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Comprehensive Evaluation of Forest Value based on Carbon Sequestration Stock Prediction

Jiaqi Wu

Minzu University of China, College of science, Beijing, 100081, China

Abstract

In order to mitigate the impact of greenhouse gases, forests need to be managed to increase carbon absorption. This paper selects waipowa forest as an example. The effective forest area is defined as the area that can carry out photosynthesis. First, investigate which forest management schemes are most effective in carbon sequestration This paper develops a carbon sequestration model. By collecting data, it is found that the number of trees at different ages in the forest roughly follows the cardinal distribution, so the effective forest area can be found by the probability distribution method. With known CO2 The absorption coefficient and carbon sequestration model were constructed, and the harvest and planting strategies leading to the best carbon sequestration were obtained. Considering other aspects of forest value, this paper selects 18 indicators. Firstly, the comprehensive evaluation indexes of forest ecosystem are obtained by using TOPSIS method and entropy weight method. Then, taking the area as the independent variable and the index as the dependent variable, the regression model is established, and finally the optimal effective forest area is 1.11 million mu. In order to determine the forest management plan, this paper takes the best effective area as the transition point. If the effective forest area does not reach the transition point, managers should not harvest. If so, they should harvest in order to achieve their goal. In order to find CO2, a CO2 adsorption model is built in this paper, and the calculation result is about 129.89 million tons. In order to verify the effectiveness of the model, this paper forecasts the carbon sequestration stock in the next 100 years through time series analysis, and obtains the total absorption of 13676.158 million tons. The model results are basically consistent with the predicted values.

Keywords

Forest Management Plan; Carbon Sequestration; TOPSIS; Forest Evaluation Model.

1. Introduction

Climate change poses a great threat to life, and in order to mitigate the effects of climate change, we need to work to increase the amount of carbon dioxide stored in the atmosphere through biospheric or mechanical means, i.e. "carbon sequestration", to reduce the amount of greenhouse gases in the atmosphere.

Within the biosphere, forests are an integral part of any effort to mitigate climate change.Forests sequester carbon dioxide in living plants and in the products produced by their trees, such as furniture, lumber, and other wood products. These forest products sequester carbon dioxide due to the combination of carbon sequestration in forest products and carbon sequestration due to regeneration of young forests, potentially allowing more carbon to be sequestered over time.

Forest managers must find a balance between the value of harvesting forest products and the value of allowing the forest to continue to grow and sequester carbon, so forest managers need

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to consider a combination of age, type, economic value, and ecological value of trees to make forest management decisions to facilitate carbon sequestration.

This paper establishes a carbon storage model to determine how much carbon dioxide can be stored by forests and their products, and to determine the forest management plan that can store carbon dioxide most effectively. use the Waipowa forest area as an example and collect data on the age of the trees to obtain the probability distribution of the number of trees at different age stages. A carbon sequestration model is defined as well as the concept of effective forest area. The growth rate is used to classify and discuss the different forests in relation to their composition, climate, population, interests and values, and to develop management plans for the different forests.

2. Carbon Sequestration Model

2.1. Distribution of Tree Ages

The Waipowa forest has a long history and has reached a more mature stage through continuous succession. After obtaining the age data of recent years, we obtained the age stage distribution of trees in Waipowa forest. Then, by fitting the graphs, we can get a conclusion - the number of trees at different age stages in this forest roughly follows a cardinal distribution. The resulting probability density function of tree age can be obtained as follows.

$$f(x) = \frac{1}{2^{\frac{n}{2}}\Gamma\left(\frac{n}{2}\right)} e^{-\frac{x}{2}} x^{\frac{n}{2}-1}, x > 0 \tag{1}$$

The fit gives an n value of 6, with an overall right skewed distribution. This indicates that the number of trees in the growth stage is relatively large and the number of trees in the mature stage is low. It can be seen that the management plan of Waipowa forest has been felled more frequently, resulting in fewer trees at the mature stage within the forest. At the same time, the forest is largely in the growth stage as the area of reclaimed forest is also increasing, which is conducive to the application of carbon sequestration models.

