# Study on Comprehensive Management Model of Forest system based on Entropy weight method and biomass expansion factor method

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**Keywords:** carbon sequestration; forest management; dynamic optimization; WRSR.

**Abstract:** The forest was divided into three categories by RSR comprehensive rank-sum ratio evaluation (WRSR ) method, and two transition points were obtained, which were 0.178 and 0.6343. We found that the inclusive value of the two types of the broad-leaved forest was the highest, which was 0.83 and 0.67, respectively. The inclusive value of the alpine vegetation area is the lowest, which is 0.14, and the model's goodness of fit can be derived to be 0.966 through the test. The forest was divided into three categories by RSR comprehensive rank-sum ratio evaluation (WRSR ) method, and two transition points were obtained, which were 0.178 and 0.6343. We found that the inclusive value of the two types of the broad-leaved forest was the highest, which was 0.83 and 0.67, respectively. The inclusive value of the alpine vegetation area is the lowest, which is 0.14, and the goodness of fit of the model can be derived to be 0.966 through the F test.

## 1. Introduction

According to the latest World Meteorological Organization (WMO) bulletin, the amount of heat-trapping greenhouse gases in the atmosphere will set a new record in 2021. Carbon dioxide (CO2) is the dominant greenhouse gas, accounting for 66% of the warming effect, with its concentration reaching 413.2 ppm in 2020, 147% of pre-industrial levels, and the highest level in 4.5 million years.

Cultivating forests is an effective way to do this. Forests are important carbon sinks on the planet, as trees produce the energy they need through photosynthesis while fixing CO2in their bodies. The carbon sequestration capacity of trees varies by age: young plants grow vigorously and have a far greater capacity to sequester carbon than mature trees growing steadily. However, the role of forests is diverse, and forests are not only essential carbon sinks but also have many other values, such as ecological and recreational values. In addition, different forest farms have different geographic environments and different characteristics. For these reasons, forest management often cannot be generalized.

## 2. Calculation method of forest carbon storage

According to the background information and related literature [4], the factors that affect the carbon sequestration of a forest are the age of the forest, precipitation, topography, elevation, fire, nitrogen deposition, and different tree species. Based on FAO's global carbon sink data, we used principal component analysis to derive four key indicators: tree species, forest age, and volume and storage area.

The forest carbon sequestration function includes carbon sequestration by forest trees, understory plants, and humus, carbon sequestration by forest soils, and carbon sequestration by forest products. In order to avoid double calculations, forest product sequestration is generally not included [1]. Accordingly, we can obtain the following equation:

$$Z = Og + Ug + Hu + So$$

Where $Z$ is the total forest carbon, $Og$ is the carbon sequestered in the above-ground part, $Ug$ is the carbon sequestered in the below-ground part, $Hu$ is the carbon sequestered in humus, and $So$ is the carbon sequestered in the soil.

Above-ground biomass consists of trees (standardized to a starting diameter at breast height of 5CM), shrubs (shrubs and all live young trees less than 5CM at breast height), and grasses [5]. According to the biomass expansion factor method, we can arrive at the biomass formula for trees:

$$W_{ij} = A_i \cdot W_{\mathrm{single}ij} = A_i \cdot V_{\mathrm{single}ij} \cdot BEF_{ij} \cdot SVD_{ij}$$

Where $W_{ij}$ denotes the above-ground biomass of the jth tree species of the ith forest type; Ai denotes the area of forest type i. $W_{singleij}$ denotes the biomass per unit area of tree species j of forest type i. $V_{singleij}$ denotes the storage volume per hectare of tree species j of forest type i. $BEF_{ij}$ denotes the biomass expansion factor of tree species j of forest type i, and $SVD_{ij}$ denotes the wood density of tree species j of forest type i.

