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Forest Value Evaluation Based on Entropy Weight Method and RBF Neural Network Model

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Abstract

The factors influencing forest value were studied. Eight quantifiable indexes were selected from social, ecological and economic aspects, and a forest value evaluation model was established based on entropy weight method. Given the forest value at the transition point, the forest development and forest management were divided into different stages. Taking chugaqi National Forest Park as an example, a prediction model of photosynthesis rate related to temperature was established based on RBF neural network algorithm. On this foundation, the change trend of forest photosynthesis rate in one year was predicted, which provided suggestions for forest management at the transition point. Finally, the sensitivity of the decision model developed in this paper was analyzed.

Keywords

Entropy weight method, RBF neural network, Forest value.

1. Introduction

Forests are of irreplaceable significance to mankind. They provide oxygen, fix carbon, contain water and maintain biodiversity. In the rapid development of human society, the value of forests was once ignored, so that a large number of forests were destroyed. Nowadays, with the deterioration of the environment, forests have gradually attracted people's attention. Some countries or regions have issued protection policies now in the hope of restoring and developing forests.

Hence, there is an urgent need for a widely applicable assessment method to describe the value of a specific forest at a certain time and provide a basis for forest management departments around the world to formulate management plans. At the same time, this method should be intuitive and easy to implement among managers. In addition, due to the impact of the greenhouse effect and the continuous warming of the earth's climate, more forests are needed to play the role of carbon absorption. The carbon sequestration value of forests should also be given more consideration.

In this context, based on the existing research results, this paper collects typical data, establishes a mathematical model of forest value evaluation, and puts forward some views and suggestions on the management measures in different stages of forest development.

2. Model establishment

2.1. Identification of influencing factors

In order to scientifically and comprehensively evaluate the value of forests and provide reference for forest managers, forests are examined from three aspects: ecology, economy and society. From these aspects, the following eight quantifiable indicators and their data from

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2000 to 2013 are objectively selected. They will be processed in the article to help researchers describe forests in a data-based way.

Table 1: Influencing factors of forest value

Analysis of global forest value from 2000 to 2013	Forest area applied to production and social services
	Employment hours in forestry and logging
	Climate regulation capacity
	Soil and water conservation capacity of forest
	Fruit consumption per capita
	Total global forest area
	Above-ground biomass in forest per hectare
	Atmospheric carbon dioxide concentration

Total global forest area

Obviously, the value of forests with thousands of trees is far greater than that of forests with only dozens of trees, and the forest area is the most intuitive reflection of the number of trees. At the same time, the larger the area of forest, the stronger its ability to absorb carbon, and the greater its value in preventing climate warming[1].

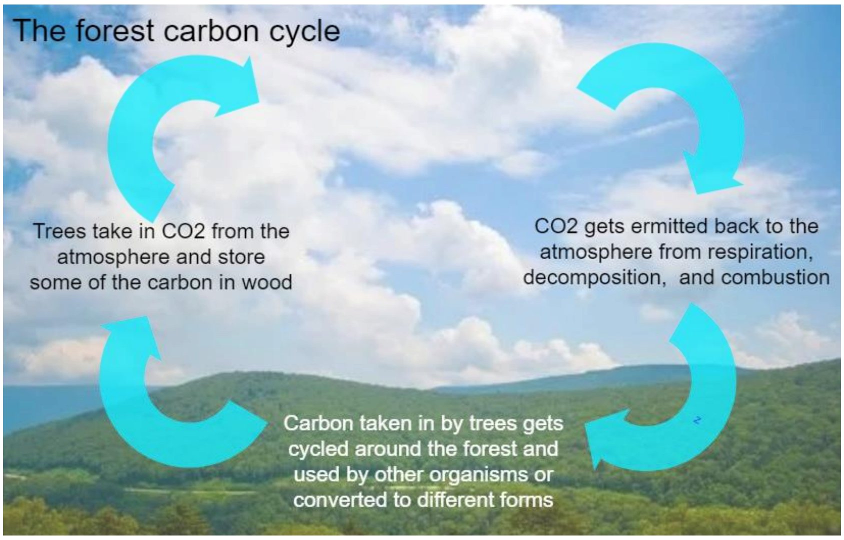

Figure 1: The forest carbon cycle

Climate regulation capacity

Climate regulation ability is one of the important abilities of forest. When examining different forests, it is found that significant spatial and temporal differences in water, gas, and heat exchange due to differences in geographic location, soil composition, and management practices, all of which affect microclimate factors like light, temperature, humidity, and precipitation within the forest. At the same time, these microclimate factors also influence the Climate regulation capacity of forest, such as photosynthetic respiration and water transpiration, so as to carry weight with the regional climate of a certain region, particularly the maximum temperature in summer and its daily or annual changes[2].

