Problem Chosen	2022	Team Control Number
E	MCM/ICM Summary Sheet	2223003

Forestry for Carbon Sequestration

Summary

Carbon sequestration is an important way to sequester carbon dioxide from the atmosphere and mitigate climate change. By considering three main aspects: social, ecological, and economic, several indicators were developed, and a forest management plan model was developed that can be applied to most forests using entropy weighting, cluster analysis and BP neural networks.

For problem 1, a forest evaluation model was developed using the entropy weight method, considering the indicators related to natural factors, and then a reasonable model for calculating carbon sequestration in forests and their products was developed by means of market analysis and material use surveys. Firstly, we proposed indicators that are highly correlated with forest development in terms of natural factors, then we found relevant data, calculated objective weights for each indicator using the entropy weighting method, and used the weights and indicator values to calculate scores for the corresponding forest area. After that, the carbon sequestration equation about the forest carbon sequestration capacity and wood products composition was established, and the carbon sequestration model was derived.

For problem 2, a decision model was constructed after considering social, economic, and ecological factors to help forest managers understand how to protect the forest. By expanding the indicators, we propose several indicators including human impact, and use cluster analysis to classify the indicators in social, economic, and ecological aspects, and calculate the correlation between the indicators, to find out the degree of impact of each indicator on the forest, and then use BP neural network and combine with genetic algorithm to derive a prediction model for the optimal forest area. By setting the optimal forest area as a transition point, we propose management solutions for the forest in different situations.

For problem 3, this paper combines the carbon sequestration algorithm from problem 1 with the optimal area prediction model derived from problem 2 to derive an equation that can be used to calculate carbon sequestration under realistic conditions. In addition, the sensitivity of the model is derived by comparing the area change of the previously derived forest management approach with the forest change of the traditional approach, and its generalizability is analyzed.

In summary, this paper provides a comprehensive analysis of the impact of multiple value approaches and related factors on forest managers' decisions based on the conditions given in each question and identifies the optimal forest management plan under different conditions and evaluates various forest valuation approaches (including carbon sequestration) in a balanced manner. After analysis and verification, the model in this paper is reasonable and has some practical significance.

Keywords: Carbon Sequestration, Forest Management, Entropy Weight Method, Cluster Analysis, BP Neural Network

Contents

1 Introduction

1.1 Problem Background

In recent years, global warming caused by the greenhouse effect of increasing greenhouse gases has become a hot issue of international concern and discussion, and the impact of this problem poses a great threat to the natural ecology, factory production, and our lives. In order to mitigate climate change, it is not enough to reduce carbon emissions. Forest CarbonSinks (FCS) are carbon dioxide sinks where forest plants absorb carbon dioxide from the atmosphere and fix it in the vegetation or soil, thereby reducing the concentration of this gas in the atmosphere. As the largest carbon reservoir in terrestrial ecosystems, forests play a very important role in mitigating climate change.

In response to the call of the International Collaborative for Carbon Management (ICM) to develop guidelines for forest managers around the world, we decided to build a decision model to help forest managers develop the best way to manage forests in a way that balances planting and cutting. By balancing various approaches to assessing forests (including carbon sequestration), we will design a reasonable level of tree cutting to achieve an optimal solution to both the demand for carbon sequestration and the demand for social goods. The model will consider multiple approaches to forest values and will be applied to a wide range of forests.

1.2 Restatement of the Problem

Considering the background information and constraints identified in the problem statement, we need to solve the following problem.

- Problem 1: Develop a carbon sequestration model to determine how much carbon dioxide can be sequestered by the forest and its products over time and to determine which forest management plan is more effective at sequestering carbon.
- Problem 2: Develop a decision model that considers alternative ways of valuing the forest and determines a forest management plan that balances various valuation approaches (including carbon sequestration). The scope of the model's proposed management plan is discussed, whether there are conditions that result in forests that should be left uncut, whether there are transition points that apply to all forests, and how to manage the transition points between plans based on specific forest and location characteristics.
- Problem 3: Applying the established decision model to a variety of forests, identify a forest to include harvesting in its management plan and discuss how much CO2 is sequestered in this forest and its products over 100 years. Discuss what forest management plan should be used for this forest, and explain why this is the best approach. Assuming that the best management plan harvests for 10 years longer than the current plan, discuss strategies for transitioning from the current time to the new time in a way that is sensitive to the needs of forest managers and all those who use the forest.

1.3 Our work

First, we designed an evaluation model and extracted five indicators, and used the entropy weighting method to obtain the weights of these five indicators, from which we calculated the information related to forest area and environmental indicators, and extracted the optimal forest area, which was used as a criterion to determine the best management method for the forest. Then, we developed a carbon sequestration model, setting the age distribution of trees in the forest to follow a normal distribution, and based on the effective forest area, the CO2 absorption coefficient of the forest and the growth time of the forest, we can calculate how much CO2 can be sequestered by the forest and its products over time.

We then expanded the model to include social, economic and ecological dimensions. We extracted more impact indicators, objectively classified them through cluster analysis, and calculated the correlation between them and their impact on management practices. The data from the indicators were applied to a BP neural network and combined with a genetic algorithm to predict the optimal forest area, resulting in a more comprehensive model of the optimal forest management practices.

Finally, a sensitivity analysis of our model was conducted to further illustrate the generalizability of our model and to suggest management practices for various forest scenarios.

In summary, the whole modeling process can be shown as follows:

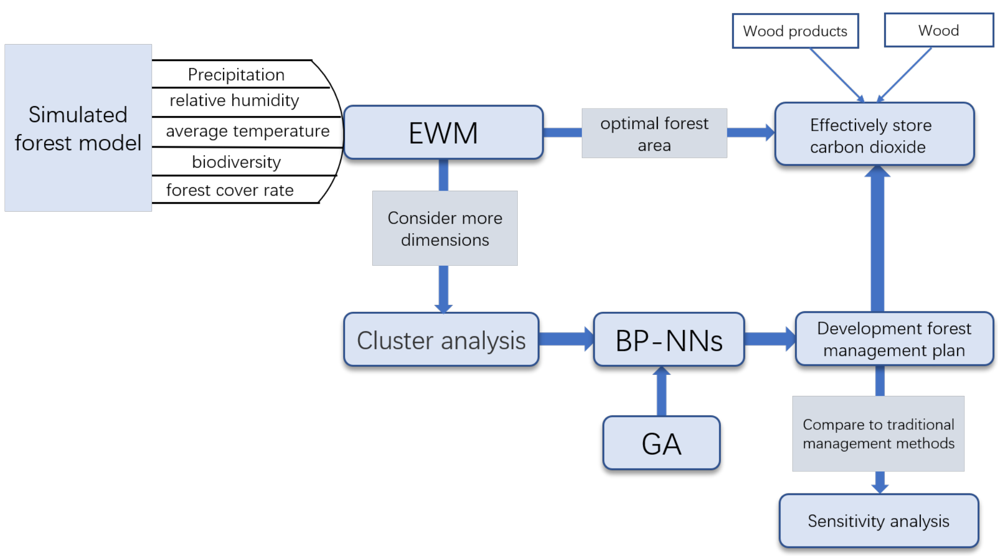


Figure 1: Flowchart

2 Assumptions and Notation

2.1 Assumptions

To simplify the problem, we made the following basic assumptions, each of which is reasonable.

