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Analysis of Forest Carbon Sink Projections in China

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ABSTRACT

As carbon emissions continue to increase, forest carbon sinks can effectively neutralize carbon emissions, and predicting the potential of forest carbon sinks is of great significance to the achievement of the “double carbon” goal. In view of this, the forest carbon sink in the study area was calculated using the forest stock expansion method based on the national forest inventory data. On this basis, future forest carbon sinks were simulated and trended using a gray prediction GM (1, 1) model. The results show that the national and provincial forest carbon sinks are in an increasing trend from 2019-2028, with differences in forest carbon sinks in different provinces. Therefore, in the construction and management of forests in the future, we should comprehensively combine the geographic characteristics of different regions in China, follow the principle of adapting to local conditions, reasonably formulate forestry development plans for each region, give full play to the radiating role of provinces rich in forest carbon sinks, make full use of the advanced experience of their forest carbon sinks, improve the quality of existing forests, promote the enhancement of the function of forest carbon sinks, and effectively drive the development of forest carbon sinks in other regions, so as to promote the realization of China's “dual-carbon” goal.

KEYWORDS

Forest carbon sinks; GM (1, 1) model; Prediction

1. INTRODUCTION

In order to meet the challenge of global warming, which is becoming increasingly serious as a result of the continued rise in carbon emissions, the international community has generally agreed to mitigate the climate crisis through the implementation of carbon emission reduction measures and the enhancement of the capacity of carbon sinks. To this end, several countries and regions have participated in the signing of a number of global climate agreements, which have set higher standards for the future development of forest carbon sinks. At the same time, China has also clearly put forward the national strategic objectives of “carbon peaking” and “carbon neutrality” in order to actively respond to the trend of global climate change. Forests are powerful carbon sinks, absorbing atmospheric carbon dioxide and fixing and storing it in vegetation or soil, absorbing about 80 per cent of carbon dioxide in terrestrial ecosystems. On the one hand, forest carbon sinks are a key countermeasure to global climate change and an important way for China to realize the “double carbon” goal; on the other hand, China has become a major carbon emitter in the world, and energy conservation and emission reduction are essential to slow down global warming. Therefore, it is of great practical significance to analyze the forecast of forest carbon sinks in China: on the one hand, it can provide a basis for decision-making on the scientific development and sustainable use of forest resources, and on the other hand, it can help to improve the forestry management policy system, and thus promote the realization of China's “dual-carbon” strategic goal.

Forest carbon sink refers to a capacity or process of forest ecosystem as a main body to absorb and store CO2. Currently, forest carbon stock measurement methods can be divided into three main categories: sample survey method, micrometeorological method and remote sensing estimation technology. Overseas researchers often combine one or more of these methods to assess forest carbon stocks. In contrast, China's research in the field of forest carbon stock measurement started relatively late, coupled with the limitations of technology and equipment conditions, and mainly focuses on the sample-plot survey method for relevant measurements. Existing studies generally use forest resources census data as the basic data source, mainly centered on national or regional scale forest carbon stock assessment to carry out empirical analysis [1], on the estimation of forest carbon sinks are relatively more applications of the average biomass method, the biomass conversion factor continuous function method and the expansion of the forest stock method, the price of the unit of forest carbon sinks are mainly used in the market price, silvicultural cost and carbon tax, etc. [2, 3]. Li Shunlong pioneered the use of the stock expansion method to systematically measure the dynamic changes of China's forest carbon stocks during the period of 1973-2003 for the first time [4]. This research method has significant advantages: firstly, the calculation method is simple and efficient; secondly, it is practical and operative; thirdly, it provides a replicable research paradigm for the economic analysis of forest carbon sinks, which is of great significance in guiding the methodology of subsequent related studies. Scholars generally agree that the stock extension method is technically less demanding and easy to operate, and also fully considers and distinguishes the carbon sequestration of different types of vegetation in forests, and the calculation is more macroscopic, which is suitable for calculation on a provincial basis.

