E3S Web of Conferences **352**, 02021 (2022) https://doi.org/10.1051/e3sconf/202235202021
*ESAT 2022*

# Forest management plan based on carbon sequestration model

Yunlu Cao, Mingzhu Guo and Xinhui Ma

School of ocean and environment, Tianjin University of science and technology, Tianjin 300457, China.

**Abstract:** With the increase of carbon dioxide emissions in various countries, greenhouse gases surge, posing a threat to life systems. In this context, how to balance the multifaceted value of forests and improve the relationship between climate change through carbon sequestration of forests and forest products, so as to achieve the sustainable development of forests, is an urgent problem to be solved. The forest management decision-making model established in this paper includes comprehensive considerations such as carbon sequestration, biodiversity, socio-economic and cultural entertainment. The forest carbon sequestration model consists of direct absorption by vegetation and indirect sequestration of carbon dioxide by forest products. We use Cara model to comprehensively estimate forest net primary productivity and establish a model of carbon dioxide storage of forest products based on analytic hierarchy process. In order to realize the sustainable development of forest, we also applied fuzzy comprehensive evaluation and entropy weight method to establish a forest management plan model integrating biodiversity, social economy, culture and entertainment. Finally, we applied the model to Saihanba National Forest Park in China and got positive feedback. The forest management model established in this paper provides theoretical basis and technical support for forest sustainable development.

**Keywords:** Forest management planning model; Forest carbon sequestration model; Analytic hierarchy process; Fuzzy comprehensive evaluation; Entropy weight method

## 1. Introduction

In August 2021, the sixth assessment report of the Intergovernmental Panel on climate change (IPCC) pointed out that the global average temperature has increased by about 1 ℃ since 1850-1900, and the global temperature is expected to reach or exceed 1.5 ℃ in the next 20 years. The report further notes that the goal of limiting warming to 1.5°C or 2°C is difficult to achieve if humans do not take immediate steps to reduce greenhouse gas emissions[1]. In the face of the increasingly obvious greenhouse effect, scientists constantly call on the world to take joint measures to reduce greenhouse gas emissions. China has also made clear its position and commitment to adopt more effective policies and measures to reach the peak of carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. In order to mitigate the impact of climate change, it is not enough to only reduce greenhouse gas emissions. We also need to increase the amount of carbon dioxide storage, that is, carbon sequestration. Carbon sequestration can be defined as the replacement of carbon dioxide directly discharged into the atmosphere by capturing and safely storing carbon dioxide in the atmosphere. Specifically, it includes the capture and storage of carbon emitted by human production activities, as well as the separation and storage of naturally occurring carbon dioxide in the atmosphere. The biosphere sequesters carbon dioxide in plants (especially large plants such as trees), soil and water environment.

Forests are therefore an integral part of any effort to mitigate climate change. As the largest carbon pool in terrestrial ecosystem, forest plays an important role in regulating climate, maintaining ecology and promoting economic development. The process of forest carbon sequestration mainly depends on photosynthesis to absorb carbon dioxide in the air and seal it in plants; At the same time, forest products, including furniture, wood, plywood, paper and other wood products, absorb carbon dioxide during their life cycle and may produce more carbon sequestration over time. Therefore, the carbon sequestration capacity of forests has great potential. However, the value of forests is not limited to carbon sequestration and forest products, but may also include potential carbon sequestration, conservation and biodiversity, recreational uses and culture. consequently, it is necessary to further study the problem of forest carbon sequestration and put forward management decisions that can promote the sustainable development of forests.

In order to carry out sustainable forest management and fully tap the potential of forest carbon sequestration, the follow-up structure of this study is as follows: (1) establishing a forest carbon sink model considering the impact indicators such as original forest productivity, wood product benefit and service life; (2) Establishing a decision-making model and formulate a forest management plan that can balance the value of various forests, including carbon sink;(3) apply the model to verify the sustainability and applicability of the model. This study fully exploits the carbon sequestration potential of forests, takes into account the value utilization of forests in many aspects, points out the direction for the sustainable management of forests, and is of great significance for maximizing forest management and environmental benefits.

