Building a Forest Fortress to Sequester Carbon: A Forest Management Plan

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Abstract. Greenhouse gas emissions seem to have thrown global warming into an irreversible spiral, while the scarcity of forest resources also facilitates the global greenhouse effect. Unfortunately, irrational forest management plans are adding to the problem of today's low carbon society and economy. By applying the OSM model (object-strategy-management), a clear framework is established between the carbon sequestration model and the forest management decision system which is divided into the Forest Management Level Index (FLI): WFLI and MFLI. Meanwhile, each index's weights and related indicators were obtained and incorporated into FLI by EWM. Overall, the model constructed in this paper provides a set of scientific and effective solutions for forest management decisions, and in the end, the rationality and strengths and weaknesses of the model are analyzed and the future is prospected.

Keywords: Global warming; OSM model; EWM; Goal planning model.

1. Introduction

1.1. Background

In 2004, the 20th Century Fox made a movie - "The Day After Tomorrow", which mainly tells the story of the global climate change caused by the greenhouse effect. The film makes people think about environmental protection and sustainable development. In recent years, an increasing number of countries have begun to pay attention to the priority of greenhouse gases reduction. According to the issue paper, carbon sequestration is an efficient process to reduce the amount of greenhouse gases. CCS is viewed as a technology that can significantly reduce greenhouse gas emissions from the use of a large number of fossil fuels, and has received support from developed countries such as the United States and Germany [1]. Therefore, it is particularly significant to consider the establishment of a carbon sequestration model and a decision model, which can make suggestions for many countries to figure out an efficient way to manage their forests.

1.2. Job Overview

First, we propose the OSM model based on the theory of market economics. In light of the overall OSM framework, we have developed a new forest management plan that could optimize the current plan by screening and reordering. Then, the model is applied to global forest and regional forest management recommendations.

2. Model building and solving

2.1. Establishment of carbon sequestration models

2.1.1. OSM model

Based on market economics, we construct a goal-strategy-measure model, called the OSM model, to determine the Forest management plan. The OSM model answers two important questions, "how much carbon sequestered by the system in a specific time period and how to develop a forest management plan". (Object) obtains the calculation formula of carbon storage, and S (strategy) defines three schemes of ecological benefit, economic benefit, and social benefit. At the same time, carbon sequestration reflects changes in forest biological conditions and the environment itself over a period of time, including the status quo of the natural environment and the quality of human life. Finally, we formulate a finer evaluation index, which corresponds to the M (measure) in the model, where M refers to how society and people act to prevent and prevent disasters.

2.1.2. The model of carbon storage

We use the difference in carbon storage of forests and forest products at different times as the carbon sequestration in a certain period of time. According to the carbon storage calculation method proposed in the literature, we took into account the two indicators of light energy use and land cover, and carried out the carbon storage calculation according to the XX forest-related data on the World Bank. The principle of OSM model is shown in Fig. 1[2].

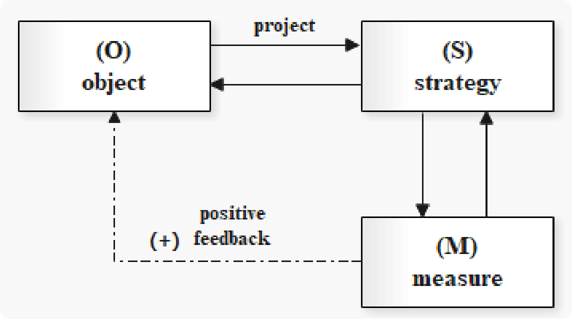

Fig 1. The principle of OSM model.

a) Aboveground carbon storage based on light energy utilization

According to forestry, the carbon sequestration of forests depends on two processes of carbon input and carbon output. Here we introduce NPP (Net Primary Productivity). We fully consider environmental conditions and vegetation characteristics, and classify relevant factors into three types of input variables: remote sensing, plants variables, environment variables.