Assumption 1: We assume that sudden changes in the environment are negligible, excluding man-made disturbances in the environment, but taking into account natural fires. Justification: Because sudden changes in the environment are very rare, man-made disturbances (war), major natural disasters (earthquakes, tsunamis, volcanic eruptions, etc.) are excluded from our consideration, and these are force majeure.

Assumption 2: We assume that the data we collect from our online database is accurate and reliable. Justification: Since our data sources are credible and reliable websites, we can reasonably assume that their data are of high quality. For some indicators with missing data, other available data can be used instead. This is because all aspects of the FMP decision assessment model cannot be reflected by one indicator alone. It can be the result of many factors working together.

Assumption 3: We assume that forest managers around the world will actively and effectively apply our decision model and the identified forest management plan. Justification: Because global warming, caused by the greenhouse effect of increasing greenhouse gases, is a major issue worldwide today, we expect forest managers around the world to take a proactive approach to improving and optimizing their forest management plans.

Assumption 4: We assume that the number of growing and maturing trees in a forest follows a normal distribution. Justification: A normal distribution is one of the most common distributions in nature, such as the height and weight of a person. Since there are many indicators that affect the growth of trees in a forest, we can assume that the growth and maturity periods of trees follow a normal distribution.

2.2 notation

Notation that we use in the model are shown in the following table.

symbols	Definition
A_p	Tree planting area
A_c	Tree cutting area
A_0	current(original) planting area
A_e	Maximum effective area
σ	Variance
A_n	Forest area in the following year
ρ	Percentage of over-mature forest in trees
A_g	Area from young to mature grow
T_m	the overripe time
T_d	the death time of tree
W_{ij}	Carbon sequestration capacity of the jth tree species in region I
ξ_i	Carbon sequestration capacity of the ith forest product
X_{ij}	the value of the influence index of the jth term in the ith sample

3 Carbon sequestration in forests and their products

Based on the requirements and background of the topic, we reviewed information and conducted an in-depth study. We need to develop a carbon sequestration model and determine which forest management plan is most effective in sequestering CO2. Therefore, we first developed a basic model to evaluate forest management plans, considering mainly the main indicators that have an impact on carbon sequestration.

3.1 Development of a basic evaluation model on forest management plans

We have reviewed the relevant information. Through Anton Fischer's research we found that climatic conditions are closely related to forest development, which is greatly affected by global climate change . In order to understand the important indicators regarding the development of forests, we modeled a large forest in the northern hemisphere (which is in the subtropical zone with a temperate monsoon climate) based on the relevant data presented here.

Forest carbon sequestration is closely related to the effective area of the forest, e.g., the stocking method. The effective forest area is the area of a forest that can fix carbon dioxide and is influenced by many factors. Based on the review of related literature and information, we extracted five main indicators, which are: precipitation, relative humidity, average annual temperature, biodiversity and forest cover, all of which will affect the changes of forest effective area and forest carbon sequestration,. To facilitate the subsequent calculations, we use set I to describe these broad indicators.

$$I = \{PR, RH, AT, BI, FCR\}$$

Where PR ,RH ,AT, BI, FCR respectively refer to the Precipitation, relative humidity, average annual temperature, biodiversity and forest cover rate.

3.1.1 Impact of five main indicators on effective forest area and forest carbon sequestration

In the process of modeling, we consider the effects of five main evaluation indicators on the effective forest area and forest carbon sequestration.

- **Precipitation**

  The amount of carbon sequestered by forests increases with the increase of precipitation. Precipitation can promote plant growth and increase plant productivity and biomass, so precipitation can promote carbon sequestration in forest ecosystems.

- **relative humidity**

  Relative humidity also has a great influence on trees in forests. An appropriate increase in humidity can improve the environmental condition of the dry atmosphere, optimize the growth of crops, improve photosynthetic characteristics and water transport status, and thus improve the growth condition of the forest.

- **average annual temperature**

  The effect of temperature on carbon sequestration in forest ecosystems: Under certain conditions, as temperature increases, forest productivity increases the rate of carbon sequestration and the amount of carbon sequestration increases, and in general, the rate of carbon sequestration and plant carbon stocks are high in tropical compared to temperate forests.

- **biodiversity**

  According to relevant literature, the relationship between biodiversity and forest productivity is a ”single-peaked” model, in which biodiversity increases forest productivity through the combined effect of ecological niche complementarity and selection; the increase in forest productivity helps increase carbon sinks; and the increase in carbon sinks effectively mitigates climate change, maintains ecosystem stability, and has a positive feedback effect on biodiversity.

- **forest cover rate**

  Forest cover is the ratio of forest area to total land area. The higher the forest cover, the larger the area of forest, and the effective area of forest will increase accordingly. Therefore the amount of carbon sequestered will also increase.

3.1.2 Model for solving the weights of each index using the entropy weighting method

Entropy weighting method is an objective weighting method, which determines the weight of an indicator by calculating the information entropy of the indicator and determining the weight of the indicator based on the impact of the relative change degree of the indicator on the system as a whole, based on the principle that the smaller the change degree of the indicator, the less information is reflected, and the indicator with a large relative change degree has a larger weight. Therefore, in this paper, we use the entropy weight method to solve the weights of each of the five indicators of the basic evaluation model about the forest management plan. The calculation process is as follows.

Step 1. Collect and organize raw data affecting forest management plans

We needed to evaluate the forest management plan, so n=5 evaluation indicators were selected and m samples were chosen to form the initial data matrix of the evaluation system.

$$\boldsymbol{X} = [a_{ij}]_{m\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}_{m\times n} \qquad (0 \le i \le m, 0 \le j \le n)$$

where a_{ij} represents the value of the jth evaluation index of the ith object.