Soil an water conservation capacity of forest

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Planting more trees on the mountain is equal to erecting a reservoir, which can swallow more rain and spit out less rain. As a result, a forest's soil and water conservation capacity is considerable, and forest managers often need to adjust their management plans according to the water and soil conservation capacity of forests.

Above-ground biomass in forest per hectare

Globally, 424 million hectares of forests are used primarily for biodiversity conservation. Forests ensure the diversity of life on the planet, and if they are damaged in some way, It will interfere with human beings, such as fire, pests and global temperature rise.

Atmospheric carbon dioxide concentration

The concentration of carbon dioxide in the atmosphere determines whether many organisms on earth can survive well or not, and it mainly regulates the temperature of the earth. Absorbing greenhouse gases is one of the abilities of forests. Forests are of great significance to prevent global warming and promote human sustainable development.

Forest area applied to production and social services

Forests may benefit not just the environment, but also society, promoting social and economic development and advancing human civilization. Human beings need forests for entertainment, scenic spot tourism, education and scientific research, medical resources, chemical raw materials and other social services.

Fruit consumption per capita

The fruit of trees is an important source of food and nutrition for human beings. Every year, a large number of fruits are produced from the forest to maintain human survival. Therefore, the per capita consumption of fruit can directly reflect the value of forest in diet.

Employment hours in forestry and logging

As the ecological environment becomes more and more momentous to people, jobs related to it, such as forestry and logging, will also gradually develop. For the sake of a better reflection of the value of forests, it is necessary to take into account the employment of forestry and logging worker[3].

2.2. Entropy method analysis

This chapter considers how forest value is reflected in the eight indicators representing forests. Through the analysis of entropy weight method, the forest value of different years is evaluated.

In entropy weight method, information entropy can be used to judge the dispersion degree of an index and calculate the weight of each index, so as to provide basis for multi index comprehensive evaluation. The specific steps are as follows:

2.2.1. Data standardization

By observing the data, it is found that the types and units of the above eight indicator variables are not exactly the same. Intended to eliminate the magnitude effect of the variables and make each variable have the same expressive power, it is necessary to standardize the data. There are many methods of standardization. This paper adapts the Z-score standardization method based on the mean and standard deviation of the original data.

Let the data involve m indicators, and there are n sample data. Express the value under the jth indicator of the ith sample by x_{ij}, and each factor is normalized according to the number of each option as

$$x'_{ij} = \frac{x_{ij} - \overline{x_i}}{S_j}, \tag{1}$$

where i and j satisfy the following equation:

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$$1 \le i \le n, 1 \le j \le m. \tag{2}$$

2.2.2. Evaluation index weights

To give more objective weights for all the above index systems, the weights of each index are determined using the full weight method.

Step1 Data normalization

The data preprocessing has normalized the data accordingly.

Step2 Find the information first of each indicator

Calculate the weight of the ith sample value for the indicator under the jth indicator.

$$y_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \tag{3}$$

Calculate the entropy value of the jth term.

$$e_j = -K \sum_{i=1}^{m} y_{ij} \ln y_{ij} \tag{4}$$

The K, in the above equation satisfy the following properties:

$$K = \frac{1}{\ln m} \tag{5}$$

Calculate the redundancy of information entropy.

$$d_j = 1 - e_j \tag{6}$$

Step3

In the context of global warming, it is hoped that forests can play a greater role in carbon sequestration. In the forest stock conversion factor method, there is a direct link between the amount of carbon sequestered by the forest and the forest area. The average forest carbon sequestration (AFCS) was calculated according to the equation proposed by Kitzes in 2008[4], and AFCS represents the amount of atmospheric CO, sequestered by photosynthesis in forest ecosystems with long-term carbon sequestration capacity per unit area.

$$AFCS = \frac{NFP}{AF} \tag{7}$$

Where NFP is the total annual production of above-ground forest biomass and AF represents the forest area.

