ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

May Thousands of Miles Remain Green: How to Choose Between Carbon Sequestration and Social Benefits

Zixin Jiang

College of Artificial Intelligence, Beijing Normal University, Beijing, 100091, China

Abstract: *In order to mitigate the impacts of climate change on human development and reduce carbon levels in the atmosphere, we conduct research on how forests are managed. Specifically, we propose a carbon sequestration model, using the Gompertz model to study the change of tree diameter at breast height over time, and analyze the amount of forest carbon sequestration. In addition, based on the TOPSIS analysis and the evaluation method of InVEST, the most suitable forest management decision-making model for society is proposed, and the Person correlation coefficient method is used to calculate the harvesting intensity that maximizes the comprehensive benefit of the forest and minimizes the trade-off value. Finally, the carbon dioxide sequestration of the forest over the next 100 years was calculated and the optimal harvest interval of 10 years was determined.*

Keywords: *Forest, Carbon sequestration, Management decision, Gompertz Model, TOPSIS*

1. Introduction

Carbon sequestration refers to the process of capturing carbon and replacing CO2 directly into the atmosphere in a safe manner in order to effectively reduce CO2 emissions to the atmosphere. The captured CO2 is safely stored in the geological structure layer, and there are three key storage methods: geological storage, marine storage, and chemical storage. In the context of global climate change, the carbon sequestration potential of forests has been widely concerned [1]. According to statistics, the above-ground carbon storage of forest ecosystems is 4.52×1010t, accounting for 86% of the total carbon storage of the global terrestrial plants above-ground, which is of great significance to the global carbon balance and climate change. The carbon sequestration capacity of some forest products is higher than that of the forest itself [2]. Therefore, research on forest management strategies, including appropriate logging, has important theoretical and Practical significance.

The purpose of this paper is to measure carbon sequestration in forests and to plan optimal forest management strategies. We need to address the following questions: Model carbon sequestration assessments to determine how much carbon dioxide forests and their products can store, and explore which methods are most effective for carbon sequestration. Model decision-making that balances forest values, including carbon sequestration, from a forest manager's perspective to understand the best use of forests. The model is further extended to various forests to develop optimal forest management plans and analyse their impacts.

To simplify the problem so that we can simulate real life, we make the following basic assumptions, each of which is correct and valid: CO2 fixed by forests includes what is fixed by trees, the vegetation under trees, and what is sequestered in soil [3]. In the model, we only consider the fixed part of the tree. Due to its biodiversity, forests are one of the most stable ecosystems. Cutting down parts of trees will not have a large impact on other organisms, so changes in biotic and abiotic factors other than trees are not considered, which means that changes in carbon sequestration in these parts are negligible [4]. It is assumed that the trees in the forest are planted evenly and at appropriate intervals, meeting the preconditions of not causing intense competition and wasting resources such as sunlight.

2. Best Forest Management Model for Carbon Sequestration

In order to establish a carbon sequestration evaluation model, the Gompertz model with the best fitting effect was first used to explore the variation law of tree diameter at breast height over time for three typical forest types. The biomass of the forest community was calculated by the allometric model

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

[5]. In order to further explore which forest management method has the best effect on carbon sequestration, we found that the carbon storage brought by different forest ages is not the same, and the carbon sequestration phenomenon will decrease when the forest is near-mature [6]. In order to comprehensively and systematically understand the carbon sequestration capacity of forests worldwide, we use ArcGIS analysis method and ArcGIS software to comprehensively analyze the global forest carbon sequestration [7], which is shown in Fig.1.