Step 2.Data normalization

By observing the data, we can get that the above five index variables do not have exactly the same magnitude and order of magnitude. In order to eliminate the influence of different magnitudes of the dependent variables on the evaluation results and make each variable have the same expressive power, it is necessary to standardize the data. There are many methods of standardization, and this paper is based on the standardization method of the mean and standard deviation of the original data, namely

$$x_{ij}^{'} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \text{ positive index, } x_{ij}^{'} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \text{ negative index}$$

Where x_j is the value of the jth indicator, x_max is the maximum value of the jth indicator, x_min is the minimum value of the jth indicator, and $x_{ij}^{'}$ is the normalized value. The former formula is used for positive indicators (e.g., biodiversity and forest cover in this question) and the latter formula is used for negative indicators.

Step 3.Calculate the weight of the ith sample value under the jth indicator for that indicator.

$$y_{ij}^{'} = \frac{x_{ij}^{'}}{\sum_{i=1}^{m} x_{ij}^{'}} \, (0 \leq y_{ij} \leq 1)$$

Step 4.Calculate the information entropy value and information utility value of the jth index.

Information entropy value of the jth indicator :

$$e_j = -K \sum_{i=1}^{m} y \ln y_{ij} \left(K = \frac{1}{\ln m} \right)$$

Information utility value of the jth indicator :

$$d_j = 1 - e_j$$

The information utility value of an indicator depends on the difference between the information entropy e_j of the indicator and 1. Its value directly affects the size of the weight; the larger the information utility value, the greater the importance to the evaluation, and the greater the weight.

Step 5.Calculate the evaluation index weights

$$\beta_j = \frac{d_j}{\sum_{i=1}^{m} d_j}$$

The essence of estimating the weight of an indicator using the entropy weighting method is to use the information value coefficient of the indicator to calculate, the higher the value coefficient, the greater the importance to the evaluation, the greater the weight.

Step 6.Calculate the evaluation value of the sample

$$U = \sum_{i=1}^{n} y_{ij} \beta_j$$

We use a weighted sum formula to calculate the evaluation value of the sample, where U is the comprehensive evaluation value, n is the number of indicators, and wj is the weight of the jth indicator. the larger U is, the better the sample effect is. The initial data of the five indicators involved in this model as the **Table 1** show.

Table 1: **Five indicators data statistics**

year	Point	Precipitation	RH	TEMP	Biodiversity	Coverage rate/%
type		Positive	Positive	Positive	Positive	Positive
1975	0.0525659	580.1	65	5	371	65
1980	0.061174	494.2	59	5.8	372	67.45
1985	0.078128	567.5	62	4.7	399	67.53
1990	0.04352	531.5	57	5.3	380	66.38
1995	0.091449	608.7	58	6	403	66.5
2000	0.165339	508.7	60	6.6	423	71.96
2005	0.212183	684.8	65	5	433	74.9
2010	0.261765	613.8	70	4.5	432	80.3
2015	0.314109	720.8	67	5.8	435	81.76
2020	0.298364	730.3	67	4.6	431	82.94

Based on a balanced assessment of the FMP model, we took a curve fit to the data for the five indicators. Using a polynomial exponential function fit, we obtained a fitted curve. The expression of this curve is given by :

$$\max y = \sum_{i=1}^{n} a_n x^n + b \tag{1}$$

In the process of fitting, we found that the fit is large when n is taken as small, and overfitting occurs when n is taken as large. To prevent overfitting, we n=3 is the best fit. By looking at the fitted curves in Fig.2, we found that the data near 2015 had the highest score, i.e., the effective forest area in 2015 was the largest, and in our model this area is 1962. with the best forest management plan and the corresponding carbon sequestration.

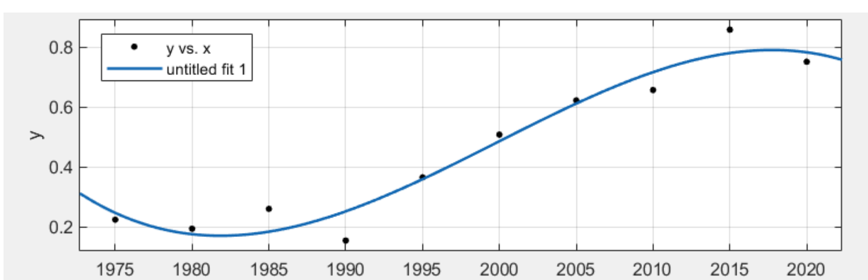


Figure 2: Flowchart

Therefore based on our basic evaluation model about forest management plan, we can get the effective area of the optimal forest in our sample.

3.2 Development of carbon sequestration models

Based on the requirements related to the topic, we need to develop a carbon sequestration model and determine how much CO2 can be sequestered by the forest and its products over time.

3.2.1 Effects of tree growth and maturity on the carbon sequestration capacity of trees

Trees have five major periods, namely young, middle, near, mature, and over-mature. According to the surface of international research in forestry and ecology, we give priority to cutting down species in the over-mature stage to achieve ecological recycling in most cases because of their fixed carbon sequestration capacity and slow growth rate.

3.2.2 Considering the total carbon sequestration of different tree species

The total carbon sequestration has two parts, one is the carbon sequestration of different tree species, for example, in the study area, the tree species types are mainly trees, shrubs, evergreen trees and deciduous trees; the second is the carbon sequestration from forest products. Among the area cut down, only timber forests are carbon sequestration benefits, and timber forests can mainly be made into paper, board, lumber.

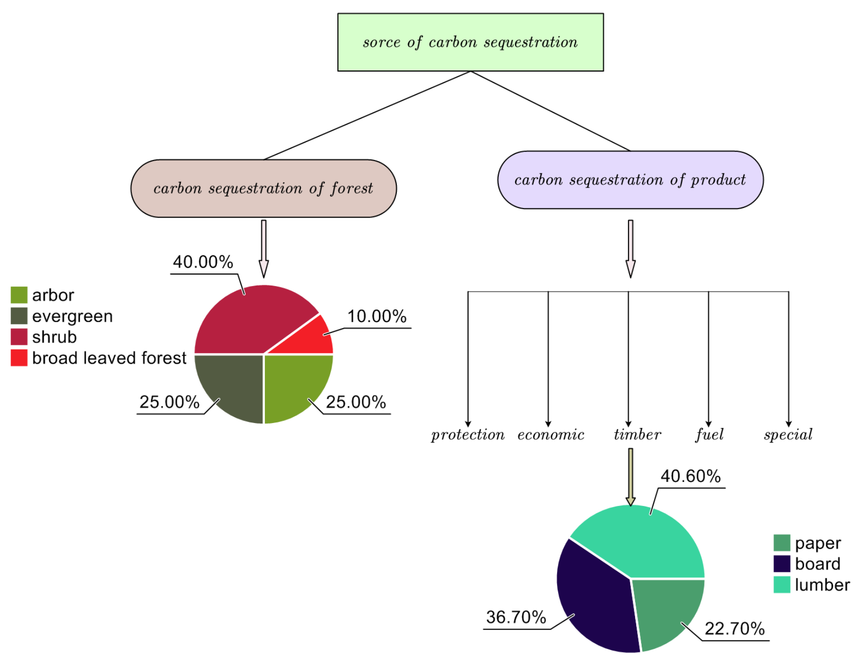


Figure 3: Carbon sequestration sources

3.2.3 Detailed calculations for carbon sequestration of forest products

For forest products, forest products include furniture, lumber, plywood, paper and other wood products. These forest products are more complex as they sequester carbon dioxide during their life cycle.

