A comprehensive evaluation of forest value based on carbon sequestration stock prediction

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Abstract. The increasing greenhouse effect globally, the excessive deforestation of forests and the weakening of forest carbon storage capacity have brought about drastic changes in the global climate and posed a great threat to the biosphere. Therefore, the issue of "making efficient use of forest carbon storage capacity and diversified value of forests" has attracted our attention. To better analyze the problem of carbon sequestration and forest value and formulate a reasonable forest management plan, this article established two models: the "grey system model" and "BP neural network prediction model." The two models used China's forest inventory data in the past 40 years to predict that the average value of total forest carbon sequestration in China in a hundred years is 189.37×108t. Aiming at the problem of forest value evaluation, this article apply "grey correlation analysis method," "main component analysis model," and "fuzzy comprehensive evaluation model." This article considers the value of forests from two aspects: ecological value and economic value. In terms of ecological value: this article found that forests have various values such as "carbon sequestration, water conservation, soil conservation, and biodiversity maintenance"; Most forests have a "U-shaped transition period" in carbon sequestration capacity. "Tree age and tree composition structure" are the main factors affecting carbon sequestration capacity. In terms of economic value, this article found that "increasing the proportion of young trees and suitable for the production of forest products" is a good way to increase the economic value of forests. In addition, the research shows that there are obvious differences in the degree of carbon sequestration capacity and economic value of forests in different climate areas such as "subtropical zone, warm temperate zone, and middle temperate zone.".

Keywords: Carbon sequestration, Forest value, Gray model, BP model;

1. Introduction

The increasing greenhouse effect in the world, the excessive deforestation of forests, and the weakening of forest carbon storage capacity have brought about drastic changes in the global climate and posed a great threat to the biosphere. Therefore, the issue of "making efficient use of forest carbon storage capacity and evaluating the value of forest diversification" has attracted much attention.

Forest should have other ecological values besides carbon sequestration, and its economic benefits must exist. In order to make efficient use of its carbon storage capacity and comprehensive value, it is necessary to study the factors affecting its carbon storage capacity, such as climate and geographical location. In addition, the impact of the deforestation cycle and forest products on forest value should be studied for reference to local communities.

Therefore, to better deal with the problem of greenhouse effect, it is necessary to master a reasonable and more accurate prediction method of carbon sequestration stock and evaluate the value of diversified forests.

2. Grey model

The establishment of a grey prediction model is mainly used to solve two problems:

Predict the forest carbon reserves in China in 100 years. Firstly, the model predicts the carbon reserves during the past 9 forest resource inventories, tests the residual and a posteriori error between the predicted value and the actual value to evaluate its accuracy, and then predicts the forest's carbon sequestration in the future.

The prediction of forest carbon reserves in China in the next 30 years is mainly used to judge the stage of forest development and construct the evaluation standard of the forest transition period.

The establishment steps of forest carbon sequestration prediction are as follows: The time series $X^{(0)}(1), X^{(0)}(2), \ldots X^{(0)}(n)$ represents carbon reserves during the nine forest resources. The randomness of time series is weakened by generating new series by accumulation.

$$X^{(1)}(n) = \sum_{k=1}^{n} X^{0}(k) \tag{1}$$

Then the corresponding differential equation of GM (1,1) model is: $\frac{dX^{(1)}}{dt} + aX^{(1)} = \mu$, of which: Called development grey number; It is called endogenous control grey number, two of the characters are the recognition parameters, which are obtained by least-squares fitting.

$$\begin{bmatrix} a \\ \mu \end{bmatrix} = \left(B^T B\right)^{-1} B^T Y_n \tag{2}$$

B is the constructed data matrix

$$B = \begin{bmatrix} \frac{(1)}{2} X^{(1)}(1) + X^{(1)}(2) & 1 \\ \frac{(1)}{2} X^{(1)}(2) + X^{(1)}(3) & 1 \\ . & \\ \frac{(1)}{2} X^{(1)}(n-1) + X^{(1)}(n) & 1 \end{bmatrix} \tag{3}$$

