A study of forest management plans based on single-objective optimization

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Abstract. The global decline in forest area and massive greenhouse gas emissions have increased concern about the scale of forest carbon sinks, but the social value of forests as a source of timber and of forests themselves for tourism is also a focus of attention. The balance between forest carbon sinks and other values becomes a research question in this paper. We propose a forest management plan for forest managers by developing a carbon sink model and a forest management decision model. First, we developed a carbon sequestration model to determine how much carbon dioxide can be sequestered by the forest and its products over time. Then, we developed a single-objective optimization model with the goal of maximizing the amount of carbon sequestered. To develop a forest management plan, we selected six influencing factors: carbon storage, forest trees and their products, biodiversity, soil water storage, climate regulation, and landscape value, and then used hierarchical analysis to determine the influence weights of each factor, and then built a forest management decision model based on the single-objective optimization model. For specific forests, we initialize the model with specific parameters of the influencing factors and determine the transition points so that the model can be suitable for diverse forests and make a targeted management plan.

Keywords: Carbon sequestration; Single-objective optimization; Analytic Hierarchy Process; Forest management decision model.

1. Introduction

Forests are a major site for capturing carbon to reduce net greenhouse gas emissions due to high greenhouse gas emissions, global warming and glacial melting. Plants use photosynthesis to absorb carbon dioxide, and conditions such as biodiversity, forest products, climatic factors, and soil environment can affect the carbon sequestration effect of forests. Therefore, a carbon sequestration model is developed in this paper to determine the management plan of the forest.

In addition, it is shown that photosynthesis is more important than respiration in tree growth, which is called carbon sequestration. When respiration is close to photosynthesis, carbon sequestration becomes carbon emission, so the best forest management plan is not to prohibit deforestation, but to properly cut the forest to help produce forest products for economic benefits and better absorb carbon dioxide from the atmosphere, thus achieving carbon sequestration.

2. Forest carbon sequestration mode

2.1. Modelling of woody source biomass

The IPCC uses forest stock, wood density, bioconversion factor, and rootstock ratio as parameters to build a woody source biomass model from which carbon stocks are calculated, and its basic equation is.

$$C = V \cdot B_{EF} \cdot W_D \cdot (1 + R_{SR}) \cdot C_F \quad (1)$$

Where C is the carbon density of tree forest biomass (Mg /hm^2), V is the unit area of tree forest storage (m^3/hm^2); WD is the essential wood density (Mg/m^3) for converting trunk storage into biomass; BEF is the expansion factor for converting trunk biomass into above-ground biomass; RSR is the ratio of below-ground biomass to above-ground biomass; CF is the ratio of organic carbon to the total organic matter in tree biomass, also called carbon content ratio.

According to the criteria for the division of age groups of different dominant tree species and the renewal cycle as stipulated in [1], the average stand age of this age group was expressed by the middle value of the stand age band, and the average stand age of over-mature forest was set as 1.5 times of the lower limit of stand age, and the Logistic growth equation was used to fit the unit area accumulation of each dominant tree species in each region by combining the data of the unit area of each dominant tree species in different provinces in two successive forest resources inventories The correlation between the accumulation volume and the average forest age of each dominant tree species in each region was fitted using the logistic growth equation, namely.

$$V = a/\ (1 + b \cdot e{-}ct) \quad (2)$$

Where a, b, c are constants.

According to the research results of Qi Li et al. [2], finding a balance between the value of forest products and the value of carbon allowed to be sequestered in the forest. The Logistic equation curve [3] can be used to fit the relationship between area storage better - stand age for each dominant tree species in each region by examining the age, diameter at breast height, height, geography, and topography of trees in the field. As shown in Figure 1.

