Forest Management: Carbon Sequestration and Forest Value

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Abstract: Carbon sequestration, which is highly related to greenhouse gas emissions, is a primary function of a forest. This paper examines the measurement of carbon sequestration, forest value evaluation, comprehensive evolution of a forest's carbon sequestration capability, and prediction of a forest's carbon sequestration amount. This paper conducts curve fitting, data analysis, and evaluation model about the multifactorial measurement of carbon sequestration and prediction of Jiangxi's Province using grey prediction models. Suggestions were put forward for the problems of forest carbon sink, biodiversity, and tourism value in Jiangsu Province.

1. Introduction

With the rapid development of the global economy, environmental protection, especially carbon sink, has become critical. Forests play an essential role in carbon sequestration, but also, products made from these trees can absorb a certain amount of carbon from the atmosphere. Moreover, as many local people depend on forests for their livelihood and rely on forests to form their unique culture, the total value of forests should not be limited to environmental protection. However, it should also consider the use-value of forests. This paper aims to propose a method to measure the value of forests from the perspective of environmental contribution and social connection. The paper also puts forward a model to assess dynamic forest value, which can help forest managers implement more sustainable forest management plans and balance environmental and social values.

2. Assumption and Notations

2.1 Assumptions

1) When building the carbon sequestration evaluation model, we take the height, diameter, and density of trees in the forest as the world's average level, which is 215 feet and 5feet (especially a 10-year-old tree is expected to be 13.5 feet in height and 1.5 inches in diameter), and 479 trees per ha.

2) Set the carbon content of one cubic meter of sawn wood to be about 200kg. Although many scholars have analyzed the factors that affect carbon sequestration, such as the initial density of human afforestation, whether thinning or not, plantations account for only 7% of the global total. Hence, it can be ignored.

3) It is assumed that all forest Products mentioned are Harvest Wood Products (HWP), and once they become forest Products, the stored carbon will not be released. There is no raw material loss in all forest products' manufacturing processes.

4) The types of trees are divided into natural forests and artificial forests.

5) Assume that the carbon content of plants is 50%. Although some scholars have carried out detailed studies on the carbon content of plants in various regions, the maximum error is only within the range of 18%, so the average value is 50%.

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1. Notations

Symbol	Description
FAS	Forecast Amount of CO_2 Sequestered per year
FPHA	Forecast Percentage of Area Harvested in ha per year
FHA	Forecast Harvesting Area in ha per year
AST	Amount of CO_2 Sequestered by One Tree in-lbs.
FTVFP	Forecast Total Volume of Forest Products in a year in m^3

3. The Build of carbon sequestration Evaluation model

3.1 Total Carbon Sequestration of a Forest

First, a model that can precisely calculate the quantity of carbon sequestration in one forest has two primary mathematical expressions to avoid repeated calculations. One is a math expression about carbon sequestration from a forest excepting the whole sequestration part of a forest tree TCw. The other one is total carbon sequestration only for forest products TC_{FP}. The expression below is based on the stock volume extension method [1].

$TCw = V_f \delta \rho \gamma \qquad V_f = S_i V_i$

TC_w is carbon sequestration of the forest tree, V_f is the total stock volume of the forest, V_i is the stock volume per unit of area of i-th forest, which indicates that i = 1 stands for natural forest while i = 2 stands for plantation. Stock volume per unit is of forest refers to the ratio of total standing wood volume in the growth process to the forest area. The constant δ is the volume converted into the biological stock with a forest as the main body. According to previous research, this parameter is always valued at 1.90 [1]. Bulk density ρ has a value range between 0.45 and 0.5 t/m3. It equals 0.5 in this paper. The carbon ratio γ has always been valued at 0.5.

3.2 Total Carbon Sequestration of Forest Product

$TC_{FP} = FPAH \times FD \times FFA \times (ASFP \times K)$, where K is the conversion coefficient of the unit from kilogram to pound.

3.3 Result and Discussion

According to related data, the trend of the total area of forest and volume of forest products is shown after time-series analysis. First, do a time-series analysis for a total area of forest. Using SPSS as a modeling tool, the forest area greatly meets the Brown linear trend model. The parameter α is estimated to be 1 with a 44.778 t-value, passing the significance testing. The specific model is listed below:

$$l_t = x_t$$
$$b_t = l_t - l_{t-1}$$
$$\hat{x}_{t+h} = l_t + hb_t, h = 1,2,\cdots$$

In this model, t represents the current period, h stands for the number of periods exceeding the current period, x_t represents the actual observation of period t, l_t represents the estimated smooth of period t, and b_t represents the predicted trend of period t.