In order to ensure the fitting accuracy, the prediction model can be obtained by fitting the grey prediction process twice and solving the differential equation:

$$\hat{X}^{(1)}(K+1) = \left(X^{(0)}(1) - \frac{\mu}{a}\right) e^{-ak} + \frac{\mu}{a} \tag{4}$$

The residual calculation formula is $\Delta X^{(0)}(k) = \left|X^{(0)}(k) - \hat{X}^{(0)}(k-1)\right|$ and the calculation formula of relative error is:

$$\Phi(k) = \frac{\Delta X^{(0)}(k)}{X^{(0)}(k)} \times 100\% \tag{5}$$

The calculation steps of posterior error are:

$$S_1 = \sqrt{\frac{\sum\left[X^{(0)}(1) - \bar{X}^{(0)}\right]^2}{n-1}}, S_2 = \sqrt{\frac{\sum\left[\Delta^{(0)}(k) - \bar{\Delta}^{(0)}\right]^2}{n-1}} \tag{6}$$

Small probability error $P = \rho\left\{\left|\Delta^{0}(k) - \bar{\Delta}^{(0)}\right|\right\}$

Test the prediction results of forest carbon sequestration. The relative error is generally considered to be within 5%. It is generally considered that the prediction accuracy is good if the posterior error is less than 0.35 and unqualified if it is greater than or equal to 0.65.

3. Carbon sequestration

3.1 Grey prediction of carbon reserves

The data of China's forest carbon sequestration calculated based on the forest storage area method above are as follows: The carbon storage unit is $10^8 \cdot t$.

Table 1. Carbon stocks and changes of forest resources in China

Period	1993	1998	2003
Forest carbon storage	49.59	53.52	59.17
Period	2008	2013	2018
Forest carbon storage	63.47	70.2	81.03

After data screening and level ratio test, the data after 1988 are taken for prediction. The data is sorted out by Excel and programmed by MATLAB software. The time response function of grey GM (1,1) of forest area is obtained as follows: $\hat{X}^{(1)}(K+1) = 607.9833e^{0.086301k} - 548.5641$ (7)

It can be seen from the following table that the average relative error of the model "= 1.425% <5%, and the posterior error C = 0.1029 < 0.35. Comparing the inspection index p with the grey prediction accuracy grade standard, the result indicates that the fitting degree of the model prediction is good and the result is credible, which can predict China's forest carbon reserves. The unit of carbon storage is 10^8 t.

The carbon storage of the forest system will reach 168.85 after 100 years. It is calculated by t = 26, which is more accurate.

3.2 Neural network prediction of carbon sequestration

According to the description of the grey model, the forest system in each cycle has a different forest structure. The BP neural network model still selects the forest resources

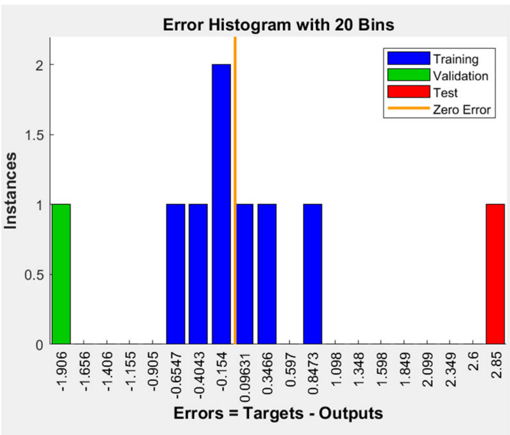
Table 2: Carbon stocks and changes of forest resources in China

