Research on optimal Forest Protection algorithm based on simulated annealing algorithm

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Abstract: The situation of global greenhouse gas emissions is becoming more and more serious. This paper aims to design a forest management plan that can effectively fix carbon and achieve economic benefits. According to the practical application background and specific management requirements of carbon sequestration in the forest ecosystem, a mathematical model of optimal management scheme of forest ecosystem was established to balance the benefits of environmental protection and economic development. The optimal forest ecosystem management scheme is determined comprehensively by using a simulated annealing algorithm, taking into account many factors, including tree age, tree species, terrain distribution, and tree lifespan, to find a balance between the value of cutting forest products and the value of allowing forests to continue to grow and carbon sequestration as living trees, including the design of forest management strategies, including appropriate logging.

1. Introduction

With the deterioration of the global climate and environment, greenhouse gas emissions have threatened the survival and development of human beings. The environmental situation is not optimistic. However, it is far from enough to reduce the emission of greenhouse gases in production and life [1]. We need to increase the amount of carbon dioxide storage sequestered from the atmosphere by the biosphere or mechanically. This process is called carbon sequestration.

The concept of forest ecosystem management strategy began in the United States in the last century and was subsequently practiced in the state-owned forests of the United States, forming a preliminary theoretical and research model [2]. Forests can sequester carbon dioxide in living plants and products made from trees, including wood, plywood, paper, and other wood products. These forest products can still sequester carbon dioxide during their life cycle.

2. Carbon sequestration model

2.1. Model building

Calculating carbon sequestration in forest ecosystems is generally calculated by multiplying the existing amount of vegetation biomass directly or indirectly measured by the carbon content rate in the biomass [3]. Sample carbon content= Sample carbon content/sample dry weight × 100%.

According to the survey of each tree, the vegetation of the cold temperate coniferous forest per unit area is mainly divided into four categories. Namely, trees (trunks, branches, leaves, bark, and roots), shrubs (including roots), herbs (including roots), and Litter, taking the data of the average carbon sequestration of each component of the arbor layer of five forest types in different periods as an example: (standard average carbon sequestration

Table 1. Average annual carbon sequestration of different tree species.

Forest types	stage	Trunk	Branch	Leaf	Bark	Root	Total
	young	10.2	1.98	0.13	0.17	5.79	18.27
Native larch	middle	51.46	12.06	0.44	0.76	20.7	85.45
	old	107.61	27.51	0.76	1.23	37.08	174.19
Betula	young	4.81	4.3	0.73	2.1	3.64	16.04
platyphylla	middle	17.81	17.6	1.66	5.46	9.3	49043
forests	old	26.01	72.11	2.25	7.78	13.15	75.36
Pinus	young	4.53	11.65	0.71	0.63	4.72	43.47
sylvestris	middle	26.15	28.44	1.64	1.24	8.94	103.81
var	old	35.17	62.24	2.55	1.7	12.52	165.46
Quercus	young	3.94	8.05	0.48	1.1	1.72	9.15
mongolica	middle	32.87	15.82	1.21	2.4	3.95	212
forests	old	144.21	39.77	2.74	7.24	12.74	69.02
Populus	young	4.34	1.51	1.47	1.27	5.53	25.02
davidiana	middle	10.14	3.64	2.79	2.47	8.82	43.04
forests	old	48.7	12.6	6.07	2.41	15.54	80.38

From this data, it can be seen that with the increase of time (tree age) of different tree species, the content of biological carbon sequestration in different parts of the tree species is increasing[4], and the carbon sequestration capacity is also gradually improved.

2.2. Carbon capacity estimation

In order to simulate the growth process of forest volume, it is necessary to calculate the annual growth of forest volume by region, tree species, and forest age group (5 forest age groups). The age combination is used as the annual growth curve of the stock volume of this tree species [5]. After all tree species in each region have established their annual growth curve of stock volume, trees grow each year according to this curve; the sum of the growth of all tree species in all regions is the annual growth volume of national forest volume.

(1) First, calculate the stock volume per unit area of the forest within the five forest age groups.