Aimed to lay stress on carbon sequestration in assessing the value of forests, the impact of the total global forest area and aboveground organisms per hectare of forests on forest value is laid emphasis on. Thus, the redundancy of the total global forest area and the aboveground biomass per hectare of forest are multiplied by the weight gain coefficient μ= 2 respectively.

Through the above steps, the result is:

Table 2: Redundancy of influencing factors

Factor	Information entropy e	Redundancy	Redundancy after weight gain
Forest area applied to production and social services	0.911	0.089	0.089
Employment hours in forestry and logging	0.948	0.052	0.052

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Climate regulation capacity	0.909	0.092	0.092
Soil and water conservation capacity of forest	0.886	0.114	0.114
Fruit consumption per capita	0.9	0.1	0.1
Total global forest area	0.906	0.094	0.188
Above-ground biomass in forest per hectare	0.911	0.089	0.178
Atmospheric carbon dioxide concentration	0.918	0.082	0.082

Step4

Calculate the weights of each indicator.

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{8}$$

Thus, the following weights are obtained:

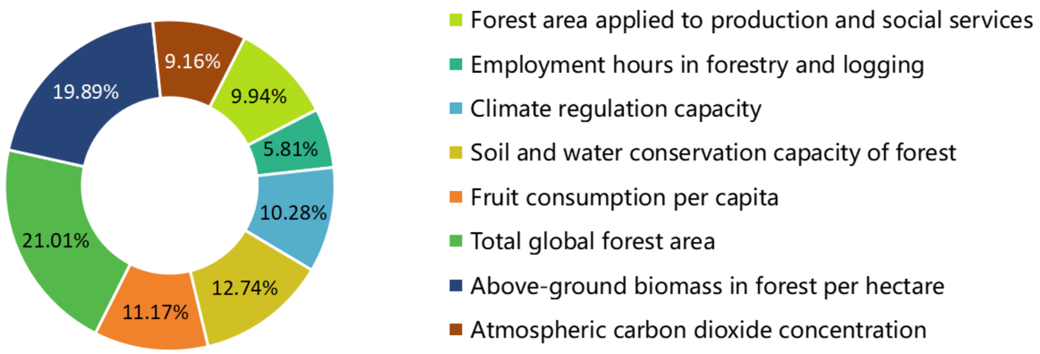

Figure 2: Weight of the influencing factors

Total forest area and above-ground biomass per hectare of forest have the highest weights, while soil and water conservation, per capita fruit consumption, and climate regulation capacity all have weights of more than 10%. The impression of these factors on forest value is similar in magnitude. In the following analysis, the influence of factors with high weight will be paid attention to, such as total forest area and above-ground biomass per hectare, and different forest management plans will be formulated according to these factors.

2.2.3. Calculate the composite score of each sample

Through the above analysis, the quantitative value of the forest value has been obtained, and a linear function has been established by the linear weighted synthesis method as a comprehensive evaluation value, i.e.

$$S_i = \sum_{j=1}^{m} y_{ij} w_j \tag{9}$$

The change pattern of Si value quantitatively describes the change of forest value from 2000 to 2013, to this point, the samples can be ranked and evaluated based on each sample score, and the evaluation composite index is obtained as shown in the following table:

Table 3: Score of forest value in different years

Year	Comprehensive index value of forest value evaluation
2000	-0.457909917
2001	-0.421381098
2002	-0.315413108
2003	-0.276869328
2004	-0.164711371
2005	-0.058558995
2006	0.036976885
2007	0.057190461
2008	0.094083427
2009	0.18574621
2010	0.294613559
2011	0.30698888
2012	0.335741998
2013	0.383502397

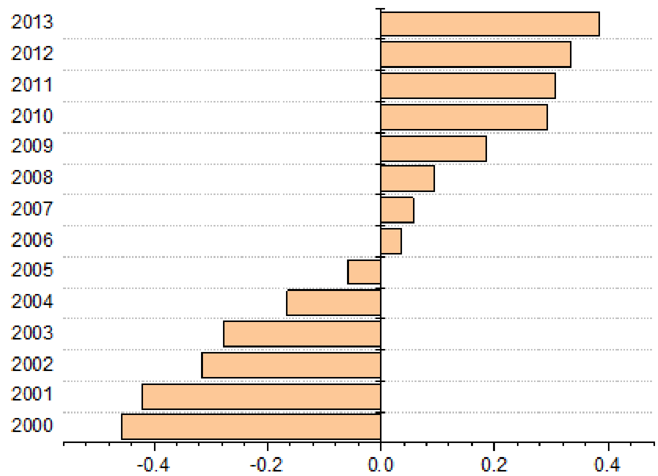

Figure 3: Score of forest value in different years

On a worldwide scale, no change in the weight value of each indicator is found in the short term. With the above line graph, it is found that the world forest value as a whole belong to an upward trend.