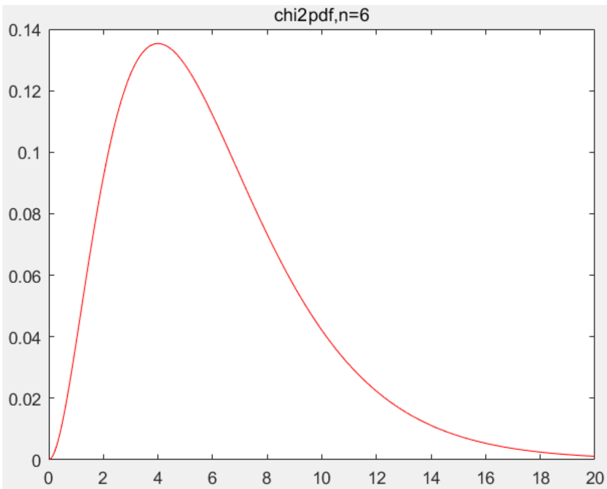

Figure 1. Tree distribution image

2.2. Carbon Sequestration Model

Forest ecosystem is one of the most important terrestrial ecosystems. The functions of forests, such as supplying timber and forest products, sequestering carbon and releasing oxygen, preventing wind and sand, maintaining soil, regulating temperature and humidity, and maintaining biodiversity, are the material basis and ecological environment conditions on which human beings depend for survival.At present, when formulating carbon sequestration roadmaps, local communities consider forest-based ‘green carbon’ as the main natural ecosystem carbon sink, and propose various measures to enhance the carbon sink potential of forests, including afforestation, reforestation, forest closure, and forest nurturing.

There are many factors affecting carbon sequestration, such as effective area, photosynthesis, respiration, etc. First, the effective area where photosynthesis can take place is analyzed as follows.

It is assumed that the total forest area is st, the tree growth period is t_1, and the maximum age of the forest in recent years is t_2. Since the effective area of photosynthesis is the area of growing forest, the area of growing forest can be calculated according to the distribution function of the number of trees in different age groups, that is, the effective area:

$$S^* = S_T \cdot \int_0^{t_1} \frac{1}{2^3\Gamma(3)} e^{-\frac{x}{2}} x^2 dx, 0 < x < t_2 \tag{2}$$

Forests can absorb large amounts of carbon dioxide and release oxygen through the photosynthesis of trees and plants.

It is assumed that the CO_2 absorption coefficient per unit effective area of the forest is k . For the long-term development of the forest as a whole, the effective area of the forest remains largely unchanged in order to seek ecosystem stability. So in the long run, the amount of carbon dioxide that can be sequestered at any time t (C) is :

$$C = \int_{t_s}^{t_e} S^* \cdot k dt = S^* \cdot k \left(t_e - t_s\right) \tag{3}$$

Where t_s is the start time of a time period, t_e is the end time of a time period, and C is the amount of carbon dioxide stored in this time period.

The above is the carbon sequestration model provided in this essay. C is a function of time t. A balanced forest ecosystem always consumes carbon dioxide from the air at a constant rate to create carbon sequestration and produces a constant amount of forest products over a fixed period of time.

This model idea can be applied to a variety of forest types. the most effective means of carbon sequestration that forest managers can take to find a stable and balanced ecosystem is to keep the effective area constant.Therefore, forest management plans in different areas should control the effective forest area to be maintained at a reasonable level by determining a reasonable planting and harvesting cycle.

The effective forest area in the above model is approximately constant. It is assumed that the growth cycle of trees in the forest is t_s (the maximum age of the forest in recent years). If the effective area of forest management is greater than the effective area of forest management during the steady-state period, t_2. In this case, carbon sequestration is not the most effective.

