Advances in Computer, Signals and Systems (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2023.070509
ISSN 2371-8838 Vol. 7 Num. 5

Decision Modelling and Analysis of Carbon Sequestration for Forest Management

Xuehong Du*

Department of Computer Science and Technology, Northeastern University, Shenyang, 110819, China

**Corresponding author*

Keywords: Forest management, carbon sequestration, factor analysis, GM (1,1) model

Abstract: Forest carbon sequestration is an effective way to tackle the serious climate change and reach the goal of carbon peaking and carbon neutrality. Now, there have been four major forest regions in China used as the research objects of carbon sequestration, which cover three research aspects: vegetation area, tree species, and tree age. In this study, we establish a mathematical model of annual carbon sequestration benefits. Then we analyze the situation of deforestation in ten countries including China by dividing the forest value into socio-economic benefits and ecological benefits. Factor analysis is used to select three main influencing factors including national ecological protection value, economic benefits, and types of trees harvested in order to make a comprehensive analysis. After that, the relationship between forest benefits and deforestation are deduced through fitting and a comprehensive evaluation index system is established for balancing the forest value. Then a GM (1,1) model is used to estimate the amount of carbon sequestration by China's forests and obtained an average increase of 2.8 billion tons over five years. The results are 90% accurate when compared with the eighth carbon stock of forest resources in China officially published by the National Forestry and Grassland Bureau. In addition, by comparing different forest management strategies, it is found that reasonable harvesting can bring higher economic benefits. The results of this study can provide a theoretical basis for optimizing forest management strategies.

1. Introduction

Climate change presents a massive threat to our life and the most significant phenomenon in climate change is the global warming. The release of carbon dioxide and other greenhouse gases is the main cause of the greenhouse effect. In 2015, the Paris Agreement proposed to limit global average temperature rise to less than 2℃ by 2080 [1]. This requires not only scientific methods to improve energy efficiency and reduce CO_2 emissions, but also practical solutions for carbon sequestration.

To mitigate the effects of climate change, we need to take drastic action such as reducing greenhouse gas emissions and enhancing our stocks of carbon. Forests sequester carbon dioxide in living plants and in the products created from their trees including furniture, paper and other wood products[2]. At the global level, the forest management strategies include appropriate harvesting can be beneficial for carbon sequestration. However, overharvesting can limit carbon sequestration[3]. Forest managers must find a balance between the value of forest products derived from harvesting and the value of allowing the forest to continue growing and sequestering carbon as living trees. Besides, the concerns of forest managers are not limited to carbon sequestration and forest products. They must make forest management decisions based on the many ways their forest is valued.

This remains controversial among some researchers and the media. Some researchers consider that cutting trees should be reduced to increase carbon storage, while others think that cutting mature trees should be increased appropriately to make forest products to increase carbon storage[4]. The results of an online survey indicated that the second strategy has more supporters [5]. However, due to the neglect of some factors, the existing methods of carbon sequestration estimation are not accurate enough. In this study, the effects of forest product import and consumption are introduced into the forest stock expansion method, so as to provide a more accurate measurement of the total forest carbon sequestration.

2. The Proposed Mathematical Model

2.1. General Assumptions and Justifications

To simplify the problem, the following basic assumptions are properly justified.

The consumption and the carbon sequestration ability of forest resources are determined and can be measured by statistic method. As both of them include countless details which are hard to measure accurately, and the main purpose of our model is to determine a management plan instead of measuring the explicit statistic data.

Each tree species in the forest is cut down in the same way. That is to say, the amount of wood loss is the same when cutting down different trees.

Woody materials such as wood residues, which are burned or oxidized in the year of harvesting, are not included in the woody forest products carbon pool. According to the IPCC guidelines, this assumption is more reasonable in order to avoid double measurement of carbon storage.

The statistical data is valid. It is supposed that the true value of every index locates right nearby the statistic data.

The methods utilized are all scientific and reasonable. Since the various calculation methods used in this paper have been practiced, the real results can be approached to the maximum extent, despite of the existence of certain errors.