## 2. Construction of forest carbon sequestration model

Forest carbon sequestration model is mainly composed of two parts: Forest direct carbon sink and indirect carbon sequestration of forest products.

### 2.1 Estimation of forest net primary productivity (NPP) using CASA model

The model estimates NPP based on solar radiation, normalized vegetation index (NDVI), land use type, climate and meteorological data and maximum light energy conversion rate. The CASA model parameter formula for the model application is as follows[2]:

$$NPP(p,m)=APAR(p,m)\times\eta(p,m)$$

APAR(p,m) represents the photosynthetically active radiation absorbed by pixel p in month t(gC/m2/month), and η(p,m) represents the actual light energy utilization rate of p in month t(gC/MJ).

$$APAR(p,m)=TSR(p,m)\times FPAR(p,m)\times 0.5$$

The constant 0.5 represents the proportion of solar effective radiation that vegetation can use to the total solar radiation.

$$FPAR_{NDVI}=\frac{NDVI(p,m)-NDVI_{(n,\min)}}{NDVI_{(n,\max)}-NDVI_{(n,\min)}}\times(FPRA_{\max}-FPRA_{\min})+FPRA_{\min}$$

In the formula, NDVI （n,max） and NDVI (n,min) correspond to the maximum and minimum NDVI values of the nth vegetation type, respectively, and FPAR min and FPAR max are 0.001 and 0.95, respectively.

$$FPAR_{RVI}=(RVI_{(p,m)}-RVI_{(n,\min)})/(RVI_{(n,\max)}-RVI_{(n,\min)})\times(FPRA_{\max}-FPRA_{\min})+FPRA_{\min}$$

In the formula, RVI (n,max) and RVI (n,min) correspond to the percentiles at 95% and 5% of the NDVI of the nth vegetation type, respectively.

$$FPAR(p,m)=\beta FPAR_{NVDI}+(1-\beta)FPAR_{RVI}$$

In the formula, the β value is taken as 0.5.

$$\eta(p,m)=T_{\eta 1}(p,m)\times T_{\eta 2}(p,m)\times V_{\eta}(p,m)\times\eta_{\max}$$

In the formula, Tη1 (p,m) and Tη2 (p,m) respectively represent the stress effects of low temperature and high temperature on the utilization of light energy.ηmax is the maximum light energy utilization rate under ideal conditions.

$$T_{\eta 1}(p,m)=0.8+0.02\times T_{best}(p)-0.0005\times[T_{best}(p)]^2$$

In the formula, when the average temperature of a certain month is ≤-10°C, (p,m) is 0.

$$T_{\eta 2}(p,m)=(1.184/(1+\exp[0.2\times(T_{best}(p)-10-T(p,m))]))\times(1/(1+\exp[0.3\times(T_{best}(p)-10-T(p,m))]))$$

When the monthly average temperature T(p,m) is 10°C higher or 13°C lower than the optimum temperature Tbest (p), the value of Tη2 (p,m) is equal to 1/2 of that when the monthly average temperature is the optimum temperature.

$$V(p,m)=0.5+0.5\times E(p,m)/E_p(p,m)$$

E(p,m) is the actual evapotranspiration of the area, Ep(p,m) is the regional potential evapotranspiration.

### 2.2 Service life assessment of forest products

Assuming that the carbon emission during the production and preparation of forest products is far less than the carbon sequestration, the proportion of production and consumption of forest products remains unchanged for a long time, and the accumulated carbon sequestration after the service life of forest products will not change, we selected three secondary indicators of forest product quality, use environment and use frequency, and adopted the analytic hierarchy process to establish the hierarchical structure model of the service life of forest products, build the judgment matrix The weights of product quality, use environment and use frequency in the three types of forest products were reasonably given, and the basic evaluation model of indirect fixed carbon dioxide was established[3].

