ISSN 2616-5872 Vol.4, Issue 3: 11-15, DOI: 10.25236/AJEE.2022.040303

Study on Tree Growth Model and Carbon Sequestration Based on ABM Model

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Abstract: *Environmental protection is a key link in the process of global greening. It is very important to formulate a scientific forest management plan to meet the comprehensive social interests of different regions while increasing forest carbon sequestration. Therefore, this paper first constructs an ABM simulation model to describe forest growth. The growth model of single tree and its interaction with environment were introduced, and then the carbon absorption model of forest and its products was developed. We use genetic algorithm to describe the model, phase out the solution with low fitness value, and maximize the total carbon sequestration of the whole forest in a given time.*

Keywords: *Sustainable development; Effective strategies; GA optimum*

1. Introduction

With the economy continues to evolve, our human activities are affecting climate change more and more frequently, and the main reason for this is the increasing greenhouse gas emissions. Data show that the concentration level of carbon dioxide has increased by 50% in the past 30 years. Carbon dioxide can cause a range of adverse effects, including rising sea levels and the occurrence of extreme weather. Apparently, it has seriously affected all the creatures living on Earth. Forests, as the lungs of the earth, can effectively reduce the amount of greenhouse gases that have been emitted in the air, and the various wood products produced by forests also have the function of isolating carbon dioxide [1]. But forests are valuable asset and we need to use them sparingly. Therefore, we need to construct a model of the management to forest can meet all aspects of human needs as much as possible.

2. Forest Community Model

2.1. Establishment of Forest Community Model

This paper found that forests have differences in many ways, such as composition, region, rate of deforestation and so on. For better description, we first define a sub-model named Single Tree to record the situation of an individual tree [2]. Then, we can include multiple sub-models into our Forest Community Model, which forms a forest.

2.2. Single Tree Growth Model

For the sake of simplification, we choose some representative indicators here to identify a tree, and other less important attributes are ignored. The parameters are as follows:

TYPE: species of the tree, quantized as a number between 0 and 1, 0 refers to coniferous, 1 refers to broad-leaved, and mixed is between 0 and 1.

MASS: current mass of the tree, in t.

KMASS: the maximum mass tree can grow to, in t.

2.3. Growth of a Single Tree

Introduce a growth factor called K0 to quantify the growth rate of the tree. Here, K0 is determined by the type of the forest. We assume that, if the forest is coniferous K0 is 1.5; if it's broad-leaved K0 is 1.8. If it’s a mixed forest, we assume that all trees grow at the same rate, and K0 is defined as:

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$$K0=1.5+0.3*TYPE \tag{1}$$

At the same time, based on the general growth law, we assume that a tree grows in an S-shaped curve. Considering that the growth speed of trees in reality is usually related to the environmental factors and forest density, so the actual mass of trees is defined as:

$$MASS = envir \times rou \times MS(t) = envir \times rou \times K0 \times KMASS \times \frac{1}{1+e^{-t}} \tag{2}$$

Where *envir* is the coefficient determined by environmental conditions, *rou* is the coefficient determined by the density of the forest.

The new mass can be determined below:

$$MASS=MASS-resize \tag{3}$$

Where resize is the amount the tree has been cut down.

For convenience, we select three main parameters to measure the forest, they are:

TYPE: the type of the forest, same as the type of Single Tree Sub-Model.

NUMBER: the number of trees in the forest.

AREA: the total area of the forest, in m^2.

Seeing that a forest can be diverse, we take a random approach here to generate a forest named treelist [3]. We use the Single Tree Sub-Model above to instantiate each tree in treelist, and assign it a random number between 1 and 100 as its mass. The species of each tree is determined by the type of forest, which means we assume that a forest is either pure coniferous, pure broadleaf, or mixed. Since the growth and deforestation of a forest is largely determined by larger trees, we also need to count and mark them first. According to the literature, we define that tree with a mass greater than 70t is marked as big tree, and record their number as parameter bignum.

2.4. Growth of Forest Community

The growth of forest consists of two parts, one is the growth of original trees, and the other is the reproduction of new trees. Assume that the time period of both is one year.

(1) Growth of original trees

We first calculate the density factor *rou* of the forest using the following formula:

$$rou=max(2-bignum/AREA,0) \tag{4}$$

When *bignum* is greater than *AREA*. Otherwise, *rou* is 1.

