The Research on Forest Value Evaluation Model

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Abstract

Climate change poses a great threat to life. In order to reduce the impact of climate change, we need to take actions to reduce the amount of greenhouse gases in the atmosphere. This paper focuses on how to design a forest value model to optimize the arrangement of plant planting cycles and harvesting cycles, and then design the forest value evaluation model. And the robustness and sensitivity analysis of the model are tested, and the model performs stably. Besides, Using AHP to evaluate the target, we find the data of the secondary evaluation indicators and calculate its weight with Entropy Weight Method, which makes the model more objective and reliable.

Keywords

Forest Value Model; AHP; Greenhouse Gases; Evaluation.

1. INTRODUCTION

Climate change poses a great threat to life. In order to reduce the impact of climate change, we need to take actions to reduce the amount of greenhouse gases in the atmosphere. Considering that sustainable forest management is of great significance in maintaining soil fertility, increasing species diversity and improving community stability, it is of great research value to assess forest adaptive management and carbon sequestration potential under the background of global climate change.

This paper used the data of environment to design a forest value evaluation model to optimize the arrangement of plant planting cycles and harvesting cycles.

2. FOREST VALUE MODEL

Our management strategies focus on the arrangement of plant planting cycles and harvesting cycles, which affect the area of the forest, so we turn the problem into finding the optimal effective area of the forest, the actual area of the forest can absorb CO_2 through photosynthesis.

2.1. Model Preparation

According to the above ideas, the index system constructed in this paper includes three links: natural conditions, regional eco-environmental effects and social effects. Ten indexes including eco-environmental index, carbon emissions, forest coverage, population and tourism output value are constructed.

(1) Natural conditions. We choose the three most important and representative indexes of annual average temperature, annual precipitation and annual sunshine hours, which are the basic components of forest climate conditions.

(2) Regional ecological and environmental effects. we choose three indicators of per capita carbon emissions, eco-environmental status index and forest coverage rate to estimate.

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(3) Social effects. Our preliminary indicators include the number of local permanent residents, the average student rate in higher education per 100,000 population, the annual timber output and the annual tourism income.

Then, we deal with the data in the following methods.

Standardization of data. Because of unit differences, each index needs to be standardized before adding up to calculate the index. The treatment process is as follows:

$$y_{ij} = \frac{x_{ij} - x_{j\,min}}{x_{j\,max} - x_{j\,min}} \quad (1)$$

Among them, y_{ij} is the j index value of the i unit after dimensionless treatment; x_{ij} is the original value of the j indicator data of the i unit. There are:

$$Y_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \quad (2)$$

Find the information entropy of each index. According to the definition of information entropy in information theory, if the information entropy value of the index is expressed as eand the information utility value is expressed as d,then the information entropy value of the j index can be expressed as

$$e_j = -\frac{1}{Inm}\sum_{i=1}^{m} Y_{ij}\, InY_{ij} \quad (3)$$

Among them, the information utility value $d_j = 1 - e_j$

Weight of evaluation index: The greater the information utility value, the more important the index is, the more important it is for evaluation. Finally, the weight of each index can be obtained as follows

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (4)$$

Calculate the comprehensive score, expressed as F

$$F = \sum W_j\, y_{ij} \quad (5)$$

2.2. Establishment of Model

2.2.1 Definition of effective forest area

According to the problem analysis, the forest area is related to the planting period, felling period and the growth rate of trees, so the definition of the effective forest area S_y is as follows

$$S_y = S_0 + S_z(1+v)^t - S_k \quad (6)$$

Among them, S_0 means the area before forest management, that is, the existing area, S_z means the area newly planted in the future, S_k means the area cut down in the future, and the v means natural growth rate of newly planted trees.

2.2.2 Analysis of effective forest area

As far as a tree is concerned, it exists in growth period and maturity period. If a new batch of tree species is planted in the forest, there are growth and maturity stages in this batch of tree species. Therefore, when we manage the existing forest, that is, adopt planting and cutting

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strategies, the distribution of trees of different ages in the forest will certainly change. Therefore, we divided the whole forest into growth period and maturity period for analysis. For all the trees in the growing period in the forest, the mature trees may be cut down before the end of the growing period, so the effective forest area in the whole growing period is used as the actual effective forest area. Tree species absorb carbon dioxide through photosynthesis. For the growth period of trees, the effective area of carbon dioxide absorption changes with time. For the mature period of trees, the effective area of trees no longer changes with time. Therefore, calculus method is adopted to estimate the effective forest area in the growth period.

