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Evaluation of forest value based on multiple evaluation model

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Abstract: Since the 20th century, with the rapid development of the world economy, the process of industrialization and urbanization has accelerated and greenhouse gases such as carbon dioxide has soared in the atmosphere. The global climate has undergone immense changes. Yet forests play an indispensable role in mitigating the impact of climate change. Therefore, it is important to build a management system that can give full play to the carbon sequestration value of forests. Considering that wood forest products also have the ability of carbon sequestration, our team established the I-S-A model of carbon sequestration by wood forest products and forest based on this aspect. We establish a forest value evaluation model after considering other forest values. Our model selects biodiversity, wood forest product yield, forest product carbon storage and total carbon storage. Then, we analyze their relationship through Pearson index, and conclude that there is no condition that will lead to the forest not being cut down through the PCA model. We comprehensively evaluate the forest values of Florida, Mississippi and California in the United States by using Topsis model. Depending on the score, we obtain three indicators of forest value classification through cluster analysis: 0.02291, 0.04872 and 0.07163. The value of forests below 0.04872 gradually deteriorates, and we need to manage forests below this score. Meanwhile, we obtain the scope and transition point of the forest management plan according to the change heat map.

1. Introduction

At present, climate change poses a great threat to life. To reduce the effects of climate change, we need to take action to reduce greenhouse gas emissions. For this reason, forests are essential to climate change by storing carbon dioxide[1]. Forests sequester carbon dioxide in living plants and forest products, which have a higher sequestration benefit when combined with living plants than if they were not cut at all. At a global level, forest management plans that include appropriate logging may be better for carbon sequestration[2]. We need to strike a balance between logging and not logging, and we need to look for maximum value based on the diversity of forest[3].

Therefore, it is very important to establish a management system that can fully utilize the value of forest carbon sink. Considering that woody forest products also have the ability to sequester carbon, our team built an I-S-A model of woody forest products and forest carbon sequestration on this basis[4]. We developed the forest value assessment model after considering other forest values. Our model selected biodiversity, woody forest product production, forest product carbon storage, and total carbon storage[5].

2. Model analysis

2.1 I-S-A Model

IPCC: Intergovernmental Panel on Climate Change. HWP (wood forest products) carbon pool is the "buffer" of the greenhouse effect. Establishing and developing national forest carbon pool including forest carbon pool and HWP carbon pool has important practical significance for mitigating greenhouse effect and coping with climate change. HWP accounting methods recommended by IPCC official guidelines include default method, atmospheric flow method, reserve change method and production method. Based on the relationship of the United States, we choose a default method, atmospheric flow method and reserve change method to establish the I-S-A model[6].

2.1.1 Life cycle of wood forest products

First of all, we looked at the life cycle of wood forest products, wood forest products can store carbon in it, but any wood product has a life cycle. The life cycle of wood forest products includes a series of processes from forest harvesting, wood material manufacturing, production and use for wood waste treatment. As trees grow, they use photosynthesis to absorb carbon dioxide, water and minerals to form wood, which stores a large amount of carbon. A series of processes, such as logging, create a flow of carbon in the opposite direction. After logging logs are transported out of the forest in the form of logs, the processed wood semi-finished products consume most of the logged logs, and the leftovers of sawn logs are used as raw materials in the production process of other products. Consumption and life expectancy to determine how much wood carbon is stored in the wood forest product carbon bank.

The service life of various wood forest products is different, usually expressed in two ways: half-life and average service life. In this model, we adopt the expression of half-life, which assumes that the decomposition of wood forest products follows exponential change. In wood forest products, the half-lives of hardwood and softwood is completely different. According to IPCC good guidelines, the half-lives of hardwood and softwood is 30 years and 2 years respectively[7].

2.1.2 Carbon content and carbon factor

The proportion of carbon in the dry weight of plant organic matter is called carbon content. We refer to a large number of data and conclude that the carbon content of different tree species and regions at home and abroad is relatively consistent, basically close to 0.5. Therefore, we take the carbon content at 0.5.

Carbon factor is the carbon content of forest products, which are the default factor for conversion from forest product yield to carbon quantity. Through the conversion of carbon factors, the carbon content of various wood forest products can be unified and comparable, which is also convenient for the overall calculation of carbon storage and carbon emissions of all forest products. The transformation formula of carbon factor is:

$$F = D \times R \tag{1}$$

Where F is the carbon conversion factor of wood forest products, D is the basic density of wood forest products, and R is the carbon content rate.