#### *2.2.1 Establish hierarchical structure model*

The model is divided into three layers: target layer m, standard layer C and plane layer P. the specific layers and corresponding indicators are shown in Fig. 1:

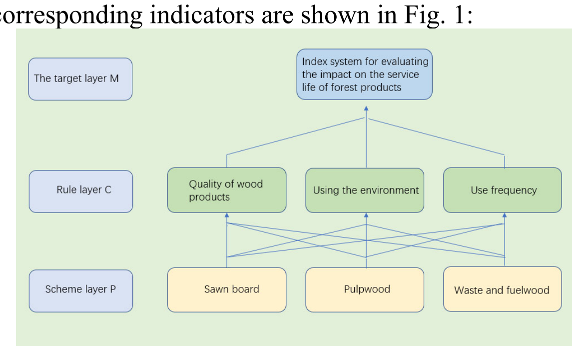


Fig. 1 Analytic hierarchy process structure diagram

#### *2.2.2 Judgment matrix construction*

Step1: Construct a judgment matrix M-C: compare the three elements C1, C2, and C3 in the criterion layer in pairs to obtain a pairwise comparison matrix.

**Table 1** Comparison matrix

| M | C1 | C2 | C3 |
|---|---|---|---|
| C1 | 1 | 3 | 5 |
| C2 | 1/3 | 1 | 2 |
| C3 | 1/5 | 1/2 | 1 |

Solving the eigenvalues of M-C, the solution is 3.0036, according to the formula $CI=\dfrac{\lambda_{\max}-n}{n-1}$ , so according

 https://doi.org/10.1051/e3sconf/202235202021

to $CR = \frac{CI}{RI}$, the calculation is 0.0036 < 0.1, which passed the consistency test.

**Table 2** The relationship between N and RI

| N | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 |

Step2: Determine the construction matrix C1-P, C2-P, C3-P:

**Table 3** C1-P judgment matrix

| C1 | P1 | P2 | P3 |
|---|---|---|---|
| P1 | 1 | 5 | 4 |
| P2 | 1/5 | 1 | 1/3 |
| P3 | 1/4 | 3 | 1 |

**Table 4** C2-P judgment matrix

| C2 | P1 | P2 | P3 |
|---|---|---|---|
| P1 | 1 | 1/5 | 1/3 |
| P2 | 5 | 1 | 2 |
| P3 | 3 | 1/2 | 1 |

**Table 5** C3-P judgment matrix

| C3 | P1 | P2 | P3 |
|---|---|---|---|
| P1 | 1 | 1/5 | 1/7 |
| P2 | 5 | 1 | 1/3 |
| P3 | 7 | 3 | 1 |

### *2.2.3 Hierarchical sorting and consistency test*

The weight, maximum eigenvalue and consistency index calculated by the above three judgment matrices are listed in the table.

**Table 6** Calculation results of selecting the most reasonable indicators forevaluating the service life of forest products

| Gradation C / Gradation P | C1 | Gradation C / Gradation P | C2 | Gradation C / Gradation P | C3 |
|---|---|---|---|---|---|
| | q1 | | q2 | | q3 |
| P1 | 0.6709 | P1 | 0.1095 | P1 | 0.0725 |
| P2 | 0.1017 | P2 | 0.5815 | P2 | 0.2803 |
| P3 | 0.2274 | P3 | 0.3091 | P3 | 0.6472 |
| $\lambda_{max}$ | 3.0858 | $\lambda_{max}$ | 3.0036 | $\lambda_{max}$ | 3.0648 |
| $CR_j$ | 0.0825 | $CR_j$ | 0.0036 | $CR_j$ | 0.0624 |

According to the value of CRj in the table, it can be concluded that matrices C1-P, C2-P and C3-P have passed the consistency check.

In order to ensure the robustness of the results, this paper uses three methods to obtain the weight and calculate the average weight, which avoids the deviation caused by a single method, and the conclusion will be more comprehensive and effective.

