Research on forest management based on carbon sequestration and forest-human strategy model

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Abstract. According to the FAO, we can see that the world's forests are large and growing. However, forest system also faces some problems. Challenged by ICM, we decided to build a model to balance carbon sequestration, forest products, biodiversity aspects, recreational uses, and cultural considerations, making improvements to existing forest management systems. Develop an optimal carbon sequestration model, and calculate how much CO2 the forest and its products can absorb. Identify a forest management plan that needs to be the most beneficial to society and to balance the various uses of the forest. We also write the specturm of the management plan, calculate the conditions under which the forest will not be deforested, and determine the transition points in the management plan.

Keywords: Forest, Forest management, Carbon sequestration.

1. Introduction

1.1 Background

Nowadays, the global forest management system still faces some problems. Our current practices are not perfect enough to promote the power of forests, as evidenced by the fact that the utility of the forest is not being maximized. The models we have developed take a variety of factors into account to optimize the dual role of forests for ecology and society, and we hope that the solutions we propose will solve some of these problems.

We developed a Tree evaluation system and a Carbon sequestration model. The evaluation system has three indicators, namely the amount of carbon sequestration of trees and the lifespan of their forest products. the adaptability of trees to the environment, and the benefits of forest products, in order to determine which part of the forest can be cut and which part should be retained. The carbon sequestration model contains the carbon sequestration of forest products and the carbon sequestration of living trees

We developed the Forest-Human Strategy Model. The model comprehensively considers five factors, including carbon sequestration, biodiversity, recreational uses, cultural considerations, and potential carbon sequestration. To determine the transition points for the management adapted to different forests, we divided the globe into roughly four vegetation types and selected a representative country for each, and compared the same indicators for each region to obtain three sets of transition points for the globe.

1.2 Work overview

In this paper, first, we developed a Carbon Sequestration Model. This model can derive the most effective forest management plan in terms of sequestering CO_2 by finding the balance between the forest and its products. We chose the Greater Khingan Range Forest as the subject of our study and obtained its forest management plan. Besides, the best forest management plan should not only consider the amount of carbon sequestration. We have developed a Forest-Human Strategy model, and by substituting data on five indicators from different regions, we can derive the forest management plan that is most beneficial to the whole society. The five indicators are carbon sequestration, biodiversity, recreational uses, cultural considerations, and potential carbon sequestration.

2. Carbon Sequestration Establishment and Solving

2.1 Selection of indicators

Based on some data on the website and the information given in the paper[1], we built a carbon sequestration model containing several indicators, determined the weights of different indicators by using AHP(Analytic Hierarchy Process), and then substituted the relevant data, we can calculate the management plan that is most conducive to carbon sequestration in a certain forest. The aim is to find out how many and what species of trees should be cut, and to derive the approximate amount of carbon sequestration over time. For convenience, our carbon sequestration model has three indicators: the amount of carbon sequestered by different trees and the longevity its forest products, the adaptability of the tree species to the local geography, and the benefits of the forest products[2].

2.1.1 Carbon sequestration by different trees and the survival of their forest products

According to our survey, the carbon sequestration of different trees varies considerably, and they have a wide range of its forest products. We derived the results by comparing the importance of the carbon sequestration of the tree itself and whether the longevity of its forest products are greater than the life span of the tree. Two secondary indicators are included in this condition: the amount of carbon sequestered by the tree and whether the survival of the forest product is greater than the life span of the tree.

2.1.2 Adaptation of tree species

There are many kinds of geographic environments on earth, and each tree species has a different ability to adapt to different geographic conditions. For tree species with a strong ability to adapt to local geography, the amount of cutting can be reserved, and conversely, tree species with a weak ability to adapt to local geography can be cut more to produce forest products[3]. This indicator is governed by two conditions: the ability to adapt to the terrain and the ability to adapt to the climate.

2.1.3 Benefits of forest products

Different tree species are suitable for the production of different forest products. The economic return of forest products and the human demand for it are the most influential factors on this indicator.

2.2 Allocation of weights

We used the Analytic Hierarchy Process for expert scoring and determined the judgment matrices of three secondary and six tertiary indicators, which are Figure 1 and Figure 1[4].

