Problem Chosen	2022	Team Control Number
E	MCM/ICM Summary Sheet	2209548

Reasonable Logging Helps Sequester More Carbon

Summary

Climate changing is taking place quickly around the world, with the greenhouse gases being one of the accomplices. The main component of greenhouse gases is carbon dioxide, which can be absorbed by plants. The problem of reducing atmospheric carbon dioxide content has aroused global concerns. Hence, for a bright future of humans, establishing scientific methods of managing the forests is of great importance.

First, we use the **cellular automata method** to simulate the state of forest under different management plan. We also establish a **logistic function** according to the age and biomass of a tree. With the help of the function, we discover the relationship between the age of the tree and the amount of carbon tree sequester. we figure out the maximum quantity of carbon sequestered corresponding to each management. Thus, we find the management that maximize the quantity of carbon sequestered.

Second, we improve the first model by considering tree's natural growing rates and planting degree.

Third, we refer to large quantity of papers and statistic and name **four indicators** considering the economic value and ecological value of fours: oxygen released and carbon sequestered, water conserved, proceeds from the state of wood, and cost.

Forth, we simulate **2250 sets** of data with the modified model which makes the indicators more objective. We record the four indicators corresponding with each set of data as data sets. We then process the data sets using **the entropy weight method** to value the importance of each indicator. After that, we change the weight base on **geological environment of the forest**. Optimal forest management plan can be designed for every specific forest on earth by using the formula. Considering that the different forests are with different optimal management plans, we introduce the **McKinsey Matrix** to help classify forest management plans. By searching for statistics of forests around the world, we obtain the transition points between different forest management plans.

Fifth, we apply the model to a specific forest and bring the data we search of this forest into the model. Then we get the optimal management plan of the target forest and calculate the overall amount of carbon sequestered within 100 years.

Sixth, we discuss that the current management is probably not the best one. When transitioning from the current management plan to the optimal, a stable and slow transition may help maximize the comprehensive benefits.

In addition, we write a non-technical newspaper article to convince the majority that reasonable logging actually helps sequester more carbon that simply doing nothing.

Finally, a **sensitivity analysis** of the modified model is made at the end of the passage.

Keywords: carbon sequestration; cellular automata; entropy weight method

Contents

1 Introduction

1.1 Problem Background

Since the two industrial revolutions, the climate has being changing intensely against the natural laws. The content of carbon dioxide in the atmosphere is soaring up. On one hand, this is an inevitable result of large amount of human activities. On the other hand, the decrease of forests which sequester carbon also worsens the problem.

However, it is unrealistic to stop most of the human activities that contributes to the increase in the atmospheric carbon dioxide content. In the meantime, human beings scarcely have any space for plantation. In order to mitigate the deterioration of the current situations, people has to take advantage of the forests to the greatest extent and make them sequester as much carbon as possible.

Therefore, an accurate model is in urgent need which helps to establish the optimal management for different forests .

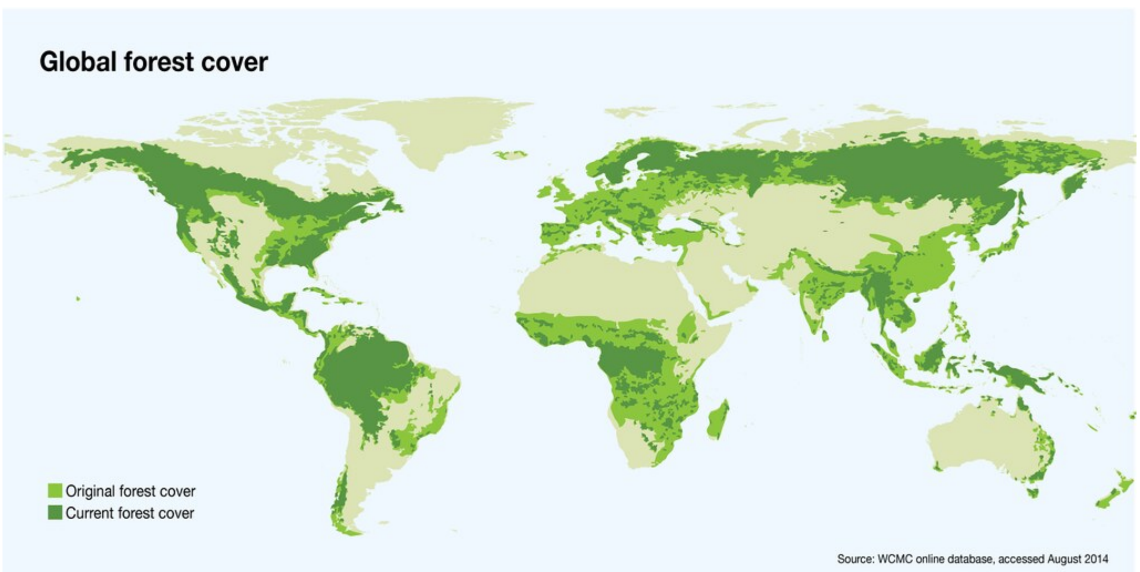


Figure 1: Global Forest Cover

1.2 Restatement of the Problem

We are required to establish a carbon sequestration model to simulate the quantity of carbon dioxide sequestered by the forest and its products. In the meantime, the model should be able to determine the most effective forest management that sequesters the most carbon. Then, we are expected to take more factors, such as location, into account to make the model more practical and profitable. Finally we are asked to put the model into practical use. In addition, we present our idea in the form of newspaper articles to get the access to the majority as well as the local community and make people aware of the environmental problems.

2 General Assumptions and Notation

2.1 General Assumptions

Forest management is complex and interdisciplinary. The realistic situation relates to local ecosystem, geology, topography, forestry, politics, economy and so on. Thus, it is nearly impossible to take every factor when modeling. On that account, we make a couple of general assumptions and simplifications, other assumptions based on specific situations will be listed in the following model-related sections. Each of the assumptions is properly justified.