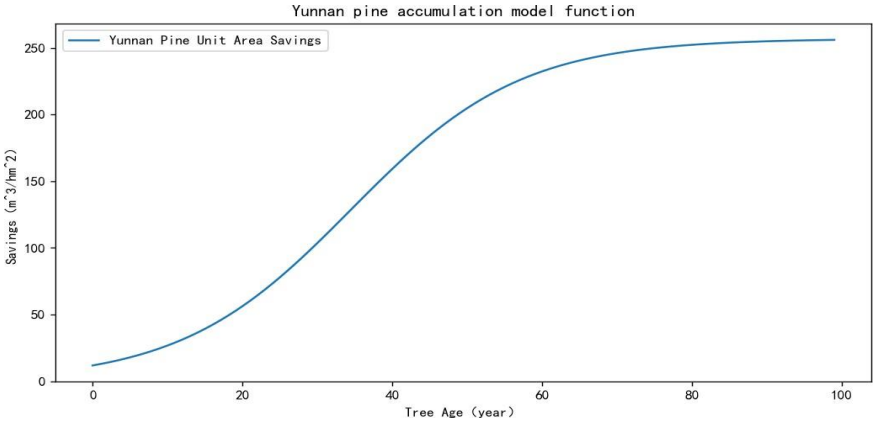


Fig 1. Yunnan pine accumulation model function.

2.2. Establishing a carbon stock estimation model

Since we need to protect the carbon sequestration of the forest and its products over time, we define Z as the carbon sequestration over some time. Z is the sum of the initial carbon sequestration of the forest and the changes in the forest and its products over a while. Here we make the first year of the study the base year, and here we assume that the loss of carbon stock due to tree cutting is ignored, and Z_1 is the initial carbon stock of the forest in the base year.

$$Z = Z1 + \Delta Z \quad (3)$$

$$\Delta Z = Z2 - Z3 + Z4 \quad (4)$$

Where Z_2 is the amount of carbon stored in a cycle due to forest growth, Z_3 is the amount of reduction due to deforestation in a time cycle, and Z_4 is the amount of carbon stored in a time cycle due to planting new trees.

$$Z_1 = \sum_{i=1}^{5} S_i C_{i,0} \quad (5)$$

$$Z_2 = \sum_{i=1}^{5} S_i \Delta C_i \tag{6}$$

$$Z_2 = \sum_{i=1}^{5} S_i \Delta C_i \; Z_3 = S_k \Delta C_{old} \tag{7}$$

$$Z_4 = S_k \Delta C_{new} \tag{8}$$

Where S_i is the area of the ith age group of the dominant tree species, ΔC_i is the carbon stock per unit area of the ith age group of the dominant tree species due to natural growth, and S_k is the area of the age-appropriate average forest trees felled. ΔC_{old} Is the carbon stock per unit area of age-appropriate trees due to felling, and ΔC_{new} is the carbon stock per unit area that can be sequestered by newly loaded trees in a time cycle.

$$\Delta Vi = Vi, \; t1 - Vi, \; t0 \tag{9}$$

$$Vi, t1 = a/\left(1 + b \cdot e{-}c\left(ti, 0{+}T\right)\right) \tag{10}$$

$$Vi, t0 = a/\left(1 + b \cdot e{-}cti, 0\right) \tag{11}$$

Where $V_{i,t1}$ is the carbon accumulation per unit area after one time period for the age group i of the dominant species, $V_{i,t0}$ is the accumulation per unit area in the base year for the age group i of the dominant species, $t_{i,0}$ is the average stand age in the base year for the age group i of the dominant species. T is the average life cycle of wood products.

$$\Delta Vold = V'old - Vold \tag{12}$$

Where $\Delta V_{old}$is the unit-area stocking of age-appropriate trees due to felling, V′old is the unit-area stocking of age-appropriate trees after the one-time cycle of growth. V_{old} is the unit- area stocking of age-appropriate trees in the base year, and t_{01} is the average stand age of age group I of the dominant tree species in the base year.

$$V'old = a/\left(1 + b \cdot e{-}c\left(t01 + 1\right)\right) \tag{13}$$

$$Vold = a/\left(1 + b \cdot e{-}ct01\right) \tag{14}$$

$$\Delta V\text{new} = V'\text{new} - V\text{new} \tag{15}$$

Where ΔV_{new} is the accumulation per unit area of newly planted trees due to growth, V'_{new} is the accumulation per unit area of newly planted trees after a one-time cycle. V_{new} is the accumulation per unit area of newly loaded trees in the base year.

$$V'new = a/\left(1 + b \cdot e{-}c\left(t\text{n} + 1\right)\right) \tag{16}$$

$$V\text{new} = a/\left(1 + b \cdot e{-}ct\text{n}\right) \tag{17}$$

It is by taking into account the felling of trees that the objective function is established, within the limit of the total area of forest-age trees, from the sum of carbon dioxide absorbed by the unfelled age-appropriate trees and the newly loaded trees and forest products.

$$\begin{aligned} &\min Z\{Z_1, \Delta Z\} \\ &s.t.\; S_t \le S_{old} \end{aligned} \tag{18}$$

S_{old} Is the total area of age-appropriate trees?