Then plug *rou* into Single Tree Sub-Model to figure out the growth of each tree. We can see that *rou* is between 0 and 1, which means the denser the trees are, the smaller the *rou* is, and the slower the trees grow.

(2) Reproduction of new trees

When the density of large tree (defined as *bignum* / *AREA*) in the forest is between 0 and 1, we agree that large trees can produce small ones. The number of births in this forest is determined randomly by the formula below:

$$ranbreed=int(bignum*random,uniform(0.05,0.1)) \tag{5}$$

Where *ranbreed* is the number of births by forest, and *bignum* is the total number of large trees in the forest calculated above.

Then, instantiate new trees at the number of bignum with Single Tree Sub-Model.

After the calculation of the old and new numbers, the reproduction rate ranges from 0.1 to 0.3. Therefore, we randomly generate a number within the range above, and calculate the number of stumps that can be regenerated after felling:

$$Ran=int(random.uniform(0.1,0.3)*felllenth) \tag{6}$$

Where *felllenth* is the number of trees to be cut down, and it is calculated by the following formula:

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$$felllenth=int(fellrate*bignum) \tag{7}$$

Where *fellrate* is the rate of deforestation.

Stumps marked in the range of 0 to *ran*-1 will regenerate, while stumps marked between *ran* and *felllenth* will be removed.

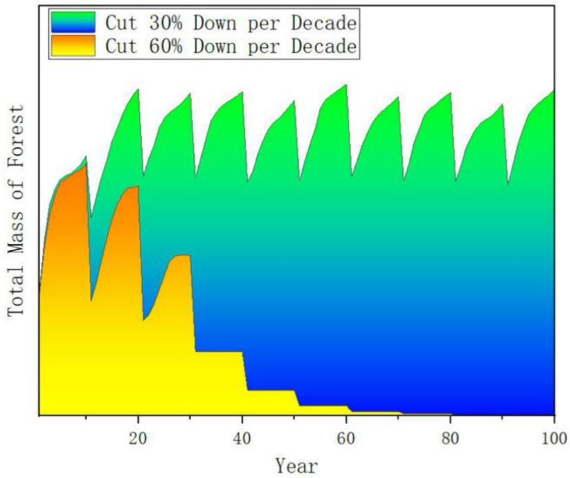

Figure 1: Forest growth model

3. Carbon Sequestration Model for Forests and its Products

We use the genetic algorithm (GA) to describe this model. By simulating growth, reproduction and deforestation these three processes of a forest population, the solution with low fitness value will be gradually eliminated, and a set of optimal solutions will be chosen to maximize the total carbon sequestration of the whole forest over time. Two variables are taken as the input of the model. They are: Felling Time Interval (unit: year), and Felling Rate (per time). Firstly, we use the Forest Community Model to randomly generate a initial forest. Then, we calculate and evaluate the adaptability of each individual in the forest community through the process of parent crossover, offspring mutation and repeated iteration, until we reach an optimal solution for the objective function given to this model.

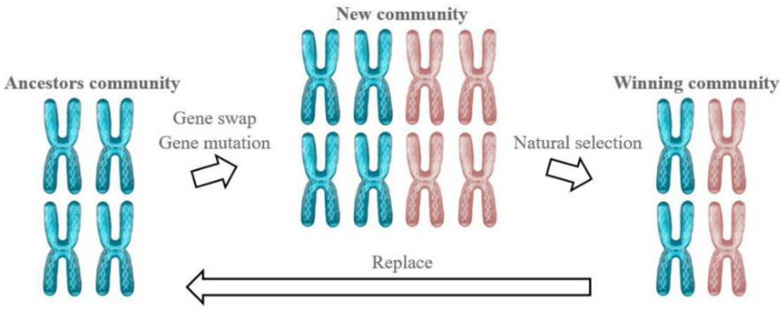

Figure 2: Genetic algorithm

3.1. Forest Community Growth-Felling model

The growth of original trees is mainly related to environmental conditions and forest density, in which the environment is only related to the geographical location, while the density is related to the ratio of the number of large trees to forest area.Therefore, Growth in this community model mainly depends on the physical composition of the forest itself, while Felling is determined by the input parameters of the whole model.