- Assuming that the forest is in a steady state. Coverage of the tree has reached maximum density.
- Wood products made from trees which have been chopped down are part of carbon sequestration. Disregard that any carbon from trees chopped down is released into the natural environment.
- Assuming that the data collected are accurate.

2.2 Notation

Table 1: Notation

Symbol	Definition
S	Biomass of a tree;
k_i	Number of trees aged i;
k_{max}	Maximum of trees in a forest;
CSPT	Carbon sequestered by per tree;
CSF	Biomass of a forest;
CSH	Carbon sequestered in forest products;
CST	Total carbon sequestered;
m	Logging interval;
n	Logging criteria;
g	Planting degree;
ET	Comprehensive benefits;
E_1	Oxygen released and carbon sequestered;
E_2	Water conserved;
E_3	Proceeds from the state of wood;
E_4	Cost;
h_2	Degree of water shortage;
h_3	Degree of wood price ;
h_4	Degree of labour cost ;

3 Model of Carbon Sequestration

3.1 Theorem

In this section, we devise a model to calculate the quantity of carbon sequestration and thereby determine the most effective forest management plan. Trees help reduce the amount of carbon dioxide in the air. The theory lies behind is that plants can restore carbon by turning them into forms of organic matter. Thus, it is quite reasonable to say that carbon sequestration hold a positive correlation with trees biomass. In our model, we define ***CSPT*** as the quantity of carbon sequestered by per tree. The expression of *CSPT* follows[1],

$$\boldsymbol{CSPT} = \boldsymbol{aS} \tag{1}$$

Where *S* represents the biomass of a tree. a is a coefficient which represents the percentage of carbon to the total mass of organism. In this model, we take a as 0.47[1].
The growth of trees can be approximately divided into three stages: young, middle-aged and mature. Young trees own relatively small number of leaves with correspondingly small size. Thus, young trees' capacity of sequestering carbon is relatively low, and their biomass increases at a low speed. Middle-aged trees grow at a high speed. They have more leaves with larger size compared with young trees. They possess stronger capacity of absorbing carbon than trees at any other stage. When trees get into the stage of mature, their biomass tend to be stable.
The change of tree biomass with age shows as "S" shaped curve. Logistic function is capable of simulating the growth pattern of biomass[2],as

$$\boldsymbol{CSPT} = \frac{\boldsymbol{aC_1}}{1 + \boldsymbol{C_2} e^{\boldsymbol{C_3} t}} \tag{2}$$

where C_1, C_2, C_3 represents different coefficients. These three coefficients can be changed to

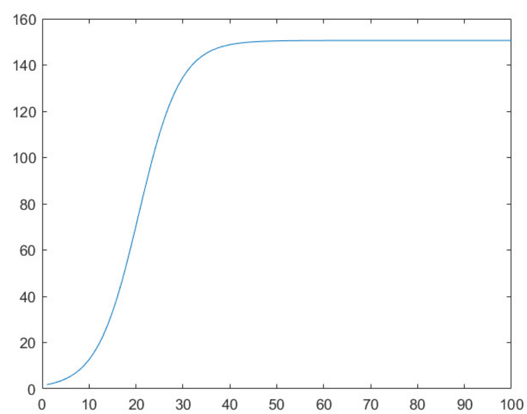


Figure 2: Logistic Model

simulate different tree species. The total relative error of this equation is within ±1%and the prediction accuracy is above 92%. The prediction accuracy of total volume, wood and bark was above 95%.

3.2 Basics of CAFS Model

Different forest management plan exert different influences on both the forest and the amount of carbon sequestered by the forest and its products. In order to simulate the first question in a reasonable way, we choose the model of cellular automata, which simulate the complex world with simple rules controlling the interacting cells. The cells of cellular automata are defined in finite time and space. We name the model Cellular Automata of Forest(CAFS).

- Our cellular automata is defined on matrix. We assume the forest to be a sufficiently large 500×500 matrix and each element represents one cell. Each cell only has one finite state. All cells share the same principle of altering and thus change simultaneously.

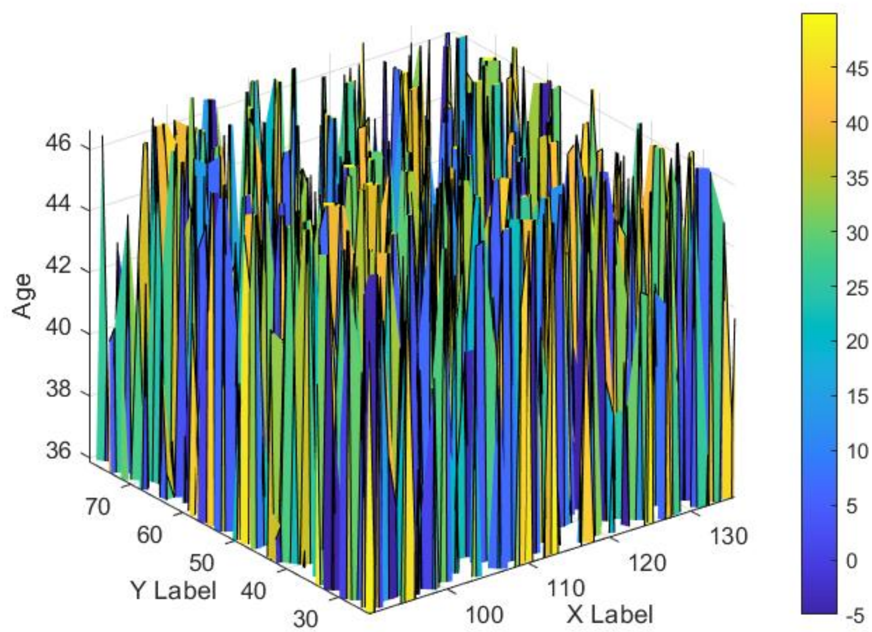


Figure 3: the simulation of cellular automata

- Out of randomness, a cell as a set of trees which share the same age and at the same time randomly scatter within the forest. Possibilities used in our model are processed by random numbers. In other words, when processing with each cell, we call the normalized number to compare with the probability interval. We proved that this method is both practical and practicable through several experiments.