Second grade indexes	LCSB	ACGC	BFP
Weight	0.6370	0.1047	0.2583

Figure 1 weight 1(second grade indexes)

Third grade indexes	ACFT	LFPMTT
Weight	0.2500	0.7500
Third grade indexes	FDT	FDC
Weight	0.1667	0.8333
Third grade indexes	EB	RFP
Weight	0.1667	0.8333

Figure 2 weight 2（third grade indexes）

We calculated the weights of each factor in each layer, and finally the combined weights of the 6 factors. Combined weights is shown in Figure 3.

Third grade indexes	ACFT	LFPMTT	FDT	FDC	EB	RFP
Weight	0.1592	0.4777	0.0175	0.0873	0.0430	0.2152

Figure 3 Combined weights

2.3 Our Forecast

Located in the northeastern part of China, Greater Khingan Range forest is the bestpreserved and largest primary forest in China. We developed a forest management plan using the Greater Khingan Range forest as an example. According to the data in the literature[5], there are five main species of trees in the Greater Khingan Range forest, namely Larches, Asens, Birches, Mongolian Oaks, and Pinus sylvestris. After we derived the weights of each index by AHP, we applied the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) to get the priority of trees to be cut down, the higher the score, the higher the priority to be cut down. Ranking of 5 kinds of trees is shown in Figure 4.

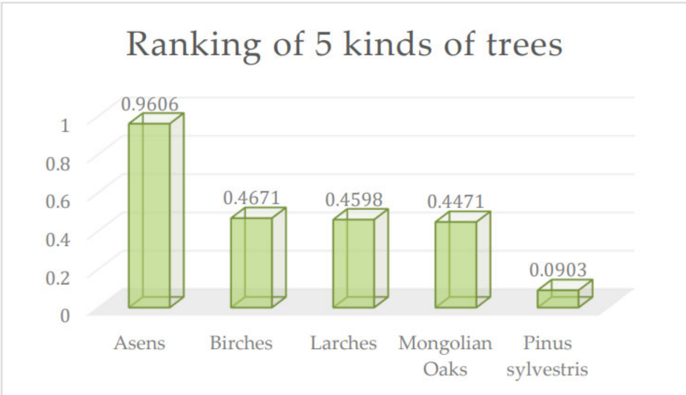


Figure 4 Ranking of 5 kinds of trees (Greater Khingan Range Forest)

It is not difficult to understand the reason for this result, Asens is one of the main raw materials of wood, Birches plays a very big role in making medicine and furniture, and these trees are relatively small amount of carbon sequestration, so these two trees should be cut down as a priority. Pinus sylvestris and Mongolian oaks should continue to retain, mainly because of the high carbon sequestration of Pinus sylvestris, Mongolian oaks is a strong environmental adaptation, and is an excellent species to create fire forests, in 1987 there was a huge forest fire in the Greater Khingan Range forest, resulting in huge losses, we believe that the protection of fire species is also an important factor in forest management. Through the analysis, we derived the carbon uptake of the Greater Khingan Range Forest and its products at different times[6].

According to our research, different kinds of trees have different carbon sequestration ratio, we assume it as a_{1i}, and trees' carbon sequestration per year as x_{1i}, and make a calculation to the amount of carbon sequestration for all the trees. Different trees have different uses, so we calculate each percentage of the annual output a_{2j} of forest products based on the different purposes of felled trees., suppose the annual output is a_{3j} , and annual fixed carbon content of forest product x_{2j} ,then we make a calculation about annual fixed carbon content of all forest products.

$$\sum_{j=1}^{5} a_{2j} a_{3j} x_{2j} \tag{1}$$

Here is the formula.

$$W = \sum_{i=1}^{5} a_{1i} x_{1i} + \sum_{j=1}^{5} a_{2j} a_{3j} x_{2j} \tag{2}$$

In this formula, W refers to whole fixed carbon content, and the unit is ten million ton.