The key mathematical notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Description
CF	Forest carbon stock
TB	Tree biomass carbon sequestration
UP	Understory plant carbon sequestration
FC	Forest carbon sequestration
IH	Carbon content of imported HWP
EH	Carbon content of exported HWP
RH	Carbon released of HWP
PW	Carbon content of harvested wood
CSH	Carbon sequestration of HWP

2.2. Carbon Sequestration Model

In the Carbon sequestration Model, we establish a mathematical model of annual carbon sequestration benefits and then the GM(1,1) model is used to predict the amount of carbon sequestration by China's forests over five years.

2.2.1. Carbon Sequestration of Forest Products

Firstly forest products are divided into hardwood products and paper products. Hardwood products include sawn wood, round wood, charcoal, wood pulp, wood board and paper products include pulp and all kinds of paper.

In chapter 12 of volume 4 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 4 HWP carbon accounting methods are proposed. They are IPCC default method, atmospheric flow method, storage change method[6] and production method. According to some studies, the IPCC default method assumes that the carbon stored in HWP is released to the atmosphere at one time. Considering the absorption process, this hypothesis lacks certain scientific rationality. Besides, production method is easy to cause confusion in practical measurement and it is difficult to apply. So most researchers prefer the reserve change method and the atmospheric flow method. However, the atmospheric flow method mainly considers the decay and decomposition of the HWP introduced into the country. So HWP increases the amount of the carbon sink in the importing country but the method does not consider the carbon release caused by the export HWP. What's more, the decay and decomposition not only take a long time, but also has little influence[7], which is not reasonable. Therefore, as is shown in Figure 1,the method of storage change is used to calculate the amount of HWP carbon storage and carbon sink in China, and then calculate the carbon sequestration.

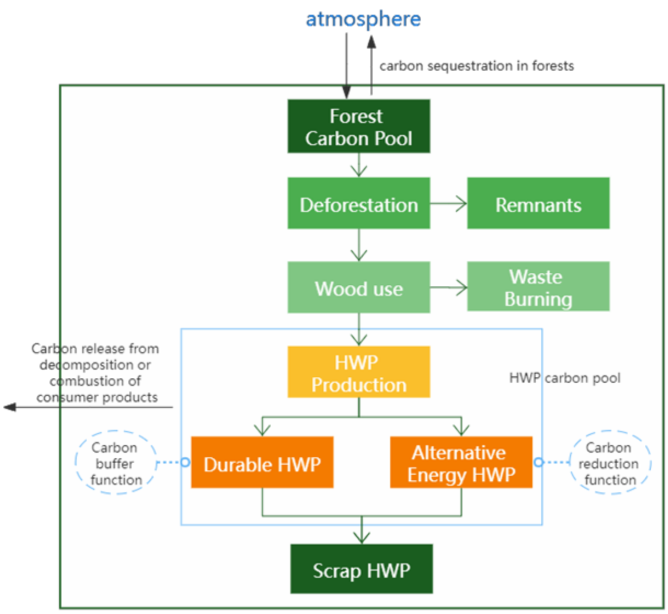

Figure 1: Storage Change Method

First of all, we get the data every five years from 2000 to 2020 in China's imports, exports and production of the forest products' volume (from https://www.fao.org/home/zh)and the charcoal emissions in the certain year(from http://www.stats.gov.cn/). Then the conversion factor is queried between the volume number of forest products and the amount of carbon sequestration in Table 2 as well as the FAO value of different products in Table 3.

Table 2: Carbon Conversion Factors for Harvested Wood Products

	Temperate species	**Tropical species**	**Charcoal**	**Plank mean**	**Pape and related**
Density(D)	0.45tons of drying/m3	0.59tons of drying/m3	0.9tons of drying/m3	0.628tons of drying/m3	0.9tons of drying/m3
Carbon content rate(R)	0.5	0.5	0.85	0.468	0.5
Carbon factor(F)	A=0.225tons C/m3	A=0.295tons C/m3	B=0.765tons C/tons of drying	C=0.294tons C/m3	D=0.45tons C/tons of drying

Table 3: FAO Variables required to analyze changes in consumption HWP carbon stocks

Variable name	**Specific variable**	**Carbon factor**
	Sawmill	A
Hardwood Product Yield(..)	Board	C
	Other industrial logs	A
Import and export volume of hardwood products	Sawmill	A
	Board	C
	Other industrial logs	A
	Paper and Board – Yield	D
Yield of paper or cardboard	Other Pulp Fibers – Yield, Import volume, Export volume	D
Import and export volume of paper and cardboard	Paper and Board	D