In summary, a logistic growth equation was fitted to the dominant species-forest age relationship using a wood volume source model with parameters such as forest stock, wood density, biological conversion factor, and rootstock ratio. Then, to ensure optimal carbon sequestration, a carbon storage model is developed under the objective function to solve for the amount of carbon dioxide absorbed by the forest and its products.

3. Forest management decision model

3.1. Determination of forest value indicators

In order to find a balance between managing forest carbon sequestration and other values of the forest, and thus to propose better management plans for forest managers, we evaluated the value of the forest in six aspects: forest carbon storage, the total value of forest trees and forest products, biodiversity, soil water storage, climate regulation, and landscape value through the results of literature [4]. The indicator system is shown in Figure 2.

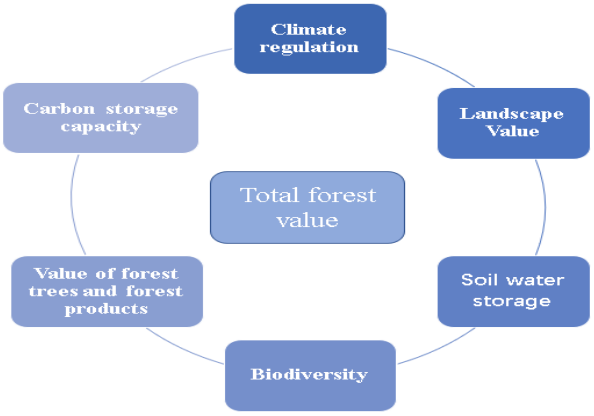


Fig. 2 Two or more references.

The value of one of the indicators is calculated by the formula.

(1) The value of carbon storage

From the carbon sequestration model of Question 1, the value of the carbon stock is:

$$E_1 = (Z_1 + \Delta Z)P_c \tag{19}$$

Where P_c forest fixed carbon cost (dollar/t).

$$Z_4' = (S_k + S_3)\Delta C_{new} \tag{20}$$

$$\Delta Z = Z_2 - Z_3 + Z_4' \tag{21}$$

(2) The total value of forest trees and forest products

$$E_2 = S_k \cdot V_{old} \cdot P_w \tag{22}$$

Where P_w is the international price of wood [5?]

(3) Value of forest for climate regulation

The most apparent microclimate improvement effects of woodlands are in temperature reduction and humidity increase. Global studies have shown that greening can reduce local temperatures by 3-5°C, up to 12°C. The climate -modifying value is measured using the alternative cost method (i.e., reducing electricity consumption for air conditioning) [6].

$$E_3 = A \cdot m \cdot n \cdot t \cdot s \cdot u, \tag{23}$$

Where E_3 is the climate regulation value of forest land (dollar), A is the area of forest land (hm^2), m is the number of trees per hectare of forest land (plants/hm^2), n is the number of trees equivalent to one air conditioner (units/plant), t is the working time of one air conditioner in one day (h/d), s is the number of working days of one air conditioner per year (d/a), and u is the power consumption of air conditioner per hour (yuan/(h-unit)).

(4) The value of forest water storage

The water conserved on forest land and water bodies is evaluated based on water balance. The value of the water conservation source is the annual water conservation volume multiplied by the water price, and the shadow project price can replace the water price.

$$W_{water} = (P - E)A = tA \tag{24}$$

Where W_{water} is the amount of cultured water (t), P average precipitation (mm/a), E is the average evapotranspiration (mm/a), A is the area of forest land (hm^2), and t is the local runoff coefficient.