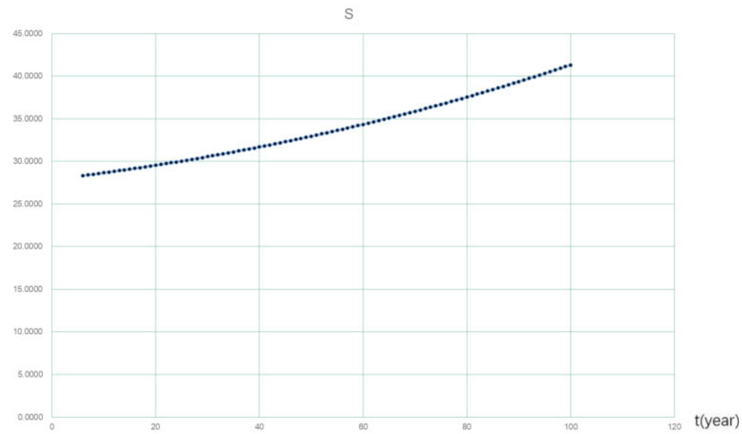


Figure 5 Average annual carbon sequestration (Greater Khingan Range forest)

After this step, we make an accumulation of S, and the formula is.

$$C_n = \sum_{i=1}^{n} \mathbf{S}_i \tag{3}$$

the range of i is $1 \le i \le 100$, then we will have a scatter diagram with the independent variable is x and the dependent variable is C.

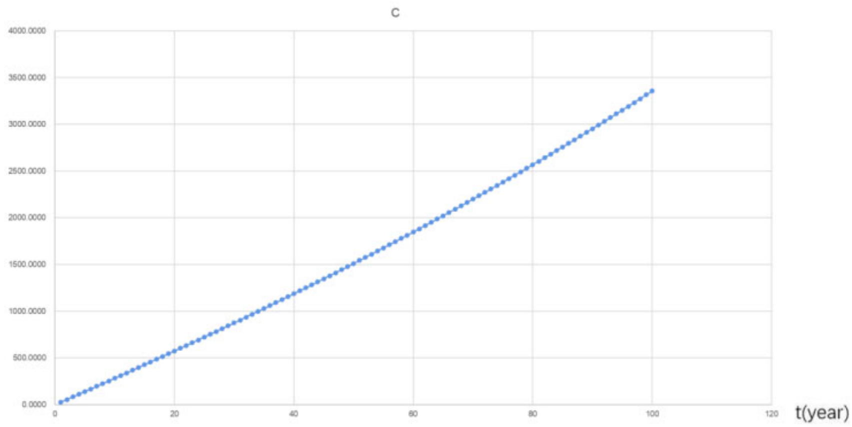


Figure 6 Total amount of solid carbon (Greater Khingan Range forest)

3. Forest-Human Strategy Modeling and Analysis

3.1 The spectrum of Management plans and its percentage

We have developed a Forest-Human strategy model. This model takes into account a variety of factors, and it has five management spectrums (indicators of the model): carbon sequestration, biodiversity, recreational uses, cultural considerations, and potential carbon sequestration.

3.1.1 Model building

We have used MOP(multi-objective programming) to build out our forest management model, using Chinese data as a reference[7]. Denoting F as the total forest area, f_i as the area required for each indicator layer, Y_i as the objective function of each indicator with as the f_i variable, yields $Z_i = f_i / F$, the percentage of each indicator. R_j represents the revenue of the forest recreation function, C_j represents the cost of the forest recreation function, Tn represents the TOPSIS composite evaluation score of the cultural function for each year, P_1 represents the soil fraction of potential carbon sequestration, and P_2 represents the water fraction of potential carbon sequestration. $C15$ is the total carbon sequestration for 15 years from the carbon sequestration model. The constraint is.

$$\text{s.t.}\begin{cases} 1 = \sum_{i=1}^{5} z_i \\ 0 < z_i < 1 \\ f_i > 0 \end{cases} \tag{4}$$

The objective function is.

$$\max\begin{cases} Y_1 = \sum_{j=1}^{n}\left(S_j - C_j\right)f_i / 15 \\ Y_2 = I^n_{\text{Biodiversity}} \\ Y_3 = \frac{1}{15} f_3 \sum_{j=1}^{n} T_n \\ Y_4 = \frac{1}{15} f_4\left(P_1 + P_2\right) \\ Y_5 = C_{15} \end{cases} \tag{5}$$

3.1.2 Our results

The results are shown in Figure 7.