Based on different levels and perspectives, domestic and foreign scholars have been increasing their research on the spatial distribution, influencing factors and value realization of forest carbon sinks, which has provided rich materials for the subsequent research on forest carbon sinks. Scholars such as Zhao Mingwei and Mao Jiangtao pointed out that estimating forest carbon sinks while exploring their spatial distribution characteristics can help to continuously improve the forest carbon cycle, and at the same time can also provide theoretical support for carbon trading decision-making [5, 6]. Scholars have explored the influencing factors of forest carbon sinks from the aspects of economic development [7], forest management capacity [8-10] and forest disasters [11], and found that all these factors have an important influence on forest carbon sinks; at the same time, the enhancement of forest carbon sequestration capacity mainly depends on the accumulation of vegetation biomass and the formation process of soil carbon pools, and the amount of precipitation and the high and low temperatures also have an influence on forest. There are also scholars who combine spatial effects and influencing factors for analysis, Fu Wei et al. used the forest stock expansion method to estimate the forest carbon sinks of China's 31 provinces (municipalities and autonomous regions) in the six times in 1993-2018, based on which the analysis of spillover effects and influencing factors was carried out, which provides theoretical support for the formulation and implementation of differentiated forest carbon sink policies in China's various regions [12]. Peng Hongjun et al. through the comprehensive study of forestry carbon sink product value realization path, concluded that forestry carbon sink value realization can be realized through the government, industry and financial paths [13], but they all have their own shortcomings, so that the realization of the value of forestry ecological products is impeded, and Dong Bingrui et al. put forward a brand new way of green asset securitization, which can effectively solve the problem of the funding of the main body of the green project of the long cycle and large investment [14]. Zhang Qian et al. examined the relationship among the three subsystems of forest, carbon and socio-economic interactions and the degree of mutual influence from the perspective of “forest resources-carbon market-socio-economic” system, and explored the path of realizing the value of carbon sinks in forestry and the influencing factors on this basis [15].

Summarizing the existing research results, the academic community has accumulated a rich research foundation in the field of forest carbon sinks, and these theoretical explorations and methodological innovations provide important support for the in-depth development of future research. However, relevant research on forest carbon sinks mainly focuses on spatial distribution, influencing factors and value realization, and seldom predicts the amount of forest carbon sinks. In view of this, based on the forestry statistics of provincial-level administrative units (excluding Hong Kong, Macao and Taiwan) across the country, a quantitative assessment of the carbon sequestration capacity of forest ecosystems at the regional scale was carried out by applying the method of expanding the forest stock, and a gray system GM(1, 1) model was constructed to predict the amount of carbon sinks in forests, with a view to providing scientific basis for formulating the strategy of responding to climate change, enhancing the function of forest ecosystems in carbon sequestration, and planning for the path of regional differentiated development. In order to provide a scientific basis for the formulation of climate change response strategies, the enhancement of forest ecosystem carbon sequestration functions and the planning of regional differentiated development paths, and thus to promote the realization of the strategic goals of carbon peaking and carbon neutral.

2. OVERVIEW OF THE STUDY AREA

In the beginning, although China was very vast, forest resources were not abundant, and there was some variation from region to region. However, with the continuous implementation of the natural forest protection project, forest resources are being enriched, and the data of the ninth national forest resources census show that the total area of forest vegetation in China accounts for 22.96% of the national territory, and the total standing wood stock is about 17.56 billion cubic meters. Considering the convenience of obtaining raw data, 31 provinces (cities and districts) in mainland China were used as the study area.

3. DATA SOURCES AND RESEARCH METHODOLOGY

3.1. Data Sources

In this study, provincial-level administrative units across the country (excluding Hong Kong, Macao and Taiwan) were selected as the study sample, and the forest resource data were obtained from the authoritative statistical sources China Environmental Statistical Yearbook and the National Forest Resources Inventory Report. Considering the continuity and availability of the research data, and taking into account the fact that China's forest resources census is characterized by a five-year cycle, data from the sixth (1999-2003), seventh (2004-2008), eighth (2009-2013) and ninth (2014-2018) inventories were selected for the relevant analysis.