For the convenience of calculation, it is assumed that the number of trees of different ages in the forest obeys the same normal distribution in the growth period, that is, the newly added and cut-down amount of trees of different ages are approximately equal in the growth period. The effective forest area S_y calculated by this method is defined as the product of the total existing forest area $S_{0,}$ and the proportion of growing forest area, where the proportion of growing forest area is expressed as p. Meanwhile, there are

$$S_y = S_0 \times p \tag{7}$$

$$p = \int_0^{t_1} \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds,\ 0 < s < T \tag{8}$$

Among them, t_1 it is the average growth cycle of all tree species in the forest, that is, the period when all tree species in the forest grow to maturity on average. T is the longest tree cycle in the forest, that is, the felling cycle of the longest tree in the forest.

According to the equation (7)-(8), then the effective area at any time can be expressed as

$$S_y = S_0 \int_0^{t} \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds\ ,\ 0 < s < T \tag{9}$$

2.2.3 Make a preliminary management strategy

Based on the idea of "carbon sequestration", we first make management strategies from the perspective of carbon sequestration. Since planting and felling will change the effective forest area, we assume that the effective forest area will remain unchanged at least for a period of time from the perspective of maximizing carbon dioxide absorption. That is, carbon dioxide in the air is always consumed at a quantitative rate. In the above calculation model, it is assumed that the number of trees of different ages in the forest follows the same normal distribution in the growth period, so that the effective area of the forest is a fixed value. Suppose that $t > T$,if the number of trees in different ages in the forest still keeps the normal distribution in time, that is, the effective area of the forest remains unchanged in time T， then it is necessary to cut down some mature trees and plant a number of tree species. We can approximately estimate the number of trees to be cut down according to the change value of the effective area of trees in the growing period in time T, which could be expressed as ΔS_y.

$$\Delta S_y = S_0 \left[\int_0^{t} \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds - \int_0^{T} \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds \right], 0 < s < T \tag{10}$$

That is,

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$$\Delta S_y = S_0 \int_T^t \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds, 0 < s < T \tag{11}$$

Among them, ΔS_y represents the effective area of trees felled in time t, and defining felled amount S_k represents the ratio of the effective felled area to the proportion of trees in the growing period. Similarly, as we have assumed in the above management plan that the effective area of forest will remain unchanged within time T, ΔS_y can also represent the effective area of trees planted within time T, and defining planting amount S_z represents the ratio of the effective planting area to the proportion of trees in the growing period.

2.2.4 Optimize management strategies

Further, considering that the forest management plan should comprehensively consider the ecological, economic and social benefits of the forest, we optimize the management plan with the evaluation model. It is known that the effective forest area S_y can be obtained by formula (9). Combined with the local comprehensive index score of 2016-2020 calculated by entropy weight method, with the local effective forest area as dependent variable y and the comprehensive index score as independent variable x, the linear regression model is used to fit the local comprehensive score and forest data over the years, and the model is used to predict the optimal effective forest area that can be achieved in the future, which is defined as x_0.Then there is

$$\begin{cases} max\, y = f(x) \\ f(x) = \sum_{k=0}^{n} a^k x_k \\ x \in [0.T] \end{cases} \tag{12}$$

Among them, T means the longest tree cycle in the forest.

After predicting the optimal effective forest area x_0, our management plan can consider the difference between the existing effective forest area and the optimal effective forest area, then the effective area of felling S'_k can be expressed as

$$S'_k = S_0 \int_0^{t_1} \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds - x_0 \tag{13}$$

Among them, t_1 represents the average growth period of all tree species in the existing forest, which is the total area of the existing forest S_0.

Assuming that it takes t for the existing forest area to evolve into the optimal forest effective area through planting and felling, the planted effective area S'_z can be expressed as

$$S'_z = \Delta S_y = S_0 \int_T^t \frac{1}{\sqrt{2\pi}} e^{\frac{-(s-\mu)^2}{2\sigma^2}} ds \tag{14}$$

According to the previous definition, the felling amount S_k and planting amount S_z can be expressed by effective felling area and effective planting area respectively.

$$S_k = \frac{S'_k}{p} ; S_z = \frac{S'_z}{p} \tag{15}$$

We summarized the following management plan through the discussion of the above models:

At that time $S_y \leq x_0$, our strategy was to expand the forest area only by planting trees, instead of cutting down the current total number of trees in the future, with the planting amount of S_z.There are transition points in this management plan.

At that time$S_y > x_0$, our strategy was to cut down and plant the current total number of trees in a period of time t in the future, with the cut-down amount of S_k and the planting amount of S_z; There is no transition point in this management plan. Therefore, further analysis of this plan is:

At that time$S_y > x_0, S_z < S_k$, there was a transition point in the management plan;

At that time$S_y > x_0, S_z \geq S_k$, there was no transition point in the management plan; When we plan to cut down the forest, we will first cut down the part with the largest distribution of tree age, and plant new tree species in the corresponding position, so as to realize the transition.

2.3. Model Application

We plan to apply the model to specific areas. Considering the important role of trees in carbon sequestration, we use per capita carbon dioxide emissions as the benchmark index to determine the areas that need forest management globally.