- Tree growth rates are affected by the density of the forest in realistic environment. Under that situation, we propose a variable of growth rate to simulate the disturbance of trees by their surroundings. From a macroscopic view, as a parameter of the forest, the effects caused by the forest density on the set of the trees scattered throughout the forest should be similar to its effect on single trees. In the same manner, the assignment of initial value to each cell based on randomness is equivalent to the assignment of initial value to individuals.

- we suppose that our forest management plan is to cut down larches older than n every m years.

3.3 Specific Approaches

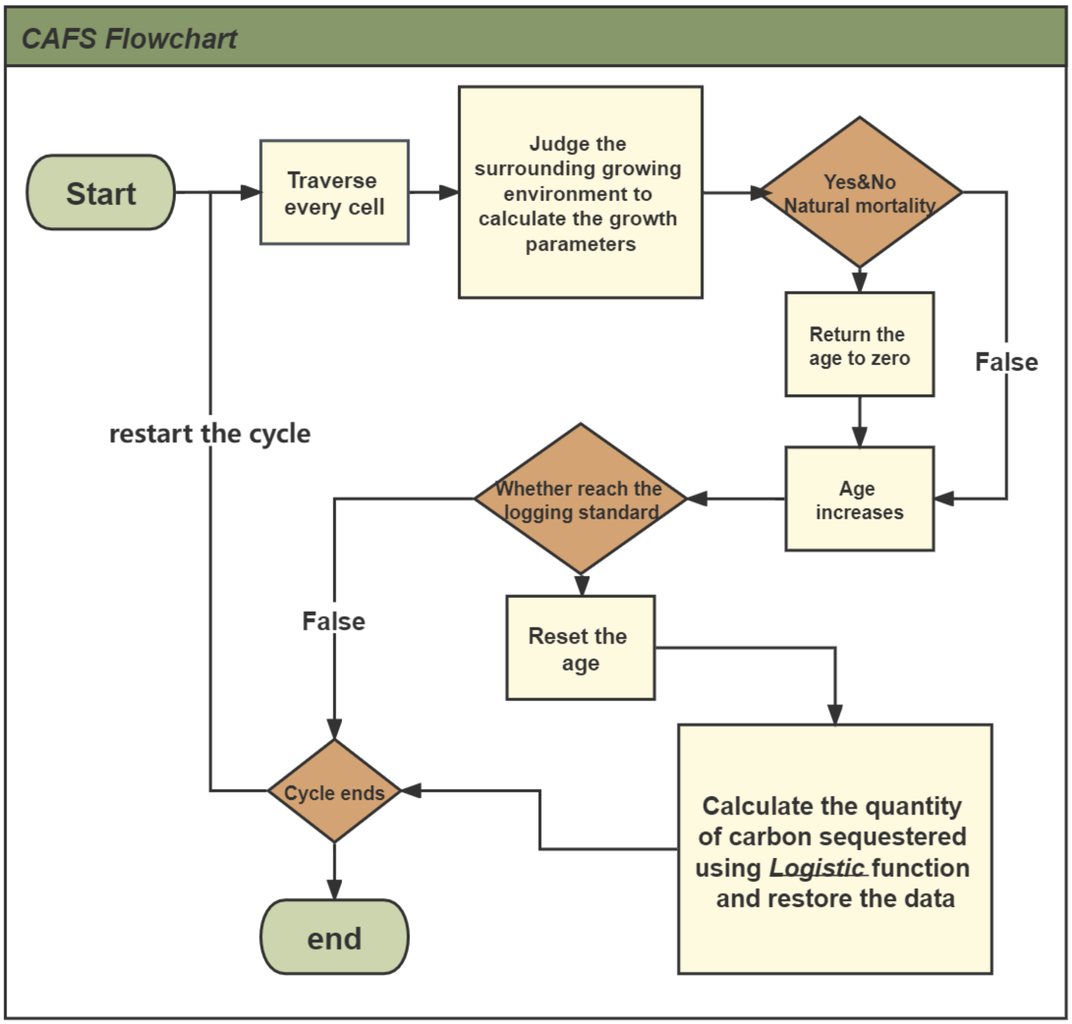


Figure 4: flow chart of CAFS

We first establish a matrix large enough. Each cycle, which is a year, traverse every element in the matrix. The first step of the cycle is to analyse the statistics from the surrounding cells to get the growing state of the aimed cell. Then, we use the method of random number to judge whether there exists any death of trees. If trees are dead, we will cut them down and turn the value of the corresponding cells to 0. At last, we judge whether the trees reach the logging standard, which is older than n. If the trees reach the standard, we set their age as parameters and bring them in the logistic model of the trees. Through operation, we can get the biomass of the trees in corresponds. Every year, we add one to each age. In the meanwhile, we randomly generate a number. If it is smaller than or equal to tree's natural mortality, we turn the value of this cell to 0. After updating the data, we select all the cells with values greater than n. We cut down trees in these cells and turn the values to 0. Then we utilize the logistic function of the specific type of trees to get the biomass of each cell through their respective value. After that we use the the formula of CSPT to get the amount of carbon sequested in wood products CSH.

$$\boldsymbol{CSH} = \sum_{i=n}^{n+m} \boldsymbol{k_i CSPT(i)} \tag{3}$$

We can also calculate carbon sequestered in trees in the forest

$$\boldsymbol{SCF} \quad = \quad \sum \boldsymbol{k_i SCPT(i)} \tag{4}$$

, we can get the final quantity of carbon sequestered through

$$\boldsymbol{CST} = \triangle \boldsymbol{CSF} + \sum \boldsymbol{SCH} \tag{5}$$

. Finally, we get our most effective management plan after calculating every possible combination of m and n,and we chose m and n that make CST maximum as the best plan.

