Carbon sequestration model based on entropy weight method and genetic algorithm

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Abstract. As the great amount of greenhouse gases release into the atmosphere, climate change gives a tremendous threat to people. To predict the amount of carbon sequestration, we establish an optimal evaluation model combined GA Model with Entropy Weight Method. Specifically, We develop a carbon sequestration model by using the entropy weight method to determine the percentage of the 6 variables. Second, we use the genetic algorithm to optimize the model.

Keywords: carbon sequestration, entropy weight method, genetic algorithm.

1. Introduction

It can not be negligible that climate change is a dire threat to countless people due to the development of our society and technology [1-2].

Besides reducing greenhouse gas emissions, Carbon Sequestration, which means stock up on carbon dioxide from atmosphere [3], is an indispensable resort to mitigating climate change. On account of the excellent capacity of sequestering carbon dioxide, forest systems and the forest products the produce create a magnificent carbon sink globally [4-5]. To optimize forest management decisions, forest managers want to get a considerate management plan [6].

How to locate serviceable data from numerous reviews and design a forest management strategy to balance these effectiveness and enable managers to maximize the comprehensive benefits through the harvesting and maintenance of forest resources? [7-8] This is a very meaningful and challenging scientific question [9-10].

2. Pre-preparation

The amount of data about annual forest area in global scope is too tremendous to enumerate them all, so we directly visualize data from 1900 to 2020.

2.1. Data processing

First, We make a line graph with the data about annual forest area in global scope from 1990 to 1993, and find a significant increase from 1990 to 1993. While from 1993 to 2020, it has been decreasing year by year, so we ignored that part of the increase from 1993 to 2020, only focus on the data from 1993 to 2020. The result is shown in the figure 1.

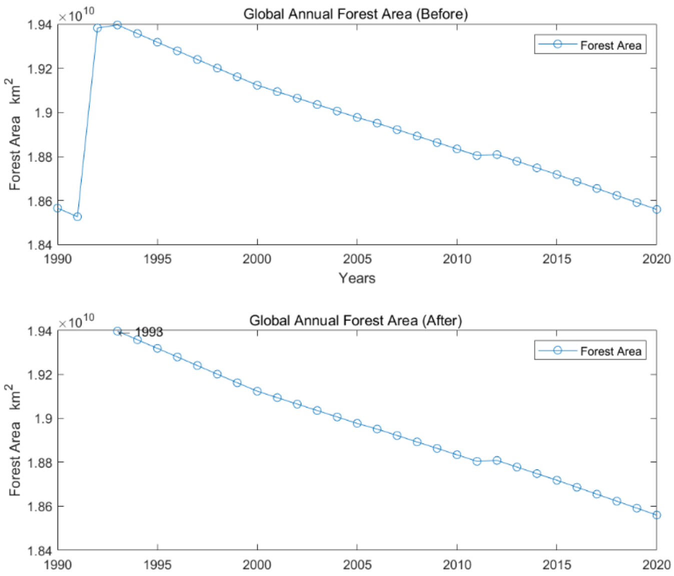

Figure 1. The result of global annual forest area

We also find that 45 per cent of global forest area is found in classified as tropical and another 11% is in sub-tropical countries. Temperate climatic domain account for 16% of global forest area and boreal countries for 27%.

Then, We pick up 6 kinds of classic species of trees from each climatic domain, and average their chest diameter, height and age. After that, we can put this average data into the following model.

2.2. Data predicting

Firstly, We use fit regression model to predict the annual forest area globally in the future.

