the ideal optimal solution. The data with the shortest distance from the ideal optimal solution is finally output.

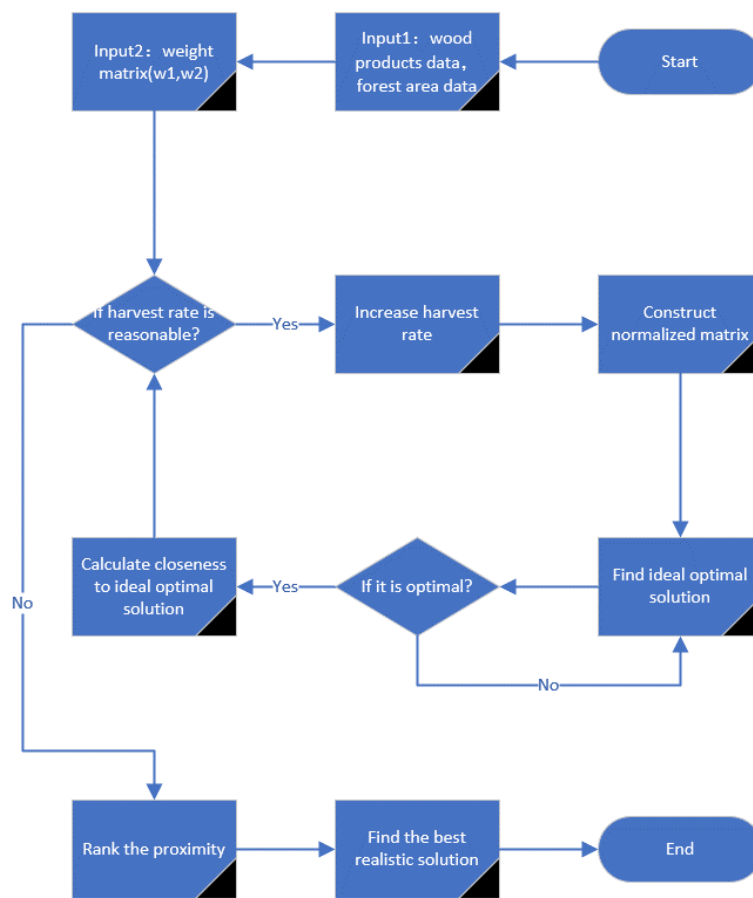


Fig. 1 Model

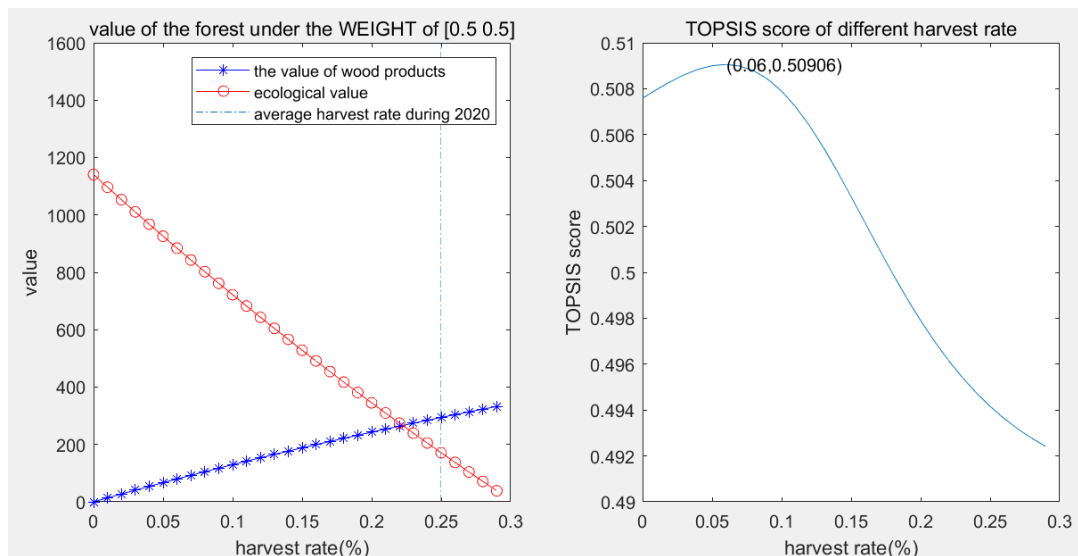


Fig. 2 The TOPSIS score curve is shown in the figure

It can be seen that as the deforestation rate increases, the economic value brought to people becomes greater, while the ecological value of the forest gradually decreases. When the economic and ecological weights are equal, i.e., both weights are 0.5, the TOPSIS score curve is shown in Fig. The highest point of the TOPSIS score curve represents the data when the combined economic and ecological benefits reach the highest. We can see that the TOPSIS score is highest when the logging rate is 0.06%. This means that if we do not increase the number of trees planted each year, we should reduce the cutting rate to achieve the highest overall benefit.