Second, conduct a time-series analysis for the total volume of each year's forest product. Data has no seasonal fluctuation since it is based on year units. Use the expert modeler in SPSS to implement time-series analysis. From the table printed out by SPSS, the volume of each year's forest product meets greatly with ARIMA (0,1,0). ARIMA (0,1,0) tells that this time series is a 1-order unit root process.

$$y_t' = \alpha_0 + \sum_{i=1}^{p} \alpha_i \, y_{t-i}' + \varepsilon_t + \sum_{i=1}^{q} \beta_i \, \varepsilon_{t-i}$$
$$y_t' = \Delta y_t = (1 - L) y_t$$

Finally, get the model $y_t = \alpha_0 + y_{t-1} + \varepsilon_t$

Use SPSS to get the estimated parameter. The constant is 129187719.4 with a 0.001 p-value, passing the significance testing. $\hat{y}_t = 129187719.4 + \hat{y}_{t-1} + E(\varepsilon_t)$where because the white noise series is smooth and steady, there is no hangover in both ACF and PACF of the residual.

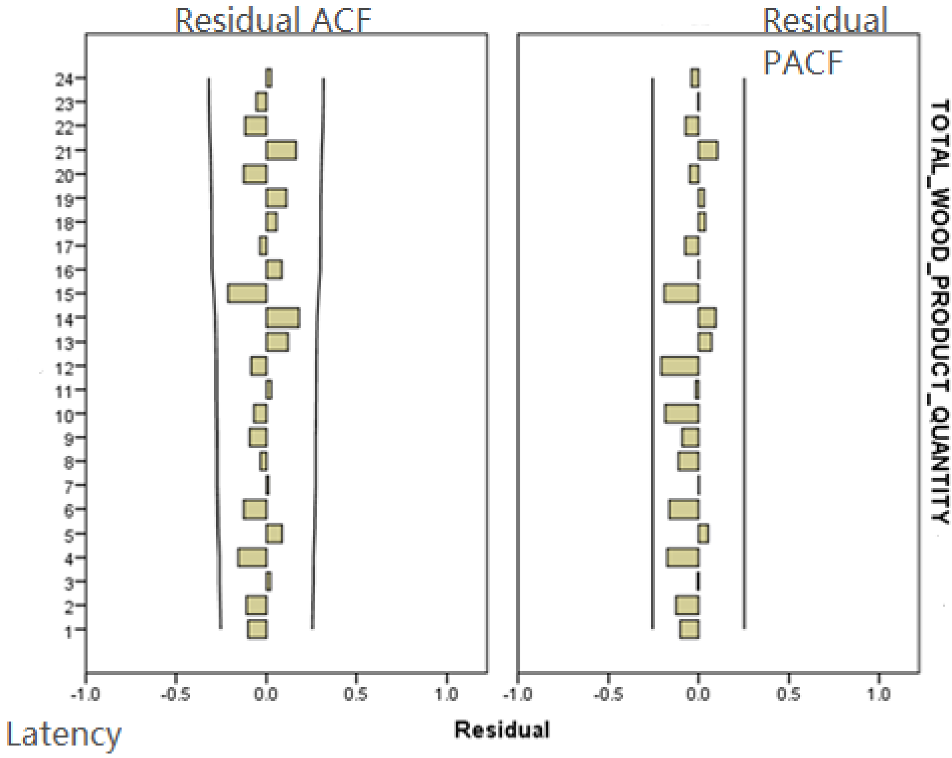

Figure 1. The result of the white noise series

3.4 The Carbon Sequestration Model

Using the curve fitting tools in MATLAB, the carbon sequestration model is:

$$FPAH = [1 - \frac{1}{1 + e^{-(x_1 - x_2)}}] \times 100\%$$

Where represents the total area of the forest (unit: hectare) and represents the total volume of each year's forest product. The goodness of fit known from MATLAB is 0.792, which indicates that this fitting process can explain 79.2% of data points.

