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Research on Forest Management System Based on Cellular Automata

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Abstract: We can't avoid the problem of greenhouse effect anymore, since the release of greenhouse gas still increases drastically year by year. It has posed a severe threat to our human beings which pushes us to cut down the release of greenhouse gas, especially the carbon dioxide. However, this is not enough and we try to look for more methods to sequestrate the carbon. There is already some evidence that we can cut down an appropriate amount of trees to reach our goal. Our model is based on cellular automata, we regard the tree as cells, and establish a rule that fully considers the tree lifespan, logging period, logging probability, planting probability on cell status, and updates the cell state with factors above. After consulting the information, we find out how to calculate carbon sequestration in this model. According to it, we observe the annual carbon fixation amount of a forest system under different logging probabilities. So that we obtain that when the cutting probability is great and extremely small, the forest ecosystem is unstable on the fluctuations of carbon sequestration over time. Only when cutting probability is moderate and suitable for the real situation of this forest, the carbon sequestration tends to be stable at last. Thus, we determine the effective forest management to store CO2.

1. Introduction

To minimize the impacts of climate change, we are forced to take immediate action to cut down the volume of greenhouse gases in the air. We used to pay more attention on simply reducing their emissions. But it turns out that we need to make efforts with biosphere or mechanical approaches to boost our storage of carbon dioxide sequestered from the air. The experts call this process carbon sequestration. [1]

Among various environment where sequestration happens, forests are integral on account of its large scale and vibrant vitality. Their function lasts long, even covering the period during which it has become a lifeless product. Surprisingly, some forest products surpass the lifespan of their matrix. Thus, with newly born trees, they result more carbon sequestration over time in comparison with the carbon sequestration benefits of not cutting forests at all. [2] From a macro perspective, proper forest management strategies instead of an excessive one can lead to better carbon sequestration. [3]

2. Forest Cutting Probability Model Based on Cellular Automata

We use an atypical cellular automata model, [4] and establish the rules of its updating process. There are 11 states in our primary model, value 0 represents an empty land, value 1 represents a newly born tree, when the tree gets older, the value gets larger. We show that in Figure 1.

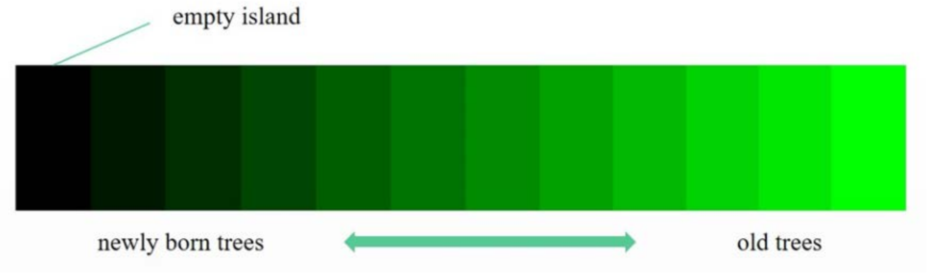


Figure 1: cell status of corresponding color

First, we judge the age of the tree to see whether the tree exceeds its lifespan, and then we can judge the state of the cell. [5]

Let the life be T, the age be i, the state of the cell be veg. Then we consider carbon sequestration. We set that the amount of carbon sequestration is proportional to time. Then, the amount of absorbed carbon dioxide per year of each tree is B, and the carbon sequestration amount of a cell is $i * B$. We show the value of veg in Equation 1.

$$veg = \begin{cases} i & i <= T \\ 0 & i > T \end{cases} \tag{1}$$

Next, we consider the remaining trees whose age is no longer than T, since the cutting only happens after a tree has grown up, we put the limit of mature age T_1 into our model, and we add the probability of cutting P_{cut} into our consideration, hence we get when $T_1 < i < T$, the value of veg will change after cutting, we show that in Equation 2.

$$\text{veg} = \begin{cases} 0 & \text{being cut with } P_{cut} \text{ probability} \\ i & \text{not being cut with } 1 - P_{cut} \text{ probability} \end{cases} \tag{2}$$

Conversely, after we replant the empty cell, the value of vegwill change accordingly, we show that in Equation 3.

$$\text{veg} = \begin{cases} 1 & \text{being replant with } P_{\text{plant}} \text{ probability} \\ i & \text{not being replant with } 1 - P_{\text{plan probability}} \end{cases} \tag{3}$$

To create a circle, we introduce the probability of planting new trees. After an empty cell being planted, the state of it will immediately change from 0 to 1.

