Vector assessment model in R3 space for forest value

Jin Wang *

School of Computer and Information Technology, Beijing Jiaotong University, Beijing 100044, China

* Corresponding Author Email: 20722022@bjtu.edu.cn

Abstract. While Forests have enormous potential and value, it is necessary to establish a valuation model to help us make decisions and make sound recommendations. To this end, I have made the following contributions. I collected nine data sets from 12 forests and integrated them into three dimensions. I combined the subjective hierarchical analysis (AHP) and CRITIC objective assignment method to obtain the weights. Using the indicators and data of these three dimensions, I constructed a vector assessment model in R3 space, where the modal length of the spatial vector represents the forest value, the angle with the standard vector (1, 1, 1) represents the space of progress, and the plane established by the two vectors together represents the direction of improvement. In addition, I found a relationship between artificial logging intensity and forest value, and established extreme value points, concluding that appropriate artificial logging helps to improve forest value. Because the modal length of Siberian coniferous forests is 1.008 and the angle of 13 degrees, there is a lot of room for improvement, and I analysed this further. I used the GM (1,1) model to predict the carbon sequestration data of Siberian coniferous forests, and the results are consistent with the analysis results of the three-dimensional vector model I established.

Keywords: AHP, 3-D Vector Evaluation, GM (1,1), CRITIC.

1. Introduction

As I realize the magnitude of the global warming problem and the tremendous role forests play, management plans for forests are particularly important. Forests have rich values in various fields, not only in the ecological field to nourish soil and water, absorb carbon dioxide and promote the carbon sequestration cycle but also in the economic and social fields, such as providing timber products and promoting. Therefore, establishing a comprehensive evaluation system is particularly important. the establishment of a multidimensional evaluation model in R3 can help to evaluate the value of forests in a comprehensive and rational way. Here I choose to use the Euclidean vector space to analyze the forest value (Fval) in three latitudes: economic (E), social (S), and ecological (Z), each of which will be represented by a unit vector, and the combined vector will represent the forest value evaluation index. For the weight assignment in each dimension, I use a combination of subjective and objective methods, I.e., the hierarchical analysis method and CRITIC to determine the weights, and finally, I can get the comprehensive factor weights. By establishing the Vector evaluation model in R3, I can quantify and compare the forest values and finally evaluate and select the best forest management plan.

2. Indices definition

For the main evaluation scope of the forest, I have selected some sub-indicators for further refinement. With the evaluation of nine indicators in three dimensions, my model will be more objective and specific. I collected a large amount of data from the World Bank and Global Ecology and selected 12 representative data sets for quantitative analysis and processing. The definitions and analysis of the indicators will be shown in the following articles.

2.1. Variable quantization of indicators

To facilitate the establishment of my model and subsequent research, I chose the following variables as indicators for my evaluation system. As in the below table, + means the indicator is positively correlated with the forest value, - means the indicator is negatively correlated with the forest value, and * means the indicator is correlated with the forest value to a certain extent, rather than being fully positively or negatively correlated.

2.2. Indics analysis and interpretation

Species richness: Forests provide natural shelters for wildlife, so I chose the plant and animal species in forests as the basis of this dimension. Carbon Sequestration: Forests are the main carriers in the carbon sequestration cycle and play a dominant role in converting inorganic carbon to organic carbon and solving the global greenhouse effect problem. Water loss rate: Forests contain water and maintain soil and water nutrients, , so they play an important role in avoiding soil erosion. Here I use the negative correlation of soil erosion rate for evaluation.

Agriculture: Forests play a role in agriculture and its arable land, and I chose to quantitatively analyse the level of agricultural development around forests. Manufacturing industry: Moderate deforestation promotes the stability of ecosystems, as well as the self-development of forests. Therefore, I chose to assess the scale of industrial development and the level of wood products of this economic value of the forest. Forestry: The forest industry is the most direct factor of forest promotion, so I chose to assess the deforestation intensity and its resilience

Education and Culture: The forest also makes its own contribution to the field of culture. Here I have chosen the proportion of green, low carbon living in the region as the indicator here. Tourism: Forests also play an important role in the field of tourist scenery and its education, Here I have chosen as its quantitative indicator the tourism investment for the forest. Scientific research literature: The forest provides an important source of data for several scientific research activities. Here I selected the degree of relevant forest literature discussion as my parameter for this indicator.