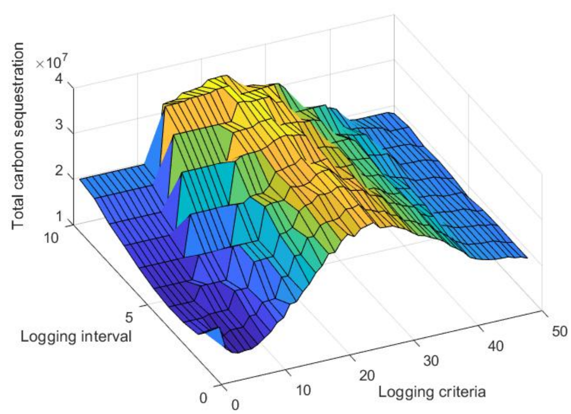


Figure 5: Result of CAFS Model

3.4 Result of CAFS Model

We suppose that our forest is consist of 250×250 trees and the forest density is 1350 trees per square hectometer. The result is that to achieve the highest efficiency of carbon sequestration, the forest manager ought to cut trees over the age of 21 every 8 years. The maximum overall biomass within 100 years is 37038290.64kg. The amount of carbon sequestered is 4.003t per square hectometer per year.

4 Model Optimization

4.1 Improvement of CAFS model

We introduce a planting strategy: each time after logging, we plant a certain quantity of trees, which is g% of the number of the trees cut down. In the CAFS model, the cell doesn't return to the growing state right after each felling. Instead, we determine whether the cell is in the growth state by a probability function related to g. We achieve this process by simulating the forest matrix through each traversal.

4.2 Indicators for Evaluating the Forest Management Plan

4.2.1 Oxygen Released and Carbon Sequestered

From the respiration equation, we can know that the total of oxygen produced by the forest and the total of carbon dioxide taken in are equal to the amount of carbon sequestered multiplied by their respective factor. As a result, we use indicator E_1 to describe the two factors at the same time.

4.2.2 Water Conservation

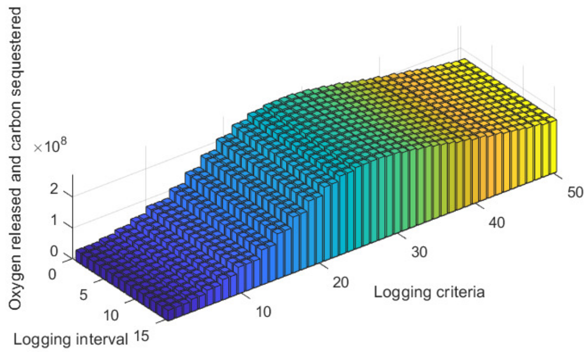
The forest's capacity of conserving water holds a positive correlation with the ratio of trees over a certain age to the maximum number of trees in the forest. We treat the water conserved by the forest as a indicator linearly related to the density of the forest. We compute the water conserved during each annual. We name it E_2.

4.2.3 Proceeds from the Sale of Wood

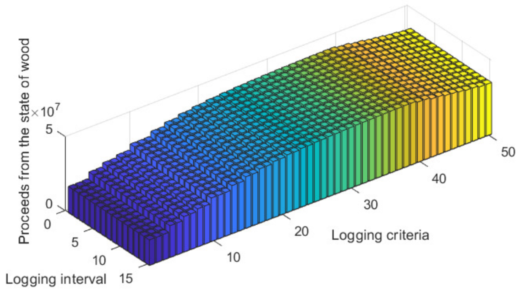
The price of a specific type of log on the market is determined by its weight. Thus the proceeds from the sale of wood are positively related to the sum of the biomass of the trees cut down. We use the indicator E_3 to represent proceeds from the sale of wood.

4.2.4 Cost

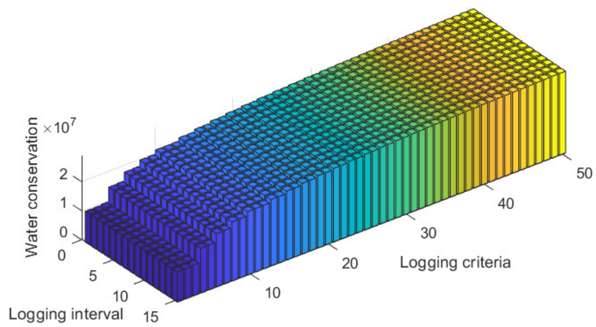
Both logging and replanting require money. On that account, cost is positively correlated with the sum of logging and that of replanting. We assume that each logging and planting require a certain amount of labour cost. Thus, we consider the total number of manual operations as labour expenditure. We use the indicator E_4 to represent the cost.



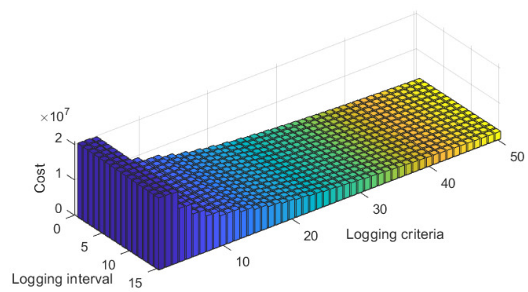
(a) Oxygen Released and Carbon Sequestered



(b) Proceeds from the Sale of Wood



(c) Water Conservation



(d) Cost

Figure 6: Indicators-Forest Management Plan

4.3 Compound Weight Evaluation of Forests-CWEF Model

In this section, we devise a CWEF model (Compound-Weights-Evaluation-of-Forests) to first calculate the weights of indicators using entropy weight method. Then modify the corresponding weights according to natural and social factors.