Then, we introduce APAR to represent photosynthetically active radiation, URL to represent light energy conversion rate, FPAR to represent photosynthetically active radiation absorption coefficient, depending on the vegetation type, and SOL to represent total solar radiation. According to the mathematical relationship of each factor in the model, NPP was calculated, and then the carbon storage amount of the above-ground forest system over a period of time was deduced [3]. : We assign spatial characteristics to each factor in the model, and list the following equations according to the relationship between the factors.

$$APAR(t) = SOL(t) \times FPAR(t) \times 0.5 \tag{1}$$

$$NPP(t) = AR(t) \times url(t) \tag{2}$$

Based on the above formula, we find the NPP of the mid-latitude region within a certain period of time, which is the $M_1(t)$, to explore other ways of carbon storage in the biosphere, we introduce the carbon storage $M_2(t)$ of the underground planted forest system, which represents the carbon storage of the living roots of above-ground plants. Considering the carbon sequestration capacity of the non-plant parts in the forest system, we respectively introduce the carbon storage $M_3(t)$ of the organic component of soil and the carbon storage $M_4(t)$ of the dead organic [4].

2.1.3. The solution of carbon sequestration

Based on the above classification of carbon storage in terrestrial ecosystems, we first define the priority factor, and each part of the carbon storage in the forest system corresponds to the priority factor α_i, $\alpha_1 > \alpha_2 > \alpha_3 > \alpha_4$. It is assumed that the priority factor has a normal distribution with time, which may be empirically confirmed later. According to the definition in ecology, we deduce the formula for calculating the carbon dioxide sequestration amount C (t) in a certain period of time.

$$C(t)=\sum_{i=1}^{4}\alpha_i\left[M_i(t+1)-M_i(t)\right] \tag{3}$$

In order to simplify the calculation, when we take the maximum value of, we can obtain that the daily maximum carbon sequestration in the mid-latitude zone studied in this paper is 146.78 Mg/hA.

2.1.4. Management system based on maximum carbon sequestration

a) The system of main indicators

According to ecological literature, the main impact indicators of forest management plan are concentrated in sustainablity (S), efficiency (E), variability (V), and benefit (B), and 17 times corresponding to these four impact indicators are divided level impact indicators, as shown in Fig. 2[5].

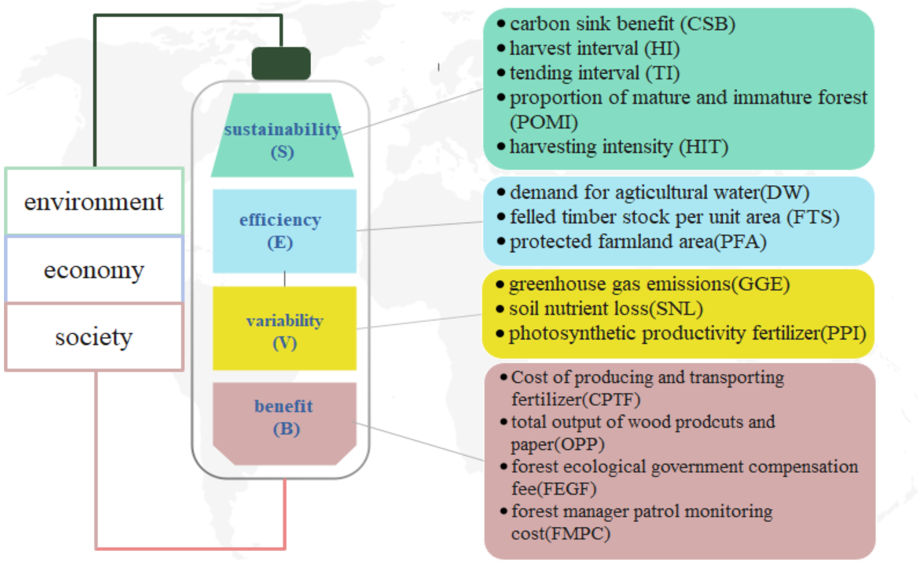

Fig 2. Framework of indicators.