According to the forest value score, the forest development is divided into three stages. The first stage is $S_i \le 0$, which is noted as the early stage of forest development; the second stage is $0 \le S_i \le 3$, which is noted as the middle stage of forest development; and the third stage is $S_i \le 3$, which is noted as the late stage. The transition points of the three stages of forest development are $S_i = 0, S_i = 3$. The corresponding management plans will also have transition stages at $S_i = 0, S_i = 3$.

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2.3. Forest management

2.3.1. Management measures

At different stages of forest development, forest management can often draw up different management plans based on the current state of forest development and various indicators, such as forest cover. Different forest management plans will include a combination of deforestation reduction, afforestation, fertilizer management, fire management, pest management, etc.

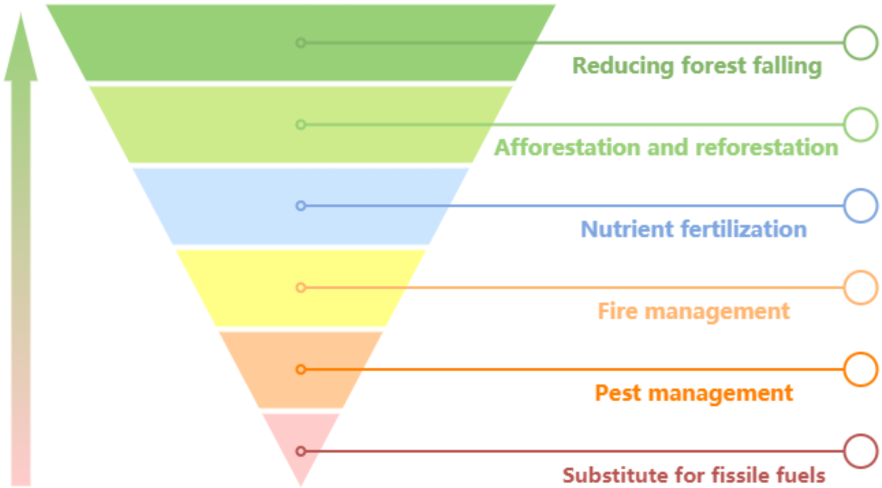

Figure 4: Forest management measures in sequence of importance

The following four forest management measures are more vital

Reducing deforestation: Reducing deforestation and maintaining forest area can effectively prevent forest degradation. Moreover, avoiding excessive deforestation can save those disappearing forests.

Afforestation: Small area of tree planting will form a forest after a certain period of time, which can expand the forest area and promote the absorption of atmospheric CO2 by the forest, and also maintain the balance of the ecosystem[5]. Plantation forestry is applicable globally, highly feasible and not costly

Fertilizer management: The deficiency of nutrients such as N and P in the soil is the main factor limiting the growth of forests, for this reason, adding fertilizers can overcome these deficiencies and increase the carbon storage. this measure is more costly and difficult to implement, and is now generally implemented in developed regions in Europe and the United States[6].

Fire management: Fire management is the enhancement of fire protection to reduce carbon losses by reducing the frequency or intensity of fires. The common ones are fire satellite prediction and the new ones are fire management system proposed by WANG[7]. However, due to the complex and variable climate, different fire management methods in the dry and rainy seasons, etc., which require high facilities, this method is costly to implement.

2.3.2. Phased forest management

Obviously, forest development in each region is often related to the level of social development in that region, and forest management plans can vary depending on the economic level. Generally speaking, economically developed regions have a higher level of forest development and are in the later stages, while economically backward regions have a lower level of forest. The comparison of the following two pictures can reflect this relation.