China mainly imports temperate logs[8] and for hardwood products[9], the carbon factor is considered as the average of A and C,0.2595. As for the carbon factor of paper products, the first is the conversion of air-dried ton and volume unit. It is found that the density of general paper is 9g/ cubic centimeter, so the volume of one air-dried ton of paper product is about 0.11 cubic meters, and the volume of one cubic meter of paper is about 9.1 air-dried ton. According to the formula:

$$CSH = (PW + IH - EH) - RH \tag{1}$$

The amount of carbon sequestration of forest products is calculated by this formula.

2.2.2. Forest Carbon Sequestration

At present, the methods for measuring carbon sequestration include Biomass method, Accumulation method, Eddy correlation method, Chamber method and so on. Some of these methods belong to the category of pure natural science, and focus on the measurement of microscopic carbon sequestration[10], and the process is relatively cumbersome. From the perspective of social science research, this study takes into account the practicality and operability of the calculation method, and mainly adopts the forest stock expansion method to calculate the carbon storage and carbon sink. Compared with The seventh and eighth carbon storage of forest resources in China as well as the monitoring data of forest carbon storage and carbon sink officially released by the State Forestry and Grass-land Administration, the accuracy rate of the data results of this research method is as high as 90%[11], which has a certain degree of accuracy. Forest carbon sequestration includes tree carbon sequestration, understory plants and humus carbon sequestration, forest soil carbon sequestration, and harvested wood products carbon sequestration. This study added the effects of evolution and consumption of forest products on the basis of the stock volume expansion method, so as to measure the total carbon sequestration of forests more accurately. The improved accumulation volume expansion formula is:

$$CF = TB + UP + FC = \Sigma(S_{ij} \times C_{ij}) + \alpha \cdot \Sigma(S_{ij} \times C_{ij}) + \beta \cdot \Sigma(S_{ij} \times C_{ij}) \tag{2}$$

$$C_{ij} = V_{ij} \times \delta \times \rho \times \gamma \tag{3}$$

where CF is the total carbon storage of the forest; S_{ij} is the area of the j-type forest type in the i-type area; C_{ij} is the biomass carbon density of the j-type forest type in the i-type area; α is the carbon conversion coefficient of understory plants; β is the carbon conversion coefficient of forest land; V_{ij} is the stock volume per unit area of the j-type of forest in the i-type area; δ is the biomass expansion coefficient; ρ is the volume coefficient; γ is the carbon content rate.

According to the default general values of the international IPCC, the biomass expansion coefficient δ =1.9, the understory plant carbon conversion coefficient α =0.195, the forest land carbon conversion coefficient β =1.244, the volume coefficient ρ =0.5, and the carbon content rate γ =0.5.

To sum up, the formula of the total carbon sequestration of forests is

$$Total = CF + CSH = TB + UP + FC + (PW + IH - EH) - RH \tag{4}$$

2.2.3. The Establishment of Prediction Model

Considering the reliability and practicality of the results, we use the GM(1,1) model implemented based on MATLAB software. The GM(1,1) model uses the original discrete data columns to generate new, more regular discrete data columns that weaken randomness by accumulating them once, and then predicts the subsequent development of the original data by modeling the differential equations and obtaining approximate estimates of the solutions at the discrete points generated by accumulating and subtracting the original data.

The time series data of forest carbon sequestration is obtained, and the carbon sequestration of previous years is taken as the original non-negative data column and set to $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), ..., x^{(0)}(n))$ and the original series is cumulated once to obtain the new series $x^{(1)}$:

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), ... x^{(1)}(n)) \tag{5}$$

where $x^{(1)}(m) = \sum_{i=1}^{m} x^{(0)}(i),\ m = 1, 2, ..., n$.