Then, we use the entropy weight method EWM to calculate the weight corresponding to each sub-indicator. The steps are as follows:

1. Carry out dimensionless unfied precessing due to the different measurement units of each indicators. The formulas of positive indicators and negative indicators are respectively shown as below:

$$x_{ij}' = \frac{x_{ij} - {}_{\min}\left\{x_{1j},\ldots,x_{nj}\right\}}{\max\left\{x_{1j},\ldots,x_{nj}\right\} - {}_{\min}\left\{x_{1j},\ldots,x_{nj}\right\}} \tag{4}$$

$$x_{ij}' = \frac{\max\left\{x_{1j},\ldots,x_{nj}\right\} - x_{ij}}{\max\left\{x_{1j},\ldots,x_{nj}\right\} - \min\left\{x_{1j},\ldots,x_{nj}\right\}} \tag{5}$$

2. Calculate the prabability matrix p_{ij} and entrophy of indicators.

$$e_j = -\ln(n)\sum_{j=1}^{n} p_{ij}\ln p_{ij} \tag{6}$$

3. Based on calculate the weight of each evaluation indicator ω_{ij} we defined before.

$$\omega_j = \frac{1-e_j}{k-\sum_j e_j} \tag{7}$$

We obtained the weights of each evaluation index, and the results are shown in the following Fig.3.

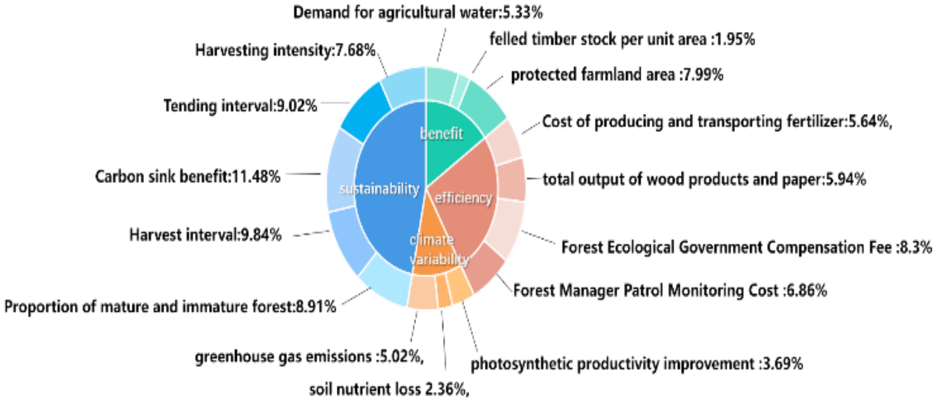

Fig 3. Framework of Basic System Model.

2.1.5. Framework of Basic System Model

We take the six indicators with the largest weights as the basis for formulating the plan. Here unhealthy, normal and healthy are introduced as evaluation criteria. Then we combine the OSM model to divide the evaluation scope of each indicator, and compare

In Fig. 4, the yellow dotted line represents the boundary between normal and healthy. According to the blue area of Fig. 5, the effect of the best management plan can be quantified. Based on this, we make some suggestions for the plan:

- Relevant departments need to give top priority to carbon sequestration and emission reduction, and pass legislation to limit the level of carbon emissions in the region.
- The government should tap the economic benefits brought by forest resources, and pay special attention to the benefits of carbon sinks, that is, focus on the development of forest tourism resources.
- Relevant organizations spread the knowledge of forest protection to the public through social media, television and radio, thereby raising the awareness of environmental protection in the community.

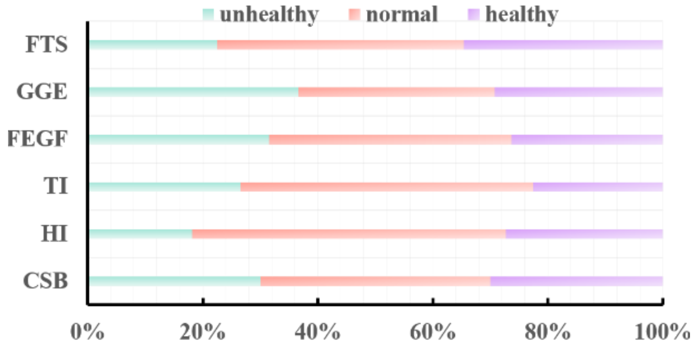

Fig 4. Evaluation standard of indicators.