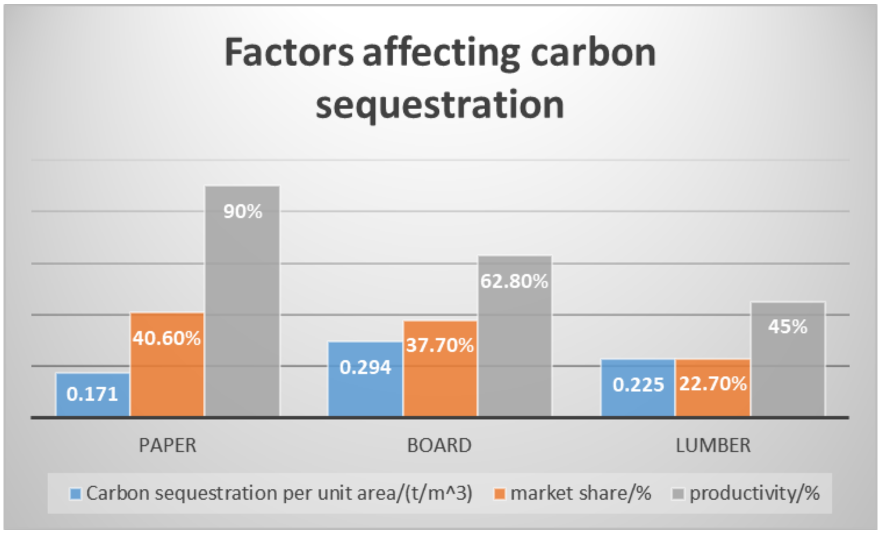


Figure 4: factors

The area of the study surface timber forest accounts for 50% of the total area cut, i.e. another $A_c^{'} = 0.5 * A_c$. By using the product yield (ρ), the market share (m), the amount of wood consumed ($A_c^{'}$) and the carbon sequestration capacity (q) of the corresponding product for each material, we can classify the carbon sequestration of forest products as

$$Q_{product} = V_u sed(m_{paper} p_{paper} q_{paper} + m_{con} p_{con} q_{con} + m_{app} p_{app} q_{app})$$

Where the volume of wood consumed (V_{used}) is the product of the area cut (S_{fell}) and the yield of the corresponding area. (Y) is the yield rate, 3101.5 ton per 1000 hectare.

On this basis, the carbon sequestration of forest species was calculated as 36923.03/1000 ha.

3.2.4 General equation for calculating carbon sequestration in forests and their forest products using carbon sequestration models.

The forest carbon sequestration and forest product carbon sequestration are assumed to be Q_{wood} , $Q_{product}$ and their sum is Q_t respectively.

In turn, we can obtain a general formula for the carbon sequestration model we have developed to calculate how much CO2 can be sequestered by forests and their products over time.

$$Q = Q_{wood} + Q_{product} \tag{2}$$

Therefore, based on the carbon sequestration model we have developed, the carbon dioxide sequestration of the forest and its products over time can be calculated by bringing in the corresponding data, while we consider the maximum carbon sequestration, and therefore use the target planning algorithm to achieve it.

The maximum benefit area (this model corresponds to 1962) is calculated by the entropy weight method, and we first determine whether the current forest area exceeds the maximum benefit area, and if it does, then we execute a deforestation plan; in our model, for example, we study the average annual growth rate of each species in the forest; at the same time, we specify that the annual planting area is the maximum benefit area multiplied by the proportion of over-mature forest, and the annual deforestation area is the current forest area The forest area for the following year is the current forest area minus the deforestation area, plus the planted area, multiplied by the annual growth area obtained from the study. In this way, the ecological demand conditions can be met over time, and the total forest area and deforested area can be given to the total carbon sequestration.

$$\max Q_t = \sum_{i=1}^{n} A_{oi} w_{1i} + \alpha \sum_{j=1}^{m} A_{cj} p_j w_{2j}$$

$$s.t \begin{cases} A_c = A_t A_c \\ \alpha A_c \geq A_c \\ A_o = A_o - A_c + A_p \\ A_p = \rho \times A_e \\ A_c = \rho \times A_o \\ \alpha = \begin{cases} 1 \ , \ A_o \geq A_e \\ 0 \ , \ A_o < A_e \end{cases} \\ A_o \eta_{1i} = A_{oi} \ \ (i = 1, 2...n) \\ A_c \eta_{2j} = A_{cj} \ \ (j = 1, 2...m) \\ A_o \times \rho < A_c < A_o, A_{cj} > 0 \, (j = 1, 2...m) \end{cases}$$

$$v = \frac{\sum_{i=1}^{n} v_i}{n}$$

$$A_n = [A_o - A_c + A_p] \, (1 + v)$$

As a result, the amount of carbon dioxide that can be sequestered in this year is $Q_t = 7, 376, 200$tons, and the amount of carbon sequestered in any future year is predicted.

4 Decision-making model for forest management plans

Since the value of forests does not only lie in carbon sequestration, the way forests are managed may change when other factors are taken into account, such as social needs and economic values to achieve more sustainable development. In the previous model, we added factors that would influence human society to predict and calculate the most balanced management approach for humans and nature through a more comprehensive analysis of indicators.

4.1 Modeling decisions that benefit both people and forests

In the decision model, under the premise of providing the best carbon sequestration, we identified several indicators that are common to both forest resources and human life through literature review and market analysis. Considering the wide applicability and reasonable design of the model, we screened 12 groups of indicators including the amount of carbon sequestration, including: precipitation relative humidity, biodiversity, tourist satisfaction, wood production, real estate development, acid rain, urban level index, floor space increase demand, forest coverage rate, forest fire time, fix carbon content.

In order to understand the intrinsic relationship of these indicators, we found the relevant data that can be applied to the model, and modeled and analyzed them in a reasonable way.

4.2 Classification of established indicators by cluster analysis to find correlations

Cluster analysis refers to the analytical process of grouping a collection of physical or abstract objects into multiple classes composed of similar objects. Through cluster analysis, metrics with the same elements are clustered. Thus, the similarity and rationality of each indicator is analyzed. We searched for 13 indicators that are directly and indirectly related to forest area. Through the systematic cluster analysis (Hierarchical Cluster Analysis) of spss, we can classify them.As shown in **table 2**.