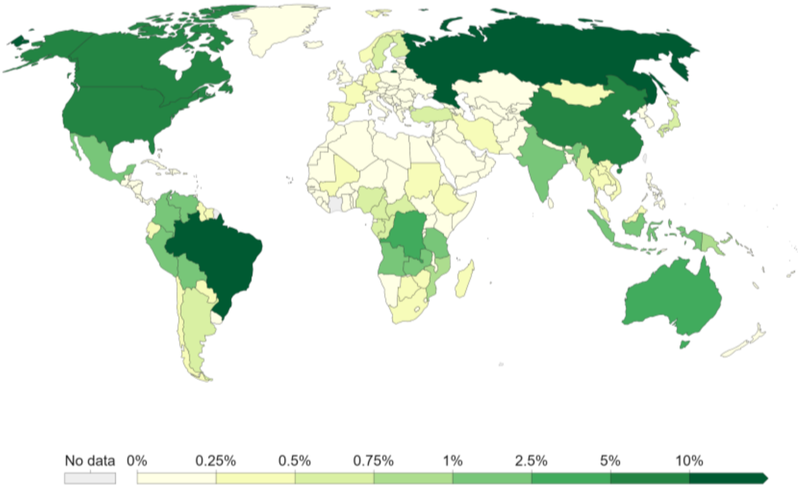

Figure 5: Distribution of active forest management plans in the world

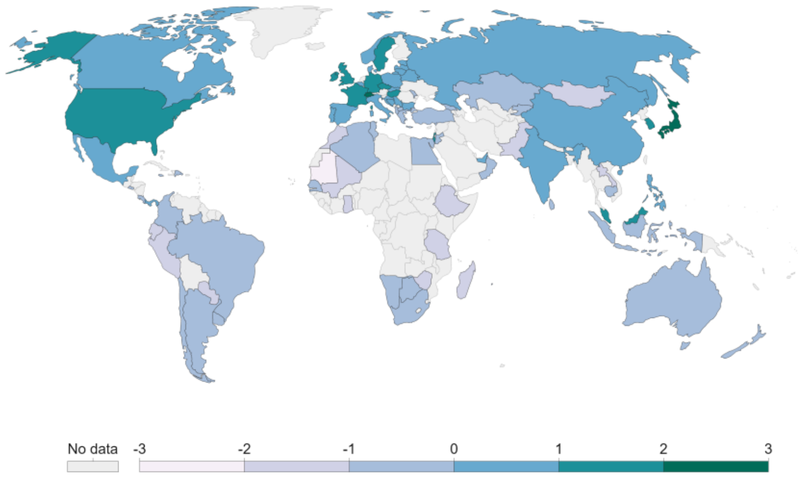

Figure 6: Economic Complexity Index (ECI) by country ranking, 2016

At different stages of forest development, different forest management plans should be formulated in detail.

(1) At $S_i \leq 0$, the early stage: This part of the forest has a low total area and above-ground biomass per hectare of forest, low forest cover and high deforestation rates, thus also leading to a weak positive impact of the forest on soil and water conservation, climate regulation social services, etc. The poor forest condition is generally due to the low level of economic development in the region, people tend to clear the land for resources through deforestation, and some areas are vulnerable to fires and pests, leading to the deterioration of the forest condition. In pursuit of the efficient improvement of the forest condition at this stage, local governments should regulate the management of arable land resources, raise people's income level by developing industries, and address the causes of deforestation at the root. Forest management departments should vigorously reduce the amount of deforestation and carry out reasonable and available afforestation. At the same time, through fertilizer management, soil fertility will be efficiently strengthend to promote the growth of forest trees. In terms of fires and pests, managers should enhance management and introduce relevant prediction and protection equipment.

(2) At $0 \leq S_i \leq 3$, the medium-term stage: This part of the forest is usually located in countries or regions where the economy is gradually developing from backwardness and people begin to return farmland to forest. However, deforestation is still occurring. In this forest development stage, the rate of deforestation slows down, the rate of forest loss gradually decreases, and the

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forest cover gradually increases. As the circumstance of forests ameliorates, the role of forests in the environment gradually increases. For the benefit of further optimization of forest conditions, forest management should continue to be strengthened, tree cutting should be reduced, and afforestation should be carried out while promoting local economic development level. At the same time, more attention should be invested in fertilizer management to improve the development potential of forests through the use of science and technology. At this stage, the impact of disasters such as fire, pests and diseases on forests will expand, and forest managers often need to spend more time and energy to prevent them.