$$y = -9.23e + 0.7x^{0.711} + 1.964e + 10 \tag{1}$$

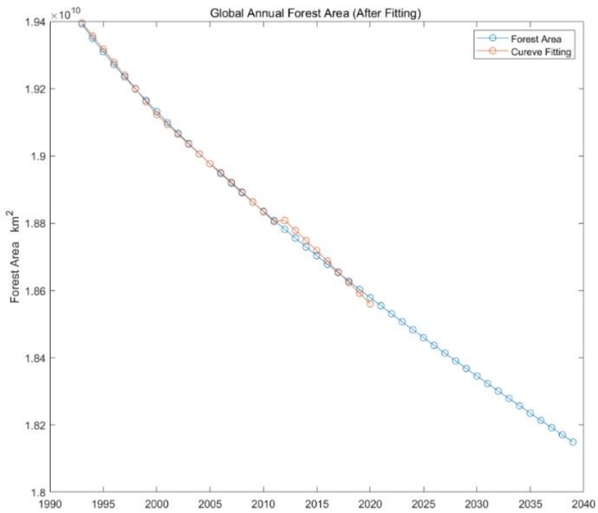

Figure 2. The goodness of fit is excellent

The goodness of fit is excellent, as show in figure 2, with R-square = 0.99756, so that based on the fit regression model, we can predict the variation tendency in annual forest area globally for the next 30 to 50 years.

The density of trees can be expressed as:

$$\rho = \frac{k}{s} \tag{2}$$

In the formula, ρ is the density of trees per square kilometer, k is the total number of trees in the world, and s is the global forest area

It is estimated that there were approximately 3.04 trillion trees in the world in 2015.We can put the data into this formula, so the density of trees in 2015 is 16241 trees per square kilometer

Next, on account of the missing data about specific numbers of trees per year, we assume that the density of trees is invariant. Based on the density of trees and the annual forest area given by the fit regression model we create, we can predict the numbers of trees per year from 1993 to 2040. The result is shown in the figure 3.

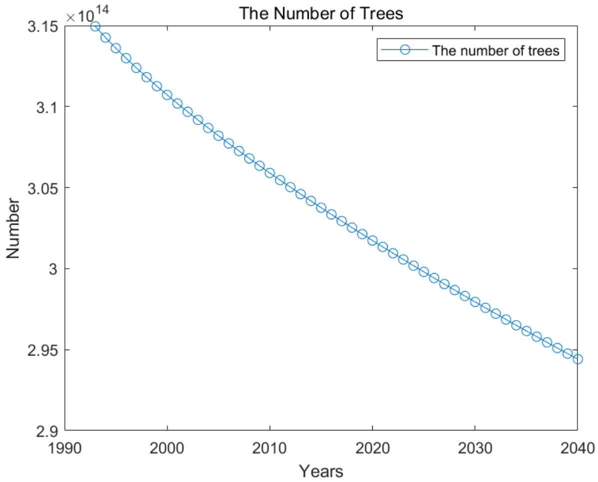

Figure 3. The result of number of trees

3. Modeling

3.1. The weight of carbon dioxide that all the trees can sequester every year

The average diameter of the forest score is affected by the forest score density. The average diameter is inversely proportional to the forest density. The greater the forest score density, the smaller the average diameter of the forest score. It can be judged that the choice of forest forest diameter simulation parameters is mainly influenced by forest density and forest average diameter. If the relationship between simulation (α,β, c) and the average forest diameter (D) and forest density can be established by certain methods, the chest diameter of the trees with different numbers of trees with different diameters can be simulated.

According to the study of Dong Wenyu (2006) the scale parameters of the Weibull distribution are closely related with the mean diameter D. It shows that the scale parameter value gradually decreases with the average diameter D value, and the regression equation is:

$$\beta = 5.2487 - 0.3959D - 0.768D^2 - 0.0025D^3 \tag{3}$$

There is also a clear correlation between the shape parameter a and the mean diameter D, increasing as the forest mean diameter D value increases, and the regression equation is:

$$\alpha = 5.228 + 0.531D - 0.001D^2 - 0.000015D^3 \tag{4}$$

According to (4-22) and (4-23), we can calculate the simulation parameters of different average diameters at the same density, thus simulating the diameters of each tree with different series of average diameter.

Determine the total (green) weight of the tree

Depending on the species, the coefficient (e.g. 0.25) could change, and the variables D2 and H could be raised to exponents just above or below 1. However, these two equations could be seen as an “average” of all the species’ equations.

The root system weighs about 20% as much as the above-ground weight of the tree. Therefore, to determine the total green weight of the tree, multiply the above-ground weight of the tree by 120%.