The excess effective forest area refers to the area that should be cut within time t_2 and the area that should be planted with new saplings after cutting within time t_2. So it should be harvested and planted at any time

$$\Delta S = S_T \cdot \int_{t_2}^{t} \frac{1}{2^3\Gamma(3)} e^{-\frac{x}{2}} x^2 dx, t > t_2 \tag{4}$$

For forest managers, reasonable harvesting and planting strategies can be developed based on the above model, with the aim of achieving optimal carbon sequestration.

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3. Construction of the Forest Evaluation Model System

3.1. Selection of Indicators

There are many indicators that affect forest ecosystems, and the magnitude of each indicator's impact on forest ecosystems varies for different forest types.

After reviewing and summarizing relevant literature and data analysis, we selected environmental protection, ecological balance, climatic shift, values of ecological civilization, economic values, and other influencing factors as the first-level indicators of the forest ecosystem evaluation system.

In turn, each primary indicator can be divided into several secondary indicators.Environmental protection is divided into the incidence of forest diseases, oxygen release, conservation of water. Ecological balance is divided into percentage of forest cover, Forest stock, forest storage, biodiversity index, carbon dioxide absorpton. Climatic shift is divided into precipitation, average temperature, media humidity, mean maximum temperature, mean minimum temperature. Values of ecological civilization are divided into environmental pollution control accounts for GDP, urban harmless waste garbage disposal rate, per capita health expenditure. Economic values are divided into public budget revenue, per capita disposable income, and other factor is total regional year-end population.

3.2. Analysis of Each Index

The indicators are isotropized, standardized and weights are obtained. This part is combined with the entropy weighting method, which can avoid the influence of subjective factors by obtaining the weights. Then the weight vector W and the normalization matrix P are obtained.

The weighted normalization matrix Z is obtained by multiplying P and W

$$Z=\left(z_{ij}\right)_{n\times m}=\left(p_{ij}*w_j\right) \tag{5}$$

Determine the positive and negative ideal solutions. The positive ideal solution means that each index is the most optimal value in the sample, and the negative ideal solution means that each index is the worst value in the sample.

$$\begin{aligned}Z^+&=\left(\max\left\{z_{11},z_{21},\cdots,z_{n1}\right\},\max\left\{z_{12},z_{22},\cdots,z_{n2}\right\},\cdots,\max\left\{z_{1m},z_{2m},\cdots,z_{nm}\right\}\right)\\&=\left(Z_1^+,Z_2^+,\cdots,Z_m^+\right)\end{aligned} \tag{6}$$

$$\begin{aligned}Z^-&=\left(\min\left\{z_{11},z_{21},\cdots,z_{n1}\right\},\min\left\{z_{12},z_{22},\cdots,z_{n2}\right\},\cdots,\min\left\{z_{1m},z_{2m},\cdots,z_{nm}\right\}\right)\\&=\left(Z_1^-,Z_2^-,\cdots,Z_m^-\right)\end{aligned} \tag{7}$$

Calculate the distance of each sample from the positive and negative ideal solution.

$$D_i^+=\sqrt{\sum_{j=1}^{m}\left(z_{ij}-z_j^+\right)^2},D_i^-=\sqrt{\sum_{j=1}^{m}\left(z_{ij}-z_j^-\right)^2},\left(i=1,\cdots,n\right) \tag{8}$$

Calculate the closeness of each evaluation object to the optimal solution. The value range is [0,1], and the closer to 1 indicates that the sample score is better.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{9}$$

3.3. The Effective Forest Area

The effective forest area is related to the planting cycle, cutting cycle and tree growth rate. To obtain the effective area of the forest, the following model was developed.

$$X = S_0 + S_1(1+v)^t - S_k \tag{10}$$

Only the planting cycle, felling cycle and tree growth rate are considered in the model.
Results of effective forest area

Table 1. Results of effective forest area

year	2011	2012	2013	2014	2015
forest area / 10000 acres	102.67	103.30	104.30	105.73	107.39
year	2016	2017	2018	2019	2020
forest area / 10000 acres	109.05	110.50	111.74	112.93	114.05