It is assumed that $\overline{V}$ is the carbon sequestration per unit area of the forest in a particular tree species and a specific age group in a certain area, m^3/hm^2. V is the forest stock volume per unit area of a particular tree species and a certain forest age group in a specific area, m^3. S is the total forest area of a particular tree species and a specific age group in a certain area, hm^2. The relationship between the three is $\overline{V} = V / S$.

Calculate the total annual increase in carbon sequestration in forests within each forest age group. Since we assumed that the forest stock volume in the forest age group increases linearly with the increase of the forest age [6], we use Δv represents the annual increase in forest carbon sequestration in a particular tree species and a specific age group in a particular area, $m^3 hm^{-2} a^{-1}$, but Δv is equal to the corresponding annual increase of the stock volume between the average forest age and the earliest forest age in a particular forest age group.

$$\Delta v = \frac{\overline{v} - V_{\min}}{\overline{A} - A_{\min}} \tag{1}$$

To make the calculations possible, we assume the average age of forests within a certain age group [7] $\overline{A}$ equals the average value of the upper and lower limits of the forest age used when the tree species are divided into age groups. Amax is the maximum age of a certain tree species and a certain age group in a certain area.

$$\overline{A} = 0.5(A_{\max} - A_{\min}) \tag{2}$$

The stock volume corresponding to the minimum forest age A_min and the maximum forest age A_max in a certain tree species and a certain forest age group in a certain area are expressed as V_min and V_max, respectively, m^3/hm^2; then the relationship between the two is:

$$V_{\max} = \Delta v(A_{\max} - A_{\min}) + V_{\min} \tag{3}$$

The annual growth curve of forest stocks depicts changes in forest stocks, so after calculating the forest stock for each year, the amount of stock needs to be converted into biomass and carbon storage. The accumulation-biomass conversion equation used has two sets of parameters available: one is to describe the relationship between carbon sequestration and biomass of the same tree species in a linear equation:

$$B=b_1 v+b_2 \tag{4}$$

Thereinto, B is forest biomass, Mg/hm^2. V is the total carbon sequestration in the forest, m^3/hm^3; b1b2 is the coefficient.

The biomass of forests and their products are converted into carbon stocks using a carbon coefficient of 0.5.

Values below the annual average total forest carbon sequestration (corresponding to forest tree distribution and tree species) have a negative impact on the forest carbon sequestration process[8], and forest ecosystems should be avoided from reaching such a state that is, moderate logging is required.

Therefore, the types of trees cut and the distribution of felled trees can be judged from this indicator. Higher than the annual average total amount of forest carbon sequestration (corresponding to the forest distribution and forest species) is suitable for the ecosystem to self-repair and regenerate forest conditions. The forest ecosystem needs to be related protection, equal to the annual average total forest carbon sequestration value (corresponding to the forest distribution and forest species) [9]. The corresponding actual situation is the transition point of the forest, which is a transition from located in two states. Due to the dynamic development of the ecosystem [10], the transition point cannot be maintained for a long time. It is also in line with the actual forest development situation.