As shown in Figure 1, the vast majority of countries with high per capita carbon dioxide emissions are developing countries, and they are countries with relatively weak comprehensive national strength and small population, but Australia, the United States and Canada still maintain high per capita carbon dioxide emissions. Therefore, considering the total population, the overall strength of the country and the per capita carbon emissions, we selected one region in developing countries and developed countries as the evaluation targets, namely Guangdong Province of China and new york of the United States. When considering the region, we expanded the tree range from forest to all tree species in the region.

Figure 1. Distribution chart of carbon dioxide emissions per capita of countries in the world in 2019

2.3.1 Evaluation of Guangdong Province of China

According to the entropy weight method in the above ideas, it can be concluded that the weight ratio of each index in Guangdong Province is as shown in Table 1.

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Table 1. Comprehensive evaluation index system of forest management.

First Level	Index	Weight
natural conditions	1. Annual sunshine hours	0.0375
	2.Annual average temperature	0.0019
	3. Annual precipitation	0.4298
Regional eco-environmental effect	4. Eco-environmental status index	0.0211
	5. Per capita carbon emissions	0.0240
	6. Forest coverage rate	0.0130
Social response	7. Tourism income	0.3547
	8. Timber output	0.0907
	9. Number of permanent residents	0.0273

Note: After calculation, it is found that the average proportion of students in higher education per 100,000 local population is 0, so it will not be considered here.

According to the requirements in the title, by solving the integral equation, it is concluded that the proportion of growing trees in all trees in Guangdong Province is 0.0623. Then, the quadratic function of comprehensive forest evaluation index and effective forest area in Guangdong Province is fitted by linear regression model, and the effective forest area with the highest evaluation index is obtained. It is estimated that the optimal effective forest area in Guangdong Province is 70,000 hectares, as shown in Figure 2. The function expression is

$$y = 40971.63x^3 - 14193.4x^2 + 1403.809x - 28.8905 \tag{16}$$

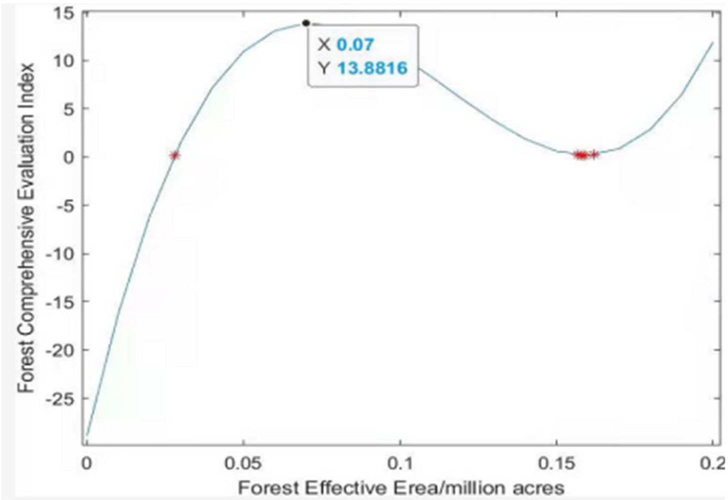

Figure 2. Function fitting results of comprehensive forest evaluation index and effective forest area in Guangdong Province

2.3.2 Evaluation of New York of USA

According to the entropy weight method in the above thought, the weight of each index is shown in Table 2.

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Table 2. Comprehensive evaluation of forest management-New York.

First Level	Index	Weight
natural conditions	1. Annual sunshine hours	0.0645
	2. Annual average temperature	0.0018
	3. Annual precipitation	0.2996
Regional eco-environmental effect	4. Eco-environmental status index	0.0074
	5. Per capita carbon emissions	0.0062
	6. Forest coverage rate	0.0003
Social response	7. Tourism income	0.5521
	8. Timber output	0.0679

Note: After calculation, it is found that the local resident population and the average rate of students in higher education per 100,000 population account for 0, so they will not be considered here.

By solving the integral equation, it is concluded that the proportion of growing trees in all trees in New York is 0.109. Then, the quadratic function of comprehensive forest evaluation index and effective forest area in New York is fitted by linear regression model, and the effective forest area with the highest evaluation index is obtained. It is estimated that the optimal effective forest area of New York is 90,000 hectares, as shown in Figure 3. The function expression of fitting is