Table 2: Cluster Membership

case	4 Clusters	3 Clusters
precipitation	1	1
RH	1	1
biodiversity	1	1
Tourist_satisfaction	2	2
wood_production	3	3
real_estate_development	4	3
acid_rain	1	1
urban_level_index	2	2
floor_space_increase_demand	4	2
forest_coverage_rate	1	1
forest_fire_time	1	1
Fix_carbon_content	1	1

According to the content related to human and nature, we divide them into ecological factors, social factors and economic factors:

1. Ecology: precipitation, relative humidity, biodiversity, acid rain, forest coverage rate, forest fire time, fix carbon content.
2. Society: tourist satisfaction, urban level index, floor space increase demand..
3. Economy: wood production, real estate development.

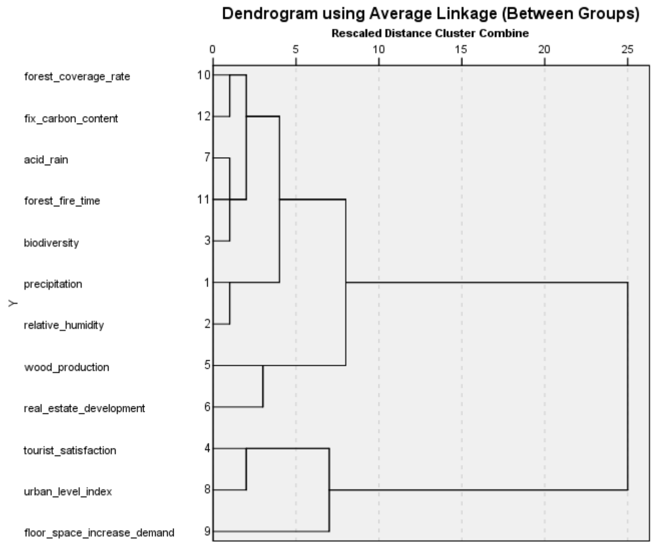


Figure 5: Dendrogram

In particular: when we set the category to 4, the floor space increase demand will be a separate category.

This indicates that the floor space increase demand is the least correlated indicator in this system, which means that changes in floor space increase demand do not have a large impact on other indicators in this model, and that it has the least impact on the design of optimal forest management practices.

After that, we performed correlation analysis between 12 indicators and forest area. Sig.(2-tailed)<0.001 indicates a strong correlation; a larger Pearson Correlation is a stronger correlation.

Correlations

		precipitation	relative_humidity	biodiversity	tourist_satisfaction	wood_production	floor_space_increase_demand	acid_rain	forest_fire_time	burned_area	forest_coverage_rate	urbanization_level_index	fix_carbon_content	forest_area
precipitation	Pearson Correlation	1	.701**	.814**	-.911**	.773**	.603**	.853**	-.904**	-.538**	.673**	.818**	.944**	.729**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.002	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
relative_humidity	Pearson Correlation	.701**	1	.855**	-.835**	.355	.048	.867**	-.633**	-.226	.984**	.944**	.685**	.216
	Sig. (2-tailed)	.000		.000	.000	.054	.803	.000	.000	.230	.000	.000	.000	.251
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
biodiversity	Pearson Correlation	.814**	.855**	1	-.927**	.640**	.426*	.926**	-.802**	-.560**	.853**	.923**	.836**	.556**
	Sig. (2-tailed)	.000	.000		.000	.000	.019	.000	.000	.001	.000	.000	.000	.001
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
tourist_satisfaction	Pearson Correlation	-.911**	-.835**	-.927**	1	-.724**	-.553**	-.950**	.890**	.541**	-.823**	-.956**	-.911**	-.684**
	Sig. (2-tailed)	.000	.000	.000		.000	.002	.000	.000	.002	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
wood_production	Pearson Correlation	.773**	.355	.640**	-.724**	1	.849**	.574**	-.840**	-.752**	.313	.527**	.755**	.919**
	Sig. (2-tailed)	.000	.054	.000	.000		.000	.001	.000	.000	.092	.003	.000	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
floor_space_increase_demand	Pearson Correlation	.603**	.048	.426*	-.553**	.849**	1	.399*	-.696**	-.690**	.006	.305	.641**	.955**
	Sig. (2-tailed)	.000	.803	.019	.002	.000		.029	.000	.000	.974	.102	.000	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
acid_rain	Pearson Correlation	.853**	.867**	.926**	-.950**	.574**	.399*	1	-.808**	-.442*	.868**	.956**	.851**	.536**
	Sig. (2-tailed)	.000	.000	.000	.000	.001	.029		.000	.014	.000	.000	.000	.002
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
forest_fire_time	Pearson Correlation	-.904**	-.633**	-.802**	.890**	-.840**	-.696**	-.808**	1	.548**	-.606**	-.771**	-.883**	-.818**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000		.002	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
burned_area	Pearson Correlation	-.538**	-.226	-.560**	.541**	-.752**	-.690**	-.442*	.548**	1	-.235	-.389*	-.547**	-.695**
	Sig. (2-tailed)	.002	.230	.001	.002	.000	.000	.014	.002		.212	.034	.002	.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
forest_coverage_rate	Pearson Correlation	.673**	.984**	.853**	-.823**	.313	.006	.868**	-.606**	-.235	1	.946**	.652**	.174
	Sig. (2-tailed)	.000	.000	.000	.000	.092	.974	.000	.000	.212		.000	.000	.357
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
urbanization_level_index	Pearson Correlation	.818**	.944**	.923**	-.956**	.527**	.305	.956**	-.771**	-.389*	.946**	1	.812**	.449*
	Sig. (2-tailed)	.000	.000	.000	.000	.003	.102	.000	.000	.034	.000		.000	.013
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
fix_carbon_content	Pearson Correlation	.944**	.685**	.836**	-.911**	.755**	.641**	.851**	-.883**	-.547**	.652**	.812**	1	.762**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.002	.000	.000		.000
	N	30	30	30	30	30	30	30	30	30	30	30	30	30
forest_area	Pearson Correlation	.729**	.216	.556**	-.684**	.919**	.955**	.536**	-.818**	-.695**	.174	.449*	.762**	1
	Sig. (2-tailed)	.000	.251	.001	.000	.000	.000	.002	.000	.000	.357	.013	.000	
	N	30	30	30	30	30	30	30	30	30	30	30	30	30

Figure 6: Correlation Analysis

By observing the data in Fig.6, we can see that the six indicators with the strongest correlation with forests are precipitation, wood production, forest fire time, tourist satisfaction, fix carbon content, Land area increases demand, it can be seen that the first two indicators can reflect ecological factors, and the last three indicators can be used as social and economic factors. We aim to select the indicators that have the greatest impact on forest area for the next step of analysis and modeling.