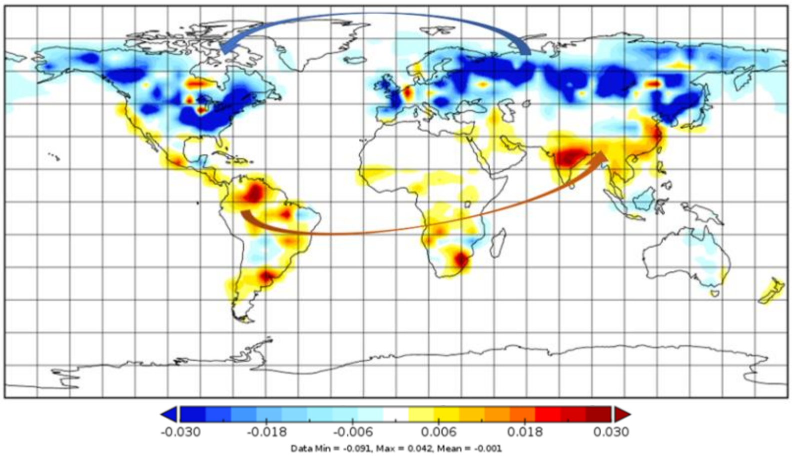

Figure 1: Total surface-atmosphere carbon (C) sequestration

We select the following three representative forests as samples to fit the carbon sink model: Yunnan pine forest in central Yunnan, larch forest in North China, and Saihanba white birch, a natural secondary forest of white clouds [8]. The tree species, environment and carbon sequestration potential of these three forests are different, so that a comprehensive and systematic understanding of forest carbon sequestration activities can be obtained. The environmental factors that affect forests in the environment are called forest ecological factors, which can be divided into climatic factors and topographic factors according to their nature [9]. Therefore, we mainly choose the annual average temperature as the consideration index of climate factor, and select the altitude and slope as the consideration index of terrain factor [10]. The sample plot data comes from the continuous inventory data of China's forest resources from 2004 to 2018 and the survey data of the Hebei Forestry Survey, Planning and Design Institute [11]. The statistics of the forest stand survey factors of various plots is shown in table 1.

Table 1: Characteristics of the selected forest

forest type	number of plots	age range of trees	tree diameter	distribution altitude
Pine Forest in Yunnan	211 pieces	2~96 years	10~80cm	925～4885 m
Deciduous Forest in North China	1578 pieces	3~45 years	2.3~20.6cm	1500~1900 m
White Birch Secondary Forest	754 pieces	3~50 years	2.4~16.2cm	1400~1780 m

Wwe use the Gompertz model to predict the change of tree diameter at breast height with age. We used the equations described below to fit tree diameter at breast height over time for three typical forest types, which can be expressed as:

$$dbh(t) = ae^{-be^{-ct}} a, b, c > 0 \tag{1}$$

The biomass of the three forest communities was calculated by:

$$(t) = e^{-3.46}(dbh)^{1.62} + e^{-2.45}(dbh)^{2.31} + e^{-2.68}(dbh)^{2.27} \tag{2}$$

where B(t) representing the change in plant biomass as a function of time.

The Gompertz model was used to fit and calculate the variation process of tree diameter at breast height with age in Yunnan pine forest in central Yunnan, larch forest in North China, and Saihanba white birch natural secondary forest. The fitting results is shown in table 2.

Table 2: Specific parameters of different forests

forest type	a	b	c	R^2
Pine Forest in Yunnan	a=34.315	b=2.281	c=0.290	0.9980
Deciduous Forest in North China	a=22.196	b=3.838	c=0.100	0.9864
White Birch Secondary Forest	a=14.616	b=2.477	c=0.0901	0.9925

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

The time-dependent trends of biomass and carbon sequestration of the three stands is shown in Fig.2.

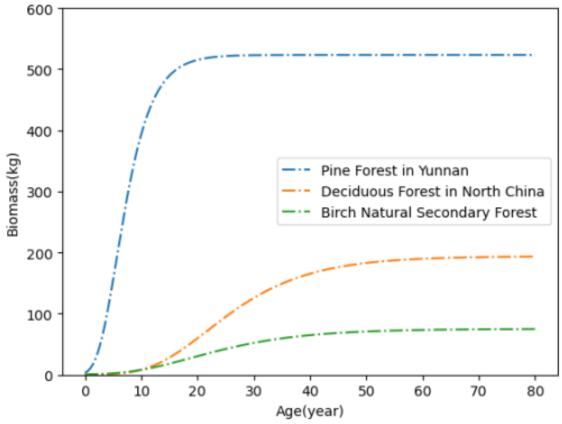

Figure 2: Time varying curves of biomass of three forests

We select Yunnan pine forests with the same slope and temperature but with altitudes of 500 m, 2500 m, and 4500 m, respectively, which can be expressed as:

$$dbh(t) = (36.986 - 0.002t_{\mathrm{LT}}) \times \exp[-(1.73 + 0.00025t_{\mathrm{LT}}) \times \exp(-0.031t)] \quad (3)$$