(3)At $S_i \leq 3$, the late stage: The forests at this stage are generally located in the economically developed areas of developed countries and a few developing countries. These areas have high forest coverage and low deforestation rate, which means paying more attention to the ecological environment and having relatively sound legal support for forest development. At this stage, the ecological, social, educational, economic and cultural functions of forests have been better reflected. For the promotion of forest optimization, managers need to pay attention to fertilizer management, prevent fire and insect pests, develop new energy such as hydropower and solar energy, and hybridize fast-growing species to meet the demand for wood.

The transition point between management plans occurs when the forest begins to transition to a new stage of development. At this stage, forest management departments ought to pay attention to the statistical management of trees, the maintenance of forest facilities and the planting preparation of new tree species.When the forest cover or forest area changes, they need to communicate with relevant departments in a timely manner and formulate appropriate policies to adjust conflicts between forest land and land types such as agricultural land. In order to avoid the reduction of the overall defense capacity of forests against disasters caused by the species homogenization in the process of forest development, forest managers also need to conduct research on the proportion of individual tree species in local forests and plant different kinds of trees according to local conditions. In the transition phase, the frequency of such research needs to be increased to grasp the development of the forest in time.

For a given forest, in order to determine the forest management plans, the first step should be to determine at which stage of development the forest is. Managers can calculate the value of forests by using entropy weight method. Alternatively, the stage of development of the forest can be roughly estimated by the level of economic development of the economy where the forest is located. After that, the forest management approach can be planned in stages.

2.4. RBF neural network algorithm prediction

Given the slow rate of tree renewal, the development stage and transition stage of the forest will be very long. Generally, it is suggested to carry out forest management at the transition point when the forest growth is slow, that is, when the plant photosynthesis rate is slow, so as to avoid cutting and other management measures interfering with the plant growth cycle[8].

According to the measured data, it was found that there was a significant correlation between photosynthetic rate and temperature. Aimed at investigating the influence of temperature variation on photosynthetic rate, chugaqi National Forest Park was taken as an example to predict. It covers an area of 6908540 acres and is located in the state of Alaska, which has high latitude, high altitude and cold and mild climate.

RBF neural network algorithm has strong nonlinear fitting. The algorithm not only has good approximation performance for complex functions, but also has fast convergence speed.

In the training of the model, the sample selected coniferous mixed forest. It is worth mentioning that the coniferous mixed forest is located in the cold temperate zone and its environmental conditions are similar to Chugach national forest. The selected examples are very typical.

The ambient temperature at different time periods was selected as the input factor and photosynthesis rate as the output factor, and 400 input samples, 40 simulated samples and 45 predicted samples were selected.

Suppose the input vector is $X = [x_1, x_2, \cdots, x_n]^T$, N is the number of input samples, $W = [w_1, w_2, \cdots, w_n]^T$ is the output weight vector, m is the number of hidden nodes, d is the offset, $h(X)$ is the network output, $g(\bullet)$ is the radial basis function. Gaussian function is usually used:

$$g(\|X - C_i\|) = \exp(-\frac{\|X - C_i\|^2}{\sigma^2{}_i}). \tag{10}$$

$\|\bullet\|$ refers to the European standard and C_i refers to the data center in the network. In this case, the output of the neural network is

$$h(X) = d + \sum_{i=1}^{m} \omega_i \varphi(\|X - C_i\|). \tag{11}$$

Through RBF neural network algorithm, the changes of photosynthesis rate on different days of the year were obtained.