By means of cluster analysis we classify the factors that influence the development of forest management practices in a comprehensive way, and by means of correlation analysis, we obtain the degree of relevance and influence of these factors on the management of forests, allowing us to build subsequent models and develop forest management programs in a more rational way.

4.3 Optimal forest management model derived using BP neural network and genetic algorithm

The bp neural network algorithm is used to determine the network mapping structure, and then the genetic algorithm is used to optimize the approximation to determine the weights and thresholds of the network connections. bp neural network algorithm is easy to fall into the local minima of the error function, and the global minima cannot be searched effectively for relatively large search space and non-integrable functions. Therefore, the introduction of genetic algorithm can effectively avoid the local minima, improve the weight coefficients, and optimize the speed by integrating the two.

For our established forest model, it is applied to this system. Firstly, the network is constructed, and for the neural network six neurons are added, corresponding to the five indicators with the strongest correlation analysis in the previous step, and 30 sets of data are used as the training basis, i.e., 1975-2015 as the training set and 2016-2020 as the validation set. The final output of the neural network is the optimal effective forest area, and the data processing and prediction of the whole system can lead to a forest management approach that achieves a balance in social, economic and ecological aspects.

The genetic neural network algorithm used in this paper is divided into 3 main parts: 1) determination of BP neural network structure; 2) introduction of genetic algorithm for optimization; 3> training and validation of genetic neural network. Through multiple generations of inheritance and variation, the selected outstanding individuals are obtained. After that, the optimal initial threshold weights are assigned to the network prediction, and then the value prediction with the BP neural network optimized by genetic algorithm can be carried out to fit the effective area of trees that best meets the index, so that a more excellent forest management plan can be derived. The algorithm flow is shown in Fig.7

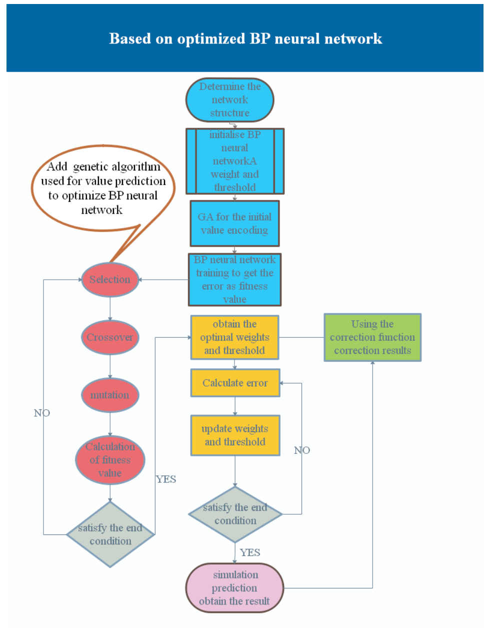


Figure 7: Algorithm flow chart

The global optimization feature of the genetic algorithm is used to optimize the weights and thresholds of the BP neural network. The optimization steps are as follows: (1) Initialize the population. The number of chromosomes, crossover probability and variation probability are set. The initial weights and thresholds are obtained based on the initialization results of the BP neural network and coded with real numbers (2) Calculate the fitness of chromosomes,. The fitness function is set as $f=\frac{1}{E(i)}; E(i)=\sum_{i=1}^{l}\left(x(i)-x_0(i)\right)^2$

f is the adaptive degree of the individual where l is the number of learned samples and E(i) is the sum of squared errors between the network output value and the expected value.

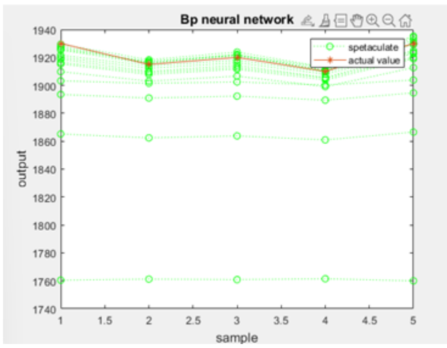
(3) To select the best individuals according to the roulette algorithm, we choose the Linear Ranking Selection strategy, in which the individuals in the population are first sorted according to the fitness value, and then all individuals are given a serial number, the best individual is N, and the probability of being selected is P_{max}, the worst individual has serial number 1, and the probability of being selected is P_{min}, so the probability of the other individuals in between them can be obtained according to the following formula: $P_i=P_{\min}+\left(P_{\max}-P_{\min}\right)\frac{i-1}{N-1}$

(4) Select chromosomes by probability for crossover and mutation operations, and insert the newly generated individuals into the original population and recalculate the chromosome fitness values for the new population.

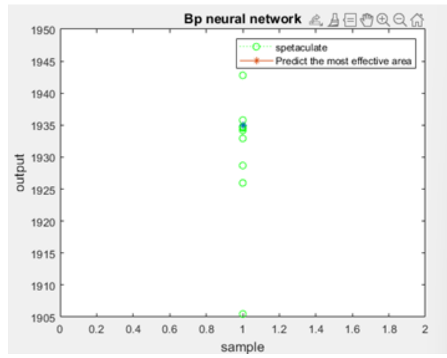
(5) If a chromosome satisfying the error requirement is generated, it is identified as the optimal chromosome and decoded to obtain the optimal weights and thresholds of the network. Otherwise, return to step 3 to continue optimization.

In this model, we set up the optimal area of trees for the next five years and obtained the following results.As Fig.8 shows.

The data curve shows that the optimal forest area under current conditions fluctuates around a certain point with a certain error, and the cumulative mean square error is calculated to be 19.5. By obtaining the forest area corresponding to this point, we can obtain a balanced forest area that meets the social, economic and ecological needs.



(a) Fitting of effective area of trees



(b) Best area forecast for trees

Figure 8: Fitting and prediction of forest optimum area

By subtracting the relevant errors and averaging the obtained predicted data, we find that the optimal area of the case forest calculated by the model is $x_0 = 19.35$ million hectares.It can be seen that this data is smaller than the optimal area obtained when only carbon sequestration is considered, and further analysis can only fit the forest management approach of the carbon sequestration model does not meet the needs of society.

4.4 Model solving

With this model, we derived the scope of the management plan for the decision model, which includes three major aspects: social, economic, and ecological. The individual indicators under these three dimensions are :

- Ecology: precipitation, relative humidity, biodiversity, acid rain, forest coverage rate, forest fire time, fix carbon content.
- Society: tourist satisfaction, urban level index, floor space increase demand.
- Economy: wood production, real estate development.

Genetic algorithms and neural network analysis were used to derive the optimal forest area x_0 when we meet the balance of these three countervailing demands.