**Table 7** The score of each indicator

| | Index weight | Sawn timber | The pulp material | Waste and fuelwood |
|---|---|---|---|---|
| Quality | 0.6482 | 0.6709 | 0.1017 | 0.2274 |
| Using the environment | 0.2298 | 0.1095 | 0.5815 | 0.3091 |
| Use frequency | 0.1221 | 0.0725 | 0.2802 | 0.65472 |

### *2.2.4 Model conclusion*

According to Step 2, we calculated the total weight of each influencing factor,and the visualization results are as follows:

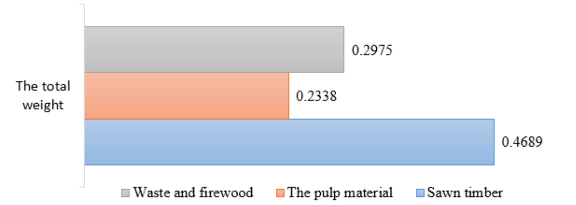


**Fig. 2** Visualization of data results

## 2.3 Carbon sequestration model of forest products

Forest products come from tree trunks and are the main body of trees. Its main components are carbon (50%), hydrogen (6%) and oxygen (43%)[4], which means that half the weight of dry wood is carbon. Therefore, the formula for calculating carbon reserves of forest products in the definition model is:

$$CSFP = TV \times \rho \times \sigma \times 1/2$$

CSFP is the amount of carbon sequestration in forest products, TV represents the volume of forest products,δ is the life weight of the product and ρ stands for wood production.

# 3. Forest Management Plan Model

## 3.1 Selection of Model Index of Forest Management Plan

Forest management refers to the process of managing forests, involving forest environmental management, forest harvesting, and forest benefits. Carbon sequestration is not the only factor that affects forest management, it is necessary to establish a decision-making model on the basis of considering the impact of other factors on forest management. Based on this model, a management plan can be developed that can balance the various forest values, thereby helping forest managers to implement the best use of forests. Based on the forest carbon sequestration model, we have established a forest management plan model combining biodiversity, social economy, cultural entertainment and other influencing factors. Among them, biodiversity considers three indicators: genetic diversity, species diversity, and ecosystem diversity. Socio-economic considers three indicators of forest product sales, GDP and total population. In terms of cultural entertainment, education and tourism are considered.

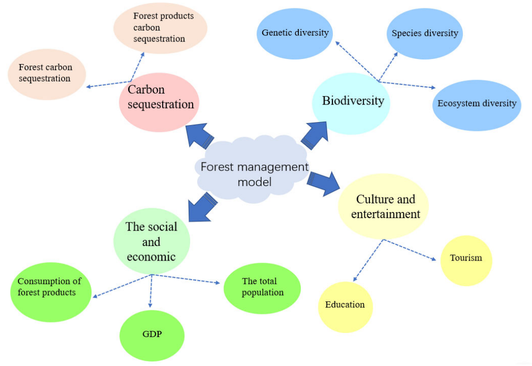


**Fig. 3** Forest management model

## 3.2 Discussion of Indicators

### *3.2.1 Carbon sequestration*

Forests can sequester more carbon than other terrestrial ecosystems, and the ability of forests to sequester carbon can be enhanced through sound forest management practices. Studies show that forest management has the potential to increase terrestrial carbon stocks[5]. Based on the carbon sequestration model in the fourth part of the article, we selected NPP and forest product carbon sequestration amount to evaluate forest carbon sequestration benefits.

### *3.2.2 Biodiversity*

At present, the protection of forest biodiversity has become one of the important objectives of sustainable forest management, some scholars have established sustainable forest management as an option for maintaining forest biodiversity, the establishment of forest management including secondary forest management, restoration of degraded land, plantation, etc. is conducive to enriching the biodiversity of forests[6]. In addition, continuous optimization of forest management can effectively achieve the protection of biodiversity in the region. Biodiversity includes ecosystem diversity, species diversity and genetic diversity, so we evaluate the role of biodiversity in forest management by studying these three factors.

### *3.2.3 Socioeconomic*

With the acceleration of social and economic transformation, forests have an increasingly prominent impact on society and economy, covering sustainable social development, employment promotion, etc. Various aspects. The optimization of forest management is conducive to the benign development of society and economy, and at the same time, the development of social economy is also conducive to forest management. For example, high-quality forest management can promote the growth of local GDP, and the development of forestry economy can actively drive people to participate in forestry management. Therefore, we select the forest product sales, GDP, population three factors to assess the socioeconomic and forest management interaction.