The value of the forest to contain water is based on the cost of water storage in the reservoir project.

$$E_4 = W \cdot C \tag{25}$$

E_4 is the value of forested land to cover water (dollar), W_{water} is the amount of water covered (t/a), C is the cost of a reservoir (dollar/t)

(25) Landscape value of the forest

The forest landscape value is calculated by the formula.

$$C = \frac{A}{A_0} \cdot D \tag{26}$$

Where C is the daily environmental capacity of the forest and A_0 is the excellent area required for one visitor.

$$E_5 = \Delta t \cdot (\frac{S_5+S_1}{A_0} \cdot D \cdot A_1 \cdot \frac{1}{2} - S_4 \cdot A_2) \times 365 \tag{27}$$

$$S_4 = S_5 + S_3 \tag{28}$$

Where $S_3$the area of newly expanded trees is, S_4 is the total area of a new expansion, and S_5 is the new expansion area used as a scenic spot. A_1 Is the admission fee for the scenic spot, and A_2 is the money needed to develop each area unit.

(6) The value of biodiversity

The equation for the value of biodiversity is known from the species conservation willingness benchmark price method as

$$E_6 = \frac{r_0(1 - B_k)}{R} \cdot Q \tag{29}$$

$$B_k = (\frac{S_k}{S_0})^3 \tag{30}$$

Where Q is the willingness to conserve biodiversity, r_0 is the species of animals protected in this forest in the base year, R is the total number of first-class protected animal species recorded in China, and B_k is the reduction of first-class protected animal species due to deforestation.

Therefore, the total value of the forest is

$$E = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 \tag{31}$$

3.2. Establishing a hierarchical model

The decision problem is divided into three levels, the uppermost level is the objective level M, which is to select the most appropriate critical indicators for evaluating the total forest value; the lowermost level is the scheme level, X; and the middle level is the criterion level, which includes forest carbon storage, the total value of forest trees and forest products, biodiversity, soil water storage, climate regulation, and landscape value, as shown in Figure 3.

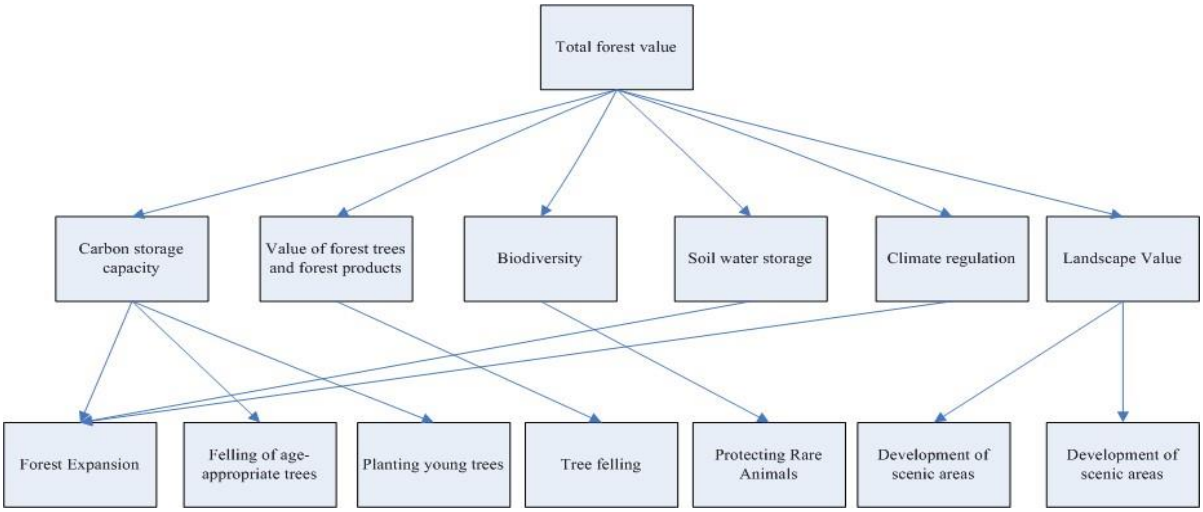


Fig. 3 Diagrammatic representation of the Analytic Hierarchy Process.

The judgment matrix M-C is constructed, and the six elements$C_1, C_2, C_3, C_4, C_5$and C_6 in the base layer C are compared two by two to obtain the pairwise comparison matrix, as shown in Table 1.

Table 1. Comparison Matrix.

M	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	8	2	5	3	9
C_2	1/8	1	1/6	1/3	1/6	3
C_3	1/2	6	1	5	5	7
C_4	1/5	3	1/5	1	1/3	2
C_5	1/3	6	1/5	3	1	7
C_6	1/9	1/3	1/7	1/2	1/7	1

Solving for the eigenvalues of M-C, it is easy to solve for $\lambda max = 6.4940$ and the weight vector ω_i =(0.3773, 0.0433, 0.3243, 0.693, 0.1568, 0.0291) ^{T}. From the formula$CI = \frac{\lambda max - n}{n-1}$, according to$CR = \frac{CI}{RI}$, it is calculated that CR=0.0784 <0.1, which passed the consistency test.