2.1.3 I-S-A algorithm

According to the United Nations Climate Conference, the formula of HWP variable for annual carbon storage of wood forest products calculated by the IPCC default method, reserve change method and atmospheric flow method is as follows:

The IPCC default method:

$$\Delta C_{IPCC} = 0 \tag{2}$$

Reserve change method:

$$\Delta C_{SCA} = \Delta C_{HWP-DC} \tag{3}$$

Atmospheric flow method:

$$C_{AFA} = \Delta C_{HWP-DC} + P_{IM} - P_{EX} \tag{4}$$

Among them, ΔC_{IPCC}, ΔC_{SCA}, C_{AFA} respectively represents the annual increment of HWP carbon storage calculated by IPCC default method, reserve change method and atmospheric flow method, $\Delta C_{HWP\text{-}DC}$ is the amount of carbon produced by HWP annually in the United States, P_{IM}、P_{EX} are the HWP carbon storage of China's annual import and export respectively.

Next, the US HWP carbon pool is estimated, and its logical formula is as follows:

$$\Delta C(i) = C(i+1) - C(i) \tag{5}$$

Where C(i)represents the carbon storage of HWP in the United States in year I, and ΔC(i) represents the change of HWP carbon storage in year I.

$$(i+1) = e^{-k} \cdot \mathrm{C}(i) + \left(\frac{1-e^{-k}}{k}\right) \cdot C_{AFA} \tag{6}$$

Where k is the annual first-order attenuation variable, and IT is pointed out in the IPCC report that C(1900)=0.

$$V_t = V_{1961} \cdot e^{[U\cdot(t-1961)]} \tag{7}$$

Among them;$V_t$is HWP production and trade volume in t year,V_{1961} is HWP production, import and export volume in 1961, U is the change rate of American industrial roundwood consumption. This formula is used to estimate HWP carbon sequestration in the United States from 1900 to 1960.

$$K = \frac{ln(2)}{HL} \tag{8}$$

Where, HL is the half-life of the product.

Various parameters are shown in the table below(Table 1 & Table 2):

Table 1 Default half-lives for “products in use” carbon pools

	Hardwood products	**Paper products**
HL	30	2
K	0.023	0.347

Table 2 Various parameters of understory accumulation

	Trees	**Undergrowth**	**Soil**
Ratio of soil carbon sequestration	41%	8%	51%
Combustion efficiency	0.200	0.335	0.080

2.1.4 Model implementation

Based on the I-S-A model, we calculated the carbon sequestration stock and HWP total carbon sequestration stock of three wood forest products from 1900 to 2020, as shown in the figure below(Figure 1 & Figure 2):

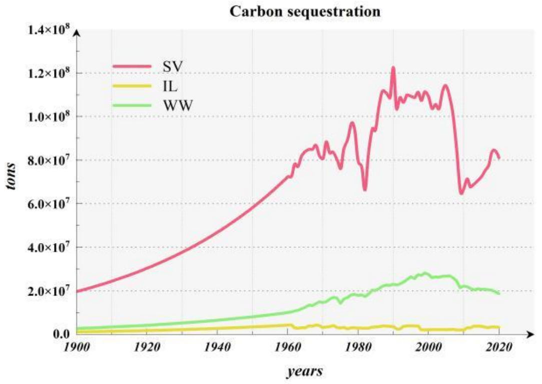

Figure 1 Carbon sequestration of three wood forest products

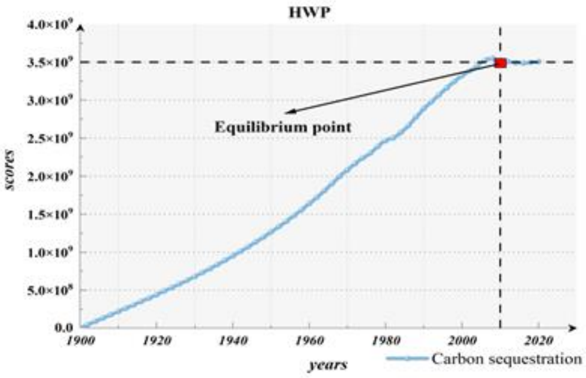

Figure 2 Carbon sequestration of HWP

From the above two figures, we can see that before 1970, carbon sequestration stock of SV, IL and WW in the United States was slowly rising year by year. We can see that the management of deforestation in the United States was relatively lax at that time, and a certain amount of forests were cut down every year to produce forest products for carbon sequestration. However, after 1970, the US authorities may have intervened in the deforestation of the United States and established a certain ban on deforestation, resulting in the instability of SV output, the slow growth of WW output, and even the trend of IL output decline. As can be seen from the HWP trend chart, the growth trend of the US HWP carbon sequestration tends to be parabolic before 2010, but it tends to be flat after 2010. Therefore, the growth of HWP tends to be stable after the government intervention in deforestation, and the annual HWP output is about 3.5 billion tons.