### *3.2.4 Cultural Entertainment*

We selected tourism and education to measure the impact of cultural entertainment on forest management. Forest culture is an inevitable outcome of people's continuous understanding of forest, adjusting the relationship between man and forest, man and nature, and the development of forest tourism is an important role in helping people understand forest culture, the sustainability of forest tourism depends on the sustainability of forest management, so forest management can promote forest culture, while forest culture is conducive to the further optimization of forest management. Education is also a major factor affecting forest management. The development of ecological education can promote people's awareness of the sustainable use and management of forests and play a positive role in forest management.

## 3.3 Establishment of Forest Management Plan Model

We use fuzzy comprehensive statistics to establish a decision-making model of forest management. It is a comprehensive evaluation method based on fuzzy mathematics. It can transform qualitative evaluation into quantitative evaluation according to the theory of membership degree of fuzzy mathematics, which has the characteristics of clear results and strong systematicness. Because there are many indexes in this model, we classify it and make two-level fuzzy comprehensive statistics. The calculation is as follows:

Determine the set of factors

The set of factors in this model is:

First factor set:

$$U=\{Carbonsequestration\ \ Biodiversity\ \ Thesocialandeconomic\ \ CultureandEntertainment\}$$

Second factor set:

$$U_1=\{Forest\ carbon\ sequestration\ \ \ Forest\ products\ carbon\ sequestration\}$$

$$U_2=\{Geneticdiversity\ \ Speciesdiversity\ \ Ecosystemdiversity\}$$

$$U_3=\{Consumptionofforestproducts\ \ GDP\ \ Thetotalpopulation\}$$

$$U_4=\{Education\ \ Tourism\}$$

Determine the set of comments

The set of comments in this model is:

$$\{Good\ \ Excellent\ \ Average\ \ Bad\ \ Very\ bad\}$$

Determine the weight distribution of each indicator

In the process of comprehensive evaluation, the difference in the importance of indicators in the process of comprehensive evaluation is shown by assigning corresponding weights to different indicators. In this paper, the entropy weight method is used to determine the weight distribution of each index. The entropy weight method is an objective weighting method, which can calculate the entropy weight of each index by using information entropy according to the dispersion degree of the data of each index, and then correct the entropy weight according to the index, so as to obtain a more objective index weight. It is an objective weighting method, which can use information entropy to calculate the entropy weight of each index according to the degree of dispersion of the data of each index, and then correct the entropy weight according to the index, so as to obtain a more objective index weight. Its calculation process is as follows:

(1) Assuming that there are n objects to be evaluated and m evaluation indicators, the matrix obtained after normalizing the normalization matrix formed by them is denoted as Z, and each element in Z is:

$$z_{ij}=x_{ij}/\sqrt{\sum_{i=1}^{n}x_{ij}^{2}}$$

(2) We calculate the probability matrix P, where each element $P_{ij}$ in P is calculated as follows:

$$p_{ij}=\frac{z_{ij}}{\sum_{i=1}^{n}z_{ij}}$$

(3) Calculate the information entropy of each index, calculate the information utility value, and normalize the entropy weight of each index. For the jth index, the calculation formula of the information entropy is:

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{n}p_{ij}\ln(p_{ij})\ \ (j=1,2,\cdots,m)$$

Among them, the definition of information utility value is: $d_j=1-e_j$, from this we get the entropy weight of each indicator:

$$W_j=d_j/\sum_{j=1}^{m}d_j\ \ (j=1,2,\cdots,m)$$

The second set of factors is evaluated and a comprehensive evaluation matrix is obtained

$$R_{i=}\begin{bmatrix} r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{1m}^{(i)} \\ r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{2m}^{(i)} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n_i1}^{(i)} & r_{n_i2}^{(i)} & \cdots & r_{n_i3}^{(i)} \end{bmatrix}$$

Then make a comprehensive evaluation of the first factor set

$$R=\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_k \end{bmatrix}$$

## 4. Applying the model to Saihanba National Forest Park in China

In order to verify the sustainability and applicability of the model, we selected Saihanba National Forest Park as the research object.