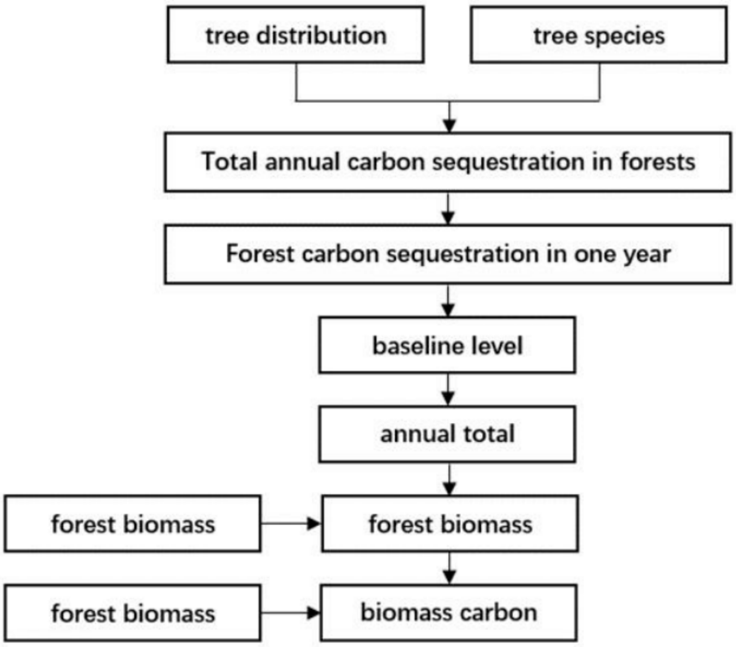

Figure 1. Specific solution ideas.

It can be seen from the curve of the forest stock growth process that when the forest age reaches the upper limit of the old stage, the forest stock reaches the maximum, that is, the carbon sequestration of the forest ecosystem reaches the peak. The forest biomass carbon storage is called the forest biomass carbon capacity. The difference between the forest biomass carbon capacity and the current (or a certain year) forest biomass carbon storage is called the forest biomass carbon sequestration capacity.

3. Establish an optimal management plan

It is modeled using a simulated annealing algorithm. The algorithm can consider the interaction between different management objectives, between forests in different regions, and even between different times on the overall carbon sequestration of forests, and according to the degree of demand of forest managers for each goal, the simulation analysis and comparison of different forest management plans can be carried out. The best management plan can be automatically selected to achieve each goal to the greatest extent.

Assuming that the carbon sequestration of a forest at a certain time α time is E(α), then the overall management plan of the forest in the time α from decision i to decision j follows the following law:

(1) If E (j) ≤E (i), then the forest management plan should be converted:

(2) If E (i) ≤E (j), then the forest management plan has a probability of acceptance in a time α state.

The probability of acceptance ise ((E (i)-E (j))/KT)

Where K is the Boltzmann constant in physics and T is the time variable in which the forest is located.

At a given moment, the various influencing factors of the forest will have a complex impact on the overall carbon sequestration capacity of the forest, and at some point, the different benefits of the forest will reach a balance, that is, the forest is at the global average carbon sequestration level.

The carbon sequestration levels of forests at the time α are consistent with the Boltzmann distribution:

$$P_T(x=i)=\frac{e^{-\frac{E(i)}{KT}}}{\sum_{j\in S} e^{-\frac{E(i)}{KT}}} \tag{5}$$

Where x represents a random variable for the current period of the forest, and S represents a set of decisions. The simulated annealing algorithm optimizes the selection and type of deforestation sites and selects D actual logging points from n-m selectable sites. Before running the algorithm, all optional felling points are encoded. In order to be consistent with the mathematical model of the forest ecosystem, the encoding starts at m+1. m+1, m+2, ..., n is assigned a value to each optional felling point with a variable of 0-1 to determine whether to choose the felling point or equal to 1 otherwise 0. When determining the initial feasible decision. D actual cutting points are randomly selected so that the decision variable X_k=1. Next, define the neighborhood, which differs from the decision variable with only one position in the initial decision.

In the process of searching for neighborhoods, if E (X_new) ≥E (X_old), the neighborhood decision is taken as the current optimal decision, and the search continues in the neighborhood of the current optimal decision.

If E (X_new) ≥ E (X_old), the decision to negate logging is accepted at the probability of $\exp(-\frac{E(X_{new})-E(X_{old})}{T})$

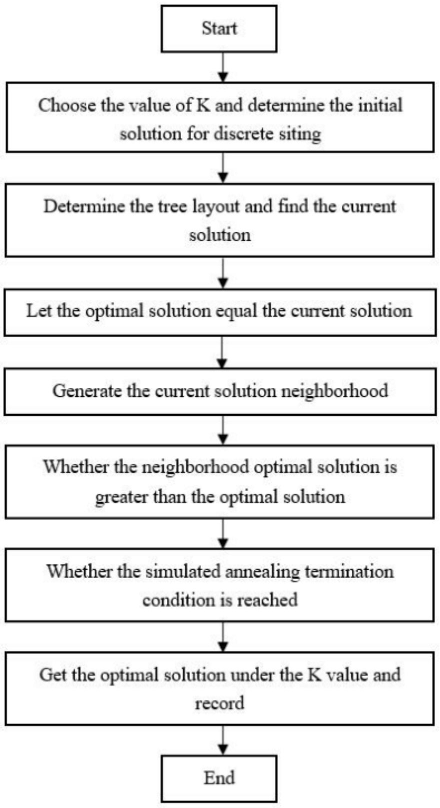

Figure 2. Algorithm step.