We select Yunnan pine forests with the same altitude and temperature but with slopes of 5 degrees, 25 degrees, and 45 degrees, respectively, which can be expressed as:

$$dbh(t) = (35.488 - 0.083S_{\mathrm{LO}}) \times \exp\{-2.27 \times \exp[-(0.026 + 0.0002S_{\mathrm{LO}})t]\} \quad (4)$$

We select Yunnan pine forests with the same slope and altitude but with an annual average temperature of 16 ℃, 21 ℃, and 26 ℃, respectively, which can be expressed as:

$$dbh(t) = (63.717 - 1.576T_{\mathrm{t}}) \times \exp[-(4.655 - 0.141T_{\mathrm{t}}) \times \exp(-0.027t)] \quad (5)$$

The effects of three different altitudes, slopes, and annual mean temperature on the growth of stand biomass and carbon sequestration, which is shown in Fig.3. By controlling for variables, we found that stand biomass and carbon storage were negatively correlated with elevation, positively correlated with slope, and correlated with temperature depending on tree age.

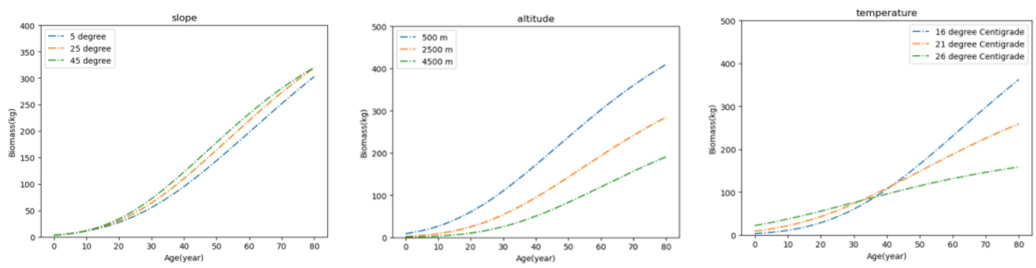

Figure 3: Influence curve of altitude, slope and temperature on forest biomass

In order to further explore which forest management method has the best effect on carbon sequestration, we found that the carbon storage brought by different forest ages is not the same, and the carbon sequestration phenomenon will decrease when the forest is near-mature, which can be expressed as:

$$\frac{dB(t)}{dt} = \begin{pmatrix} 1.62 \times e^{-3.46}(dbh)^{0.62} + 2.31 \times e^{-2.45}(dbh)^{1.31} \\ +2.27 \times e^{-2.68}(dbh)^{1.27} \end{pmatrix} \cdot abce^{-(ct+be^{-ct})} \quad (6)$$

Then, through binary search, under the condition that the absolute error does not exceed 10-6, it is concluded that B(t) = B (0) under the following conditions, and the final result is displayed in the Fig.4.

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

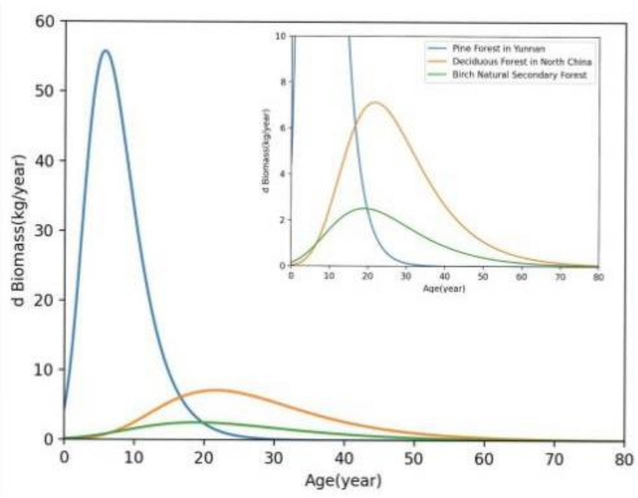

Figure 4: Optimum cutting time

Considering only carbon sequestration, the best forest management strategy: As far as a forest is concerned, trees should be cut down when the carbon sequestration declines after reaching the near-mature forest, so the resulting pine forest in Yunnan management plan is when the trees reach 25 to 25 years old.