Year	Actual carbon stock	Predicted carbon stock	Residual	Relative error(ε)
1984-1988	49.87	49.87	0	
1988-1992	49.59	49.2319	0.3581	0.72%
1993-1997	53.52	53.2518	0.2682	0.50%
1998-2002	59.17	58.7372	0.4328	0.73%
2003-2007	63.47	64.7876	-1.3176	2.08%
2008-2012	70.20	71.4613	-1.2613	1.80%
2013-2017	81.03	78.8224	2.2076	2.72%

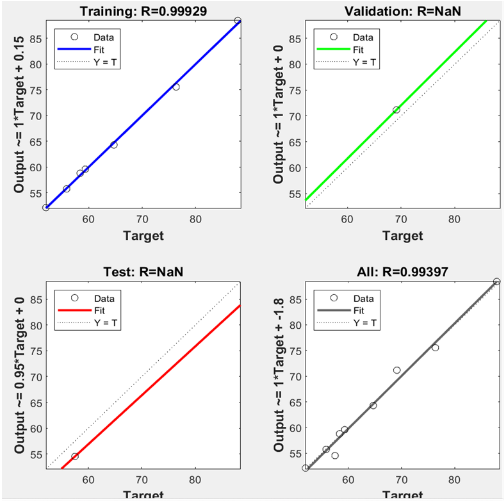
Inventory data of China in the past 9 times (once every 5 years). Considering that the forest knot is the key factor affecting the forest carbon sequestration, the BP neural network model divides the forest structure in different ways, then predicts the carbon sequestration of various types of forests respectively, and finally sums the results to the predicted value of the total forest carbon sequestration.

Firstly, according to the tree age, the tree structure is divided into five categories: young forest, middle-aged forest, near mature forest, mature forest, and over-mature forest. The data of five kinds of trees are used as the network input of the BP neural network model, and the forest carbon storage is used as the network output, and then the network is trained. The following figure describes the results of "predicting the impact of forest structure on total forest carbon storage by tree age."

Figure 1 shows the deviation between the predicted and actual values, which fits between the predicted and actual curves



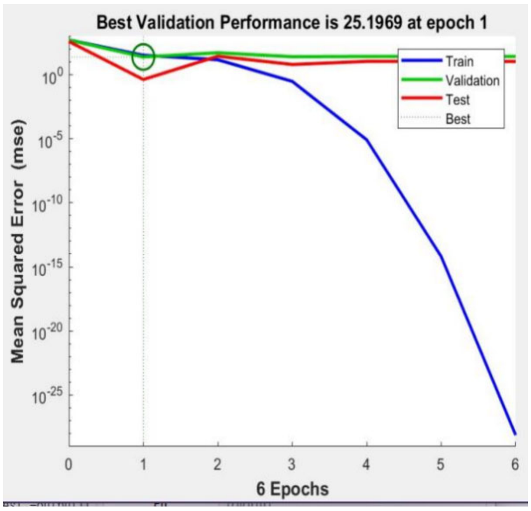
(a)Error Analysis



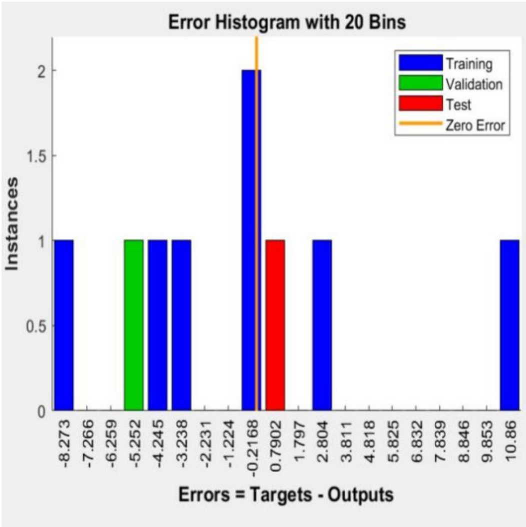
(b)Fitting Status
Figure 1 The Evaluation Trend of these two Products

Then, according to the use of trees, the forest structure is divided into five kinds: protective forest, special forest, timber forest, fuel forest, and economic forest. The data of the five kinds of trees are successively used as the network input of the BP neural network model, and the forest carbon storage is used as the network output to train the network.