4. The Build of forest value evaluation model

Considering that forests provide carbon sequestration function for society and have other social values, we use four indicators to provide a complete measurement system of forest value: carbon sequestration capacity, culture, biodiversity conservation, and tourism. The relationship between indicators and parameters is shown in Figure 2.

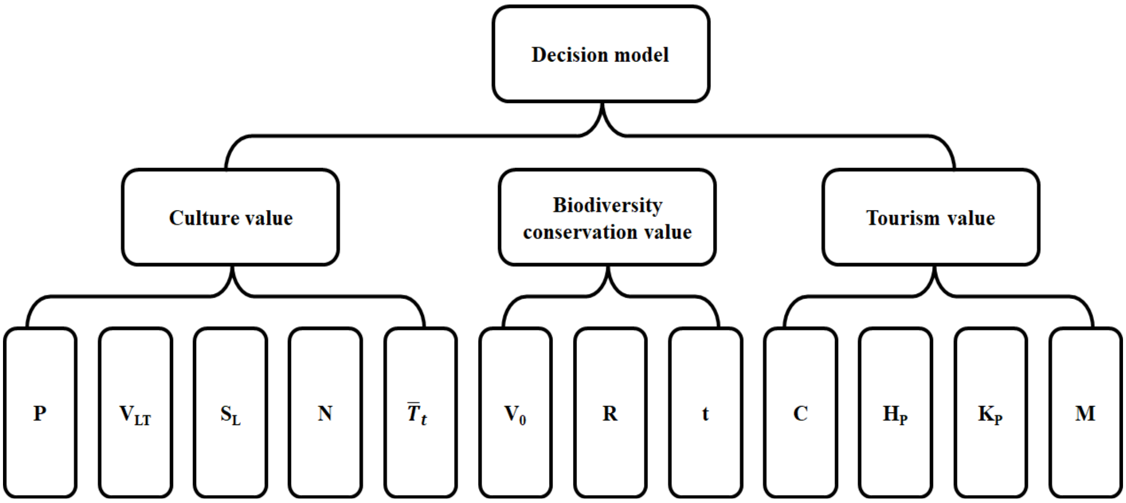

Figure 2. The relationship between indices and parameter

4.1 Culture Value

1)Forest-Park

The evaluation of forest cultural value evaluates the cultural phenomenon produced in the interaction between forests and humans and evaluates forests' ability to serve or meet human needs from the perspective of value. Hence, a famous forest should be attractive to humans. We measure the forest culture value by the time people spend together with the forest.

We assume that the time the i_th people stay in the forest is T_i, $\bar{T}$ represents the average time tourist consumed in the woods, $\frac{GDP}{p}$ Represents annual GDP per capita, I means the total gates receipts, n is the number of visitors, and 8760 is the total number of hours in a year [2]. Then the total forest value can be shown:

$$V_{FC} = \frac{\sum_1^n T_i}{8760} + \frac{I}{\frac{GDP}{p}} \times x = \frac{n\bar{T}}{8760} + \frac{I}{\frac{GDP}{p}} \times x$$

In the expression above, $x = 0$ when it applies to free forest park, $x = 1$ when it applies to charged forest park, which takes the gate receipts, as the payment of socially necessary labor time, into consideration.

2)Natural-Forest

There are two perspectives to understanding the cultural value of natural forests. The first is the primary value, representing the symbiotic time local people lived with forests. Though some may not live in the woods, they can still benefit from the forest service, such as restorative materials, food, and clean water for life. The second one is activity value, which is reflected by people's symbiotic time in forests when currying on some cultural activities, such as hiking.

$$V_{FC} = P\overline{T_F} + N\overline{T_t}$$

Where P is the local population, $\overline{T_F}$ means the average symbiotic time local people spent with forests, N represents the number of cultural activities held in forests, and $\overline{T_t}$ is the average activity time, which is estimated at three h.

Most locals depend on trees for firewood and fruits, and we define the $\overline{T_F}$ by growing stock of region (V_{LT}):

$$\bar{T}_F = \frac{V_{LT}}{s_L} \times 0.06 = FT \times 0.06$$

Where s_L means the region area, FT represents the forest thickness, and 0.06, which is based on a research theory of Taiwan forests, is the standard symbiotic time local people lived with the forest under the condition of FT [2].