Among the allocation proportions of each forest stand level, the tree layer accounted for the largest proportion, ranging from 95.1% to 98.7%; the shrub layer and herb layer accounted for smaller proportions, especially the herb layer, with 0.9% to 4.5% for the shrub layer and 0.4% for the herb layer. According to the data of the "Forest Ecosystem Carbon Storage Measurement Guide (LY/T 2988-2018)", the carbon storage of the shrub layer and herbaceous layer can be expressed with default values of 0.4672 and 0.3270; while the carbon content of the tree layer varies according to the forest species. To facilitate the calculation, we can take an approximate value of 0.5 for the carbon content of forest biomass [6], which is a common method to determine the carbon storage of forest communities, i.e., "after finding the forest biomass, multiply it by 50% of the carbon content to find the carbon storage of the forest system"[7].

The ratio of above-ground biomass to below-ground biomass is called rootstock ratio (RSr) (cited in "IPCC Reference Values for Rootstock Ratio and Biomass Conversion Expansion Factor for Temperate Forest Trees"). Because of the direct correlation between biomass and carbon storage (the relationship between the two has been discussed earlier), we can directly derive the following equation:

$$Ug = Og \cdot RSr$$

The carbon storage of forest land is expressed as the sum of carbon storage of humus and soil, i.e., $HSC = Hu + So$, the carbon storage of forest land has the following expression according to the forest volume method proposed by Xi et al. [1]

$$HSc = \beta \cdot A_i \cdot V_{ij} \cdot \delta \cdot \rho \cdot \gamma$$

Where $V_{ij}$ is the unit area of live tree storage in forest type j in forest type i. $\delta$ is the biomass expansion factor, the default value of which is 1.90 in the IPCC (Intergovernmental Panel on Climate Change). $\rho$ is the volume factor, which converts the total forest biomass storage to dry weight, the default value of which is 0.5. $\gamma$ is the carbon content, which converts the dry weight of biomass to carbon storage, the default value of which is 0.5.

From the above model, we can calculate the carbon storage of a specific forest. Based on the data found from the Geosciences Ecology website, we calculated forest carbon storage in China, which is consistent with the actual situation as shown in the following figure. It demonstrates the validity of our calculation method.

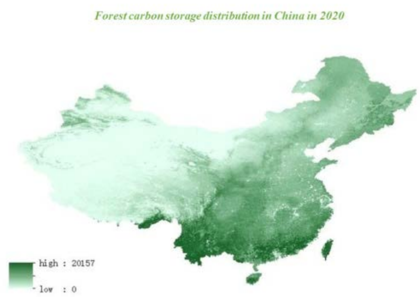


Figure. 1 Distribution of forest carbon storage by the above calculation method

## 3. Cutting Model

Based on the forest carbon storage calculation method, we will apply optimal control theory to develop a deforestation model to manage the forest. We will apply the obtained forest management strategies to achieve efficient sequestration of CO2. According to the study by Yanfeng Bai et al., the carbon content in woody forest products and the carbon content of trees are kept constant[2]. Since the wood cut out is the biomass of trees, the carbon content rate of forest product biomass is consistent with that of forest biomass, which is 0.5. For ease of calculation, we simplify our consideration of the carbon loss rate of forest products and use 1/a to represent their annual carbon stock loss.

In order to avoid "the forest was entirely cut, "we need to set a maximum annual deforestation amount max(determined by government policy): 0⩽u(t)⩽max and also to satisfy(t) > 0 (the carbon storage of forest live trees cannot be zero). Combined with the storage efficiency model of growth[3] proposed by Xiuhai Zhao et al., the state model of forest carbon storage can be derived as follows:

$$\frac{\text{dforest}}{\text{d}t} = v(t)\cdot f(\text{forest}) - u(t)$$

$$\bar{u} = v(t)\cdot f(\overline{\text{forest}(t)}) - \frac{\text{dforest}}{\text{d}t}$$

H(t)denotes the total carbon storage of the forest live wood plus wood, HSC while approximated constant in this model, so H(t) means the carbon sequestration of the forest and its products over time. Subsequently, maximizing the indicator:

$$H(t) = \text{forest}(t) - u(t) + prod(t)$$

The result is shown in the following function image:

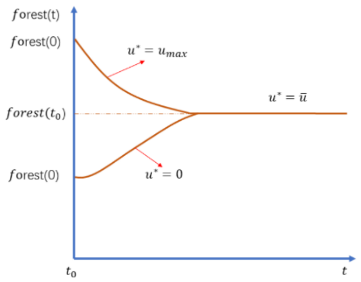


Figure. 2 The result is shown in the following function image

## 4. Forest comprehensive value assessment

### 4.1 Identification of Performance Indicators

To be able to obtain a forest management plan that balances the various forest values, our decision model includes 8 forest species as well as eight self-designed indicators: biodiversity conservation, soil conservation, nutrient accumulation, recreation, forest products, water conservation, carbon sequestration, and oxygen release, and air purification.

### 4.2 Analysis of Indicator Weights using Entropy Weight Method

The entropy weighting method can comprehensively evaluate multiple objectives and indicators, and the evaluation results are determined by objective information, which has excellent objectivity. The steps are as follows:

Firstly, the data are normalized. The biodiversity, soil conservation, nutrient accumulation, recreation, forest products, water conservation, carbon sequestration, oxygen release, and air purification were set as x1, x2, x3,·, x8 respectively. Since the units of measurement of each evaluation index are not uniform, they should be normalized before calculating the total weights, i.e., the absolute values of each evaluation index should be converted into relative values, and let $x_{ij} = |x_{ij}|$. Because all the 8 indicators are positive, use the following formula for calculation.

$$x_{ij} = 0.998\frac{x_{ij} - \min\left\{x_{1j},\cdots x_{nj}\right\}}{\max\left\{x_{1j},\cdots x_{nj}\right\} - \min\left\{x_{1j},\cdots x_{nj}\right\}} + 0.002$$ □ □ □

Next, using the formula $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} (j = 1, 2, \cdots, m)$ to calculate the weight of the ith forest indicator value under the jth evaluation indicator $P_{ij}$.. Calculate the information entropy of the j-th evaluation index of each forest. Finally, the weight of each index W1-W8 is calculated.

### 4.3 Forest Staging using WRSR

Rank-sum ratio: It is a statistical method that combines the respective points of classical parametric estimation and recent nonparametric statistics and is a broad-spectrum method in quantitative methods that is simple and effective. We calculated WRSR scores for forest values using the weights of the eight indicators obtained above and graded them according to the table. The steps are as follows:

Ordering: This paper uses the non-integer WRSR. This method uses a linear interpolation-like approach to rank the indicator values, which improves the shortcomings of the WRSR method of ranking and has wider practicality. So there is a quantitative linear correspondence between the codified rank order and the original index value.

$$\text{Positive:} Rij = 1 + (n-1)\frac{X_{ij} - \min\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right)}{\max\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right) - \min\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right)}$$ □ □ □

$$\text{Negative:} R_{ij} = 1 + (n-1)\frac{\max\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right) - X_{ij}}{\max\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right) - \min\left(X_{1j}, X_{2j}, \ldots, X_{nj}\right)}$$ □ □ □ □

Calculating WRSR: When the weights of individual evaluation indicators are different, the weighted rank-sum ratio is calculated as WRSR, which is calculated as

$$WRSR_i = \frac{1}{n}\sum_{j=1}^{m} w_j R_{ij}$$ □ □ □ □

Wj is the weight of the jth forest evaluation indicator, and $\sum_{j=1}^{m} w_j = 1$ . Calculation of probability units: The WRSR frequency distribution table is prepared in the order of smallest to largest, the frequency *fi* of each group is listed, the cumulative frequency *fi* of each group is calculated, the cumulative frequency pi= Fi/n is calculated, and piis converted into the probability unit Probit. Calculate the regression equation: Using the probability unit value P robit corresponding to the cumulative frequency as the independent variable and the WRSRi value as the dependent variable, calculate the regression equation RSR(WRSR) = a+b×probit. The least-squares method can be used to find the corresponding parameters.

Sorting by Grade: The different forest types evaluated are ranked by the WRSR estimates calculated by the regression equation (in 3 classes). There is a "balance" between each of the two classes and the characteristics of a particular forest and its location. It can be assigned to one of these forest types based on its specific attributes.