4.4 Weights

Because of the significant differences in forest composition, climate, population, people's interests, values, etc., the weights (w_1, w_2) for ecological and economic values are different for different regions of forests. For different forests, we need to use different weight values according to local conditions. Next, we will perform model sensitivity analysis to investigate the effect of different weight values on the deforestation rate under the best decision model.

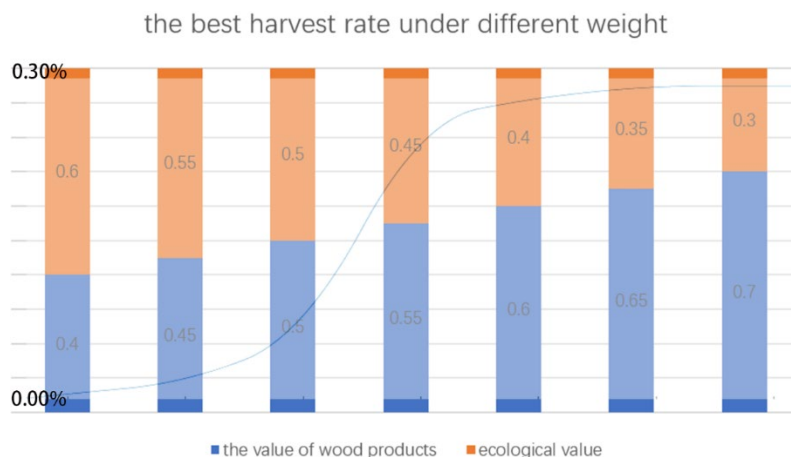


Fig. 3 Best decision model

We vary the weights for economic and ecological benefits and calculate what is the most beneficial deforestation rate for the combined benefits when each weight value is used. We can see that as the weight of economic benefits increases, one needs to cut more trees to achieve the best overall benefits. However, as the weight of economic benefits increases further, the felling rate that is most beneficial to the overall benefits does not continue to rise significantly after 0.28%. Accordingly, we believe that the number of trees cut should be maintained at a reasonable limit to achieve the optimal integrated value, regardless of how much the economy of a region relies on wood products.

5. Model Predictions and Applications

5.1 Carbon sequestration prediction

We integrated the forest growth model and the forest carbon storage equation to calculate the carbon sequestration expected to be achieved by the forest after some time under different cutting rates. Because the average life span of Xing'an larch selected for this model is long, around 300 years, which does not reflect well the carbon sequestration effect of woody forest products in a short period, we choose a prediction time of 500 years.

(1) In the absence of artificial logging, assuming that the natural forest birth and death rates are equal, carbon sequestration at this time is only related to the forest and not too woody forest products, and the following carbon sequestration curve is obtained.

Under a scenario where the forest is left to grow naturally and the rate of artificial cutting is very low, the average age of the trees will get older. Since over-mature forests are much less capable of photosynthesis than younger forests, this reduces the carbon sequestration capacity of the forest.

(2) Under the assumption of artificial logging, a certain logging rate is set, i.e., a certain ratio of trees to the total forest volume is randomly cut in the mature and over-mature forest in that year, and the same area of new trees is planted to maintain the forest area, and the carbon sequestration is related to both the forest and the product.

(3) If the deforestation rate is too high, it leads to the sum of the tree felling and mortality rates being much greater than the birth rate of the forest to the extent that it destroys the forest ecosystem. This reduces the forest area and significantly weakens the forest's carbon sequestration capacity.

Conclusion: For forest management, appropriate logging is more beneficial to the overall carbon sequestration capacity, but too high a logging rate will correspondingly weaken the carbon sequestration capacity.