4.2 Biodiversity Conservation Value

Biodiversity conservation also plays an essential role in economic and social value, providing a significant guarantee for ecological service function. A predictive model of biodiversity conservation value is given based on the economic evaluation and measurement model of Hoel and Sterner. This model focuses on analyzing discount rate and marginal price of protection value. Fundamental continued equality stands biodiversity conservation value = people's willingness to pay (WTP) = forest service value (V).

$$V = V_0(1+R)^{-t}$$

Especially, V_0 represents the current WTP. And:

$$R = \rho + \left[(1-\gamma^*)\left(\alpha - \frac{1}{\sigma}\right)\right] g_C + \left[\gamma * \alpha + (1-\gamma^*)\frac{1}{\alpha}\right] g_E$$

The notation R presents the combined formula of discount rate and marginal price. ρ is the time preference rate of people's inter-generation consumption; when it is greater than 0, contemporary people prefer to improve their well-being, which is in line with human preferences for self-satisfaction in advance consumption. However, an overestimation will probably lead to the destruction of the ecological environment; hence for consideration of the balance between environment and economic development preference, we take ρ for 0.01; γ^* is the current (t=0) share of well-being that human economies and societies derive from ecosystem services, set for 5%; α represents the elasticity of marginal utility, which is set for 1; σ is the elasticity of substitution, showing the degree of substitutability between general consumer goods and ecosystem services, with an estimated value of 0.5; while g_C representing the growth rate of CPI with an estimated value of 3.3%, g_E means the change rate of biodiversity service value with the estimated -0.87% [3].

4.3 Tourism Value

The author adopts the consumption reproduction cost method proposed by former Soviet scholar О.Н.ЛНЦ.УКЕБИЧ and quantifies the value of forest recreation by studying the conditions of the forest itself, the utilization of forest tourism resources, and the input cost of forest tourism resource managers:

$$S = \left[C \cdot \left(1 + 0.01H_p\right) \cdot k_1 + M\right] \cdot k_P [4]$$

Where S is the annual utilization rate of natural forest tourism resources (ruble·hm^{-2}); k_1 is the best coefficient of forest tourism resources; k_P is the coefficient of forest recreation; M is the income difference from the site location (ruble·hm^{-2}). The scholar used the annual growth cost C (ruble·hm^{-2}) and average profit rate H_p of the main tree species obtained by the forestry department to reflect the status of forest environmental resource producers, and P to reflect the impact of social demand on the value of forest tourism. Recreation coefficient k_P measures the value of forest environmental resources. At present, the analytic hierarchy process (AHP) is widely used to determine the forest recreation coefficient k_P of China. First, determine the main factors that affect the realization of the value of forest environmental resources, such as forest, human landscape, and forest tourism resources. Human landscape elements are evaluated from six aspects: aesthetic feeling, uniqueness, combination, historical and cultural scientific value, scale, and popularity [4]. Similarly, the constraint conditions are evaluated by several indicators, such as accommodation, transportation and communication, catering services, tourist commodities, and tour guide translation [4]. Then the index is weighted by AHP, that is, k_P = weight × score.

5. Application of Grey prediction model and decision model

5.1 Forest Identification

According to the harvest decision model in Model I, calculate FHPA for each province in China with related data features. With the testing of the Decision Model in Section IV, Jiangxi province is selected as the object of the following analysis. Jiangxi's forest is thought to undergo incomplete development.

5.2 Grey Prediction Model getting the carbon sequestration of identified forest and its products

Considering the uncertainty of external factors, we employ the GM (1,1) model.

1) Introduction of GM (1,1) model

The theory of GM (1,1) (grey prediction model) is to build a one-order differential equation of variables against time. The corresponding differential equation is:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u$$

In this equation, $x^{(1)}$ is the data sequence which is 1-AGO (accumulating generation operator) of the original data $x^{(0)}$Furthermore, t is a time variable. Variable a and u are called evolution parameter and grey action, respectively.

2) Employment of GM (1,1) on the prediction of carbon sequestration of the identified forest

Use Excel to organize the data about Jiangxi's Forest resources inventory every five years from China Statistic Department, use MATLAB software to do coding and related prediction. First, do a Quasi exponential law test to test the accuracy of the original data.