Write the program with Matlab 2018b, set the algorithm parameters: T=100, the number of iterations N_c=50, the time speed γ=0.75, and the calculation is terminated when the year drops to t_{min}=0.01. When running the algorithm program, the k value is taken sequentially(k=1,2,3,4,5) to obtain the objective function value, running time, and total annual carbon sequestration in each case.

4. Model result

Through computer simulation, some trees need to be cut down, and the distribution of trees is shown in the following figure. The structure of the stand system has been improved to a certain extent: The spatial distribution density of large-diameter forest trees has been optimized, and the minimum radius of large-diameter trees has been increased from the original 2.1 to 3.6 now, which is closer to the world's average forest area radius, and the data are more consistent with the annual average carbon storage data of forest ecosystems, and the retained forest distribution also provides nutrient space for the growth of large-diameter trees, and the management plan including logging obtained is more reasonable, effectively balancing ecological benefits and economic and social benefits, and achieving optimal management decisions.

Figure 3. The specific distribution of trees to be felled.

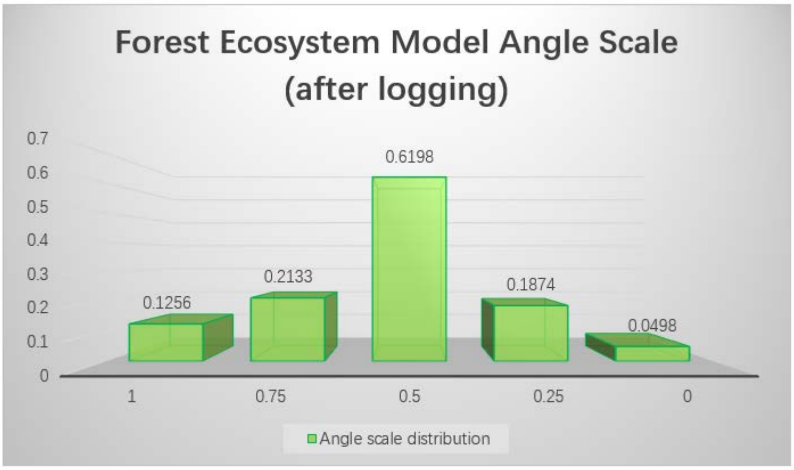

Figure 4. Forest Ecosystem Model Angle Scale (after logging).

Management decision factor priority: health index → diameter size → purpose index→ diversity index→ angle ruler→ minimum radius ratio→ size ratio. Determine the operating parameters: select the felling intensity of 15%, the diameter of the felling is 3m. In order to maintain the forest ecosystem health, stability, sustainability, and efficiency of carbon sequestration, it is necessary to ensure that each hypothetical individual tree in the model is healthy and pest-free. To ensure that the felled trees are mature, "maintaining the balance between environmental benefits and economic benefits of the forest ecosystem" is the goal and principle of the forest management plan. The forest with a low purpose index and diversity index should be preferentially taken as a decision to cut.

5. Conclusions

Because forest ecosystems can effectively reduce carbon dioxide content in the atmosphere by carbon sequestration. Therefore, this paper studies the forest ecosystem's carbon emission and uses MATLAB software to model and simulate the carbon emission of the forest ecosystem based on a univariate control experiment and simulated annealing algorithm. Based on the forest ecosystem, the carbon sequestration model needs to comprehensively consider ecological benefits (carbon sequestration) and economic and social benefits (proper cutting) and calculate the suitable cutting time and tree distribution position according to specific data. And then draw a specific implementation plan.

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