Table 1. Quantitative index table

Dimension	Index	Effect
Ecology(Z)	Index of species diversity richness(Z1)	+
	Carbon storage efficiency index(Z2)	+
	Forest soil and water loss rate index(Z3)	-
Economy(E)	Agricultural average annual productivity index(E1)	+
	Index of forest utilization rate in manufacturing industry(E2)	+
	Forest cutting proportion index(E3)	*
Society	Forest industry to education culture investment rate index(S1)	+
	Forest contribution rate to tourism index(S2)	+
	Forest contribution rate index in literature research(S3)	+

3. Weighting calculation

I used a combination of the objective weighting method of hierarchical analysis and the objective weighting method of CRITIC to calculate the weights of different indicators in the three dimensions.

3.1. Use of AHP

Hierarchical analysis (AHP) was used here to visually assign weights to the corresponding indicators. First, I divided the decision problem into four levels. The goal level represents the three dimensions, the criteria level includes my nine indicators, and the plan level represents my target forest. In this section, I define the result of weight by AHP as W_A. Thus there are three corresponding pairwise comparison matrices, followed by my consistency test with the variables CI and CR, whose formulas and matrices are as follows.

$$CI = \frac{X_{\max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

Here I find that the CR values are all less than 0.1, so the test is successful. Therefore, I can get the weighting result data as follows.

Table 2. Weighting result of AHP

Ecology(Z)	Carbon sequestration	Species diversity	Soil erosion
	0.65	0.15	0.2
Economy(E)	Agriculture	Manufacturing	Forestry
	0.15	0.59	0.26
Social(E)	Education and culture	Tourism	Literature
	0.49	0.2	0.31

3.2. Use of CRITIC

The CRITIC method is a superior objective weighting method. I have here 12 samples to be evaluated and 9 evaluation indicators, and the data are dimensionless using forward or reverse normalization. In this section, I define the result of weight by AHP as W_C.

The conflicting indicators are as follows:

$$R_j = \sum_{i=1}^{p}\left(1 - r_{ij}\right) \tag{3}$$

r_{ij}denotes the correlation coefficient between evaluation indexes I and j.

The amount of information are as follows:

$$C_j = S_j \sum_{i=1}^{p}\left(1 - r_{ij}\right) = S_j \times R_j \tag{4}$$

The larger C_j is, the greater the role of the j_{th} evaluation indicator in the overall evaluation system, the more weight should be assigned to it. The objective weights are as follows:

$$W_j = \frac{C_j}{\sum_{j=1}^{p} C_j} \tag{5}$$

In summary, I can obtain the following weighting indexes by CRITIC method.

Table 3. Weighting result of CRITIC

Ecology(Z)	Carbon sequestration	Species diversity	Soil erosion
	0.26	0.38	0.35
Economy(E)	Agriculture	Manufacturing	Forestry
	0.32	0.25	0.43
Social(E)	Education and culture	Tourism	Literature
	0.58	0.37	0.05

3.3. Combined calculation of weights

By using the above two methods of calculation, I can derive their weights separately. Now I combine them into the final weights, whose expressions are:

$$W_{\text{total}} = m_A W_A + m_C W_C \tag{6}$$

Here m_A, m_C represent the coefficients of the two weights respectively, and here I consider that m_A = 0.4 and m_C = 0.6.The final weighting results are shown below.

$$W_Z = (0.416, 0.288, 0.29)^T W_E = (0.408, 0.458, 0.134)^T W_S = (0.388, 0.23, 0.382)^T \tag{7}$$

3.4. R_3 spatial model building

Based on the discussion of the above issues, I finally established a 3D assessment model for each forest with the following equation:

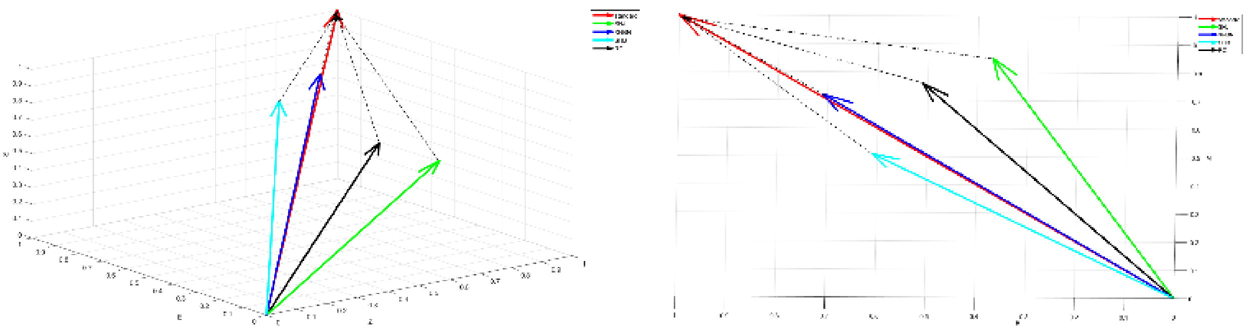
$$\begin{cases} \vec{Z} = W_z * \vec{ZI} \\ \vec{E} = W_E * \overrightarrow{EI} \\ \vec{S} = W_s * \overrightarrow{SI} \end{cases} \tag{8}$$