Determine the dry weight of the tree

This is based on an extension publication from the University of Nebraska.4 This publication has a table with average weights for one cord of wood for different temperate tree species. Taking all species in the table into account, the average tree is 72.5% dry matter and 27.5% moisture.

Therefore, to determine the dry weight of the tree, multiply the weight of the tree by 72.5%.

Determine the weight of carbon in the tree

The average carbon content is generally 50% of the tree’s total volume.

Therefore, to determine the weight of carbon in the tree, multiply the dry weight of the tree by 50%.

Determine the weight of carbon dioxide sequestered in the tree

CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen. The atomic weight of Carbon is 12.001115.

The atomic weight of Oxygen is 15.9994.

The weight of CO_2 is C+2*O=43.999915.

The ratio of CO_2 to C is 43.999915/12.001115=3.6663.

Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.6663.6

Determine the weight of CO_2 sequestered in the tree per year

Divide the weight of carbon dioxide sequestered in the tree by the age of the tree

$$W\_ct = \frac{W\_sc}{At} \tag{5}$$

3.2. The weight of carbon dioxide that wood products can sequester every year

Table 1. The carbon sequestration of trees

Item	Amount	Percentage	Mean Life
Wood Pulp(paper/cloth)	408421	32.34%	2 months
Sawnwood & Roundwood	282634	22.38%	25 years
Wood Fuel (fuel)	54905	4.35%	2 weeks
Veneer Sheets (industrial material)	91981	7.28%	50 years
Wood-based Panels (architecture)	271170	21.47%	80 years
Plywood & fibre Board (furniture)	130191	10.31%	30 years
Forest Products (forest product)	23459	1.86%	8 months
Total Amount	1262761		

As mentioned in table 1, the carbon sequestration of trees is related to D, H and At, while the weight of carbon dioxide that wood products can sequester is correspondence to the carbon sequestration of trees.

On the other hand, the carbon sink of wood products is related to its mean life, the percentage of carbon sequestration and the proportion of each product in the number of harvested trees.

3.3. Entropy weight method

Entropy weight method is a universally mentioned weighting method that figures out value dispersion when we make decisions. The greater the degree of dispersion, the greater the degree of differentiation, and more information can be obtained. Besides, more valuable weight should be given to the index, and vice versa.

When we master the information about different wood product’s mean life, its percentage of carbon sequestration and the proportion of each product, we find that the dimension is inconsistent. To solve this problem, we use Entropy weight method to calculate their weight.

3.4. The Total Amount Of Carbon Sequestration Of Forest And Wood Product

$$cs\_all = cs\_tr + cs\_pr \tag{6}$$

3.5. Genetic Algorithm Model

A genetic algorithm is a systematic way for tackling both controlled and uncontrolled optimization questions based on a natural selection process that simulates biological evolution.

Problem one asks us to develop a carbon sequestration model to determine how much carbon dioxide a forest and its products can be expected to sequester over time.

This model should determine what forest management plan is most effective at sequestering carbon dioxide.

Solving which forest management plan is most effective in sealing carbon dioxide is essentially building an optimization model to make the tree carbon fixation amount of and as large as possible. Therefore, we corrected the variables in the total carbon fixation model (cs_all) described above. We developed a "single-target multivariate genetic algorithm model" based on the proportion of different kinds of tree products in the cut trees and the number of the harvested trees.

The genetic algorithm

The basic flow figure 4 of the model is on the left and the pseudo-code of the model on the right.