3. Best Forest Management Model for Society

We have established a comprehensive decision-making model to evaluate the utilization of forests [12]. According to the relationship between forest ecological resources and human beings, the value of forest ecosystem can be divided into four categories: carbon sequestration value, product economic value, cultural value and ecological value [13]. The carbon sequestration value has been calculated in the carbon sequestration model, which is shown in Fig.5.

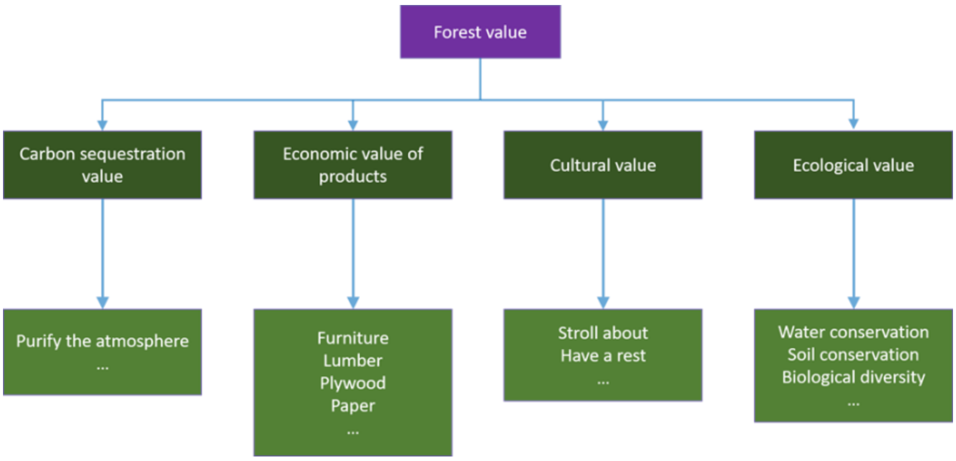

Figure 5: Forest value framework

The calculation method of wood production is:

$$\text{TVolume} = \sum_{x=1}^{n} \text{Parcl\_area}_x \times \frac{\text{Perc\_harv}_x}{100} \times \text{Harv\_mass}_x \times \frac{1}{D_x} \quad (7)$$

TVolume is the total wood production in the study area (m^3), Parcl_area_x is the total area of the x forest type (hm^2); Perc_harv_x is the area proportion (%) of each cutting for the x forest type, Harv_mass_x is the biomass per unit area (t/hm^2) of trunk and bark per cutting of the x forest type, D_x Is the average wood density of the x forest type (T/m^3).

The decision-making model clarifies the trade-off relationship and process between various forest values. The optimal forest management plan is determined by the comprehensive benefit (mean) and trade-off value (standard deviation) of various ecosystem values, which can be expressed as:

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

$$B_A = \frac{A - A_{min}}{A_{max} - A_{min}} \tag{8}$$

Where B_A is the income value of ecosystem value A after standardization; A is the income value of ecosystem value A; A_{max} and A_{min} are the maximum and minimum values of ecosystem value a and income value respectively.

Taking commercial forest as an example to analyze the transition point, which is shown in Fig.6.