The three judging dimensions are established in the form of a three-dimensional vector and unitized so that the value of each dimension is between [0, 1]. The modal length of this vector can represent the forest value, the angle with the standard unit vector S_0 = (1, 1, 1). T-transformation can represent the distance to the optimal forest, and the modal length of the three sub-vectors can represent the value in each direction. Based on this information, I can analyze the weaknesses and their improvement directions. For $\delta \vec{S}$, which is expressed as a vector variation of the vector S. Since it has scalar and vector characteristics, it can be described using its geometric properties: the size represents the space that can be improved, while the direction represents the dimension of the forest that needs to be improved.

4. Model application

From the three-dimensional evaluation system, I can obtain the relationship between carbon sequestration and forest value. Combined with the analysis of the carbon sequestration model, I can summarize the relationship between the intensity of artificial disturbance, I.e., the amount of deforestation, and forest value. There is a great value of artificial disturbance intensity for forest value and it shows a trend of increasing and then decreasing. Therefore, tree felling needs to match the extreme value point of its forest and show a sustainable development trend.

Here I find that there are excess points between coniferous, broadleaf evergreen, deciduous broadleaf, and tropical rainforest, and the trend decreases toward the poles with latitude. Also based on is data to explore the excess points, I analysed the figure and found that between deciduous broadleaf and evergreen broadleaf, the effect of tree species is small, so other measures can be considered between these two management plans. Also, tropical rainforests and coniferous forests, the tree species are very different, so you can choose to plant the appropriate species. Also, when considering ecological values, social and economic values have an impact on the transition point.



(a) (b)

Figure 1. Three-dimensional drawings and projection planes

5. Case study

In the following, I will select the gray prediction model-GM (1, 1), and its modified new information GM (1, 1) model and metabolic GM (1, 1) model to predict the carbon sequestration of

Siberian coniferous forests. And I divided the original data into experimental and training groups to increase the goodness of fit. I collected and consolidated the data for the past eight years. Through the gray prediction analysis, the model was found to fit well with the original data, with a

residual test of 0.00045491 and a grade difference test of 0.0012208, which met the requirements; therefore, I obtained the final predicted data plot in Figure 2. Ultimately, I learned about the change in carbon sequestration in Siberian coniferous forests over the next hundred years through a gray time projection model, with dark blue to light blue representing the progression from low to high carbon sequestration efficiency. In Figure 3, I can visualize the trend.