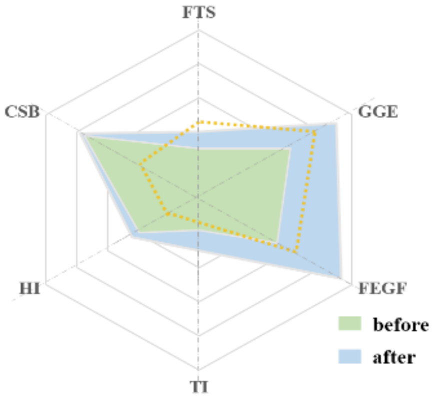

Fig 5. The score of indicators.

2.2. A Controllable Decision Model for Forest Management

2.2.1. Change priority goals

We develop forest management plans that are most conducive to carbon sequestration based on the weights of sub-indicators. However, in practical problems, we need to weigh the pros and cons and formulate a plan to maximize the benefits of society [6]. Therefore, we use the method of target programming to build a forest management system that can flexibly adjust target priorities. Inspired by operations research, we still introduce the priority factor P. If there are n priority factors, they should be satisfied, indicating the level of priority between the two. Furthermore, we add positive and negative bias (d^+, d^-) variables to the objective programming model. We build a target programming model:

$$\min z = P_1 d_1^+ + P_2 d_2^- + P_3 d_2^- + P4\left(d_3^+ + d_3^-\right) \tag{8}$$

Under constraints, simultaneously limiting (d^+, d^-) means reaching the target value. Our objective function minimizes the weighted sum of all positive and negative biases and constrains inferior indicators. Get a score for the best management plan for each inferior indicator in TABLE 1

Table 1. Optimized solution of inferior indicators.

indicators	(HI)x12	(TI)x13	(POMI)x14	(DW)x21
optimized solution	541.3	1269.8	817.3	78.2
indicators	(FTS)x22	(GGE)x31	(SNL)x32	
optimize solution	95.3	1.89	1.77	

2.2.2. Find the Best Forest Management Plan

Inspired by the Gini coefficient and environmental economics, we derive the Forest management level index FMLI. If the value of FMLI in the model is larger, it means that the corresponding priority forest management plan should be adopted. n˜i represents normalization of negative indicators. As a comprehensive evaluation method for optimizing the system, the formula is written as follows.

$$FMLI = 100\left(\pm\sum_{i=1}^{n}\omega_i \tilde{n}_i + 4L\right) \tag{9}$$

$$\tilde{n}_i = \frac{x_j - x_{j\min}}{x_{j\max} - x_{j\min}}, 1 \le i \le n \tag{10}$$

Finally, we draw a hierarchy chart to show the pros and cons of the management plan. According to the distribution of the 24 FMLI values in the rank graph, we can determine that the sequence from high to low is: sustainability, benefit, variability, efficiency and FMLI is equal to 65.7. The hierarchy diagram of the management plan is shown below.

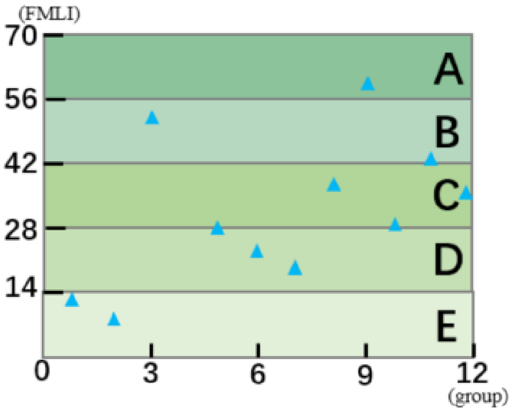

Fig 6. Evaluation standard of indicators.

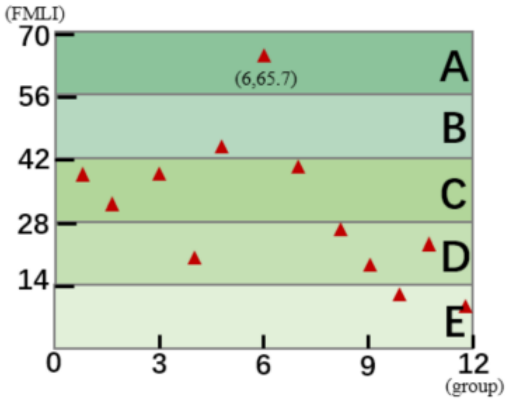

Fig 7. The score of indicators.