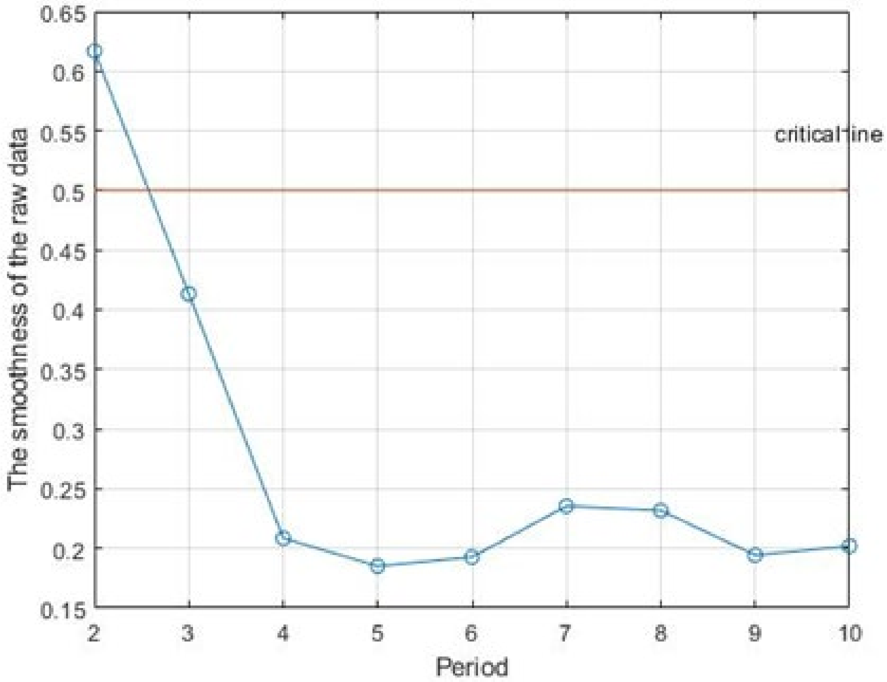

Figure 3. The Result of Quasi exponential law Test

From the picture, we can see that except for the first two periods, the data with a smoothness ratio of fewer than 0.5 accounts for 100%, which indicates that this data can be used to make a grey prediction. To ensure that we get the model with the best fitness effect, we separate the data into train and test datasets.

We also use the dataset to prepare different grey models instead of using the two randomly separated data to train our grey model. After running the code, we conclude that the sum of squared errors of the traditional, new-information, and metabolic GM (1,1) model is 11273.4974, 11353.2655, 6685.4647, respectively. Since the SSE of the metabolic GM (1,1) model is the smallest number, we choose the metabolic GM (1,1) model to predict. Since one period of this dataset represents five years, we choose to predict 20 periods. The expected carbon sequestration of Jiangxi's Forest is listed in the picture below:

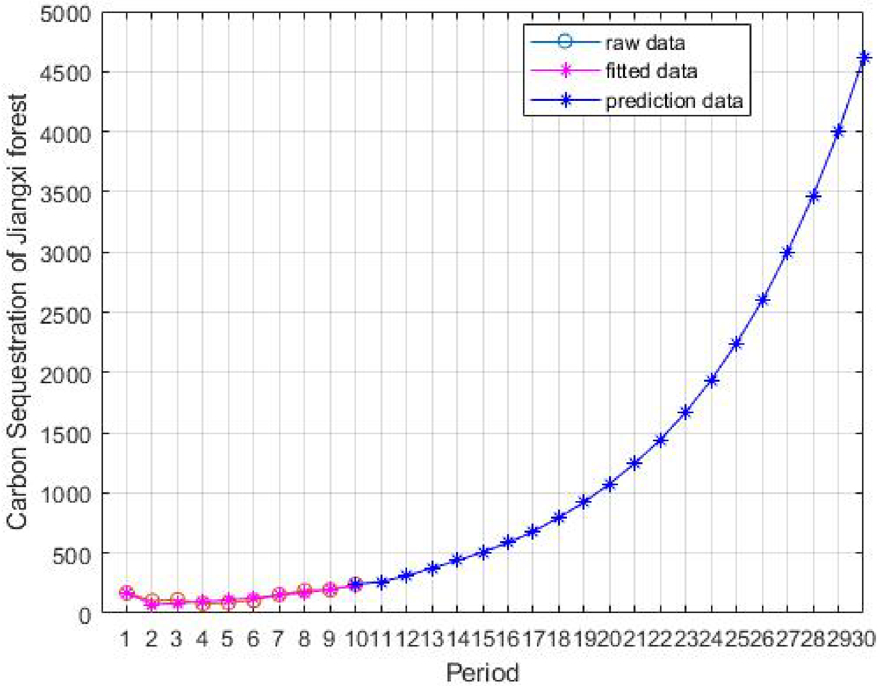

Figure 4. The result of the following 100 years

This forest sequesters carbon dioxide over 100 years is 46.15×108 tons. The residual test process of GM (1,1) tells that the mean relative residual $\overline{\varepsilon_r}$ equals 0.16334 < 0.2, which indicates that the fitness of good the metabolic GM (1,1) model effects on original data achieve a decent level.