4.3.1 Introduction of Entropy Weight Method

The entropy weight method is an objective evaluation method. According to the basic principles of the information theory, information entropy is a measure of the order degree of the system. From the definition of information entropy, we can use the entropy value to determine the discrete value of the indicators. The smaller the information entropy value of the indicator, the greater the discrete degree of the indicator. The greater the amount of information provided, the greater the impact weight of the indicator on the overall comprehensive evaluation. If all the values of an indicator are equal, the indicator is worthless in the comprehensive evaluation. Thereby, the tool of information entropy can be used to calculate the weight of each indicator and provide a basis for the comprehensive evaluation of multiple indicators.

4.3.2 Procedures of Applying Entropy Weight Method in this Question

Step1: establishing the data set. In order to reasonably determine the information entropy of each indicator, we make a series of improvement based on the CAFS model.

- First, we assume that the cell doesn't return to the growing state right after each felling. Instead, we determine whether the cell is in the growth state by a probability function related to g and natural growth rate. We achieve this process by simulating the forest matrix through each traversal.
- Second, we treat the water conserved by the forest as linearly related to the density of the forest. We compute the water conserved during each annual traversal.
- Third, we assume that each logging and planting require a certain amount of labour cost. Thus, we consider the total number of manual operations as labour expenditure.
- Forth, we treat the amount of carbon sequestered and oxygen released in the same way as we did in question1.

By foundation of the ideas above, we evenly divide g into four sections to simulate the forest. We can work out any group of the four indicators corresponding to each coordinate(m,n) under different g. We collect all these statistics as the data set of our evaluation model.

Step2: processing data. Different indicators have different units, orders of magnitude and meanings. In addition, different indicators has different directions of optimization. Thus, it is necessary to perform appropriate data processing.

We define that E_j of the i-th plan equal to e_{ij} In this section, we suppose than the larger the E_1, E_2, E_3 the better. The smaller the E_4, the better. As a result, we follow the formula:

$$\boldsymbol{e_{i4} = max(e_{i4}) - e_{i4}} \tag{6}$$

to process the raw data of labour cost and standardize the method with the maximal value and the minimal value.

$$\boldsymbol{e_{ij} = \frac{e'_{ij} - min(e'_j)}{max(e'_j) - min(e'_j)}} \tag{7}$$

and mapping to the interval[0,1].

Step4: calculating data entropy. After processing, we can form the data matrix $R = (r_{ij})_{m\times n}$, for a given indicator r_j, the relevant information entropy is V_j,

$$\boldsymbol{V_j = -\frac{1}{lnm}\sum_{i=1}^{m} P_{ij} ln p_{ij}} \tag{8}$$

where

$$\boldsymbol{P_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}} \tag{9}$$

4.3.3 Calculating Weights and Scores

$$\boldsymbol{w_j = \frac{(1 - V_j)}{\sum_{j=1}^{n}(1 - V_j)}}$$

We compare the information entropy to the overall information entropy to get the parameter of the indicator. Thereby, we can form a relatively reasonable formula,

$$\boldsymbol{ET_i = w_1 r_{i_1} + w_2 r_{i_2} + w_3 r_{i_3} + w_4 r_{i_4}} \tag{10}$$

where i represents the number of different managements.

The coefficient h_2 indicates the importance of the forest's water storage capacity, which is related to the local water resources. If the local climate is humid and water resources are abundant, then the water-conserving capacity of the forest is less important. On the contrary, if the climate is relatively dry and water resources are scarce, the forest's ability to conserve water should be valued. We assign a value to h_2 based on the humidity of the area.

The coefficient h_3 indicates the value of the trees that make up the forest. It is related to the type of trees. If the economic value of the trees is high, there is a greater incentive to cut them down. We work out the main tree species of the forest, check its market price, and assign a value to h3 based on the price.

The coefficient h_4 represents the price of labor. Both logging and planting require hiring and paying. Wages vary from region to region depending on the level of economic development. In general, the higher the level of economic development of a region, the higher the wages and the higher the cost of employing people. We assign a value to h_4 according to the level of economic development of the region.

$$\boldsymbol{ET_i' = w_1 r_{i_1} + h_2 w_2 r_{i_2} + h_3 w_3 r_{i_3} + h_4 w_4 r_{i_4}} \tag{11}$$

After completing the assignment, we can calculate the overall score of each solution, and the solution with the highest score is the optimal management plan for the local forest, and we record the values of logging standard n and planting strategy g corresponding to this solution. Obviously, the optimal solution is different for different regions. It can be assumed that the smaller the n the greater the logging degree and the greater the g the greater the conservation effort. Based on the values of n and g, we use the McKinsey Matrix (GE matrix) to categorize the forest management options into four categories:Different regions get different optimal forest management mode:

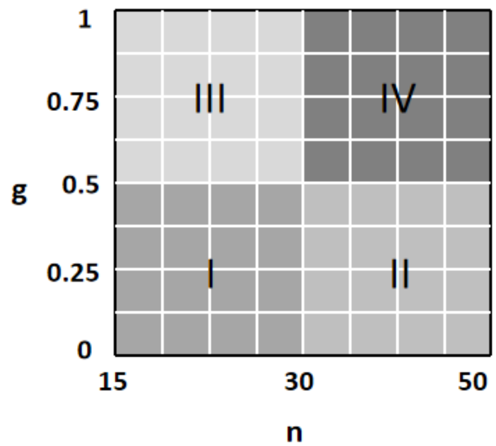


Figure 7: GE matrix

- I Logging-Oriented(LO)
- II Laissez-Faire(LF)
- III Combination of Conservation and Logging(CCL)
- IV Conservation-Oriented(CO)

Table 2: Indicators classification

h2	humidity	h3	wood price	h4	cost
0.2-0.5	High	0.2-0.5	Low	0.2-0.5	Low
0.5-0.8	Relatively High	0.5-0.8	Relatively Low	0.5-0.8	Relatively Low
0.8-1.25	Medium	0.8-1.25	Medium	0.8-1.25	Medium
1.25-2.0	Relatively Low	1.25-2.0	Relatively High	1.25-2.0	Relatively High
2.0-5.0	Low	2.0-5.0	High	2.0-5.0	High

We comprehend the existence of transition points as there being at least two managements that have similar effect on a specific forest. In the figure we can see that there are transition points between the different forest management options. Based on the data, we discover that different natural and social factors also have different effects on the management options.