Forest System outcomes mainly consider biodiversity, forest products and carbon sequestration, while forest management system outcomes also include environmental and socio-economic drivers. So when we analyze the forest environment and social economic driving factors, we consider the forest system, the results of optimization direction by determining the proportion of the part to determine points, in order to consider the forest system interactions between the parts, so to establish a biodiversity, woody forest products, HWP, total decision evaluation system composed of carbon.

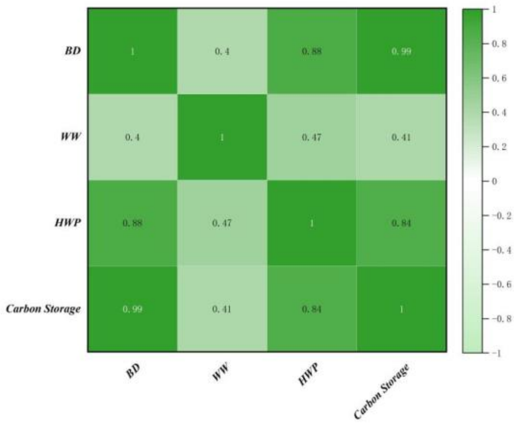

Figure 3 Thermodynamic diagram of four indexes

First of all, we conducted Pearson correlation analysis on these four indicators to obtain the heat map (as showed in Figure 3) between the four indicators and the correlation between them. We can see that these four indicators are interrelated and inseparable with the forest value, which is the planning scope that forest managers need to consider.

3. Model solving and analysis

3.1 TOPSIS evaluation and decision models

This question requires that the scope and transition point of the management plan for the forest be proposed, and a decision-making model be established so that forest managers can understand the best way to use the forest. In forest management, biodiversity, wood forest products, HWP, total carbon storage and other indicators should be considered comprehensively.

In this problem, we will collect data according to the characteristics of these four indicators, and use the collected indicators and data to establish a multi-indicator evaluation model

Set the value of forest as I_i, biodiversity, wood forest products, HWP and total carbon storage as$D_d(i)$, $J_j(i)$, $G_g(i)$, $F_f(i)$, weights are used separately as W_d, W_j, W_g, W_f There are:

$$I_i = W_d D_d(i) + W_j J_j(i) + W_g G_g(i) + W_f F_f(i) \tag{9}$$

For wood forest products, the first step is to carry out the forward processing:

$$\overline{J_J(\iota)} = max(J)\text{-}J(i) \tag{10}$$

In order to eliminate the influence of data dimension, we need to conduct standardized processing for each column of data:

The decision matrix of forest value is established according to the forward index data$A = \left(a_{ij}\right)_{mn}$, The decision moment after standardization$B = \left(z_{ij}\right)_{mn}$, Among them.

$$z_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}{}^2}}, i = 1,2,\dots,m;\ j = 1,2,\dots,n \tag{11}$$

Determine the maximum value of positive and negative:

Define maximum value:

$$Z^+ = (z_1^+, z_2^+, \dots, z_m^+) = (max\{z_{11}, z_{21}, \dots, z_{n1}\}, max\{z_{12}, z_{22}, \dots, z_{n2}\}, \dots, max\{z_{1m}, z_{2m}, \dots, z_{nm}\})$$

Define the minimum

$$z^- = (z_1^-, z_2^-, \dots, z_m^-) = (min\{z_{11}, z_{21}, \dots, z_{n1}\}, min\{z_{12}, z_{22}, \dots, z_{n2}\}, \dots, min\{z_{1m}, z_{2m}, \dots, z_{nm}\})$$

Determine the distance between each evaluation object and the maximum or minimum value, and define the $i(i = 1,2,\dots,n)$ the distance between each evaluation object and the maximum value$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(z_j^+ - z_{ij}\right)^2}$, define the$i(i = 1,2,\dots,n)$the distance between the evaluation objects and the minimum value$D_i^- = \sqrt{\sum_{j=1}^{m}\left(z_j^- - z_{ij}\right)^2}$。So, we can get the$i(i = 1,2,\dots,n)$ scores of evaluation object indexes: $s_i = \frac{D_i^-}{D_i^+ + D_i^-}$.