China Saihanba Forest is located at the junction of Inner Mongolia Plateau and northern Hebei, China, with a total area of 1.41 million mu, including 1.06 million mu of forest landscape and a forest coverage rate of 75.2%.The proximity of the region to desert areas makes its ecosystem fragile and vulnerable to climate and long-term human activities.

Forest ecosystem NPP, as an important indicator of forest carbon sequestration capacity, is affected by topography, landform, climate, natural disasters and so on[7].Fig. 4 and Fig. 5 are the annual temperature change and total solar radiation change of the forest in 2020, respectively. The CASA model estimates that the NPP of Saihanba Forest in 2020 will be 8397 $gC/m^2$, and the carbon sequestration will be 5.94 million tons. The Fig. 6 shows the output and carbon sequestration of major forest products in Saihanba Forest in 2020. It is estimated by algorithm that the total carbon sequestration of forest products in Saihanba Forest in 2020 is 3.08 million tons.

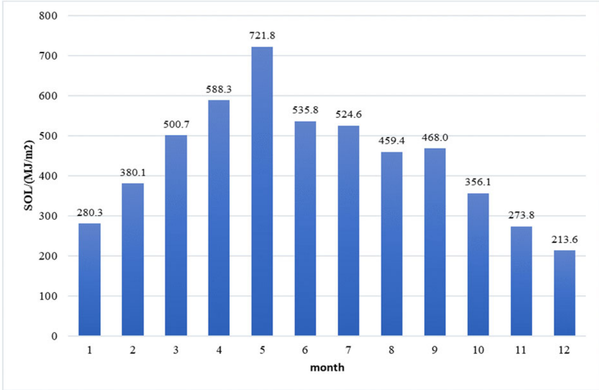


**Fig. 4** Annual temperature change in this forest in 2020

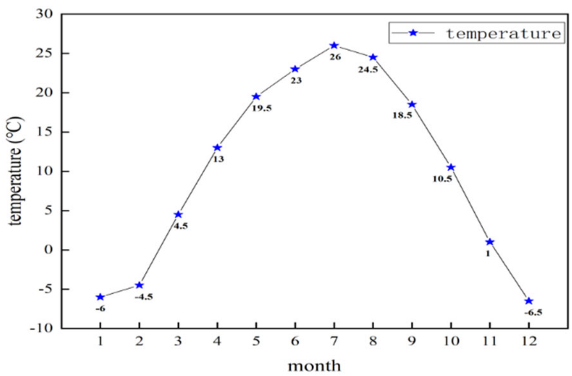


**Fig. 5** Change map of total solar radiation in the forest in 2020

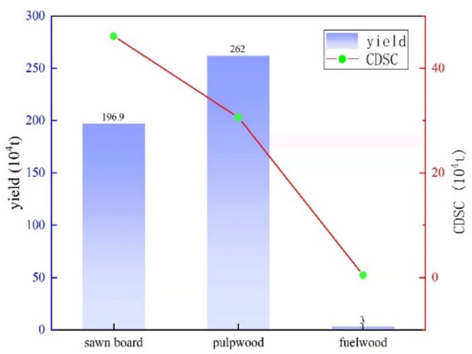


**Fig. 6** Output of major forest products and carbon sequestration in Saihanba Forest in 2020

In order to verify the decision-making model of forest management, we used the entropy weight method to calculate the weights of the first-level indicators and the second-level indicators of the Saihanba forest management system. The calculated results of the weight indicators are as follows:

**Table 8** Weight indicator results

| | Index 1 | Weight | Index 2 | Weight |
|---|---|---|---|---|
| **Forest management Plan** | Carbon sequestration | 0.4865 | Forest carbon sequestration | 0.6035 |
| | | | Forest Products carbon sequestration | 0.3965 |
| | Biodiversity | 0.3027 | Genetic diversity | 0.6709 |
| | | | Species diversity | 0.2274 |
| | | | Ecosystemdiversity | 0.1017 |
| | The social and economic | 0.1400 | Consumption of forest products | 0.5580 |
| | | | GDP | 0.3198 |
| | | | The Total population | 0.1222 |
| | Culture and Entertainment | 0.0709 | Education | 0.5900 |
| | | | Tourism | 0.4100 |