Let $z^{(1)}$ be the immediate mean generation sequence of the sequence of the sequence a ,that is:

$$z^{(1)} = (z^{(1)}(2), z^{(1)}(3), z^{(1)}(4), ..., z^{(1)}(n)) \tag{6}$$

where $z^{(1)}(m) = \delta x^{(1)}(m) + (1-\delta)x^{(1)}(m-1), m = 2, 3, ..., n\ and\ \delta = 0.5$

Then the basic form of the GM(1,1) model:

$$x^{(0)}(k) = -az^{(1)}(k) + b, k = 2, 3, ..., n \tag{7}$$

where a represents the ash action and b represents the development coefficient. The development coefficient represents the development law and trend of the sequence, and the gray action reflects the changing relationship of the sequence.

In order to facilitate the calculation, we introduce two matrices below:

$$T = (a,b)^T, Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}, B_n = \begin{bmatrix} -z^{(1)}(2) \\ -z^{(1)}(3) \\ \cdots \\ -z^{(1)}(n) \end{bmatrix} \tag{8}$$

Thus, the equation $x^{(0)}(k) = -az^{(1)}(k) + b$ can be expressed as

$$Y_n = B_n T \tag{9}$$

Then we can use the least squares method to obtain estimates of a, b as

$$\hat{V} = \begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix} = (B^T B)^{-1} B^T Y \tag{10}$$

Since is a function of time t, then establish the whitening equation equivalent to the gray equation GM(1, 1)

$$\frac{d\hat{x}^{(1)}(t)}{dt} + \hat{x}^{(1)}(t) = b \tag{11}$$

2.2.4. The Solution of Prediction Model

We take the initial value $\hat{x}^{(1)}(t)|_{t=1} = x^{(0)}(1)$, then we can find the solution corresponding to the GM(1, 1) whitening equation as

$$\hat{x}^{(1)}(t) = \left[x^{(0)}(1) - \frac{\hat{b}}{\hat{a}} \right] e^{-\hat{a}(t-1)} + \frac{\hat{b}}{\hat{a}} \tag{12}$$

For ease of observation, the solution of the variational whitening equation based on the sequence characteristics is

$$\hat{x}^{(1)}(m+1) = \left[x^{(0)}(1) - \frac{\hat{b}}{\hat{a}} \right] e^{-\hat{a}m} + \frac{\hat{b}}{\hat{a}},\ m = 1, 2, \ldots, n-1 \tag{13}$$

$$x^{(1)}(m) = \sum_{i=1}^{m} x^{(0)}(i), m = 1, 2, \ldots, n, \tag{14}$$

we can get:

$$\hat{x}^{(0)}(m+1) = \hat{x}^{(1)}(m+1) - \hat{x}^{(1)}(m) = (1 - e^{\hat{a}}) \left[x^{(0)}(1) - \frac{\hat{b}}{\hat{a}} \right] e^{-\hat{a}m}, m = 1, 2, \ldots, n-1 \tag{15}$$

To make a prediction on the raw data, simply take the above equation $m \geqslant n$.

The GM(1,1) prediction result is shown in Figure 2.

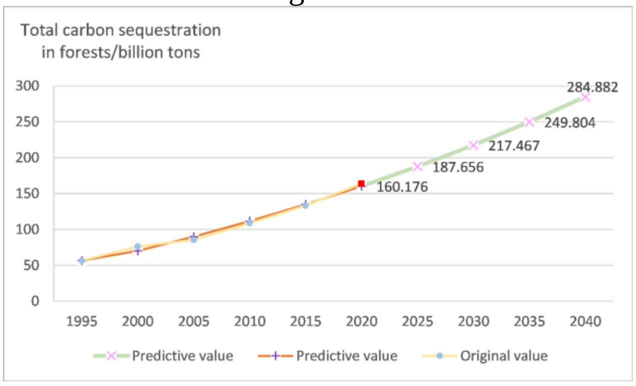

Figure 2: GM(1,1) prediction result

2.3. Decision Model

The value of the forest is one-sided considering only the ecology, so the Decision Model is established to consider the forest value more comprehensively in Figure 3.