There are 4 options for an optimal forest management plan, with both sustainability (S) and benefit (B) included in the top two priority rankings. Among them, the inferior indicators with greater weight of sustainability includes harvesting intensity, and the larger-weight index of benefit includes carbon accumulation per unit area of harvested wood, all of which are directly related to deforestation. Therefore, we are fully confident that the proposed trade-off forest management scheme does not have conditions that will lead to forests not being deforested.

3. Forest management planning

3.1. Model modification

In the previous paper, based on the developed target planning model with priority factors, we develop the most socially beneficial forest management plan. In this paper, we classify forest systems into national forest systems, state forest systems, and urban forest systems [7]. So the forest areas studied in section 3 are classified as state forest systems. So, it is necessary to adjust the model, including the modification of the model index system and constraints, in order to find the transition points between different forest management plans. If the decision model is used for large scale areas, we need to optimize the superior indicators of the forest management. Similarly, if the model is used for small-scale areas, we need to remove some of the inferior indicators of the above model. A schematic representation of the constraint changes is shown in Fig. 8.

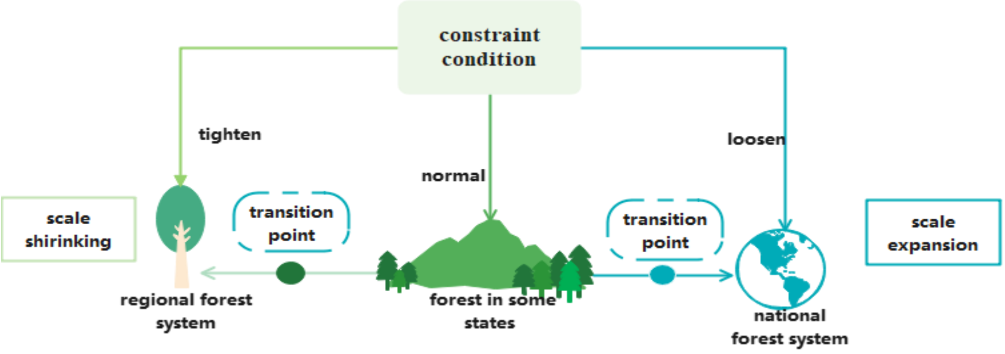

Fig 8. Scalability analysis of management plan.

3.2. Transition points of global forest system

If we only change the priority of the optimal forest management plan, it will be difficult to find the transition point between the plans [8]. Because it involves many aspects of impact indicators at all levels, for example, climate variability (V) is determined by 3 impact indicators and these indicators have a very small impact on the target value. In order to optimize the model, we consider two main factors in the ecological forest management plan: environmental and economic. Environmental (EN) contains sustainability (S) and climate variability (V), economic (EC) contains and efficiency (E), and society (SO) contains benefit (B). Therefore, the world forest level indicator (WFLI) is listed.

$$WFLI = \mu_1 EN + \mu_2 EC + \mu_3 SO \tag{11}$$

Where μ_i are the coefficients of the variable in the formula.

3.2.1. Introduction of new indicators

1. Environment (EN) to simplify calculations, we narrowly understand environmental indicators in national forest systems to include only the extent of forest destruction, greenhouse gas emissions, and forest age structure classification. Then we select a few sustainability-related indicators to construct the environmental score formula. The indicators we selected include harvest intensity (HI), proportion of mature to immature stands (POMI), tending interval (TI), greenhouse gas emissions

(GGE), and carbon sink benefits (CSB). The EN can be calculated by weighting and summing the indicators.

$$EN = \gamma_1 HI + \gamma_2 POMI + \gamma_3 TF + \gamma_4 GGE + \gamma_3 CSB \tag{12}$$

Where λ_i are the coefficients of the variable in the formula.