Figure 2 describes the results of forest structure prediction of forest carbon reserves by forest use." The two Figure 2 (a) and (b) show the fitting effect of prediction curve and error between the predicted value and actual value.



(a) Fitting Effect



(b) Error Analysis

Figure 2 The Evaluation Trend of these two Products

Finally, the forest structure is divided into "natural forest and artificial forest" according to the source of trees. The data is used as the network input of the BP neural network model, and the forest carbon storage is used as the network output.

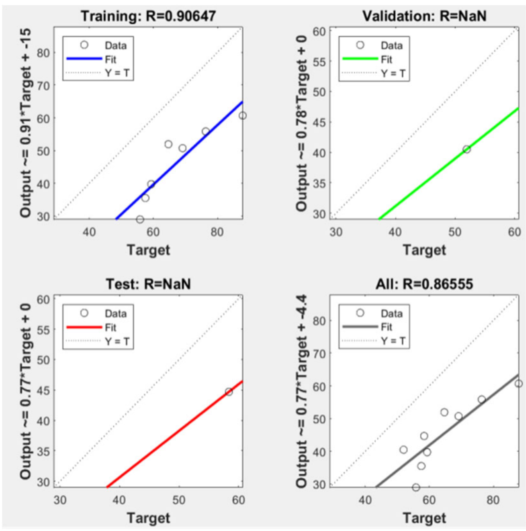
Figures are used to describe the results of "forest structure prediction of forest carbon reserves by forest source. The two figures respectively show "the prediction curve is the fitting effect of the actual curve" and "the deviation between the predicted value and the actual value."

It can be seen from the following table that the residual error between the predicted value and the actual value is small, and the relative error is less than 2.1%.

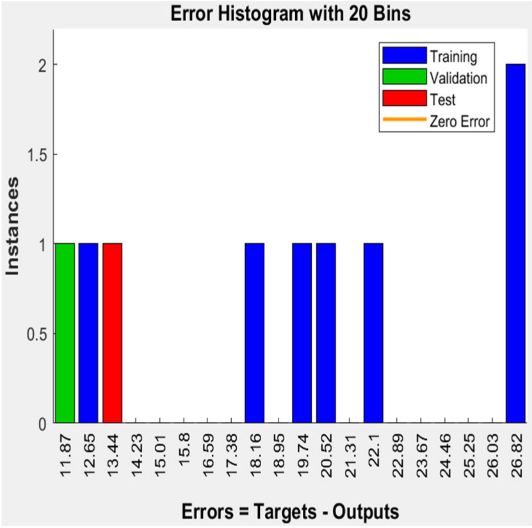
Table 3. Carbon stocks and changes of forest resources in China

Index	Aging structure	Forest use	Origin division sequestration
Actual value	58.37	87.9	76.35
Predicted value	57.2398	87.4009	77.9554
Residual	1.1302	0.4991	-1.6044

Based on the above prediction of forest carbon sequestration according to forest structure, using the same idea,[4] BP neural network model summarizes the prediction results into the predicted value of total forest carbon sequestration. It predicts that the total carbon sequestration of the forest system in 100 years is 171.4.