3.3. Modeling forest values

By evaluating the six indicators of forest value and applying the Analytic Hierarchy Process method to determine the value weights of each indicator, the total forest value is the sum of the product of the value of each indicator and its weight.

$$E = \sum_{i=1}^{6} H_i \cdot \omega_i \cdot E_i \quad (i=1, 2, 3, 4, 5, 6) \tag{32}$$

Where $H_i$the special parameter of influence is factor i, ω_i is the weight of influence factor i, and E_i is the value amount of influence factor.

3.4. Building a decision model for forest management

In order to determine the management plan of the forest and the balance between the forest carbon stock and other values of the forest, we decided to manage the forest by modeling the forest values in a way that maximizes the sum of their values. In this case, we qualified the decision model for felling trees.

$$\max E \{\sum_{i=1}^{6} H_i \cdot \omega_i \cdot E_i\} (i = 1,2,3,4,5,6) \tag{33}$$

$$s.t. = \begin{cases} \dfrac{S_0 - S_k}{S_0} \geq \dfrac{3}{5} \\ 60 \leq t \leq 100 \\ 0 \leq S_4 \leq 4000 \\ E_5 \geq 0 \end{cases} \tag{34}$$

3.5. Special treatment of forest value models

We initialize the decision model for a particular forest and achieve a special treatment for a specific forest by introducing parameters that influence factors Hi, i.e., transition points. We apply the special treatment to the woods for the following cases.

Due to the requirements of national laws and regulations, there are clear regulations for some forests prohibited from being logged, so we treat the impact factor H2=0 for forests that cannot be logged to achieve the special treatment.

4. Summary

In this paper, we propose a forest management plan for forest managers by building a carbon sink model and a forest management decision model. In building the carbon sequestration model, we apply the classical logistic growth equation to make the results more accurate. We use the life cycle of forest products as the time period to make the results more convincing. When modeling forest management decisions, the total value of the forest is considered from five aspects: forest carbon sink and its conservation, forest products, maintenance of biodiversity, water conservation, and recreation and leisure. In addition, by introducing specific parameters that influence factors, our model can be applied to different types of forests. However, the logistic growth equation contains characteristic covariates, and its parameters are complicated to calculate, are influenced by forest characteristics, and do not consider the case where the forest is a mixed forest.

Proper deforestation can absorb more CO2 than leaving the forest intact. When old trees are cut down and young trees are planted, not only can the capacity of the forest to absorb CO2 be increased, but the felled trees can be processed into wood products that still absorb CO2, and at the same time can generate economic benefits. The value of forests is not only in absorbing carbon dioxide, but also in water supply, climate regulation, and landscape tourism. As a forest manager, developing forest landscape without destroying the forest will lead to the development of local tourism and service industry; moreover, proper deforestation can increase the carbon absorption rate and promote other social values.

References

[1] Chen, X.-F., Zeng, W.-S., Xiong, Z.-B., & Zhang, M. (2004). New progress of national forest resources continuous inventory - Revision of technical regulations on national forest resources continuous inventory. Forest Resource Management, 000(005), 40-45.

[2] Li Q, Zhu JH, Feng Y, et al. Prediction of forest tree forest carbon stocks and their carbon sequestration potential in China [J] Progress in Climate Change Research, 2018, 14(3): 287-294

[3] Mo H, Chen E. Modeling and optimal analysis of plant growth process based on logistic equation[J]. Journal of Jiaozuo University, 2006, 20(4):70-71. doi:10.3969/j.issn.1008-7257.2006.04.034.

[4] JIN Fang, LU Shaowei, YU Xinxiao, et al. Evaluation of forest ecosystem service functions and their values in China[J]. Journal of Applied Ecology,2005,16(8):1531-1536.

[5] Qin Yan. (2012). Global wood and wood products market overview. International Wood Industry(4), 1-2.

[6] Yao, T. Q.. (2017). Assessment of ecosystem service value of plain afforestation in Beijing. Modern Horticulture (20), 1-2.