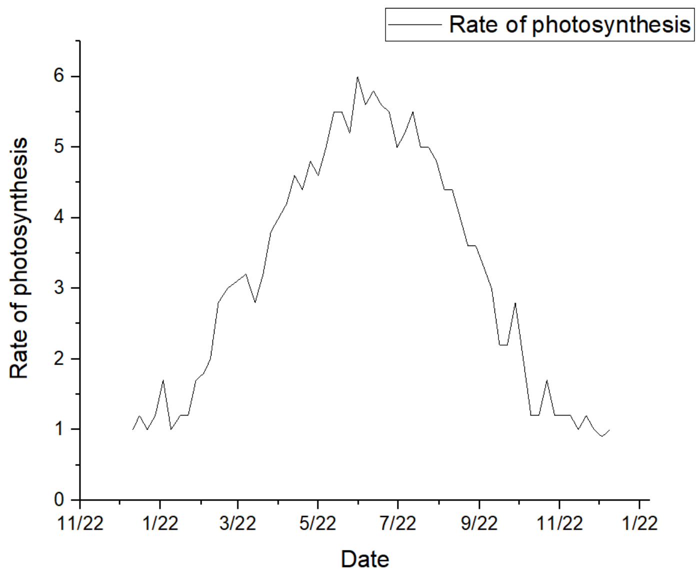

Figure 7: Changes of photosynthetic rate in different days of the year

According to the research results, the period from November of the previous year to January of the next year is a period of low photosynthetic efficiency. During this period, forest management at transition points such as deforestation shall be carried out. In addition, the statistical management of trees in winter, the maintenance of forest facilities and the preparation of planting new seedlings in spring can also have a positive impact on the development of forests.

3. Sensitivity Analysis

It should be noted that when considering the carbon sequestration capacity in this forest value evaluation model, the redundancy of the total global forest area and the aboveground biomass per hectare of forest were multiplied by the weight gain coefficient μ= 2 respectively. On this basis, the weight of each index was calculated. If μ takes different values, the weight of each indicator will change. Consequently, it is necessary to determine whether there is a similar result for different values of μ to prove the stability of the model. The verification results are as follows:

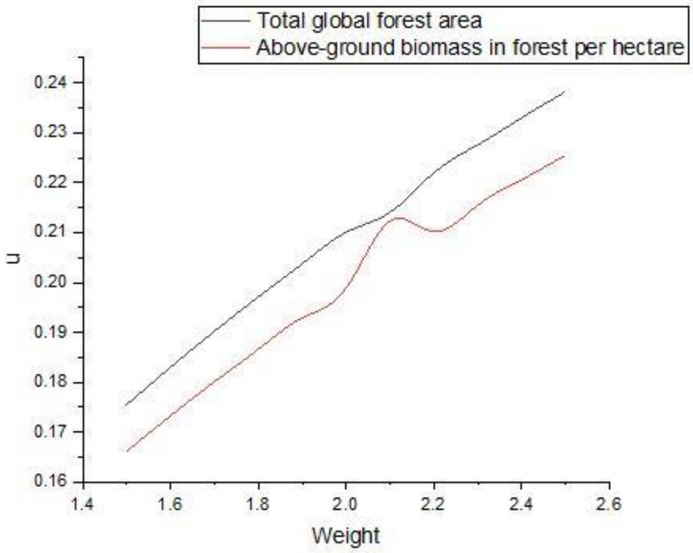

Figure 8: Sensitivity analysis of the model for calculating index weights based on data normalization

As can be seen from the figure, when the weight gain coefficient changes, the proportion of the two factors does not change much from the proportion when the weight gain coefficient is equal to 2, so it can be considered that the choice of μ=2 is reliable.

4. Conclusion

Following the principles of systematicness and practicability, this paper constructed a forest value evaluation model based on entropy weight method. Forest development and forest management were divided into different stages, and suggestions on forest management in different development stages were made. When constructing the model, the paper focused on the objective weighting of the evaluation index with the theory of entropy weight method. Entropy weight method is an objective weighting method. If the information entropy of the index is smaller, the amount of information provided by the index will be larger, and the weight will be higher. As a consequence, the entropy weight method is used to calculate the weight of each evaluation index. Whereafter, intended to emphasize the positive role of forests in preventing global warming, a weight gain coefficient μ= 2 was established and the weight of two parameters were increased to reasonably quantify the forest value.

After that, based on RBF neural network, this paper established a prediction model of photosynthesis rate related to temperature, and took chugaqi National Forest Park as an example. RBF neural network is a novel and useful feedforward neural network, which has the best performance of local approximation and global optimization. It can cluster and learn from a large number of historical data, and get some laws of behavior changes afterwards. The training method is fast and easy, and has been widely used in nonlinear time series prediction. Therefore, RBF neural network was used to train and simulate the samples. Then, according to the temperature change of chugaqi National Forest Park, the annual photosynthesis rate was predicted, and it was concluded that winter is the most suitable for forest management activities at the transition point.

Finally, through analysis, it was proved that the model is stable.

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