(a) Fitting Status (b) Error Analysis



(b) Error Analysis

Figure 3 The Evaluation Trend of these two Products

3.3 Time series prediction of carbon sequestration

For forest carbon reserves, combined with AIC information criteria (the lower the value, the better), use Excel software to sort out the data and use SPSS software to automatically model, compare, and select multiple potential alternative models. Finally, the optimal model is found to be ARMA(2, 1, 0), and its model formula is:

$$y(t) = 4.809 + 1.065 * y(t-1) - 0.424 * y(t-2) \quad (8)$$

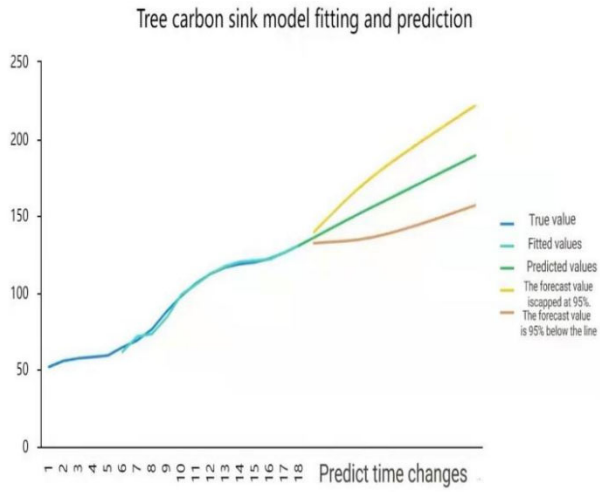


Figure 4 Tree carbon sink model fitting and prediction

From the results of Q statistics, if the p-value of Q6 is greater than 0.1, the original hypothesis cannot be rejected at the significance level of 0.1. The residual of the model is white noise, and the model meets the requirements.

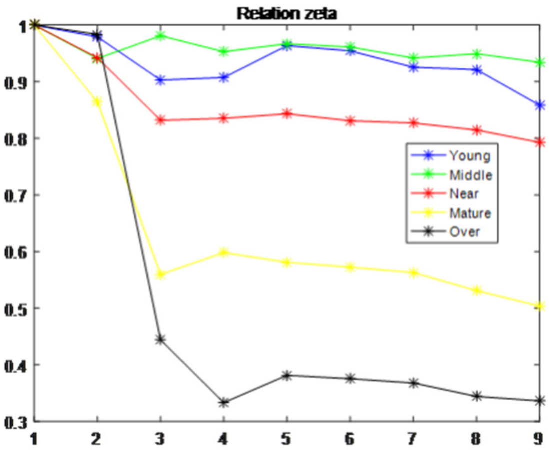
4. Forest Comprehensive Value Assessment

The value of the forest system has many ways, including its carbon storage capacity, water conservation, soil conservation, production of forest products, and human tourism. In addition, the forest itself has economic value through carbon sequestration of forest products. When evaluating the comprehensive value of the forest system, the research evaluates the essential influencing factors such as "forest structure, climate conditions, number of human felling and felling cycle."

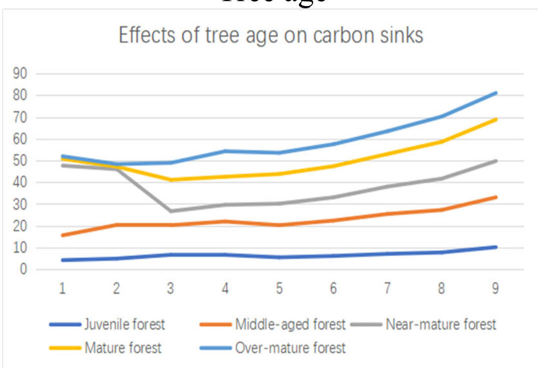
4.1 Value analysis of forest structure

For the same forest system, the carbon dioxide storage capacity of the whole system is mainly contributed by above-ground trees, and the carbon sequestration capacity of trees is mainly affected by the composition of the forest structure.[5] Firstly, this study focuses on the impact of forest structure on forest carbon sequestration. Based on the public data of China's forest resources inventory, this study selects China's forest structure resource data in the past 9 cycles (each cycle is 5 years).