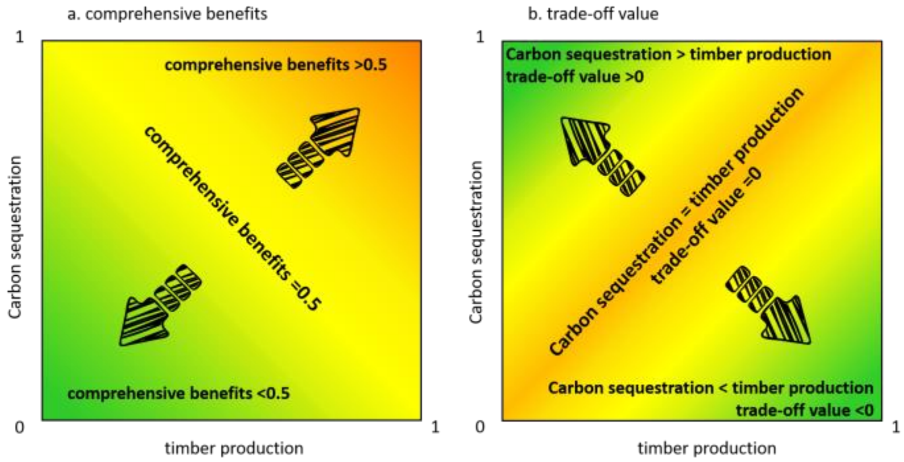

Figure 6: Determine the transition point

4. Extension of Decision Model

We use ArcGIS spatial analysis method and ArcGIS software to comprehensively analyze the carbon sequestration of Thai forests under the influence of biological communities, which is shown in Fig.7.

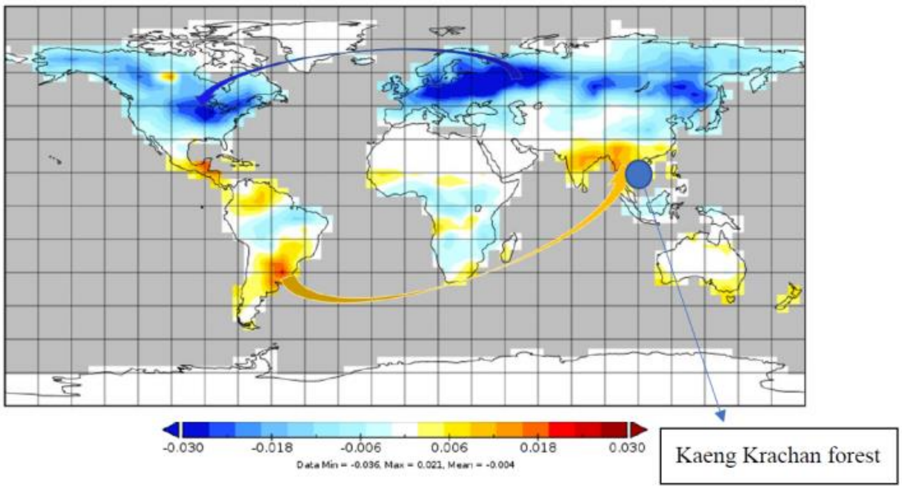

Figure 7: Carbon (C) sequestration (consider biological communities)

A total of six management modes are set to simulate the growth and cutting of the forest in the next 100 years, which is shown in table 3.

Table 3: Potential management regimes

management model	Proportion of cutting area /%	Cutting cycle / year	principle
N0	0	10	Small area clear cutting (clear cutting area ≤ 5hm², interval area between clear cutting areas ≥ clear cutting area)
N1	10		
N2	20		
N3	30		
N4	40		
N5	50		

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

Under different management modes, wood production, carbon storage, understory biological species and tourists show different characteristics with cutting time, which is shown in Fig.8.

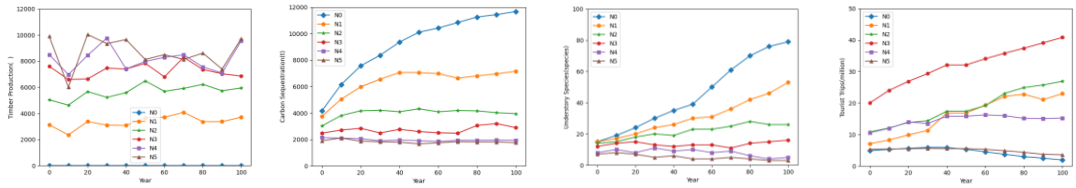

Figure 8: Different variation characteristics

By fitting, we get the binomial fitting equation of four benefit factors varying with cutting intensity, which is shown in Fig.9.