### 4.4 Model Solution

By collecting data, we can get eight forest values for each of the eight forest land types as follows:

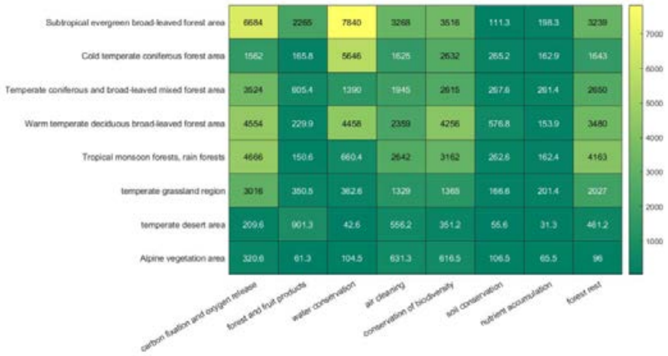


Figure. 3 Eight forest values & eight forest land types (Unit:million yuan / a)

According to the above data, it can be seen that forests have the highest value in carbon sequestration and oxygen release, water connotation, recreation, and biodiversity conservation. Therefore, managers should pay attention to these values and do an excellent job in forest fire prevention and disaster prevention. In order to prevent natural disasters from occurring, the carbon sequestration and water connotation capacity decreases, the forest ecosystem becomes unbalanced, and a large amountofcarbondioxideisreleased,causingthegreenhousebenefitstoincreaseandotherhazards.

After calculating the entropy weighting method, the weights of the eight indicators of forest value can be calculated in the following table.

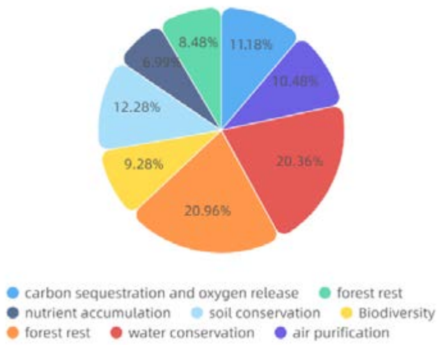


Figure. 4 Weighting of various forest values

The results of the entropy weighting method show that the weights are, in descending order, forest products, water conservation, soil conservation, carbon sequestration and oxygen release, air purification, biodiversity conservation, recreation, and nutrient accumulation, with the maximum indicator weight being forest products (20.968%) and the minimum value being nutrient accumulation (6.989%). The greater the weight, the lower the information entropy, the greater the information utility value, and the more sensitive the forest value is. Therefore, we can plant more fruit trees or other trees with economic benefits to increase the ecological value of the forest while selling the forest products to generate more economic benefits and develop tourism to increase the value of recreation. It also aligns with our familiar knowledge of life, which shows that the weight is reasonable.

The following is calculated by the weighted rank-sum ratio comprehensive evaluation method (WRSR ), which is set to be divided into three grades, and the critical value of grading and sorting can be obtained as follows :

Tab.1 Grade Table

| Grade | RSR Regression |
|---|---|
| First grade | <0.178 |
| Second grade | 0.178~ |
| Tird grade | 0.6343~ |

After dividing the eight forest types into three grades, the critical value between the adjacent two grades can be set as the transition point, namely 0.178 and 0.6343. The specific classification results are given below.

Tab.2 Forest grading results

| Vegetation type | RSR_Rank | RSR Regression | Level |
|---|---|---|---|
| Subtropical evergeen broad-leaved forest | 1 | 0.831069363 | 3 |
| Warm temperate deciduous broad-leaved forests | 2 | 0.668550136 | 3 |
| Cold temperate coniferous forests | 5 | 0.406115425 | 2 |
| Temperate mixed coniferous and broad-leaved forests | 3 | 0.559990001 | 2 |
| Tropical seasonal rain forests and rain forests | 4 | 0.478808149 | 2 |
| Temperate grasslands | 6 | 0.333422702 | 2 |
| Temperate deserts | 7 | 0.25224085 | 2 |
| Alpine vegetation area | 8 | 0.143680714 | 1 |

It can be seen that the subtropical evergreen broad-leaved forest region and the warm temperate deciduous broad-leaved forest region have the highest forest value per unit area, belonging to the first grade, and the lowest in the third grade of alpine vegetation region, and other types are divided into the second grade.