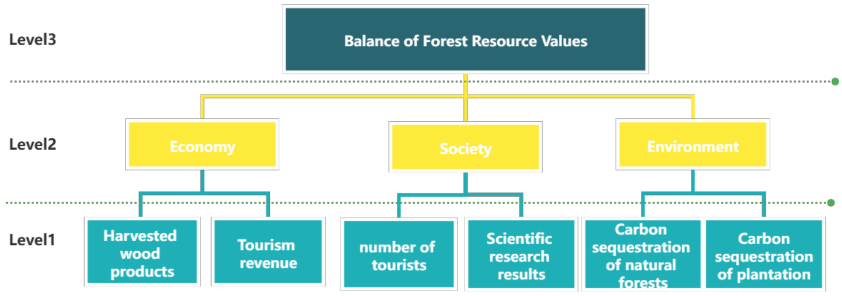

Figure 3: Balance of Forest Resource Values

Forest values are mainly divided into socio-economic benefits and ecological benefits, but the two are relatively parallel and difficult to reconcile. The socio-economic benefits of forests are mainly the income from forest tourism and forest products sales, which can only be achieved through logging. Ecological benefits, such as prevention of soil avalanches, water conservation, and air purification[12], can only be achieved through forest protection. The decision model proposes the theory that the two opposing benefits can be reconciled through artificially constrained logging policies[13].

Firstly factor analysis is used to divide the six indicators indicating socio-economic and ecological benefits into two categories, and calculated the factor scores as a comprehensive evaluation index of forest values.

Table 4: Bartlett's Test of Sphericity

Bartlett's Test of Sphericity			KMO Sampling Suitability Quantity
Approximate Chi-Square	Degrees of Freedom	Salience	
106.867	15	0.00	0.832

Kaiser gave a KMO test standard: KMO>0.9, very suitable; 0.8<KMO<0.9, suitable; 0.7<KMO<0.8, general; 0.6<KMO<0.7, not very suitable; KMO<0.5, not suitable.

As is shown in Table 4, the KMO value is equal to 0.832, indicating that the data is suitable for factor analysis; The p-value of Bartlett's Test of Sphericity is equal to 0.00, which is less than 0.05, indicating that the null hypothesis is rejected at the 95% confidence level. Therefore, the data is suitable for factor analysis.

Table 5: Component matrix after rotation

	Element	
	1	**2**
Total number of forest tourism/100 million	0.859	0.496
Forest tourism revenue/100 million yuan	0.806	0.574
Natural forest area/10,000 hectares	0.918	0.375
Plantation area/10,000 hectares	0.908	0.398
Number of papers/article	0.397	0.915
Harvested wood products/ton	0.915	0.398

The factor loading coefficients after rotation are shown in Table 5. Factor loadings are the correlation coefficients between a variable and a public factor. When the absolute value of a variable's loading in a public factor is larger, it means that the variable is more closely related to the public factor, that is, the public factor is more representative of the variable. Thus, the first public factor in this example is more representative of the five variables except the number of journals, which can be called the actual value factor; the second public factor is more representative of the variable number of journals, which can be called the research value factor.

The following factor score function is obtained:

$$F_1 = 0.209Z_1 + 0.080Z_2 + 0.388Z_3 + 0.354Z_4 + 0.633Z_5 + 0.360Z_6 \tag{15}$$

$$F_2 = 0.006Z_1 + 0.207Z_2 - 0.282Z_3 - 0.227Z_4 + 10.275Z_5 - 0.234Z_6 \tag{16}$$

(Z_1~Z_9 are standardized data)

Composite score calculation formula:

$$\text{score}=\frac{67.502F_1 + 31.188F_2}{98.690} \tag{17}$$

According to the formula, the finally factor score is shown in Table 6.

Table 6: Factor score table

Year	Overall Score	Numberof forest tourism/billion people	tourism revenue/billion yuan	Natural forest area/10,000 hectares	Plantation area/10,000 hectares	Number of papers
2010	-4.84	3.96	294.94	20768.73	6933.38	10050
2011	-2.82	4.68	376.42	20782.32	7025.32	12800
2012	-2.67	5.48	453.31	20952.32	7362.85	11600
2013	-1.37	5.89	491.11	22044.62	7835.56	11900
2014	-0.23	7.10	572.13	22352.24	8003.10	12200
2015	0.76	7.95	705.60	22835.64	8125.32	12400
2016	1.47	9.17	781.60	23026.56	8265.85	12400
2017	2.29	9.62	878.50	23056.22	8368.11	13000
2018	3.20	9.86	943.20	23178.69	8456.23	14000
2019	4.21	10.19	1005.45	23423.63	8536.85	15100

3. Management Plan Analysis

Since there are many factors influencing a country's attitude towards forest protection[14] and deforestation, three main factors are chosen for analysis: national ecological protection value, economic interests and types of deforestation.