3.2. Carbon Sequestration Model for Forests and its Products

The carbon sequestration mainly comes from two aspects, one is the carbon sequestration of forest living trees, and the other is from the forest products. After consulting literature, we find that carbon

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sequestration in forest living trees is mainly determined by the relationship between biomass and growing stock [4]. However, considered that the relationship between them is relatively complex, we assumed that carbon sequestration in forest living trees here is only related to the mass and carbon content of trees. We record the remain mass of the forest after cutting as Mr, the carbon content per t as Cf, and the biomass expansion factor as ρ, so the total carbon sequestration in living trees can be defined as:

$$C_B = \sum M_r \times C_f \times \rho \tag{8}$$

Where C_f is determined by the type of the tree. The average carbon content of broad-leaved tree is about 0.45, while conifers is about 0.55.

For forest products, since the flow direction is hard to track, we refer to the general classification of forest products and carbon attenuation to calculate their carbon sequestration. We assume that the total mass of felled trees is M_h, and the yield rate after processing is γ. So the carbon sequestration in the final forest products is:

$$C_{HWP} = \sum M_H \times C_f \times \gamma \tag{9}$$

Generally, the yield rate of paper is 0.7 and that of artificial board is 0.65. Here, for convenience, we uniformly take the yield rate γ as 0.67.

To sum up, the total carbon sequestration finally is:

$$C_t = C_B + C_{HWP} = \sum M_r \times C_f \times \rho + \sum M_h \times C_f \times \gamma \tag{10}$$

4. Conclusions for Carbon Sequestration Model

For contrast, we formed three kinds of forests as examples: pure coniferous (*TYPE*=1), pure broad-leaved (*TYPE*=0) and mixed forest (half coniferous and half broad-leaved, *TYPE*=0.5). The initial number of trees is all 1000 and area is 800 m^2. And all trees in each forest are randomly generated for the first time. The most effective management plan for each forest community and its corresponding carbon sequestration are shown below.

Table 1: Carbon sequestration for different types of forests

TYPE	Felling Time Interval	Felling Rate	Carbon Sequestration
Coniferous	4	0.21	301470.35
Broad-leaved	8	0.40	332119.74
Mixed (0.5)	10	0.53	356849.27

The results show that for a random forest with 1000 trees and an area of 800 m2, the maximum amount of carbon sequestered by pure coniferous forest is 301470.35 under the condition of cutting interval of 4 years and each cutting rate of 0.21. The maximum amount of carbon sequestered by pure broad-leaved forest is 332119.74 under the condition of cutting interval of 8 years and each cutting rate of 0.40. And the maximum amount of carbon sequestered by mixed forest is 356849.27 under the condition of cutting interval of 10 years and each cutting rate of 0.53.

5. Conclusion

At present, economic development, environmental protection and social interests are major issues that need to be considered in human development. Therefore, it is very important to formulate a scientific forest management plan to meet the comprehensive social interests of different regions while increasing forest carbon sequestration. We have developed a forest management planning model to support managers' decisions. Firstly, forest growth is described based on ABM simulation model, which can be used to simulate the growth, reproduction and regeneration of individual plant or forest community in different environments and different tree species. Then the carbon absorption model of forest and its products is used and the model is described based on genetic algorithm to gradually eliminate the solution with low fitness value and maximize the total carbon sequestration of the whole forest in a given time. Finally, the best cutting plan and cutting speed are obtained.

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References

[1] Zhang XueDong, Li Feng, Zhang JianHua. Preliminary study on forest carbon storage and carbon sink value in Wuyuan County. Modern agricultural science and technology, 2011(3): 217-218.

[2] Wu X P, Zhang Y, Ma K P. Population distribution and dynamcs of Quercus liaotungensis, F raxinus rhynchophylla and Acermono in Dong Ling Mountain Beijing [J]. Acta Botanica Sinica, 2002, 44(2): 212.

[3] Cheng Y, Lin Ming, Yang Gang, Huang X Y. Forest dynamic succession simulation based on individual plant growth model. Journal of Beijing Forestry University (06), 96-106. doi:10.13332/J.1000-1522.20170016.

[4] Guo M H, Liu Y. Research Progress on carbon sequestration and carbon content of wood. World Forestry Research, 2014: 50-54.