**The first grade**: through the analysis of the first grade of vegetation types, it can be seen that the forest value of the broadleaf forest is the highest. Through the analysis of geographical location, it can be seen that the subtropical and warm temperate environment is the most suitable for forest growth. Therefore, managers should make full use of the forest value of subtropical and warm temperate and plant more broadleaf forests to improve the total value of forests. **The second grade**: such forest geographical location, climatic environment, and other factors are diverse, and there is often no unified forest plan. According to the population and economic conditions of the country, policies that conform to the national conditions are formulated. **The third grade**: the third grade only includes alpine vegetation area, and its fitting value is only 0.14, which is about one-sixth of the first score. The main reason is that it has high altitudes and perennial snow. Therefore, in the management of such forests, more plants suitable for ice and snow and cold and drought resistance should be planted, such as shrubs and grasses, and the adjusting measures to local conditions should be fully implemented.

We can see that broad-leaved forests have the highest forest value by analyzing the first vegetation type. By analyzing the geographical location, it can be seen that the environment of subtropical and warm temperate zones is most suitable for forest growth. Therefore, managers should make full use of the forest value of subtropical and warm temperate zones and plant more broad-leaved forests to improve the economic benefits while protecting the ecology and promoting the construction of a resource-saving and environment-friendly "two types of society."

Most of the vegetation types in the second class management plans should consider multiple aspects, focusing on both economic benefits and ecological and social benefits. According to the policies of different countries, their management plans tend to be different. Developed countries tend to focus more on ecological benefits, and developing countries generally favor economic benefits. However, their common point is the pursuit of economic and ecological win-win while maintaining environmental and efficiency balance. While strengthening the forest management plan, we note that the alpine vegetation zone is in the third category, with a fitted value of only 0.14, which is about one-sixth of the first ranking score. The main reason for this is its high altitude and constant snow accumulation, so we should plant more snow- and ice-adapted and drought-tolerant plants, such as shrubs and grasses, when managing such forests, and fully implement the policy of adapting to local conditions. According to the above analysis, there are transition points between different management plans, and the RSR Regression obtained by rank-sum ratio can be used for classification. The transition point 0.6 is set between the first and second grades, and the transition point 0.3 is set between the second and third grades, according to the geographical location, climate, environment, and other aspects of different forests. Classify forests into the eight vegetation types mentioned above, and then judge which level they belong to. Different levels are often suitable for different management schemes.

## 5. Conclusions

In order to maximize the climate benefits of the forest, this paper constructs the relevant integrated forest management model, which is based on the biomass expansion coefficient method. Given that the carbon sequestration capacity of mature forests is far inferior to that of young forests, we have to cut it down. At the same time, the forest cannot be stopped down completely, so we assume its carbon loss rate and maximize the total carbon storage of the felled forest and forest products under constraint conditions. We conclude that the amount of carbon stored in forests will balance the amount of forest cut down each year. Considering that forest has more than one value of carbon sequestration, we determined eight management scopes of carbon sequestration, oxygen release, recreation, and forest products and quantified their value. The entropy weight method ( EWM ) was used to calculate their weight, and the result was that forest products had the most considerable weight, accounting for 20.968%. Secondly, the forest was divided into eight categories, including subtropical evergreen broad-leaved forest in consideration of the geographical location and vegetation type. The forest was divided into three categories by RSR comprehensive rank-sum ratio evaluation ( WRSR ) method, and two transition points were obtained, which were 0.178 and 0.6343. We found that the inclusive value of the two types of the broad-leaved forest was the highest, 0.83 and 0.67, respectively. The inclusive value of the alpine vegetation area is the lowest, which is 0.14, and the model's goodness of fit can be derived to be 0.966 through the F test.

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