3) Employment of GM (1,1) on the prediction of carbon sequestration of the corresponding forest product

Similar to section b, the data fit the Quasi exponential law. Furthermore, preparing different grey models, the SSE of traditional, new-information, and metabolic GM (1, 1) models is 97.9344, 97.9364, and 99.577. Finally, choose the traditional GM (1,1) model to predict. After analyzing the expected carbon sequestration of Jiangxi's Forest, this forest sequesters carbon dioxide over 100 years is 9.76×108 tons with an acceptable $\overline{\varepsilon_r}$= 0.19653 < 0.2.

5.3 Result and Discussion

After employing a metabolic and traditional GM (1,1) model to predict the carbon sequestration quantity of forest and related products in Jiangxi province, China, we estimate that over 100 years, the total amount of carbon sequestrated by Jiangxi's Forest and corresponding forest product is 55.91×10^8 tons. The prediction results are decent because the mean relative residuals are less than 0.2.

6. Problem and Strategy

6.1 Carbon Sequestration

Problem: Due to the heavy task of wood production, it is challenging to complete the task of only cutting down the over-mature forest, resulting in a large scale of deforestation of middle-age forest and eventually forming a large area of remnant forest and low-yield forest.

Strategy: Achieving efficient use of forest resources requires scientific forest management and adjustment. Therefore, the forestry department of Jiangxi Province should form an optimal rotation mode for forest carbon sequestration: determine the best harvesting and utilization period of trees, determine the rotation period, pay attention to the quality of forest carbon assets, and promote carbon market transactions.

6.2 Biodiversity Conservation

Problem: In selecting tree species, the manager should consider coniferous forests and neglects broad-leaved forests. A long time ago, the forest management department of Jiangxi Province built many virgin forests of Chinese fir and wetland pine, resulting in a large area of virgin coniferous forests. In contrast, the area of broad-leaved forests accounted for a small proportion and produced few timbers, which led to raising the prices of broad-leaved timbers. The contradiction between the supply and demand of broad-leaved timbers is prominent [5].

Strategy: The government can purchase agricultural land, sell broad-leaved forest saplings at a low price and encourage forest farmers to raise trees like Cinnamomum camphor. Also, the government ought to establish ecological protection bases to experimentally cultivate excellent broad-leaved tree species to enrich biological species and solve the contradiction between the supply and demand of broad-leaved trees.

6.3 Entertainment

Problem: The development of forest tourism in Jiangxi Province is too simple, mostly staying at the level of tourism, and the development of scenic spots such as leisure, vacation, and conferences is insufficient, which leads to the imbalance of forest tourism development.

Strategy: For the development of forest tourism in Jiangxi Province, it is necessary to formulate a reasonable development plan within this decade, according to the guidance of the local forest tourism development plan, consider the needs of users at all levels, and expand the scope of the forest eco-tourism system.

7. Conclusion

To sum up, with the in-depth development of the extensive data ecosystem, the operating model of financial institutions has also undergone specific changes. First, we test the validity of the data and build a model evaluating the amount of carbon sequestration of a forest by using sigmoid curve fitting. Then, based on the carbon sequestration value, we expanded the forest value evaluation model by adding three indicators: culture, biodiversity conservation, and tourism. Among them, cultural values are derived based on the time spent by people within the forest. The biodiversity conservation value is based on people's willingness to pay for ecological conservation. The tourism value is calculated based on the consumption reproduction and cost method and the analytic hierarchy process. Last, apply grey model GM (1,1) to predict the carbon sequestration quantity of forest and related products in Jiangxi Province and get the total amount is 55.91×10^8 tons. The forest in Jiangxi will have a more robust carbon sequestration capability under the forest management proposed than before by this paper.

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