3.1. National Ecological Protection Values

One study takes the Amazon rainforest as an example, with nine countries bordering it. The new study done by an international team of researchers from the UK and Brazil shows that areas with higher levels of deforestation currently have lower levels of recovery. Even parts of the overlogged Amazon landscape show no signs of recovery 20 years after logging[15]. Another study published in Environmental Research Letters shows that less than 10 percent of carbon emissions from amazon deforestation are offset by the absorption of new trees in the forest.

The nine Amazonian countries[16] also differ widely in such carbon offsets. Brazil holds more than half of the Amazon forest[17] and is responsible for most of the deforestation and associated carbon dioxide emissions. But the country's single state (Para) has more deforestation than that of the other eight Amazonian countries combined. Besides, Brazil is also lagging behind the other 8 countries in forest restoration: only 25% of previously deforested land is covered by new forest and only 9% of carbon dioxide emissions from deforesting are offset. Ecuador is leading the way, recovering nearly 60 percent of its deforested land. In Guyana, recovering forests make nearly a quarter of carbon dioxide emissions offset. Next the Japan's import forest volume is taken as an example for analysis.

As is shown in Figure 4, Japan's export of wood increased before 2018 and showed a downward trend after 2018 which reflects the country attaches more and more importance to the protection of forest resources.

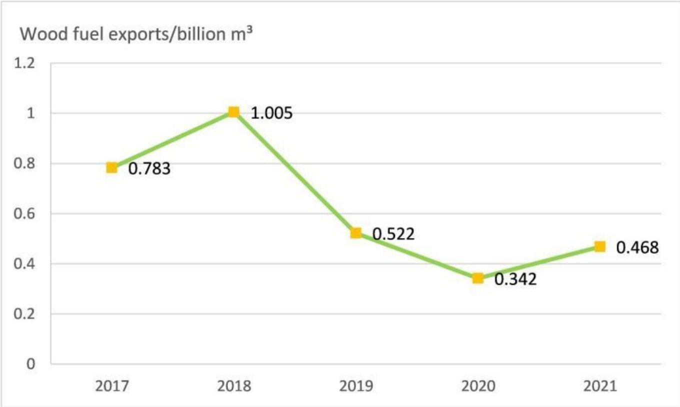

Figure 4: 2017-2021 the wood fuel exports of Japan

Generally speaking, this is related to the people's concern extent about the forest re- sources and the value of environmental protection. Therefore, for amazon countries, the countries like Brazil and other countries that attach less importance to forest restoration should strengthen management [18].

3.2. Economic Benefit

As is shown in the Figure 5, mainly 10 countries are selected and their respective harvested wood product in 2020 are analyzed. Among them, the amount of China, Switzerland and Mexico are all below 10 billion cubic meters while Canada, South Africa and France are all more than 100 billion cubic meters. France, in particular, reached 554.812 billion cubic meters, indicating that these countries are more dependent on deforestation so it is needed managing.

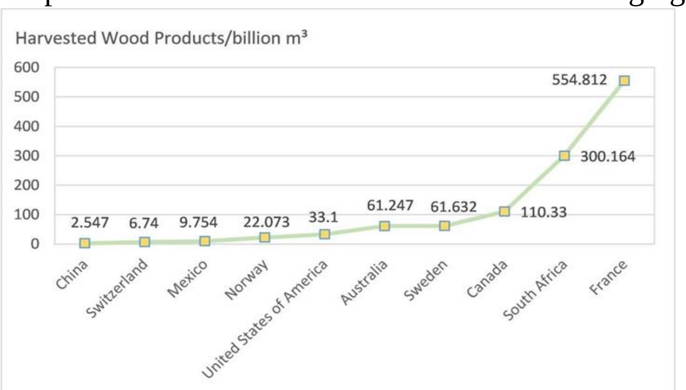

Figure 5: Harvested Wood Products from 10 countries

3.3. Deforestation Type of Forest

To determine the transition point for the forest management plan, the factor scores are fitted as the dependent variable, i.e., total forest benefits, and the amount of trees felled as the independent variable.