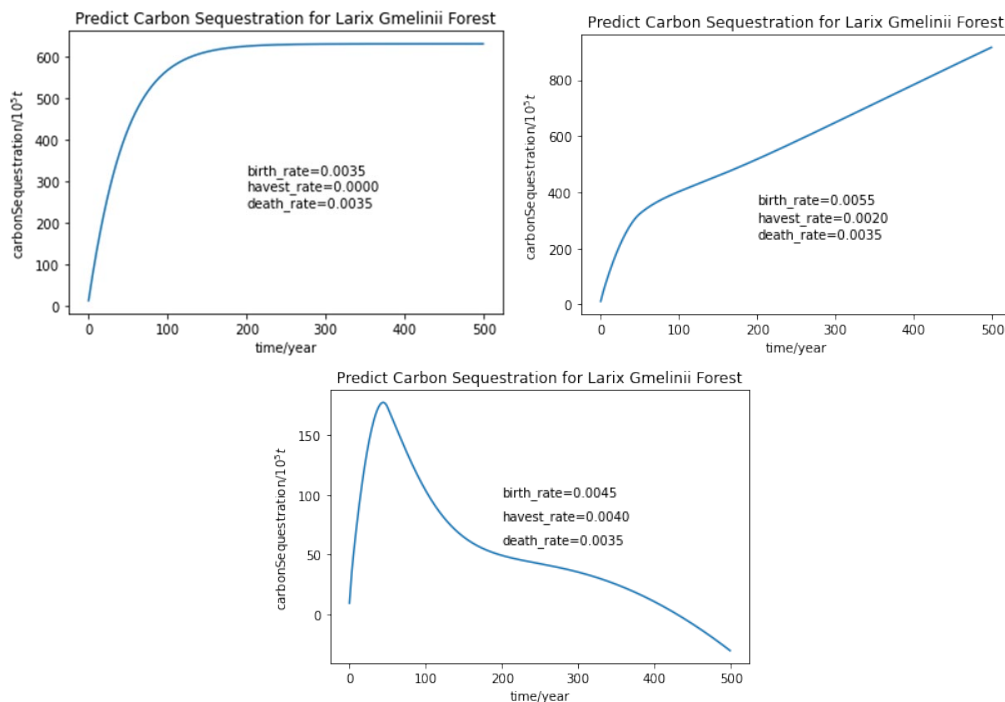


Fig. 4 Predict Carbon Sequestration for Larix Gmelinii Forest

5.2 Interval deforestation model

Based on the previous model, we propose an interval harvest model, which means that large harvest is carried out at regular intervals and the forest is closed during the two logging periods. After improving the model, we selected different time intervals and different deforestation rates and found that the carbon sequestration capacity of the forest under certain parameters was improved compared with the previous model.

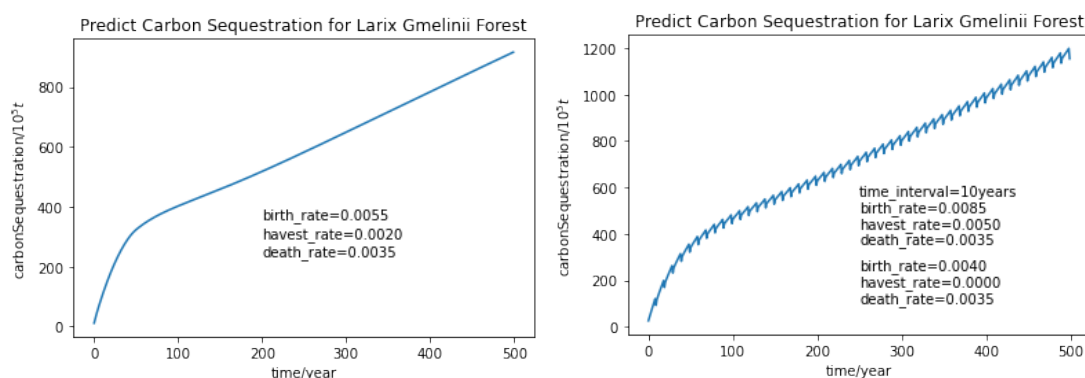


Fig. 5 Schematic diagram of extended harvesting interval

As shown in the figure, we extended the cutting interval by selecting one year out of every ten years as the cutting year to cut the forest and closed the forest for the rest of the cutting year. It can be seen that the extended cutting interval makes the forest have more carbon sequestration capacity in the 500-year range. To further enhance the carbon sequestration capacity of the forest, we should adopt a longer interval harvesting plan. When setting this harvesting transition point, we also gradually increase the harvesting interval to 3-5 years and then to 7-10 years. At the same time, we should take into account the economic benefits. During the closure period, the forest will not produce wood products, which will reduce the economic efficiency of the forest and affect the use of wood

products; likewise, the forest tourism industry will be closed and the tourism income will decrease accordingly. We can also use the previous decision model to evaluate the economic and ecological benefits of the forest during forest closure.

6. Conclusion: Reasonable forest management plan

Through the research and analysis of the model, we believe that a suitable management mode can help improve the carbon sequestration capacity of the forest. In our study, a good forest management plan must include following factors.

Properly increasing the growth rate of trees: One of the most notable ways to artificially increase the growth rate of trees is through afforestation. In order to maintain a steady growth of the original trees, it is also possible to ensure that the growth rate of trees is at a high level by means of mountain closure.

Regular harvesting: In our model analysis, the forest harvesting rate should be maintained near 0.06% (the percentage of trees harvested per year to all trees) to maximize the economic and ecological value. In addition, regular harvesting helps reduce the natural mortality of trees and contributes to the ecological balance of the forest.

Produce long-lived wood products: To sequester carbon in objects over time, we should use more long-lived wood products and reduce the production of disposable wood products, such as disposable chopsticks and toothpicks.

Tree species selection: In the forest management model, we can choose tree species with longer life span and high carbon sequestration capacity, such as spruce, to achieve longer-term carbon sequestration. Meanwhile, good tree species can provide higher economic use value for people.

Prevent forest fires: Forest fires can cause a large amount of carbon stored in the forest to be directly converted into gaseous carbon dioxide, and the ecological protection capacity of the forest will be greatly reduced after a fire.

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