Firstly, according to the tree age, the forest trees are divided into five stages: young age, middle age, near mature stage, mature stage, and over the mature stage.[6] The grey correlation analysis method evaluates the correlation between tree age and its total carbon sink. Excel processes the data, and the correlation degree is calculated by programming with MATLAB software. The calculation results show that the grey correlation degree between trees and total carbon sink in the five stages of "young age, middle age, near maturity, maturity and over maturity" is 0.9347, 0.9587, 0.8575, 0.6415, and 0.5074, respectively.



Tree age

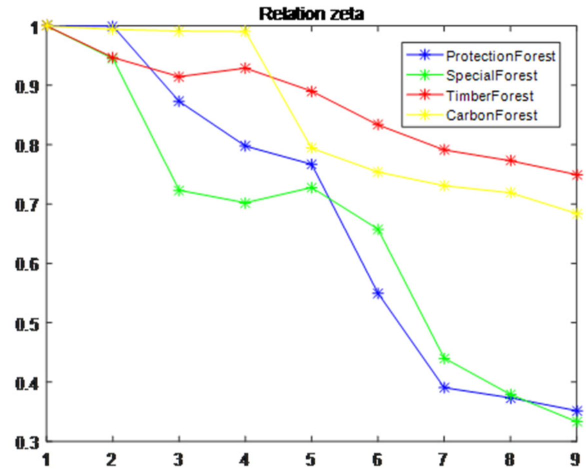


(b) Carbon sequestration stock by tree age

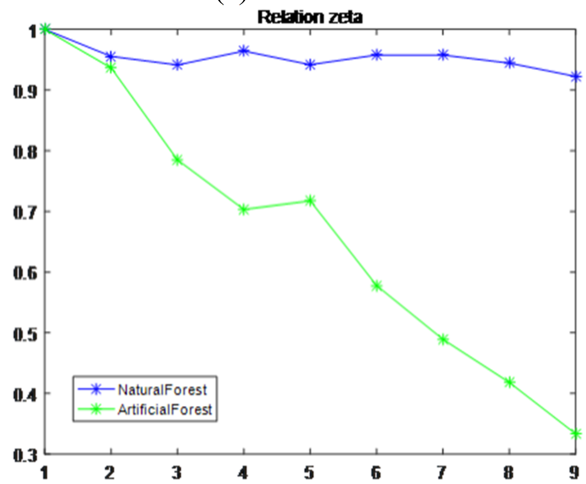
Figure 5 Effects of the tree age on carbon sinks

The above figure also shows that young and middle-aged forests have a greater correlation with the total carbon sink in the forest structure. They contribute more to the forest carbon sink, while mature and over mature forests have less correlation with the total carbon sink.

Meanwhile, two other forest structure classification methods are used to analyze the carbon sequestration capacity of trees, that is, the trees are divided into"shelter forest, special forest, timber forest, and fuel forest" according to their uses, and the trees are divided into "natural forest and artificial forest" according to their sources.[6] Grey correlation degree is used for analysis. Figure 2 shows the correlation results classified by source in the following figure. The calculation results show that if classified according to



(a)Forest use

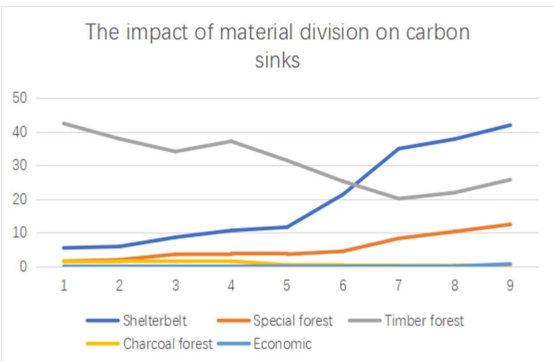


(b) Forest source

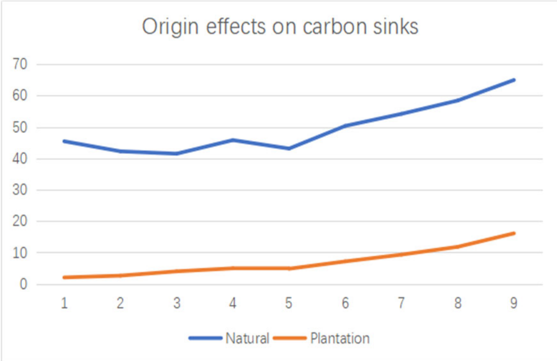
Figure 6 Effects of forest use and origin on carbon sequestration