$$y = -0.2396x^2 + 4.1539x - 17.7730 \tag{17}$$

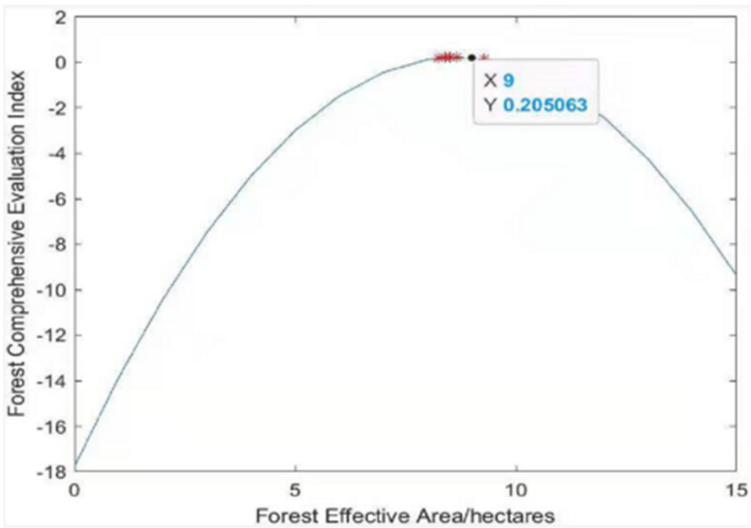

Figure 3. Function fitting results of comprehensive forest evaluation index and effective forest area in New York.

The effective forest area of New York in 2021 is 120,000 hectares. At this time, the effective forest area is greater than the predicted optimal effective forest area. Therefore, aiming at New York, the forest management strategy we have formulated is:

The time required for the tree species with the largest number of trees in New York to reach the highest point of its use value is used as the evolution time for the current effective forest area to become the optimal effective forest area. The assumption here is 20 years. In the next 20 years, the total deforested area in New York will be 275,000 hectares and the total planted

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area will be 31.99 million hectares. Because the planting amount is greater than the felling amount, there is no transition point in this management strategy. Therefore, when planning to cut down, cut down the part with the largest age distribution in the forest first, and plant new tree species in the corresponding position, so as to realize the transition.

2.3.3 Prediction of carbon absorption after 100 years

Further, we improve the above model to predict the amount of carbon dioxide absorbed by local forests and their products after 100 years. The product of the actual effective area of the forest in 100 years and the daily carbon absorption coefficient is used to predict the carbon sequestration of the forest in the next 100 years, which is expressed as M .Then there is

$$M=\int_0^{100\times365}\left(\left(S_0+S_k'-S_z'\right)\times q\right)dt \tag{17}$$

It is predicted that Guangdong will absorb 34,264.9 tons of carbon dioxide after 100 years, and new york will absorb 457.53 tons of carbon dioxide after 100 years.

3. SENSITIVITY ANALYSIS

According to the title, when the cutting cycle of all tree species in the forest is generally extended for 10 years, for forest managers and all forest users, what they are most sensitive to is the change of timber revenue brought about by the extension of cutting time and the change of forest management cost in 10 years. Therefore, we set up a theoretical model to calculate the optimal time of cutting trees from the principle of dynamic efficiency, so as to ensure the maximum net income from trees.

Because this model only considers timber revenue, a series of variables need to be defined first. S represents the net present value of total income, m represents the price of wood per unit volume, c represents the marginal cutting cost, t represents the age of trees (in years), V represents the volume of wood per plant and C_0 represents the cost of planting trees. Assuming C_0、m、c do not change with time. Because the cut forest land can be replanted with trees, it can be cut after it grows up, and so on and so forth. Therefore, an indefinite model is adopted. The objective function in this model is

$$Max\ S=[(m-c)V(t)e^{-rt}-C_0]\cdot[1+e^{-rt}+e^{-2rt}+\cdots] \tag{18}$$

That is

$$Max\ S=[(m-c)V(t)e^{-rt}-C_0]\cdot\frac{1}{1-e^{-rt}} \tag{19}$$

By making the first derivative value of this function t', it is found that the optimal cutting cycle meets the following requirements:

$$\frac{\frac{dV(t')}{dt}}{V(t')}=\left[1-\frac{C_0}{(m-c)V(t')}\right]\cdot\frac{r}{1-e^{-rt'}} \tag{20}$$

It can be seen from the equation that when the price of timber falls, or the cost of planting trees, cutting and tax increases, the optimal cutting period will be prolonged, and the opportunity cost of delaying cutting will increase, and later cutting will become more attractive. Therefore, when the felling time of all tree species in the forest is generally delayed for 10 years,

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in order to achieve a better transition, we should choose to cut down as many trees with higher relative value as possible in areas with lower timber prices and higher taxes.

4. SUMMARY

Thorough consideration and analysis, this paper design a forest value model based on the selected index. The selection of evaluation indicators is scientific. The evaluation indicators we select are determined by searching the literature of relevant forest ecosystems, with specific modifications for specific situations. And also, for the unsearchable data, we combine the trend of the data in recent years, and processing the data by means of weighting or prediction, so as to obtain a relatively effective data. When using AHP to evaluate the target, we find the data of the secondary evaluation indicators and calculate its weight with Entropy Weight Method, which makes the model more objective and reliable.

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