Through fuzzy comprehensive statistics, it is concluded that the subordinate degrees of Saihanba forest management plan to "Good", "Excellent", "Average", "Bad" and "Very bad" are 0.468, 0.276, 0.171, 0.084 and 0.015 respectively. It can be seen that the Saihanba forest management plan is good.

## 5. Conclusion

Forest carbon sinks play a major role in the function of forest system and reduce greenhouse gas emissions. They play an important role in environmental governance and contribute to the further implementation of sustainable development strategies [8]. In addition, forest carbon sinks are more cost-effective than industrial emissions reductions and are an important strategy for countries around the world to address climate change [9].

The study fully assessed the carbon sequestration, biodiversity, socio-economic and recreational aspects of forest management, starting with the establishment of a carbon sequestration model to assess the carbon sequestration benefits of forest carbon sequestration and forest products, forest carbon sequestration was measured using net primary productivity and estimated using the CASA model. The Index of service life was selected to measure the carbon storage of forest products, and the evaluation system of service life of forest products was constructed by AHP on the basis of secondary index. This study uses three methods to calculate the weight and get the average value to ensure the robustness of the results.

Then, on the basis of considering biodiversity, social economy, cultural entertainment and other factors, a decision-making model of forest management is established by combining fuzzy comprehensive evaluation with entropy weight method, effective combination of Quantitative analysis and qualitative analysis provides a more effective method for evaluating forest management plans.

In this study, the model was applied to Saihanba National Forest Park of China, and the effects of forest carbon sequestration and forest products sequestration were analyzed, the applicability and validity of the model are verified.

Forests around the world are currently experiencing much faster environmental changes than in the past few hundred years, and the abiotic factors that determine forest dynamics are also different, forest modeling faces new challenges in supporting forest management in the context of environmental change [10]. More needs to be done to fully promote sustainable forest management plans, taking into account more factors and more data.

## References

1. Jiang Kejun Sixth assessment report of IPCC working group III: where is global mitigation going[J]. Progress in climate change research, 2020,16 (02): 251-252
2. Liu Heng. Estimation and Analysis of Net Primary Productivity of Vegetation in Qingjiang River Basin Basedon Basin Based on CASA Model[D]. Hubei University for Nationalities, 2021.DOI:10.27764 /d.cnki.ghbmz. 2021. 00 0113.
3. Qin Jianhua, Jiang Zhilin The role of forests in atmospheric carbon balance [J] World forestry research, 1997, 10 (4): 8
4. Guo Minghui, Guan Xin, Li Jian Carbon storage and carbon emission of wood forest products in China [J] China's population, resources and environment, 2010
5. Jandl, R., Vesterdal, L., Olsson, M., Bens, O., Badeck, F., & Rock, J. (2007). Carbon sequestration and forest management. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2(17), 1-16.
6. Bawa, K. S., & Seidler, R. (1998). Natural forest management and conservation of biodiversity in tropical forests. Conservation biology, 12(1), 46-55.
7. Wang Xiaoke, Liu Weiwei.Factors affecting forest carbon sequestration[J]. Forestry and Ecology, 2021(03): 40-41.DOI: 10.13552/j.cnki.lyyst.2021.03.022.

8. Chiao man Yuet. Role and impact of forest management on carbon sinks [J]. Guangdong sericulture, 2022, 56(01): 34-36.
9. Zhang Ying, Li Xiao-ge, Wen ya-li. Potential analysis of forest carbon sequestration in China under the background of carbon peak carbon neutralization [J]. Journal of Beijing Forestry University, 2022,44(01): 38-47.
10. Fontes L, Bontemps J D, Bugmann H, et al. Models for supporting forest management in a changing environment[J]. Forest Systems, 2010, 19: 8-29.