the use of trees. The correlation degree of "shelter forest, special forest, timber forest, and fuel forest" is "0.6782, 0.6566, 0.8698 and 0.8510"; If classified according to the source of trees, the correlation degree of "natural forest and artificial forest" is "0.9539, 0.6623" in turn.

According to the calculation results: Among the five purpose forests, carbon forest has the greatest impact on the increase of carbon storage in the forest system, and timber forest has the least impact on the increase of carbon storage. In the origin of the two kinds of trees, the correlation between natural forest and forest carbon storage is large, which is about 1.5 times that of the artificial forest, indicating that the contribution of natural forest to forest carbon storage is greater than that of the artificial forest.



(a)Forest carbon sequestration by use



(b) Forest carbon sequestration by origin

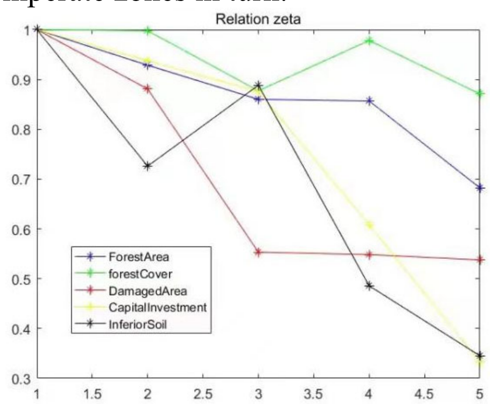
Figure 7 Changes in forest carbon sequestration by wood use and origin

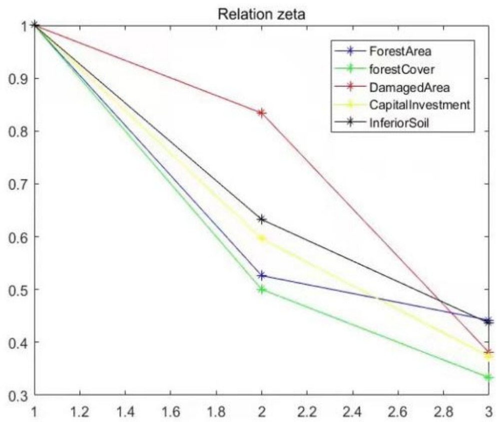
4.2 Comprehensive value of forest system

Due to differences in climate, population, and composition, different types of forests have different capacities to store carbon dioxide. In order to evaluate the impact of various factors on the ecological value of forest carbon sequestration, effective carbon dioxide storage plans are formulated for different forests. This study selected five main factors: "forest area," "forest coverage," "water conservation," "soil composition," and "deforestation degree" and evaluated the impact of these factors on forest carbon sink capacity by grey correlation analysis.

The study selects three typical forest systems in China as the research object. The three forests are located in the "subtropical," "warm-temperate," and "middle temperate" climate zones, respectively, which can be used as a representative of the carbon sequestration capacity of forest systems in the three climate zones in China to a certain extent. According to the three factors of "felling degree," "soil composition," and "water conservation," select "forest area affected by manual felling," "forest area affected by soil pests," and "net forest rainfall" as the measurement indicators.[7]

The following three figures show the correlation degree of factors of three forests in subtropical, warm temperate, and middle temperate zones in turn:





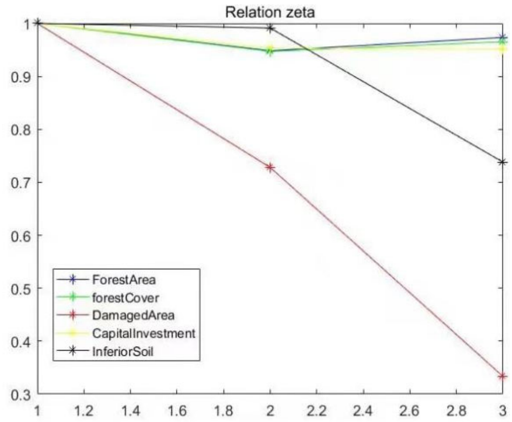


Figure 8 Correlation analysis of three temperature bands

From Figure 8, the total amount of carbon sink is related to the total area of forest and the area of forest pests, while the "carbon sink" in subtropical areas is relatively small. It is shown that the forest in this area is greatly affected by diseases and pests, the forest coverage needs to be improved, and people have a strong awareness of forest protection.

For warm temperate forests, the correlation between forest coverage and forest area on total carbon sink is still large, while the correlation between "artificial deforestation area" and "forest area affected by soil pests" and total carbon sink is also small. Compared with subtropical forests, warm temperate forests have a higher correlation with total carbon sink, and the latter two have a lower correlation with total carbon sink.[7]

In the middle temperate forest, the area affected by deforestation and the area of pest forest is related to the total carbon sink, while the "forest area" and "forest coverage" are less related to the total carbon sink. It is shown that the forest area and forest coverage in this area are at a high level, while the soil conditions are poor and the cutting volume is high.

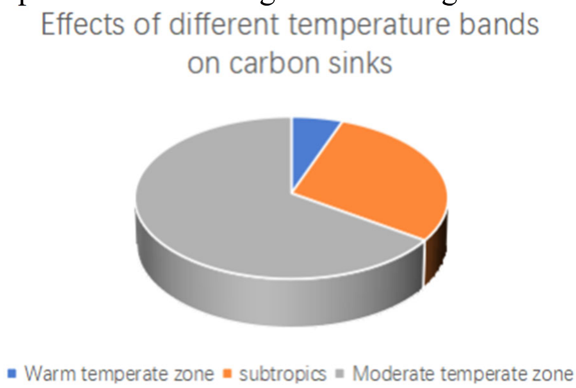


Figure 9 Temperature band carbon sink

5. Conclusion

Based on the research on carbon sequestration and the comprehensive evaluation of forest value, This article management plan applies to the forest areas in the "middle temperate zone, warm temperate zone, and subtropical" climate zone and have not suffered serious natural disasters. The following opinions are made on the formulation of the forest carbon sequestration plan:

From the perspective of the impact of climate on forests: different types of forests have different carbon storage capacities due to the differences in climate, population, and composition structure.

Forests in subtropical areas usually have good forest soil conditions and less severe deforestation. It is emphasized that the forest coverage is high. Therefore, we can focus on increasing the forest area and appropriately speed up the renewal of forest structure.

Forests in warm temperate regions have a higher degree of correlation between forest coverage and forest area and total carbon sink, which promotes the efficient storage of carbon dioxide by expanding forest area and forest coverage.

The forest area and forest coverage in the middle temperate zone are high, but the soil conditions are poor, and the logging volume is high. Communities should formulate policies to "prohibit deforestation and protect forests," enhancing people's awareness and strengthening soil conservation.

Forest structure also has a great impact on carbon sequestration, appropriately reduce the planting area of fuel forest and increase the planting density of shelter forest, in warm temperate regions have a higher degree of correlation between forest coverage and forest area and total carbon sink, which can promote the efficient storage of carbon dioxide by expanding forest area and forest coverage. The forest area and forest coverage in the middle temperate zone are at a high level. Compared with artificial forests, natural forests contribute more to forest carbon storage capacity. It is necessary to strengthen the protection of natural forests, reduce the number of natural wood felling, and appropriately increase the number of artificial forests.

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