3.4. Forest Ecosystem Systems

Through the above calculation process, we obtained the effective area of Waipoła forest and the composite level index of the ecosystem for each year from 2011 to 2020. Then the impact of forest area on the ecosystem was measured by regression model (least squares estimation). The regression model is:

$$y = -0.0030x^2 + 0.6733x - 36.9359 \tag{11}$$

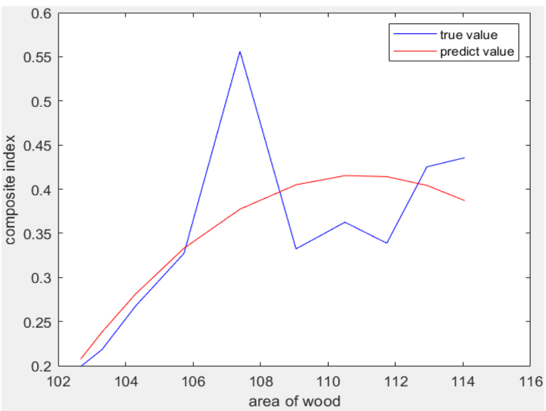

Figure 2. Regression model plot

From the model results, when the forest area is less than 1.11 million acres, the composite level index increases with the increase of area, showing a significant positive relationship. When the forest area exceeds 1.11 million acres, the composite level index starts to decrease.At the same time, it can be seen that the deforestation strategy directly affects the forest area, which in turn affects the balance of the ecosystem and ultimately the ability of forest carbon sequestration. Therefore, effective control of forest area can keep the composite level index within a manageable range.

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For the target forest, Waipowa Forest, when the forest area is about 1.11 million acres, the composite level index reaches a maximum value of about 0.42. Therefore, for the Waipowa Forest, we should control the forest area to be about 1.11 million acres and then implement a logging strategy, when the resulting forest management plan is most effective in terms of sequestering CO2. So 1.11 million acres is the optimal effective area for this forest.

3.5. Development of Harvesting Plan

In the previous discussion of the effective area, we clarified that the excess effective area is the area that should be harvested and the area that should be planted with new saplings after harvesting. So for the model, the area that should be harvested is:

$$S_k = S_T \cdot \int_{t_2}^{t} \frac{1}{2^3\Gamma(3)} e^{-\frac{x}{2}} x^2 dx - X^* \tag{12}$$

When $S_k \leq X^*$, forest managers should not adopt a harvesting strategy, but should increase the planted area until the optimal effective area, when the transition point has been reached.

When $S_k > X^*$, harvesting strategy should be adopted to control the effective area by harvesting trees in the mature stage.

At the same time, when the harvesting strategy is adopted, if the planting area is larger than the harvesting area, there is no transition point, and the harvesting strategy can be carried out directly; if the planting area is smaller than the harvesting area, there is a transition point,and in order to ensure that the effective area reaches the optimum, the effective area should be made to reach a certain level before felling.

4. Prediction of Carbon Dioxide Absorption

4.1. Carbon Dioxide Absorption Formula

From the previous model, the harvested area (Sk) can be obtained as:

$$S_k = S_T \cdot \int_{0}^{t} \frac{1}{2^3\Gamma(3)} e^{-\frac{x}{2}} x^2 dx - X^*, t > t_2 \tag{13}$$

And the corresponding planted area (S_p) is:

$$S_p = S_T \cdot \int_{t_2}^{t} \frac{1}{2^3\Gamma(3)} e^{-\frac{x}{2}} x^2 dx, t > t_2 \tag{14}$$

Then the amount of carbon dioxide that the forest will absorb over a 100-year period is:

$$Q = \int_{0}^{100\times365} \left(S_T - S_k + S_p\right) ktdt, t > 0 \tag{15}$$

where $S_T - S_k + S_p$ is the effective area of the forest after harvesting and planting; k is the carbon dioxide absorption coefficient.