Solution of model:

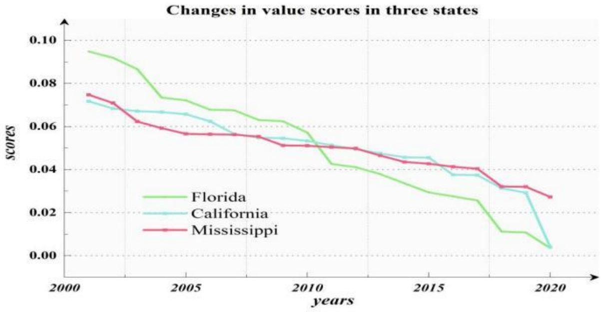

Figure 4 Changes in forest value scores in three states

Through the establishment of Topsis evaluation model, we can finally get these four indicators to evaluate the data of the three states in the past 20 years, and get the score broken line graph as showed in Figure 4.

3.2 PCA model

First, we conducted principal component analysis on selected evaluation indexes including biodiversity, wood forest products, HWP and total carbon storage to determine the most important factors affecting forest value and the weight of each index on forest value.

We take Mississippi as an example to perform Maltab analysis on four indicators, as shown in the visualization:

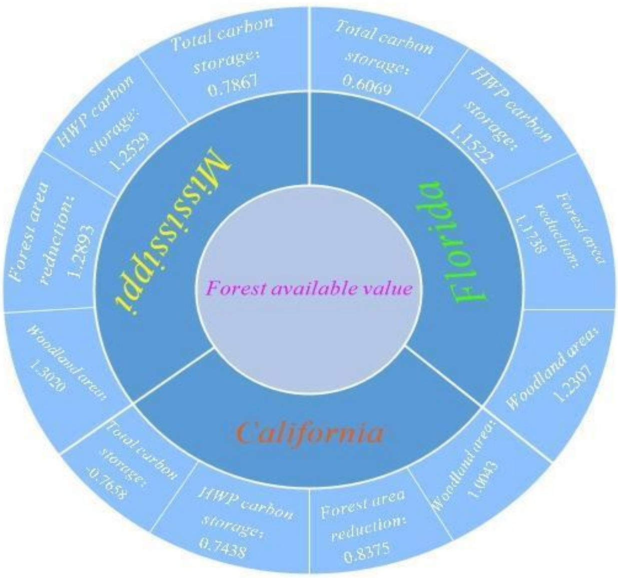

Figure 5 PCA weights

From the thermal image (Figure 5), we can see that wood forest products are related to each index. From the change of carbon sequestration after trees are cut down. It can be concluded that trees should be cut down.

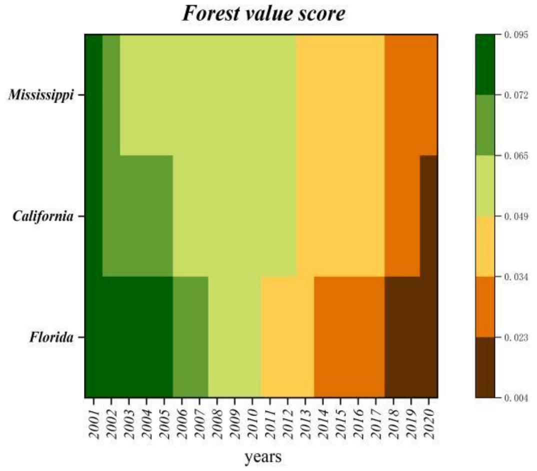

Figure 6 Thermodynamic forest value scores in three states

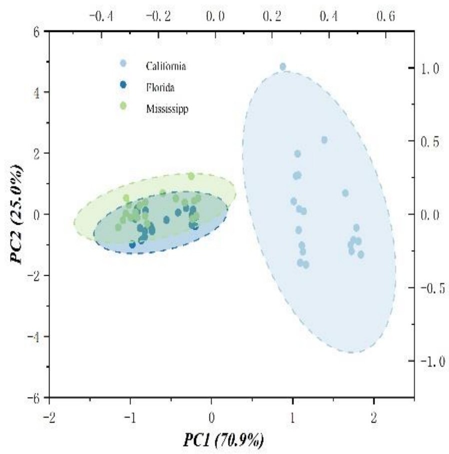

Figure 7 Principal component analysis diagram

According to the analysis in Figure 6 and Figure 7, we can see that forest products obtained by felling trees are strongly correlated with other indicators. In addition, with the growth of tree age, carbon sequestration gradually decreases, so there is no condition that will lead to the forest not being felled.

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