An assumption is made that all other variables being equal, the same felling practices are applied to each tree species in a forest[19]. An increase in harvesting then represents an in- crease in income from forest products and an increase in the economic benefits of the total forest benefits. However, the ecological benefits such as carbon sequestration value and oxygen release value will be greatly reduced due to the reduction of trees. So it can be envisaged that there may be some value of cutting that balances the economic and environmental benefits, and thus maximizes the total benefits of the forest.[20]

Based on the annual deforestation data, the total forest benefit for the year is used as the dependent variable Y and the amount of deforestation as X, and fitted them in Figure 6 using MATLAB software to obtain a functional relationship between the amount of deforestation and the forest benefit. The combined error and goodness of fit resulted in a functional equation with a good degree of fit.

$$f(x) = \frac{p_1x^4 + p_2x^3 + p_3x^2 + p_4x + p_5}{x + q_1} \tag{18}$$

where q_1 = -0.002259 , p_1 = 0.7639, p_2 = -85.33, p_3 = 3145, p_4 = 104.7 , p_5 = -15.93, the following curve-fit images were obtained.

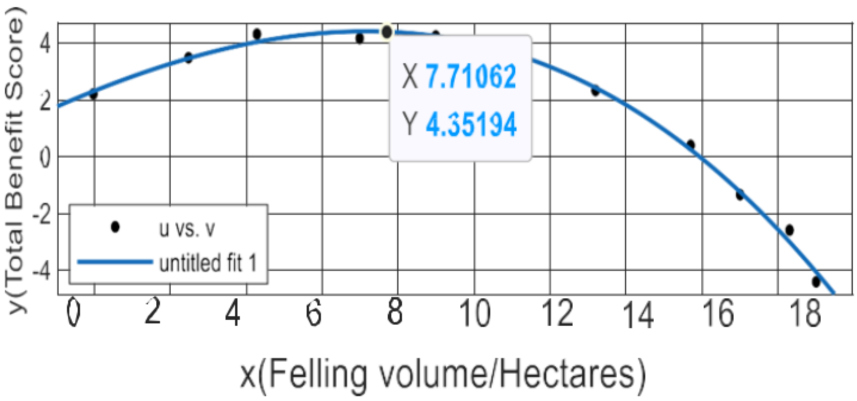

Figure 6: Fitted relationship diagram

Table 7: Fitting error

SSE	R-square	Adjusted R-square	RMSE
1.093	0.9856	0.9677	0.5228

As is shown in Table 7, the error test revealed that the SSE was small and the Adjust R-square was close to 1, indicating that the function was a good fit. Through MATLAB calculations, the extreme value point of the function was obtained as 7.7106 ha, and this point is set as the optimal deforestation of the target forest. Note that the optimum cut obtained varies with each forest's indicators and is not homogeneous, but the model for calculating the optimum cut is generic.

As there are different felling values for the different forest locations, we need to use the forest location to identify transition points between management plans.(Determining the transition point means that in analyzing different regions, the impact of deforestation species and trees on forest value.)

According to the formula of (2)(3) to measure the amount of carbon sequestered by forestry in China's provinces, the total value of the four major forest regions in China[21], analyzed from the perspective of the distribution of forest regions, are southwest, northeast, south, and north forest regions from high to low. The total value of carbon sequestration in the southwest forest region, which has the highest value, is 187.069 billion yuan, accounting for about 42% of the total value of carbon sequestration in China; the total value of carbon sequestration in the north- east forest region is second only to the southwest forest region, at 1335.41×108 yuan; the total value of carbon sequestration in the northern forest region, although it contains more provinces, is the lowest, with the total value of carbon sequestration in 11 provinces being 407.35×108 yuan.

In the strategy of creating reserve forests, the relationship between expanding the area and improving the quality is of paramount importance. It is important to expand the area of timber base afforestation, increase the total forest accumulation and substantially improve the efficiency of timber production. In the process of artificial afforestation, creating mixed forests is needed to improve the hierarchical structure of forests and pay more attention to the fact that tree species should be combined with short, medium and long cycles to adjust the ratio of tree species of different cycles. When there is a big demand gap for forest products, short-cycle fast-growing forests such as eucalyptus, fir, horsetail pine and moso bamboo can be planted appropriately to ease the contradiction between timber supply and demand.