- Cost plays a dominant role in deciding whether to choose mode CO or mode LF.
- Ecological values, such as water resources, play a dominant role when it comes to choosing mode LO or mode LF.
- Timber price plays a dominant role in the making decisions between mode CCL and mode CO.

- Tree growth rate plays a dominant role in choosing mode CCl or mode LO.

Thus, we determine the optimal management plan for the forest based on the natural and social characteristics of the area where the forest is located. If the forest correspondence point is at the junction of two regions of the GE matrix, then both options are equally applicable to it and the forest can be said to be at the transition point between the different options.
In selecting different forests and models to conduct calculation, we find that if the forest has a slow growth rate, low timber value, extremely high cutting costs, and fragile local natural ecology, the logging standard$n$, and the logging interval m are very large, then the forest can be treated as not to be cut, for example, forests located at the edge of a desert with important ecological values. However, such forests constitute only a small portion of the global forest.

5 Application of Optimized Model

5.1 Determine the Best Management Plan for Specific Forest

We apply the model to a specific forest. We choose the forest area in Xiaoxing'an Mountains, Heilongjiang.The value of parameters and results are in the following table.

Table 3: parameter and result list

parameter	value	result	value
C1	197.894	m	6
C2	204.051	n	40
C3	-0.039	g	0.25
h_2	0.5	SCT	14789.81kg $/hm^2$
h_3	1	w_1	0.503378
h_4	1	w_2h_2	0.10244
		w_3h_3	0.171952
		w_4h_4	0.119799

- the area belongs to the temperate continental monsoon climate, belongs to the humid zone. Thus,h_2 equals 0.5
- The dominate species of the local plants is pine trees, and the price of pine trees is of medium level, so we take as 1.
- The target forest is located in a developing country with a normal level of economic development, h_4 is taken as 1

We Bring these parameters,and get the value of m,g,n .In this plan, trees older than 40years are chopped down every 6 years and a small amount of trees are planted. The forest management plan belongs to mode CO.
The model considers that carbon sequestration dominates the evaluation model in the target forest,

and cutting trees over 40 years old allows most of the trees in the forest to be in their peak growing period, which makes the carbon stock larger. We calculate the carbon stock per hectare in 100 years under this scenario as 14789.81kg.
This result is in line with our expectations. The latitude of the region is high, local temperatures in winter is low. The growing cycle of indigenous trees is long. All these factors results in higher logging standard n. The timber value is average and the proceeds are limited, thus the overall benefit is improved by maintaining a relatively low amount of cutting and planting. At the same time, the region attaches importance to forest protection, with policies such as logging restrictions and mountain closure. The results from our model are generally consistent with the local policies.

5.2 Strategy of Timeline-Changing

Next we consider the transition of plans. Suppose the current plan for the forest is to regularly log at the interval of 5 years, whereas the optimal forest management plan suggest that we log every 15 years.
We have two strategy of changing the timeline:change directly,as (a) in following figure, or change progressively as (b) in the figure. We use our model to evaluate which strategy is better. And result is that the indicator of strategy(b) is 1.6% greater than (a).
The benefits will change significantly in a relatively short period of time. The adjustment of

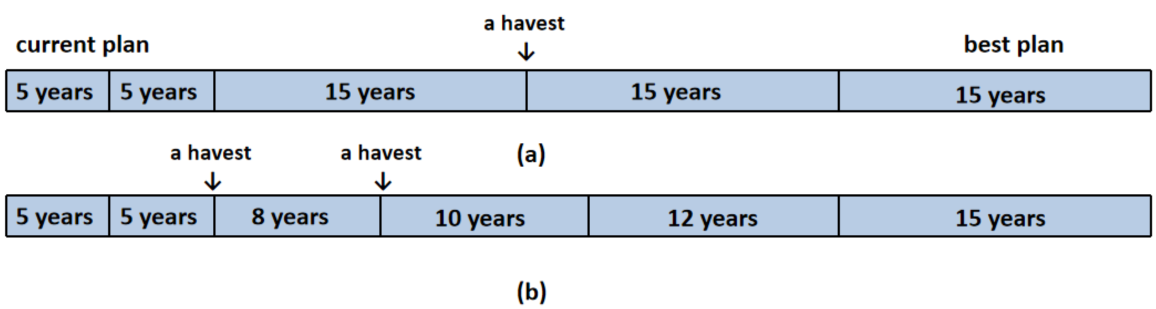


Figure 8: two timeline-change strategy

the management plan involves the cost of labor, timber markets, forest managers, and benefits of other respects, involving employment, profits, and the environment. A relatively gentle transition is needed to give all parties enough time to adapt, and we will design some gradients between 5 and 15 years to allow for gradual changes in cutting intervals.

6 Sensitivity analysis

In this section, we test the sensitivity of our evaluation model. TO obtain the sensitivity, we use the entropy weighting method by varying the coefficiency and comparing the difference between the original results and alter results.

We set a series of initial parameters as a test set (0.25,0.5,1,2,5) We make it any two parameters of h2,h3,h4 adn change another parameter to compare the difference between the results Here, we choose h2 as the test parameter and come up this the following chart by testing data. The chart shows that although the change in h2 affects the results of E to some extent, and there are differences in the indicators under each set of (h3,h4). However, the evaluation values derived from different data are overall more stable. The influence of h4 on the evaluation value is significantly stronger than that of h2 and h3. The evaluation value of h4 varies significantly for the same h2 and h3. Thereby, we can see that the sensitivity of h4 is higher and the sensitivity of h2 and h3 is lower.