To reach a situation where the forest is not deforested, it is necessary to minimize the impact of social and economic factors on the forest, i.e., there is no more human demand for the forest resources in the area, and this situation ensures that the forest is not deforested.

We establish the optimal forest area x_0 as the transition point, and for different conditions of forests, when the optimal effective forest area is calculated, if the annual growth rate of the forest area is lower than the established deforestation target, the management plan of the forest needs to be changed, and then it is necessary to strengthen the protection of the forest to prevent deforestation from occurring.

For a given forest, when the trees reach the age of maturity (i.e., when they reach the age at which they can be cut), we can change the management of this part of the forest from protection to deforestation.

5 Sensitivity analysis

5.1 Carbon sequestration in 100 years

First, based on the above model, we can calculate the Qt and the corresponding Ao for each year after 100 years In this example, our A_o is 1990, rou is 5.7%, η_1 is the share of each tree species, $25, 25, 40, 10$, η_2 is the share of each forest product is, $22.7, 36.7, 40.6$

We can average the growth rates of different trees to get the average growth rate.

$$v = \frac{\sum_{i=1}^{n} v_i}{n}$$

We then assume that the forest area for the following year is An, which is equal to the current forest area minus the area of cut trees plus the area of planted trees multiplied by the percentage of over-mature forest. Multiply the growth rate, and finally subtract the area of tree cutting.

$$A_n = [A_o - A_c + A_p]\,(1 + v)$$

In this example, we use the program written to loop 100 times to obtain the effective area of the forest convergence to Best 1935 as Fig.9 shows and the amount of CO2 sequestered over 100 years convergence to 7294132952.66832 as Fig.10 shows.

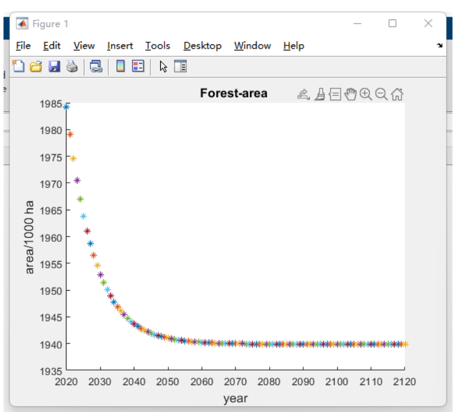


Figure 9: (a) Forest area

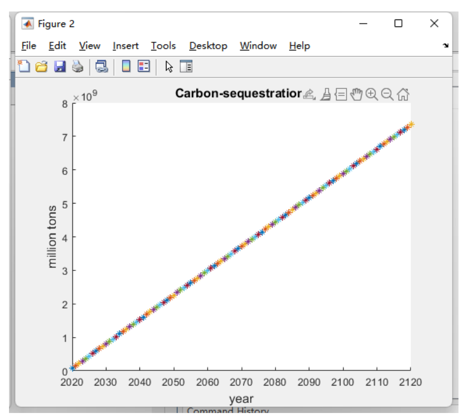


Figure 10: (b) Carbon sequestration

Figure 11: Carbon sequestration in 100 years

5.2 Determining the best forest management plan

For forests in different conditions, in order to develop management plans. First, we set up the age composition of the trees in the forest as a normal distribution and set up that only trees that reach maturity or higher can be cut down. By finding the age composition of the trees at different stages and the species composition of this local forest and bringing it into the normal distribution model through proportions, we arrive at the proportion of trees that can be cut down A_c

$$A_c = A_o \int_{T}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

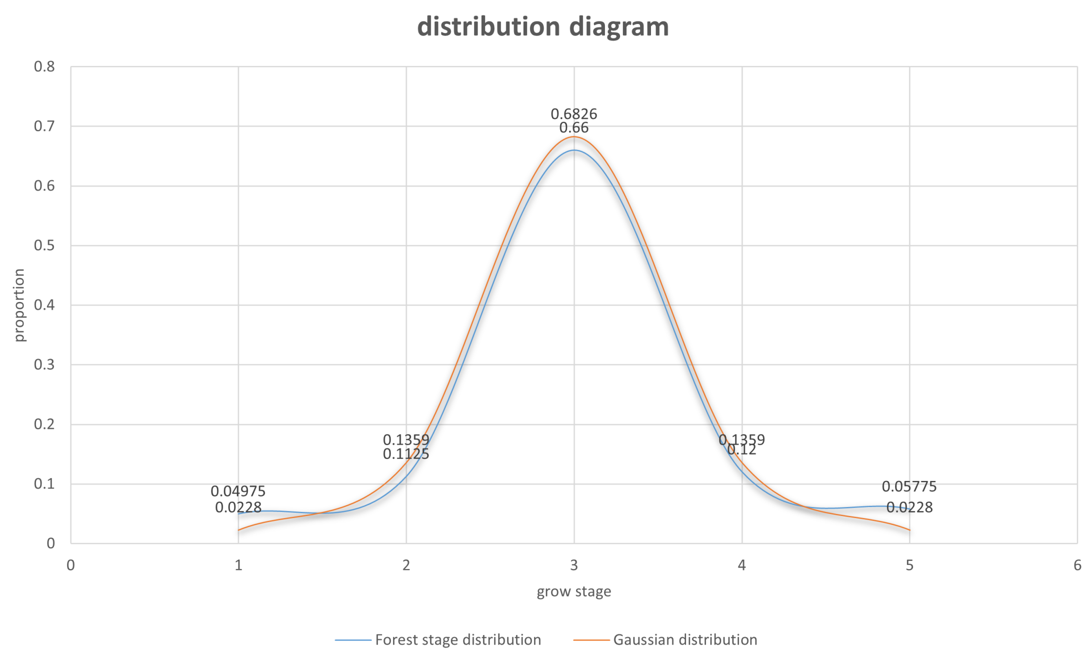


Figure 12: Distribution

Despite the different distribution and ecological conditions of forests around the world, the common impact indicators between society and forests in different parts of the world are basically the same due to the advancement of globalization and human development trends. So for different conditions of forests, the thirteen important indicators we established can be applied in general.

By first counting multiple sets of local data on these indicators and using these indicator data for the second model, we can first calculate the local correlation of these indicators by clustering them so that the degree of influence of different indicators can be derived. By bringing the indicator data into the neural network algorithm to predict the optimal forest area in the future, we can calculate the optimal forest area that is consistent with nature and human society x0. By comparing the calculated optimal area with the current forest area, we can make a decision on whether to cut down or maintain the growth of the forest. If the current forest area is smaller than the optimal area, the forest needs to be protected.

After a certain period of adjustment, the forest area can be stabilized at the optimal area, and the management plan can require that the deforested area should be no less than $x_0 \times (1 - p_0)$, while when the forest area is larger than x_0, the forest can be deforested.