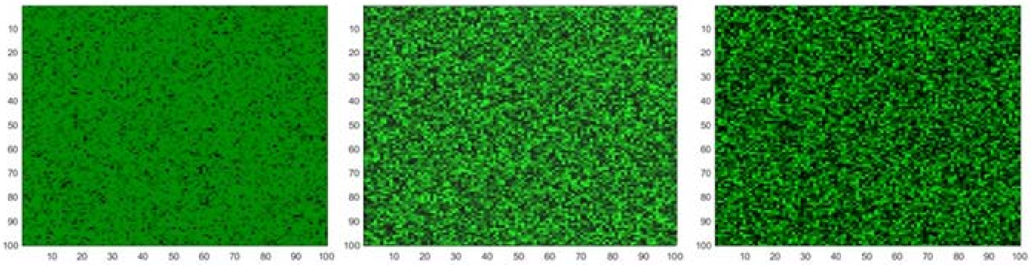
Afterward, we deal with the part being cut down. Since wood forest products can store carbon for a relatively long time, especially the landfill of waste products, or even long-term storage due to the long service life. We examine that most products made from logs have a limited life span, then we give that the product has an annual loss of carbon with A%, thereupon, we see that in trees that have been cut down, their initial carbon storage s is proportional to their age, which will be represented by veg and this value will keep decreasing year by year, we suppose that one product have been used for N years, its present value s is:

$$s = veg * (A\%)^N \tag{4}$$

Now we finish all the preparation, we can determine the equation 4 and 5 of carbon sequestration, where S represents the total value, s represents product value, sc represents the value of the living trees. Veg_{sum} represents the result of the veg value in total, 18.3 is a constant value, meaning that the amount of a tree to sequestrate carbon dioxide per year is 18.3 kilograms

$$S = s + sc \tag{5}$$

$$sc = 18.3 * Veg_{sum} \tag{6}$$



early stage middle stage later stage

Figure 2: growing situation of a forest

We build a forest here as an example. We display the growing situation of this forest in Figure 2. Black cells represent empty areas where we plant no trees. Since there were no trees at the very beginning, the image was black. The first year, we plant several trees in certain cells. As time goes by, their color changes from dark green to bright green. Given that grown trees are prone to be cut with P_{cut} probability. Thus, in the second picture, the green is exuberant and the green cells are different from the first graph, which implies that some black cells have been planted with new trees and some trees have been cut down or died naturally. But the brightness of the whole graph still changes a little in the middle stage. However, in the later stage, it doesn't change too much anymore. We can say that the whole system of this forest is stable now.

3. Model Solving

Figure 3 presents that the amount of carbon sequestration every year of this forest will change with the cutting probability P_{cut}. When the tree is older than the expected life span, they will die and after that the new trees will grow with a certain probability. If we barely cut the forest, depending more on its natural succession, we see that the curve fluctuates dramatically. It suggests its vulnerability especially in our real complex world with inevitable human-interference.

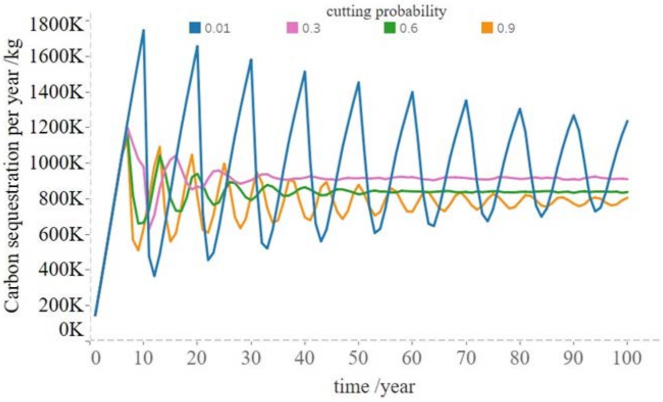


Figure 3: carbon sequestration with different cutting probability

When P_{cut} gets larger, the amplitude of the curve's fluctuation gradually decreases, and it will not increase too much unless the cutting probability is too large that is unrealistic. We know that when P_{cut} is too large, excessive deforestation will destroy the ecological balance. It corresponds with our outcome.

If we analyze one curve, we discover that when a tree starts to grow, the annual carbon sequestration amount is unstable, showing upper and lower fluctuations. When P_{cut} is at a middle range, the annual carbon sequestration amount will tend to be an equilibrium value in a relatively short period. From the figure 3 we obtain that the final tending equilibrium value gradually decreases when the P_{cut} ranges from 0.3 to 0.9. We do some research on four kinds of forests with different P_{cut}.

4. Conclusion

We find that different forests have their own proper P_{cut}. When we cut a forest with P_{cut} probability, its carbon sequestration will eventually reach an equilibrium, in the mean time, the ecosystem will reach its balance point. And the stability of forest ecosystem is a vital factor when managing this forest. Therefore, we need to find the corresponding P_{cut} to accomplish the keeping-in-balance program. And under P_{cut} probability, we get the best plan of forest management to store carbon dioxide.

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