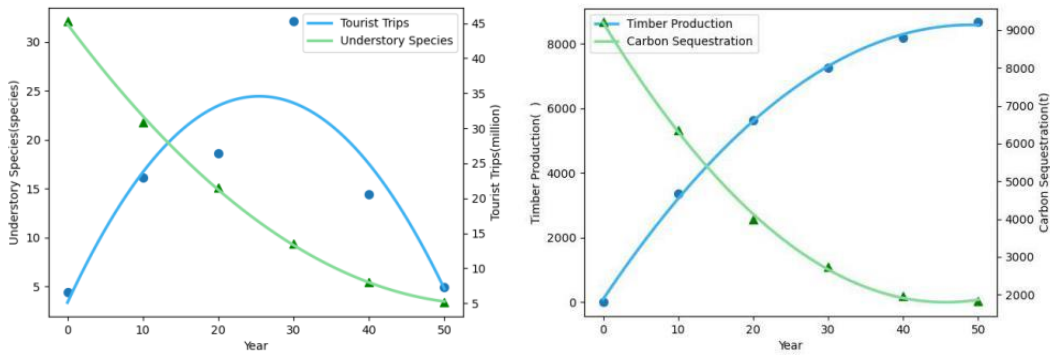

Figure 9: Changes of benefit factors with cutting intensity

Line model Poly2:

$$f(x) = p_1 * x^2 + p_2 * x + p_3 \tag{9}$$

Coefficients (with 95% confidence bound), goodness of fit is shown in table 4.

Table 4: Fitting results

	Tourist Trips	Timber production	Carbon sequestration	Understory species
SSE	88.24	1.014	5.577e+04	2.869e+04
R-square	0.8186	0.9991	0.999	0.9993
Adjusted R-square	0.6976	0.9986	0.9983	0.9989
RMSE	5.423	0.5814	136.3	97.79

$$p_1 = -0.0326\ (-0.06085, -0..004351)\ p_2 = 1.658\ (0.1871, 3.13)\ p_2 = 3.361\ (-12.28, 19) \tag{10}$$

$$p_1 = 0.01302\ (0.009991, 0.01\ 605)\ p_2 = -1.444\ (-1.602, -1.287)\ p_2 = 44.89\ (43.21, 46.57) \tag{11}$$

$$p_1 = -3.535\ (-4.245, -2.824)\ p_2 = 346.6\ (309.6, 383.6)\ p_2 = 93.32\ (-300, 486.6) \tag{12}$$

$$p_1 = 3.561\ (3.052, 4.07)\ p_2 = -324.8\ (-351.4, -298.3)\ p_2 = 9205\ (8922, 9487) \tag{13}$$

It can be found that except for the fitting of the number of tourists, other fitting effects are very good, and the number of tourists is affected by many uncertain factors, so it's fitting effect is not considered to affect the model.Through the obtained data and analysis results, we use the TOPSIS model for analysis to obtain the determination of the multi-objective forest management model, which is shown in table 5.

Table 5: Entropy method

Entropy Method			
	Comentropy	Information utility value	Weight
timber production	0.872	0.128	0.133
Carbon sequestration	0.671	0.329	0.343
Understory species	0.752	0.248	0.259
Tourist trips	0.747	0.253	0.264

The entropy weight method shows that kaeng krachan forest can obtain the maximum benefit when the weights of the four benefits are 0.133, 0.343, 0.259 and 0.264 respectively. And the management strategy of M1, that is, 10% of the total area of the forest farm cut every ten years, is the highest score.

$$X = \begin{pmatrix} x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \\ \vdots & \vdots & \vdots & \vdots \\ x_{61} & x_{62} & x_{63} & x_{64} \end{pmatrix} \tag{14}$$

Where x_{ij} ($1 \leq i \leq 4, \ 1 \leq j \leq 6$) represents the j-th index of the i-th scheme.