4. Improvement of Carbon Sequestration Model

Based on the optimum cut already obtained in management plan analysis, we refer to the conversion factor from wood volume to tons of carbon per cubic meter of wood for different species to deter- mine which species to cut, and finally obtain the total carbon sequestration of the forest plus wood products. A refinement of the equation for calculating carbon stocks from carbon sequestration model combined with the stockpile method gives the following equation.

$$Cs = (S - X) \cdot D \cdot B_{EF} \cdot (1 + R) \cdot C_f + HWP + soil + Bp + lt \tag{19}$$

$$\mathrm{HWP} = \sum_{i=1}^{n} x_i \cdot \sigma_i, \quad i = 1,2,\ldots,n \tag{20}$$

$$\sum_{i=1}^{n} x_i = X, \quad i = 1,2,\ldots,\mathrm{n} \tag{21}$$

Total forest carbon stock = forest vegetation carbon stock + forest product carbon stock + soil carbon stock + understory plant carbon stock + eroded carbon stock

where Cs is the total forest carbon stock, S is the total forest stock and X is the total stock removed by felling; D is the basic wood density; B_{EF} is the ratio of above-ground biomass to trunk biomass; R is the rootstock ratio; C_f is the carbon content of dry matter; HWP is the wood carbon stock; soil is the forest soil carbon stock; Bp is the understory plant carbon stock; lt is the eroded mass carbon stock; x_i is the species of the tree felled; and σ_i is the conversion factor for the i-th tree. The conversion factor is shown in Table 8.

Table 8: Conversion factors from wood volume to carbon tons per cubic meter for different tree species

Oak Tree	Beech	Lrb.sp(1)	Srb.sp(2)	Spruce	Fir	Douglas Fir	Pines	Larch
0.33	0.34	0.325	0.205	0.215	0.205	0.235	0.245	0.275

The calculation results are shown in Table 9.

Table 9: Forest Carbon sequestration (million metric tons of carbon)

	1990	1995	2000	2005	2010	2015	2020	% of Total
Forest Ecosystem	50913	51808	52681	53489	54302	55125	55933	95%
AbovegroundBiomass	11810	12424	13019	13584	14144	14707	15260	26%
Soil(Mineral and Organic)	31079	31078	31078	31081	31083	31081	31080	53%
Belowground Biomass	2319	2459	2594	2723	2851	2979	3103	5%
Litter and Deadwood	5705	5847	5989	6101	6225	6360	6490	11%
HWP	1895	2061	2218	2353	2462	2567	2669	5%
Total	52808	53870	54899	55842	56764	57692	58632	100%

5. Conclusions

Forests play a significant role in carbon sequestration due to their participation in the global carbon cycle. During the growth period of forest trees, trees can sequester CO2 from the air and convert it into biomass through photosynthesis. Appropriate harvesting of mature trees is conducive to improving the ecological and economic benefits of the forest and achieving a win–win situation for both the ecological environment and forest managers. In this study, a mathematical model of annual carbon sequestration benefits is established and a forest management plan is analyzed. The main conclusions are as follows.

The GM (1,1) model is used to estimate the amount of carbon sequestration by China's forests and obtained an average increase of 2.8 billion tons over five years. The results are 90% accurate when compared with the eighth carbon sequestration of forest resources in China officially published by the National Forestry and Grassland Bureau.

There is a transition point at which the total benefits of the forest are maximized, all other things being equal, and that below this transition point, appropriate tree felling will result in better use of the forest's resources; however, when felling exceeds this transition point, the forest ecosystem will be destroyed and the economic benefits gained will not compensate for the ecological benefits lost.

As for the selection of forest management solutions, the better management scenario for the forest can be obtained based on the results of the management plan analysis. With the felling volume kept at around the optimal felling volume, more large diameter timber species such as oak, ficus and fir are cut. It is also important to pay attention to the age of the trees, as middle-aged trees have the highest carbon content, so overmature and old trees are the main targets for felling. It is also important to ensure that seedlings are planted at the time of felling so that the total forest stock does not change significantly. The results of this study can provide a theoretical basis for optimizing forest management strategies.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 61872075).

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