5.3 Demand-sensitive analysis of forest managers and all those who use the forest

The analysis of the model above, assuming that the best management plan has a 10-year harvest interval longer than the current practices of the forest, indicates that the effective area of the current forest is less than the effective area of the best management plan and would need to be planted for 10 years to reach it.

Assuming that the annual amount of trees to be planted according to the model for the optimal forest management plan is A_e.

Thus the effective area of forest in the first year is

$$first\ year: A_{p1} = A_e \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

The effective area of forest in the second year is

$$\sec ond\ year: A_{p2} = A_e\left(1+v\right) \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt\ + A_e \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

$$.....$$

The effective forest area in the tenth year is

$$ten\ years\ later: A_{p10}: \frac{1-(1+v)^{10}}{v} A_e \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

Similarly, for the current practice of the forest, we assume that the annual planting volume is A_0

The effective area of the forest in the first year is

$$first\ year: B_{p1} = A_o \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

The effective area of forest in the second year is

$$\sec ond\ year: B_{p2} = A_o\left(1+v\right) \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt\ + A_o \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

$$.....$$

The effective forest area in the tenth year is

$$ten\ years\ later: B_{p10}: \frac{1-(1+v)^{10}}{v} A_o \int_{T_m}^{T_d} \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$$

$$S_i = \frac{A_{pi}}{B'_{pi}}(i = 1, 2, 3, 4, \cdots 10) \tag{3}$$

We divide the effective area obtained by the best management practice by the effective area of the current management practice, and we can find that the larger and more sensitive S_i is, the most favorable best management plan we get.

6 Model Evaluation

6.1 Strengths

a.The model is comprehensive in its selection of indicators, taking into account three major aspects: social, natural and economic. It provides a comprehensive analysis of the development of forest management practices.

b.The indicators we selected for the model are universal, and they can be applied to most regions in the world, which can help more regions to establish reasonable forest management practices.

c.The evaluation method used in this model is scientific and objective, avoiding the influence of subjective factors. The model uses clustering analysis to analyze the degree of correlation between indicators in a deeper way, which increases the flexibility of the model and can be applied to other regions with different environments.

d.We added a genetic algorithm to the BP neural network algorithm to improve the optimization of the automatic learning of the neural network and to improve the efficiency of learning.

6.2 Weaknesses

a.The model is more difficult to apply to areas with too much variability, where other indicators of greater influence will emerge.

b.As time progresses, external conditions and characteristics may change significantly and the model is difficult to predict.

6.3 Further discussion

If we look at the data from different regions of the world with different environments and economies, we can find more environmental data that can be used for testing and verification, which can further improve the general applicability of forests.

In the question, we note that carbon can be stored not only in forests and wood products, but also in nature, in oceans and soils, and through science and technology, through mechanical carbon sequestration. We can discuss and review these various carbon sequestration methods and use them as indicators in the model to analyze the environmental protection methods in a more macroscopic way.

7 Newspaper article

Article

Forest protection is not equal to not mining any trees

According to the United Nations, nearly 13 million hectares of forests are cut down every year. When we map this figure to the world map, this area is almost equivalent to the land area of Greece. Human abuse of forest resources has caused many international problems in recent decades. Human destruction of forests has led to a series of problems, including global warming, forest fires, species extinction and so on. The impact of these problems has transited from nature to human society, affecting the interests and property of each of us. In order to maintain positive and healthy development, the United Nations has repeatedly advocated that all countries should establish a green development strategy.

In order to achieve the stability of the earth's resources and the long-term development of human society, all countries should make a balance between logging and planting, and use scientific and reasonable forest management methods to develop and maintain our natural environment at the same time. However, under such a background, some people also put forward that mankind should not continue to cut down forests, and mankind should not destroy any trees. Such an idea is also unreasonable, which does not apply to contemporary society.

First of all, the current development of mankind is still inseparable from the support of forest resources. Despite the rapid development of contemporary science and technology, many past forestry products have been replaced by new materials and products designed by human beings, but wood products have not been completely replaced. For the paper, furniture and buildings used in our lives, these products still need a lot of forest resources to maintain production. With the development of science and technology, there is still no suitable and cheap material to replace it in these fields. Moreover, for underdeveloped countries, the development of science and technology still does not benefit the citizens in their society. For these countries, the production technology used is not advanced enough, and the way of maintaining production inevitably requires the use of forest resources. After all, the premise of safeguarding natural resources is not to damage the rights of all our people and not to let some countries fall victim to the protection of forests.

Moreover, the consequences of not cutting down forests may endanger human civilization. When we do not take deforestation measures, it will lead to the savage growth of forest trees. When this development reaches a certain degree, the expansion of forests will cause damage to rural and urban areas. For rural areas, if trees are not cut down, the development of forests will take away farmers' cultivated land. Once agricultural production is destroyed, mankind will lead to food shortage, famine and other problems, which is a more serious disaster for mankind. For cities, when the development of forests affects urban land, the huge supply network of urban design will also be damaged. For example, accidents such as power failure and water cut-off will occur frequently, and the traffic network in the city will also be affected. Under such destruction, the order of human society will even lead to the retrogression of civilization, and thousands of years of development will be destroyed.

A reasonable and scientific way of forest management is not to prevent all exploitation. A reasonable way of forest management is to achieve a balance between the amount of deforestation and growth, so as to maintain the forest area in the most scientific and reasonable quantity. For trees in nature, their main role is to absorb carbon dioxide produced by human beings, so as to prevent a series of problems such as global warming and environmental change. Trees mainly deal with excess carbon dioxide in the air through photosynthesis and carbon sequestration. With the growth of forest trees, the purification capacity of this system will also increase, but when the development of forest exceeds a certain degree, the growth of purification capacity will be very small. When the forest area exceeds this threshold, human beings can reduce the forest area by cutting down. This behavior will not lead to a significant decline in the purification capacity of the forest. At the same time, the products made of these trees also have the ability of carbon sequestration. There are even products that can be used for a long time, and its carbon sequestration capacity may exceed that of the trees themselves. When human beings exploit under the specified forest management mode, the purification capacity brought by the forest system and related products will even exceed that brought by the forest itself after human beings plant and grow trees again. Under such a forest management mode, human beings can not only protect nature, but also meet their own needs to a certain extent, so as to achieve the simultaneous development of society and nature.

Protecting nature is what we human beings must consider while developing, but protecting nature does not mean that we should take no share of tree resources. The premise of protecting nature is not to destroy everyone's basic rights. When a reasonable management method is adopted, human beings can achieve a reasonable balance between the exploitation of forest resources and the protection of the environment. So as to bring more long-term development to all mankind.

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