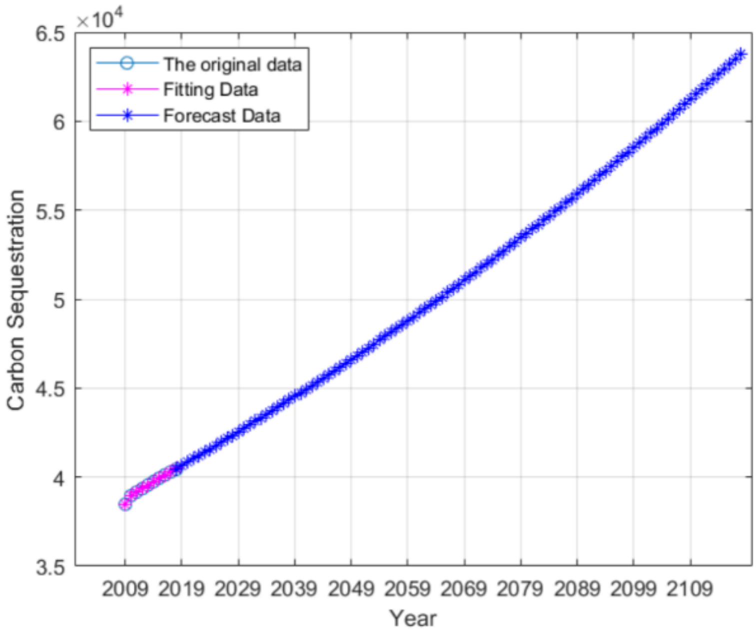


Figure 2. Siberian Forest future projection data map

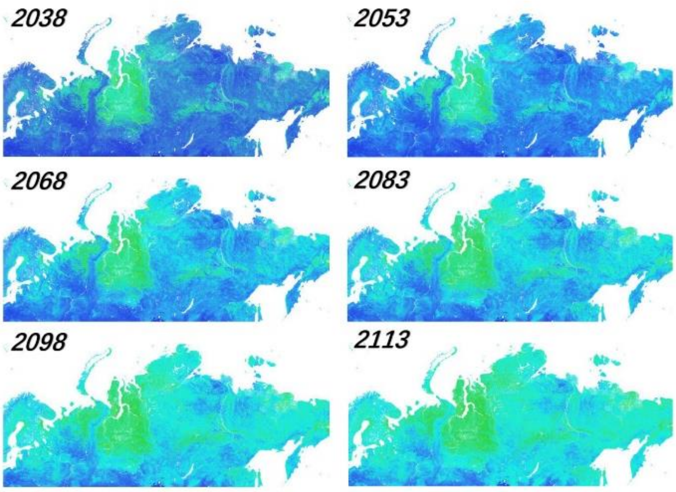


Figure 3. Map of carbon sequestration changes in Siberia projection data map

The Siberian coniferous forest was analysed using the 3D vector model constructed. As a whole, the modal length of the vector of the current forest plan is 1.008 and the angle with the standard vector is 13 degrees, which indicates that the vector of the current plan is not very different from the standard vector, which is also consistent with the prediction of CO2 uptake I got for this forest using the metabolic GM (1, 1) model for almost one hundred years (the annual carbon sequestration is gradually increasing) I obtained the prediction of CO2 uptake by making my vector to the standard vector projection to obtain an improved direction vector.

6. Conclusion

I constructed a vector evaluation model in R3 space to analyse forest value. The strength of the model is applying the innovative 3D vector valuation model, so I can determine the forest value visually and use the data of mode length, pinch angle, etc. to make further decisions. Besides, I integrate the use of subjective hierarchical analysis and objective CRITIC assignment method to get more convincing weighting results. However, the weakness of my model is that some of the data are obtained by interpolation fitting, which is not realistic. This is a problem that future researchers need to address.

References

[1] Guthrie G A, Kumareswaran D K Carbon subsidies and optimal forest management [J] Social Science Research Network (SSRN), (18p.), 2003.

[2] Barrett, Christopher B, et al. “Forest Value: More than Commercial - Response.” Science (American Association for the Advancement of Science), vol. 354, no. 6319, 2016, pp. 1541 – 1542.

[3] Zhao, Jing, et al. “Forest Carbon Reserve Calculation and Comprehensive Economic Value Evaluation: A Forest Management Model Based on Both Biomass Expansion Factor Method and Total Forest Value.” International Journal of Environmental Research and Public Health, vol. 19, no. 23, 2022, p. 15925.

[4] Keller, Victor, et al. “Coal-to-Biomass Retrofit in Alberta –Value of Forest Residue Bioenergy in the Electricity System.” Renewable Energy, vol. 125, 2018, pp. 373 – 383.

[5] Schall, Peter, et al. “Among Stand Heterogeneity Is Key for Biodiversity in Managed Beech Forests but Does Not Question the Value of Unmanaged Forests: Response to Bruun and Heilmann-Clausen (2021).” The Journal of Applied Ecology, vol. 58, no. 9, 2021, pp. 1817 – 1826.

[6] Lidestav, Gun, et al. “Forest Social Values: The Case of Dalasjö, Sweden.” Scandinavian Journal of Forest Research, vol. 35, no. 3-4, 2020, pp. 177 – 185.

[7] Bjarstig, Therese, and Emma Kvastegard. “Forest Social Values in a Swedish Rural Context: The Private Forest Owners' Perspective.” Forest Policy and Economics, vol. 65, 2016, pp. 17 – 24.

[8] Rodríguez-Piñeros, Sandra, and Yesica Mayett-Moreno. "Forest Owners' Perceptions of Ecotourism: Integrating Community Values and Forest Conservation." Ambio, vol. 44, no. 2, 2015, pp. 99 – 109.

[9] Olschewski R, Benitez P C. Optimizing joint production of timber and carbon sequestration of afforestation projects [J]. Journal of Forest Economics, 2010, 16 (1): 1 - 10.