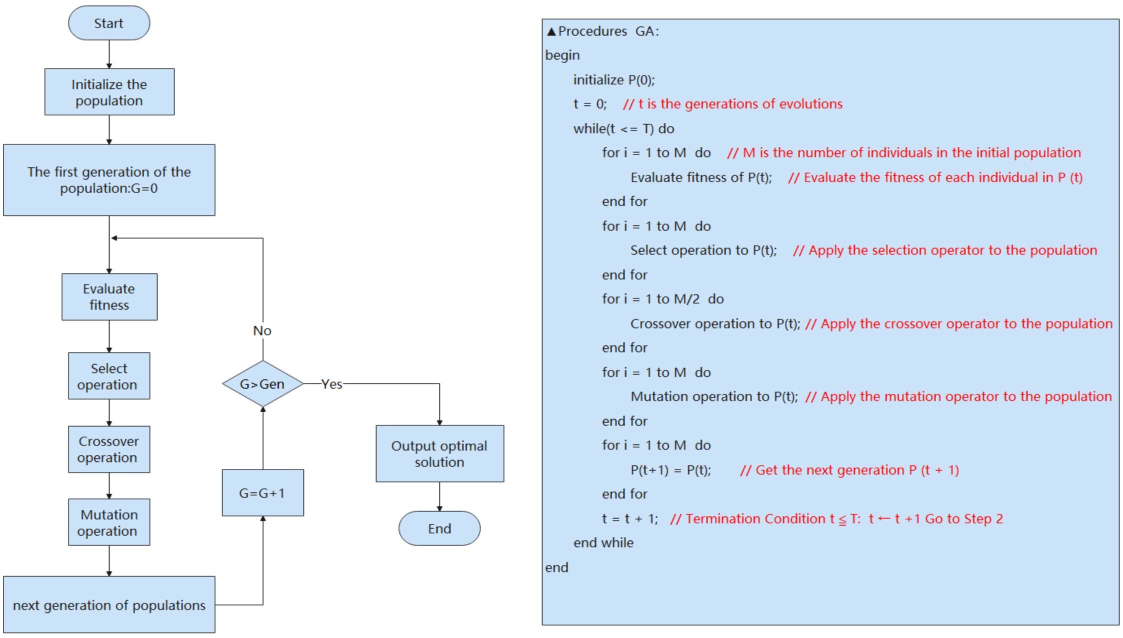

Figure 4. The basic flow chart of the model

According to the above total carbon fixation model (cs_all), we can obtain the tree carbon fixation formula and the tree products carbon fixation formula:

$$cs\_all = tree \cdot \left(cs\_fo \cdot (1 - delta\_tree) + w \cdot \sum_{i=1}^{5}(cs\_pr \cdot \mathrm{per\_tr}_i)\right) \tag{7}$$

Total amount of carbon sequestration function

$$cs\_fo = tree \cdot (1 - delta\_tree) \cdot forestry\_cs(diameter, height, ta) \tag{8}$$

Forest carbon sequestration function

$$cs\_pr = \begin{cases} tree \cdot delta\_tree \cdot w \cdot \sum_{i=1}^{5}(cs\_fo \cdot per\_tr_i \cdot \mathrm{rate\_cs_i}), & if\ \widehat{product}\_a_i < 1 \\ tree \cdot delta\_tree \cdot w \cdot \sum_{i=1}^{5}\frac{(cs\_fo \cdot per\_tr_i \cdot \mathrm{rate\_cs_i})}{product\_a_i}, & if\ \widehat{product}\_a_i < 1 \end{cases} \tag{9}$$

Wood Products carbon sequestration function

$$tree, w \tag{10}$$

is the data we can account.

$$diameter\ , height\ , ta\ , \widehat{product}\_a_i\ , rate\_cs_i\ \ (i = 1 \sim 5) \tag{11}$$

are the determined values, so it is not within the correction range of the optimization algorithm.

$$per\_tr_i\ , delta\_tree \tag{12}$$

are modifiable variables, as shown in the following table 2

Table 2. The variable names and descriptions

Variable Name	Description
$per\_tr_i\ , i = 1\sim5$	Ratio of felled trees to product i
$delta\_tree$	Percentage of trees felled per year

It is known that the typical wood products made of cut trees have 5 parameters; the number of cut trees is another variable, a total of 6 variables are optimized.

In this question, the chromosome composition form is shown in the table 3:

Table 3. The chromosome composition form

Carbon fixation	X1	X2	X3	X4	X5	X6
cs_all	per_tr1	per_tr2	per_tr3	per_tr4	per_tr5	per_tr6

1) Coding:

We need to encode the variables $per\_tr_i\ , i = 1\sim5$ and $delta\_tree$ as a symbol string. In this question, that is, it is represented by unsigned binary integers.