3.2. Research Methodology

3.2.1. Forest Carbon Sink Measurements

According to the research of past scholars, the forest stock expansion method is used to calculate the forest carbon sink [2, 4], and the accounting formula for the forest carbon sink is:

$$C_F = C_B + C_V + C_S \tag{1}$$

$$C_F = \sum(S_{ij} * C_{ij}) + \alpha \sum(S_{ij} * C_{ij}) + \beta \sum(S_{ij} * C_{ij}) \tag{2}$$

$$C_{ij} = V_{ij} * \delta_j * \rho_j * \gamma_j \tag{3}$$

The letters in the formula indicate the meaning as shown in Table 1:

Table 1. Meanings of letters related to forest carbon sink measurement

letter	connotation
C_F	Total forest carbon sink
C_B	Carbon sinks in forest biomass
C_V	Carbon sinks from understory vegetation
C_S	Carbon sinks in forest soils
S_{ij}	Area of forest type j in area i
C_{ij}	Carbon intensity of forest type j in area i
V_{ij}	Volume per unit area of forest type j in area i
α	Conversion factor for carbon sequestration by understory plants
β	Conversion factor for carbon sequestration on forest land
δ	Coefficients for converting forest stocks to biomass stocks
ρ	Coefficient of conversion of forest biomass accumulation to biological dry weight
γ	Coefficient of conversion of biological dry weight to carbon sequestration

In addition, according to a report published by the IPCC (United Nations Intergovernmental Panel on Climate Change), taking the $\alpha = 0.195,\ \beta = 1.244,\ \delta = 1.90,\ \rho = 0.5,\ \gamma = 0.5$ [16].

3.2.2. Gray Prediction GM (1, 1) Model

Gray prediction model is a research method for quantitative analysis and prediction of systems with incomplete information, which is characterized by the ability to effectively deal with the complex relationship between partially known and partially unknown existing in the system, and helps to solve the problems of small sample size, little or incomplete data information, etc. Forest carbon sinks are faced with the problem of little data information due to the law that the national forest inventory is carried out once every five years, so we consider using the Gray prediction GM (1, 1) model is considered to solve this major problem. The gray prediction GM (1, 1) model generates a new discrete data sequence by performing one cumulative generation operation on the original random discrete non-negative data sequence. On this basis, the corresponding differential equation model is constructed and the solution of the first-order linear differential equation is utilized to fit the regularity characteristics exhibited by the cumulatively generated time series. The method requires only one data series to complete the whole calculation process. Its solution steps can be divided into data checking, model building, model solving and model checking.

4. FORECASTING AND ANALYZING CHINA'S FOREST CARBON SINKS

The forest carbon sinks of each province in China were calculated by the forest stock expansion method, and the gray prediction GM (1, 1) model was applied to predict the forest carbon sinks from 1999 to 2018.

4.1. Data Verification

Before model building and solving, it is necessary to test the forest carbon sink data of Chinese provinces from 1999 to 2018 (i.e., the sixth to ninth national forest inventory) to determine whether the data are applicable to the gray prediction GM (1, 1) model. Data testing has a smooth ratio test and level test two methods, usually one of the two can be, a test method through the gray predictive GM (1, 1) model can be used. The test method used in the study is the level test, the reason is that when the level test is not passed, there is a corresponding solution, which is explained as follows: when the level test is performed, if the level test is successfully passed, which is equivalent to the constant term c = 0, then the prediction will be performed directly; if the level test is not passed, the level test can be passed by adding the constant term c for the translation, so that it will fall into the interval, and then use the new array to Prediction, accordingly, the predicted results at the same time minus the constant c is the final prediction. The python 3.9 software was used to test the level of forest carbon sink data of the whole country and provinces, and the results showed that the data of the whole country and provinces could pass the level test directly or after leveling.