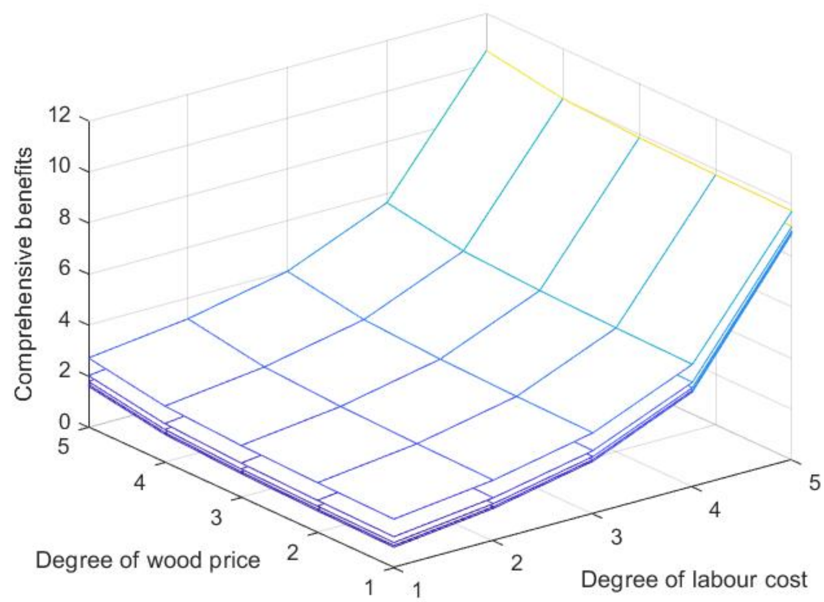


Figure 9: Sensitivity analysis of different indicators

7 Strengths and weaknesses

7.1 Strengths

- We establish the Carbon Sequestration Model according to the growing characteristics of trees, Based on concepts in biology.
- The indicators we select are representative.
- We not only utilize the entropy weighting method to score the data according to its distribution characteristics, but also flexibly take local, natural and social factories into consideration.
- Better accuracy: the model is processed by a larger amount of data, which makes it objective and accurate
- The indicators selected by the model cover a comprehensive range of fields.

- Being extensible: Our evaluation model is based on actual data, so it can be extended to any forest on earth, and a reasonable evaluation can be made by obtaining data from the target forest.

7.2 Weakness

- Derivation exists due to insufficiency of data.
- There are too much factors that influences the forest management plan, we select important ones and leave out the other. The management plan is still practical but somehow simplified.

8 Conclusion

In our paper, we establish the CAFS and CWEF model to simulate the maximum possible quantity of carbon sequestered together with the optimal forest management plans for different forests in different regions of the world.

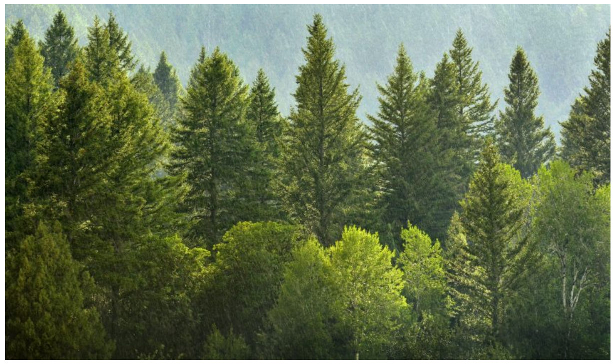
First through our re-estimation of forest values and simulation of human interventions on forest conditions, we obtain a more objective and comprehensive model for evaluating forest values. Based on this model, we use the McKinsey matrix to classify the different characteristics of the world's forests.

We found the similarities and differences in forest characteristics that apply to different management models.
We then used real data to evaluate the forest value of mixed coniferous forests in the Xiaoxing'an Mountains, Heilongjiang, China and derive the optimal management plan under this evaluation system, and describe the strategy of transitioning from the universal management scheme to the optimal management scheme.

Finally, based on the modeling results, a non-technical article was completed to convince the local community that the best management option for the forest includes appropriate logging.

9 Newspaper Article

Reasonable Logging Helps Sequesters More Carbon



Even kids in kindergarten have the impression that “trees help protect our environment”. Indeed, trees have the function of increasing species diversity, conserving water, storing water, reducing soil erosion, and natural disasters. Every year green plants all over the world take in large amount of carbon dioxide, which greatly improves the quality of the air we breathe and reduce the burden of the greenhouse effect. What’s more, the forest on earth is disappearing at a fast speed with the expansion of urban cities soaring up. As a result, most people justifiably consider it wrong doing anything relevant to the “destruction” of forests. However, these kinds of thoughts are to some degree incorrect. Assume that the coverage of forests on earth is fixed. Can simply maintaining the current situation realize the maximum profit? Quite contrary to most people’s thoughts, the answer to this question is a surprising “No”. So what is it about?

To answer this question, it is also important to think about “where does the carbon dioxide that plants absorb go?”

Actually, the carbon dioxide absorbed by plants later becomes part of the plant. Respiration of plants helps trees to store carbon dioxide in forms of organic matters. As a result“cutting trees down” don’t always represent the destruction of forests. It only a method of restoring the carbon from carbon dioxide and prevent them from going back to the atmosphere. At the same time, this action is able to give place for regeneration of new plants and thus sequester more carbon. Under refined and well-organized management, forests are able to achieve increase in the amount of carbon absorption. Forests can in some way be treated as “crops”, timely and reasonable harvest helps them sequester more carbon dioxide without increasing the density or extend the coverage.

To maximize the quantity of carbon sequestered, scientist have to work out specific management plans. Just as human beings, the plants also have a process of growth, which can be largely divided into 3 stages. Young trees own relatively small number of leaves with correspondingly small size. Thus, young trees’ capacity of sequestering carbon is relatively low, and their weight increases at a low speed. Middle-aged trees grow at a high speed. They have more leaves with larger size compared with young trees. They possess stronger capacity of absorbing carbon than trees at any other stage. When trees get into the stage of mature, their tend to grow at a low stable speed. On that account, it’s always a better choice to manually keep a certain proportion of trees at middle age. And now the questions turn into "what is the proportion?