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_n^{i=1} x_{ij}^2}} \tag{15}$$

$$S_i = \sum_{j=1}^{6} w_i * z_{ij} \tag{16}$$

The TOPSIS result analysis is shown in table 6.

Table 6: TOPSIS result analysis

TOPSIS				
pattern	Positive ideal solution distance (D+)	Negative ideal solution distance (D-)	Composite score index	sort
N0	0.3555429	0.43547026	0.55052214	2
N1	0.45810397	0.62545309	0.57722211	1
N2	0.46438069	0.3302734	0.41561908	4
N3	0.52900332	0.45559956	0.46272418	3
N4	0.65482602	0.24550015	0.27267912	5
N5	0.74304083	0.20554899	0.21668901	6

Based on this management scheme, we calculate that the carbon sequestration of the forest in 100 years is 7157 tons.

5. Conclusion

In this paper, we propose the most suitable forest management model for carbon sequestration. Based on TOPSIS analysis and InVEST evaluation method, the most suitable forest management decision-making model for society is proposed, which enables forest managers to evaluate forest value in a balanced and quantitative manner. The interaction between various social values of the forest was quantitatively analyzed by the Person correlation coefficient method, and the logging intensity that maximized the comprehensive benefit of the forest and minimized the trade-off value was calculated. Extending the model to the kaeng krachan forest, the carbon dioxide sequestration of the forest and its products was calculated over a 100-year period.

References

[1] Tong, X., Brandt, M., Yue, Y. et al. Forest management in southern China generates short term extensive carbon sequestration. Nat Commun 11, 129 (2020).

[2] Koch, A., Kaplan, J.O. Tropical Forest restoration under future climate change. Nat. Clim. Chang. (2022).

[3] R, Lal. Forest soils and carbon sequestration [J]. Forest Ecology and Management, 2005, 220(1-3):242-258.

[4] Allan, Blanchard, Nikolai, et al. Evaluating a tax-based subsidy approach for forest carbon sequestration [C]// 2018 International Conference on High Performance Computing & Simulation. 0.

[5] W. de Vries and S. Solberg and M. Dobbertin and H. Sterba and D. Laubhann and M. van Oijen and C. Evans and P. Gundersen and J. Kros and G.W.W. Wamelink and G.J. Reinds and M.A. Sutton. The impact of nitrogen deposition on carbon sequestration by European forests and heathlands [J]. Forest Ecology and Management, 2009.

[6] Guo J, Gong P. The potential and cost of increasing forest carbon sequestration in Sweden[J]. Journal of Forest Economics, 2017, 29:78-86.

ISSN 2616-5872 Vol.4, Issue 4: 60-67, DOI: 10.25236/AJEE.2022.040409

[7] Adetoye A M, Okojie L O, Akerele D. Forest carbon sequestration supply function for African countries: An econometric modelling approach [J]. Forest Policy & Economics, 2018, 90:59-66.
[8] Sohngen B, Mendelsohn R. An Optimal Control Model of Forest Carbon Sequestration [J]. American Journal of Agricultural Economics, 2011, 85(2):448-457.
[9] Huang L, Zhou M, Lv J, et al. Trends in global research in forest carbon sequestration: A bibliometric analysis [J]. Journal of Cleaner Production, 2019, 252:119908.
[10] Yao Y, Piao S, Wang T. Future biomass carbon sequestration capacity of Chinese forests [J]. Science Bulletin, 2018.
[11] Chu X, Zhan J, Li Z, et al. Assessment on forest carbon sequestration in the Three-North Shelterbelt Program region, China [J]. Journal of Cleaner Production, 2019, 215(APR.1):382-389.
[12] Eggers J, Holmgren S, Nordstr? M E M, et al. Balancing different forest values: Evaluation of forest management scenarios in a multi-criteria decision analysis framework [J]. Forest Policy and Economics, 2019: S1389934116303872.
[13] Yao R T, Palmer D J, Payn T W, et al. Assessing the Broader Value of Planted Forests to Inform Forest Management Decisions [J]. Forests, 2021, 12(6).