2. Economy (EC) in forest management plans, management costs are an important factor affecting economic indices. Countries with good transportation and manufacturing industries tend to have lower carbon sequestration costs because transporting fertilizer and forest products is more readily available and forest management has less difficulty completing forest patrols [9]. Therefore, the role of the government cannot be ignored. So, We selected the cost of producing and transporting fertilizer (CPTF), total output of wood products and paper (OPP), forest ecological government compensation fee (FEGF), forest manager patrol monitoring cost (FMPC). And we constructed the following formula to calculate the economic index.

$$EC = \theta_1 DW + \theta_2 FTS + \theta_3 PFA \tag{13}$$

3. Society (SO) the social factor, as the fundamental aspect of the forest management plan, involves the accrual of costs at various points in the entire process of carbon sequestration. So, we selected the carbon sink benefit (CSB), harvest interval (HI), tending interval (TI), proportion of mature and immature forest (POMI), harvesting intensity (HIT). Establish the formula for obtaining the social index.

$$SO = \eta_1 CPTF + \eta_2 FMPC \tag{14}$$

Where η_i are the coefficients of the variable in the formula.

We constructed formulas for finding inter-country forest managements based on the two indices mentioned above: W F L I=∂_1 E N+∂_2 E C where ∂_i are the coefficients of the variable in the formula

The *W F LI* cannot only clearly characterize the transition points of each management plan, but it can also be used to assess the quality of a country's forest management plan. We convert *W F IL* to a value between 1 and 50, with higher values indicating that the country's forest management plan is more effective.

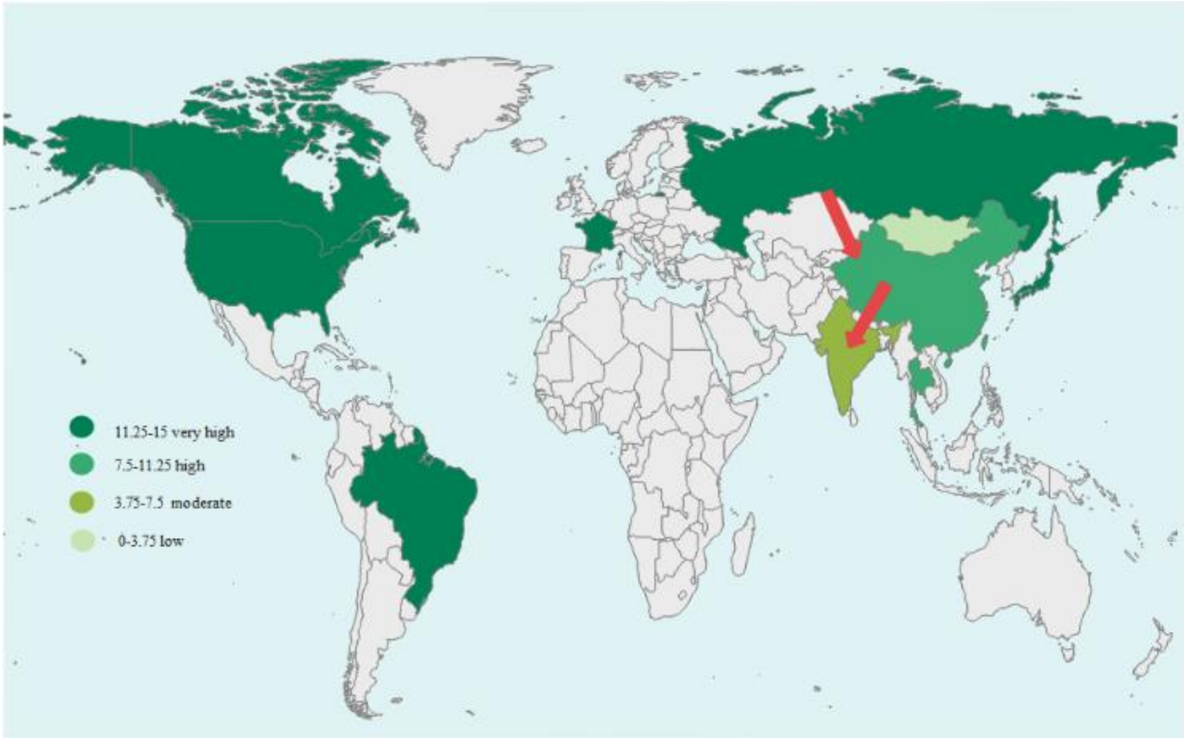

Fig 9. The distribution of W F LI in the world map.