2) The fitness function:

$$G(x) = cs\_all(per\_tr_i\ , delta\_tree)\ ,\ i = 1\sim5 \tag{13}$$

3) Population initialization:

First, because the selection of the initial population is properly related to the diversity of the population and the rate of the algorithm convergence, the formula of the initial population of the real type chromosome type is adopted

$$X_i^j = \begin{cases} \lceil X_{i\,max}^j - X_{i\,min}^j \times random[0,1] + X_{i\,min}^j \rceil,\ i = 1\sim5\ , j = 1 \\ \lceil X_{i\,max}^j - X_{i\,min}^j \times random[0,1] + X_{i\,min}^j \rceil,\ i = 6\ , j = 2 \end{cases} \tag{14}$$

In the formula:$\lceil\cdot\rceil$ shows the function up; X_i^j notes the number of j^{th} species of i^{th} locus; $X_{i\,max}^j$ and $X_{i\,min}^j$ Represents the constraint maximum value and the minimum respectively; random[0,1], Represents arbitrary values within the interval[0,1]

4) Constraint processing

Second, the traditional genetic algorithm is modified to add the penalty function in the constraints to further treat the constraints.

5) Punishment function

Punishment function: used to solve the optimization problem under constraints. A constrained objective function can be transformed into an unconstrained objective function by using the penalty function.

6) pseudo-code

Pseudo code:

```
If fit Constraint:
      y = y
else:
      y = y + C;
end
```

In these cases, the C number can be defined as a very large number. In this question, $C = 10^{30}$

Because the constraints are not satisfied, even if the function value is very large, thus affecting the selection operation even if the function value to the roulette is extremely small, that is, there is little possibility to choose this gene to continue the subsequent operation, thus completing the constraints on the variable.

According to the requirements, we want to make the total carbon sequestration amount (cs_all)as large as possible. So we establish this optimization model.

$$Max\{cs\_all\} \tag{15}$$

Four temperature bands were optimized for the next 30 years, and six variables, to obtain a variable matrix of 30x6x4.

Due to the excessive data volume, only the specific tropical parameters are presented.

As shown in the figure below, although the overall optimization of the genetic algorithm is still decreasing, the total carbon fixation amount is significantly higher than the unoptimized total carbon fixation amount. The results are shown in the Figure 5.

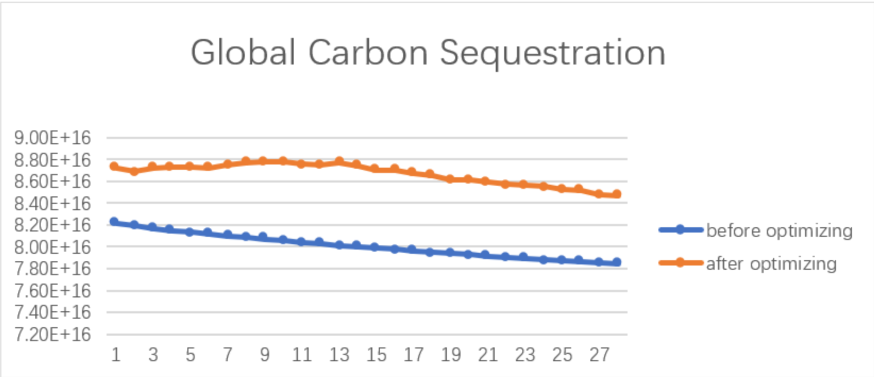

Figure 5. The global carbon sequestration

4. Conclusions

As the great amount of greenhouse gases release into the atmosphere, climate change gives a tremendous threat to people. However, forest have a strong ability to sequester carbon dioxide. To optimize forest utilization for forest managers, we develop a decision-making model.

To predict the amount of carbon sequestration, We develop a carbon sequestration model by using the entropy weight method to determine the percentage of the 6 variables. Second, we use the genetic algorithm to optimize the model.

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