4.2. Model Training

In order to prevent the degradation of data reliability, we will take another set of forest related data to train the model in the following. We choose the Sekhamba woodland in China to perform the above calculation. After sorting the data, we found that the number of trees of different age groups in the Seyhanba woodland obeyed a normal distribution, from which it can be seen that the number of over-mature and young forests in the Seyhanba woodland is roughly the same.After the information survey, the largest tree in the woodland of Seyhanba is 89 years old, and the trees per unit area absorb 1.27kg of CO2 per day. Therefore, the harvested area and planted area are:

$$S_k = S_T \int_0^t \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx - X^*, t > 0$$
$$S_k = S_T \int_{t_2}^t \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx, t > 0 \quad (16)$$

From the equation $Q = \int_0^{100\times365} \left(S_T - S_k + S_p\right) ktdt, t > 0$, the amount of carbon dioxide absorbed by the forest in a 100-year period is about 129.89 million tons.

The best management plan for a forest is closely related to the harvesting cycle and planting cycle. When the harvesting cycle changes, the corresponding effective area of the forest will also change during the cycle, so it is important for the forest manager to adjust the planting area appropriately to bring the effective area of the forest back to the transition point.

Suppose the harvesting cycle of this forest is extended by 10 years from the existing one.According to the model, if the planting cycle is not changed during these 10 years of extension, the effective area of the forest increases beyond the optimal transition point, the integrated level index decreases, and the carbon sequestration capacity also decreases, breaking the balance between carbon sequestration and economic value of the forest. The increase in the effective area is:

$$\Delta S = S_T \int_{t_2}^{t_2+10} \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx \quad (17)$$

In order to regain the transition point, the planting cycle should be extended to ensure that the ecological balance is maintained in the long-term development of the forest.

5. Conclusion

The above decision model for forest management takes into account factors such as environment, ecosystem, climate, ecological values of local people, and economic value of forest products. Six primary indicators and 18 secondary indicators were selected to measure each of these factors.

The decision model takes into account both environmental and social dimensions compared to the previous one. It not only emphasizes the optimization of carbon sequestration, but also measures other aspects of forest values. The model finds a balance between the carbon

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sequestration role of the forest and other values, and X is the optimal effective forest area at this time.

Forest managers' management plans include harvesting and planting forests.Forest management must not blindly harvest for the economic value of forest products, thus destroying the ecological balance and eventually leading to a decrease in carbon sequestration levels. This can have a negative impact on the environment. A specific scenario is that when the current effective area of the forest S_k is less than the optimal effective area X from the decision model, the manager should not harvest the forest. In this case, the forest manager should plant trees to increase the effective area of the forest.

In forest management plans, as mentioned earlier, there are transition points, and different forest types have different S_k and X ,and accordingly various forest management plans can be adopted.Between the various forest management plans, the so-called transition point is the optimal effective area of the forest X .Forests that do not reach the transition point should be planted, forests that reach the transition point should maintain the current planting and adoption strategy, and forests that exceed the transition point should be harvested to reach the transition point.

All forests have different transition points, and forest managers should implement site-specific plans to achieve a balance between carbon sequestration and other values based on the transition points.

References

[1] Ran Fuxiang. The important role of forest ecosystems in sustainable socio-economic development [J]. Gansu Forestry, 2001(3):2.

[2] Wang Bing, Lu Shaowei. Assessment of ecosystem service value of economic forests in China[J]. Journal of Applied Ecology, 2009, 20(2):9.

[3] Ma MJ, Xi FM, Ling JH, et al. Advances in carbon dioxide mineral sequestration technology[J]. Journal of Ecology, 2019, 38(12):10.

[4] Jianhua H U , Junlong S , Tao L . Rock quality evaluation of underground engineering based on RS-TOPSIS method[J]. Journal of Central South University.

[5] Lal R . Carbon Sequestration in Dryland Ecosystems[J]. Annals of arid zone, 2004, 39(4):1- 10.

[6] Shuo Yuan. Analysis of Electric Load Data Based on Time Series[J]. Advances in Applied Mathematics, 2016, 05(2):214-224.