In Fig. 9, we set the country with the highest W *F IL* level to dark green. The lower the level the lighter the primary color, and the color difference between adjacent levels indicates the appearance of transition points in the management plan.

3.3. Transition points of regional forest system

We discuss the extent of regional forests and divide mature and immature forests spatially. Then, we introduce W F LI as a division estimation index for analysis. There is an exponential tipping point between each two types of forest management plans, which is the transition point of the forest area.

From the 4 indicators, we screened out the highest priority sustainability and efficiency, and then selected the tending interval (TI), harvesting interval (HI), and harvesting intensity (HIT) as strategic indicators.

Here, we assign the same weight to sustainability and efficiency, and then use the entropy weight method formula above again to show the weights of the 7 sub-indicators [10].

Table 2. The weight of each indicator.

Optimizations	weight	indicators	targets
sustainability	50%	CSB	+21.3%
		HTP	+18.9%
		HI	+3.3%
		TI	-5.5%
efficiency	50%	GHS	+26.2%
		FMPC	-17.3%

In column 4 of the above TABLE 2, we can see the change in the weight of each indicator in the national forest system and the state forest system. Based on the rotation period and carbon sink costs in different carbon sequestration patterns, we introduce P_{CSB} to represent the net present value of carbon sink benefits. P_{htp} is the net present value of the timber harvest interval. This leads to the derivation of MFLI denoting the time division estimation index formula.

- The weight of greenhouse gas emissions has increased by 26%, indicating that forest management plans at the national level are more profoundly influenced by them.
- Forest manager patrol detection costs decreased by nearly 17%, indicating that for the National Forest System, transportation costs vary widely across geographic areas of the country due to differences in transportation mode and patrol area.
- The two sub-indicators of carbon sink benefits (CSB) harvest interval (HTP) have the most fluctuating weights of 21.3.

$$MFLI = \frac{(P_{CSB} + P_{HTP})Q(T)(1+0.03)^{-T} - C}{1-(1+0.03)^{-T}} + P_{CSB} \tag{15}$$

(Where C is the correction factor, according to linear interpolation we take $C = 3.9$) By dividing the spatial indices of mature and immature forests. Spatial index division of mature and immature forests to make a fitted curve of MFLI with time.

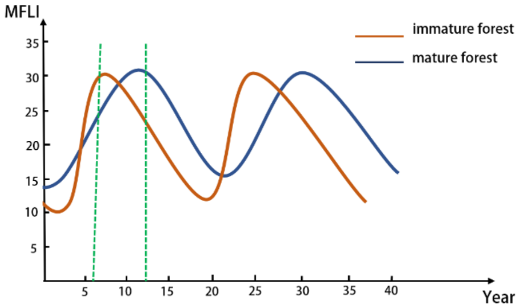

Fig 10. Fitted curve of mature and immature forsts.

In Fig. 10, we found that the total benefit of MFLI was best for mature and immature forests at 6.3 to 12.3 years.

4. Conclusion

The carbon sequestration model of this model is based on both light and use and soil cover perspectives and introduces a time-space factor. Real-life problems are often considered at only one level of resolution, allowing for greater precision in carbon sequestration estimates.

Goal planning in forest decision-making allows for flexible prioritization. The model has a priority factor that supports optimization of multiple forest management objectives, so forest managers can decide which management objective priority to use to develop the best management plan.

FMI equivalents can provide a direct reference for the development of forest management plans. Because the FMI value indicates which forest management plan has the highest priority, the forest manager can select the priority with the highest FMI value to achieve a specific strategy for the forest management plan indicator.

However, subjectivity and limitations in the selection process of forest management indicators. There is not enough literature, which is inevitable.

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