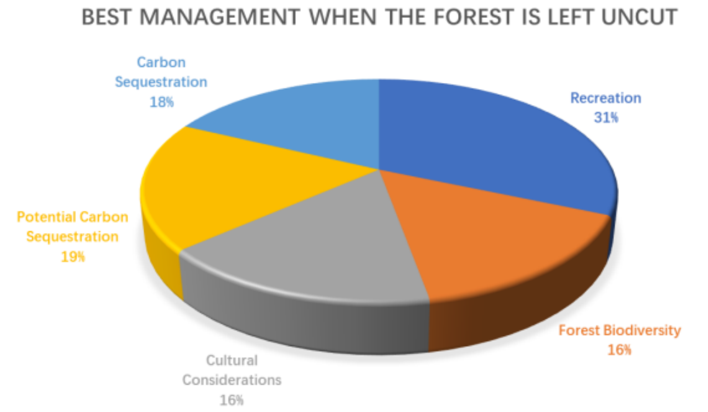
Recreation	Forest Biodiversity	Cultural Considerations	Potential Carbon Sequestration	Carbon Sequestration
0.31374	0.156097	0.162448	0.186355	0.181359

Figure 7 best management(China)

The results show that the percentages of recreation, potential carbon sequestration, carbon sequestration, cultural considerations, and biodiversity are in descending order. It can be seen that the recreational role is an important consideration in China's forest management, and the recreational role brings continuous monetary benefits to the forest management sector and drives the development of related industries; the potential carbon sequestration should not be underestimated, as forest soil and water are important components of the global carbon cycle and dominate the global carbon balance. According to statistics, soil carbon content in forest ecosystems accounts for about 73% of global soil carbon sequestration [8], which is not only the largest carbon pool in terrestrial ecosystems, but also the most important carbon pool in the global carbon cycle. Therefore, the potential carbon sequestration is perhaps an important direction for global carbon sink research.

3.2 Conditions under which forests are not deforested

We need to calculate the conditions under which the forest is not deforested, that is, the conditions under which all trees are allowed to grow freely when forest products are not needed[9]. According to the carbon sequestration model we built, the weight of forest product-related index is reduced to 0, and then the values are substituted into the forest-human strategy model for calculation, and the results are obtained in Figure 8.



Recreation	Forest Biodiversity	Cultural Considerations	Potential Carbon Sequestration	Carbon Sequestration
0.314946	0.156697	0.163072	0.187071	0.178214

Figure 8 Percentage of best management(when the forest is left uncut)

When the percentages needed for carbon sequestration, biodiversity, recreation, cultural considerations, and potential carbon sequestration are 18%,16%,31%,16%,19% , the forest can be left untouched.

3.3 Selection of transition points

According to the consist of the vegetational form, we divide the vegetational form in to four parts roughly. They are: Tropical Rainforest, Subtropical Evergreen Broad-leaved Forest/Subtropical Evergreen Hardwood Forest, Temperate Mixed Forest/Temperate Deciduous Broad/leaved Forest, Subboreal Coniferous Forest. They are mentioned in the following picture by four different colors. We select four countries in different geographic position as the symbol of vegetational form. They are:

◇Red : Tropical Rainforest

◇Orange : Subtropical Evergreen Broad-leaved Forest / Subtropical Evergreen Hardwood Forest

◇Yellow :Temperate Mixed Forest / Temperate Deciduous Broad-leaved Forest

◇Blue : Subboreal Coniferous Forest

◇Area A : Brazil

◇Area B : China

◇Area C : Ukraine

◇Area D : Russia

Using the established forest management model, we created percentage stacked bar charts using normalized data based on data from different regions, which yielded different areas of focus on forest benefits. The same data from each region were compared to find the middle value of each group of data, and the middle values of the same data from different regions were connected to obtain five sets of folds. We made three horizontal lines in the graph by analogy with the method of calculating the mean value, and the three sets of data intersecting these three horizontal lines and the five fold lines are the three transition point evaluation indicators[10]. Transiton points is shown in Figure 9.