How to manage the forest? Is it really worth it?"

From the aspect of environment, the answer is definite yes. Nevertheless the reality is much more complicated than ideal thoughts. To form a mature forest management plan, which not only benefits the environment,but also is practicable, we have to some important factors into consideration, such as the overall cost, the water conserved by the forest, the oxygen released and the carbon dioxide absorbed, benefits from the wood and its products. From the aspects of the forest manager, the plan has to be profitable.

Let's take the example of forest nearby. The main type of trees from the forest in our local community is loblolly pine. Raw loblolly pine wood can be sold at price of 90$/m^3$ while the overall cost of logging, planting, and labour for one time is about 2500$. This means, the management can be lucrative by merely selling $28m^3$ loblolly pine wood, which isn't a large number for mature pine trees. In other word, the management work is profitable with merely logging down limited number of pine trees. Logging on this kind of scale scarcely reduce the forest's water conservation, while increasing the proportion of middle-aged pine trees. Thus, it is responsible to say that with more precise forest management plan devised by professional technical team in the future, the local forest can surely benefit our neighbourhood from the aspects of both the environment and the economy.

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Appendices

Appendix A Code for CAFS

```
clear;clc;
FinalYear=0;
FinalAns=0;
FinalM=0;
y=ones(10,50);
deathrate=0.0188;
n=250;
k=500;
Temp_Final_Biomass=0;
C1=150.6036;
C2=105.1501;
C3=0.2264;
forest=zeros(n,n);
Other=zeros(n+2);
veg=forest;
Born_Rate=0.25;
E_Value=0;
Data_Temp=zeros(15,50,4);
Data_Biomass=0;
for p1=1:n
    for q1=1:n
        birth=rand();
        if(birth<=0.08)
            forest(p1,q1)=2.5;
        end
        if(birth>0.08&&birth<=0.18)
                forest(p1,q1)=6.5;
        end
        if(birth>0.18&&birth<=0.34)
                forest(p1,q1)=10.5;
        end
        if(birth>0.34&&birth<=0.46)
                forest(p1,q1)=14.5;
        end
        if(birth>0.46&&birth<=0.59)
                forest(p1,q1)=18.5;
        end
        if(birth>0.59&&birth<=0.78)
                forest(p1,q1)=22.5;
        end
        if(birth>0.78&&birth<=0.86)
                forest(p1,q1)=26.5;
        end
        if(birth>0.86&&birth<=0.90)
                forest(p1,q1)=30.5;
        end
        if(birth>0.90&&birth<=0.93)
                forest(p1,q1)=34.5;
```

```
        end
        if(birth>0.93&&birth<=0.94)
                forest(p1,q1)=38.5;
        end
        if(birth>0.94&&birth<=1)
                forest(p1,q1)=44.5;
        end

    end
end
        for M=1:10
            for i=1:50
                veg=forest;
                    for j=1:M:100
                       Other(2:n+1,2:n+1) = veg;
                        sumValue = (Other(1:n,2:n+1))+...
                        (Other(2:n+1,1:n))+(Other(2:n+1,3:n+2))+(Other(3:n+2,2:n+1));
                        for p=1:n
                            for q=1:n

                                        if(sumValue(p,q)>200)
                                        growth_speed=0.7;
                                        end
                                        if(sumValue(p,q)<=200&&sumValue(p,q)>150)
                                        growth_speed=0.8;
                                        end
                                        if(sumValue(p,q)<=150&&sumValue(p,q)>100)
                                        growth_speed=0.9;
                                        end
                                        if(sumValue(p,q)<=100&&sumValue(p,q)>50)
                                        growth_speed=1;
                                        end
                                        if(sumValue(p,q)<=50&&sumValue(p,q)>=0)
                                        growth_speed=1.2;
                                        end
                                        veg(p,q)=veg(p,q)+M*growth_speed;
                                        if(veg(p,q)>=i)
                                        Temp_Final_Biomass=Temp_Final_Biomass+...
                                        logist(C1,C2,C3,veg(p,q));
                                        veg(p,q)=1;
                                        end
                            end
                        end
                    end
                a=Temp_Final_Biomass;
                y(M,i)=Temp_Final_Biomass;
                if(Temp_Final_Biomass>FinalAns)
                FinalAns=Temp_Final_Biomass;
                FinalYear=i;
                FinalM=M;
                end

                Num_Can=0;
                Num_labour=0;
```

```
                Num_Forest=0;
                TempAns=0;
                Temp_Final_Biomass=0;
            end
        end
```

Appendix B Code for Entropy Weight Method

```python
import copy
import pandas as pd
import numpy as np
data=pd.read_excel('Data.xlsx')
print(data)

label_need=data.keys()[1:]
print(label_need)
data1=data[label_need].values
print(data1)

data2=data1
print(data2)

index=[3]
for i in range(0,len(index)):
    data2[:,index[i]]=max(data1[:,index[i]])-data1[:,index[i]]
print(data2)


[m,n]=data2.shape
data3=copy.deepcopy(data2)
ymin=0.002
ymax=1
for j in range(0,n):
    d_max=max(data2[:,j])
    d_min=min(data2[:,j])
    data3[:,j]=(ymax-ymin)*(data2[:,j]-d_min)/(d_max-d_min)+ymin
print(data3)

p=copy.deepcopy(data3)
for j in range(0,n):
    p[:,j]=data3[:,j]/sum(data3[:,j])
print(p)
E=copy.deepcopy(data3[0,:])
for j in range(0,n):
    E[j]=-1/np.log(m)*sum(p[:,j]*np.log(p[:,j]))
print(E)

w=(1-E)/sum(1-E)
print(w)

s=np.dot(data3,w)
Score=100*s/max(s)
```