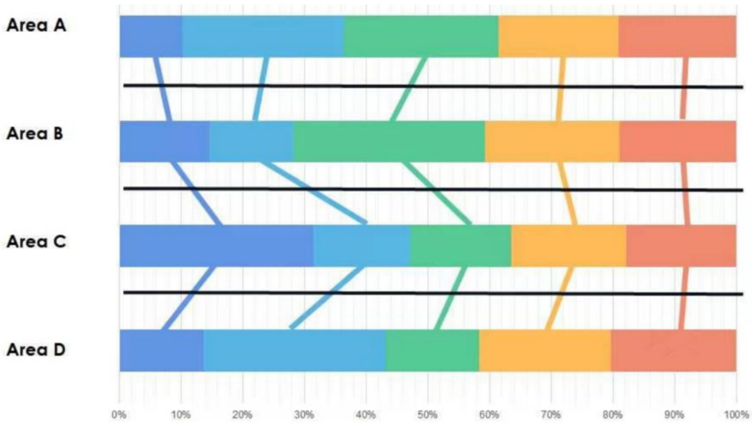


Figure 9 Transiton points

4. Sensitivity Analysis

We use the following Formula.

$$S = (1+0.006)^{t-1}\sum_{i=1}^{5} a_{1i}x_{1i} + (1-0.008)^{t-1}\sum_{j=1}^{5} a_{2j}a_{3j}x_{2j} \tag{6}$$

In our research, we choose 1.006 and 0.992 to be the coefficient. Now we change this coefficient into 1.006±0.0006 and 0.992±0.004 by a ratio of 1 : 2 . It can be seen that the error ratio is less than 6%, that means this model has passed the sensitivity analysis. We divide in to two comparable groups,1 to 5 is a group and 6 -10 is another group. Sensitivity analysis is shown in Figure 10.

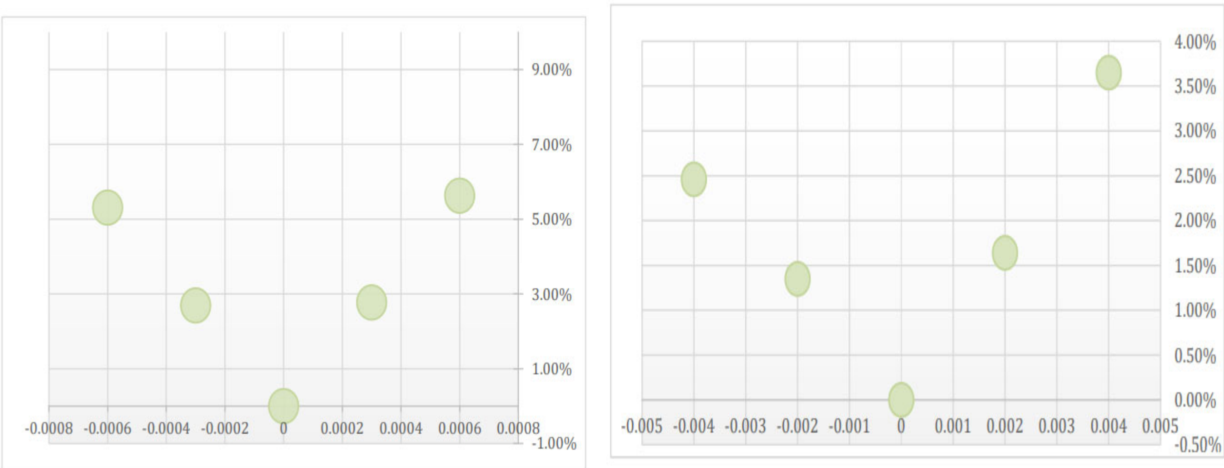


Figure 10 Sensitivity analysis

5. Conclusion

In this paper, the quantitative evaluation of each indicator uses different evaluation methods and corresponding models, for example, recreation construction uses the classical economic benefit calculation formula to consider the economy of forest tourism, cultural construction uses the TOPSIS method for quantitative scoring, and biodiversity uses a novel biodiversity index model for calculation, and includes the impact of forest fires in the biodiversity index model, which has novel features. The management scope of the forest management model involves carbon sequestration, biodiversity conservation, recreation building, cultural building, and potential carbon sequestration, taking into account the composition, climate, population, interests, and values of forests in different regions, and providing a comprehensive consideration of forest management decisions. Besides, for forests in different regions, the corresponding data can be collected and substituted into the model for calculations to obtain unique and applicable results.

However, the evaluation of trees in a certain forest is not comprehensive enough as only its main tree species are selected instead of all tree species. Only one representative country was selected for each region for calculation, and there is error in replacing one point with another.

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