4.2. Modeling and Solving

Table 2. Forecast of forest carbon sinks by province in China, 1999-2028

Region	Projected carbon sinks [Ten thousand tons]					
	1999-2003	2004-2008	2009-2013	2014-2018	2019-2023	2024-2028
China	1443040.88	1570637.00	1780235.00	2017803.00	2287074.00	2592278.00
Beijing	973.97	1078.00	1762.00	2706.00	4005.00	5796.00
Tianjin	162.60	258.00	384.00	546.00	754.00	1022.00
Hebei	7541.91	9670.00	12361.00	15801.00	20198.00	25819.00
Shanxi	7182.77	8699.00	11333.00	14765.00	19236.00	25062.00
Inner Mongolia	127615.18	136377.00	155251.00	176737.00	201196.00	229041.00
Liaoning	20247.04	23593.00	28521.00	34477.00	41678.00	50383.00
Jilin	94588.36	97633.00	106961.00	117179.00	128374.00	140638.00
Heilongjiang	159299.86	174742.00	192779.00	212677.00	234630.00	258848.00
Shanghai	38.51	80.00	253.00	489.00	808.00	1242.00
Jiangsu	2647.54	4683.00	6416.00	8543.00	11155.00	14360.00
Zhejiang	13364.57	19682.00	25177.00	32204.00	41189.00	52679.00
Anhui	12016.11	16144.00	20372.00	25707.00	32439.00	40935.00
Fujian	51389.11	56537.00	69119.00	84502.00	103308.00	126300.00
Jiangxi	37658.09	44016.00	50203.00	57261.00	65311.00	74493.00
Shandong	3709.19	7876.00	9354.00	11022.00	12902.00	15024.00
Henan	9736.99	15247.00	19181.00	24071.00	30149.00	37705.00
Hubei	17848.98	24586.00	32198.00	42167.00	55223.00	72321.00
Hunan	30740.84	38491.00	41851.00	45504.00	49476.00	53795.00
Guangdong	32862.29	33910.00	42481.00	53218.00	66669.00	83520.00
Guangxi	42259.82	51610.00	62787.00	76385.00	92928.00	113054.00
Hainan	8335.77	7390.00	11478.00	16932.00	24208.00	33915.00
Chongqing	9779.20	12676.00	17231.00	23423.00	31839.00	43279.00
Sichuan	173249.72	182969.00	197843.00	213926.00	231317.00	250121.00
Guizhou	20616.79	27367.00	35029.00	44836.00	57389.00	73456.00
Yunnan	162111.43	177276.00	200249.00	226200.00	255514.00	288626.00
Tibet	262529.19	260073.00	262210.00	264365.00	266537.00	268727.00
Shaanxi	35654.50	38781.00	46201.00	55042.00	65574.00	78121.00
Gansu	20279.20	22121.00	25289.00	28911.00	33051.00	37784.00
Qinghai	4162.14	4517.00	5037.00	5617.00	6263.00	6983.00
Ningxia	455.13	576.00	745.00	965.00	1248.00	1616.00
Xinjiang	32484.67	34507.00	39454.00	45110.00	51577.00	58971.00

According to the principle of the gray prediction GM (1, 1) model, the corresponding model code was written, and Python 3.9 software was used to predict the forest carbon sinks of the whole country and provinces from 1999 to 2028. For the provinces that passed the level test, the original data series is directly input into the code to solve and get the predicted data series; for the provinces that failed the level test, the original data series is added with the corresponding constant term c to get a new set of data series, and the new data series is input into the code to solve and get the predicted data series, and then subtracted from the corresponding constant term c to get the final predicted data series. Finally, the projected forest carbon sinks of each province in China from 1999 to 2028 were obtained as shown in Table 2. It is predicted that the forest carbon sinks of all provinces in China are in a growing trend from 2019-2028, and the predicted forest carbon sinks of China for the 10th National Forest Inventory (2019-2023) and the 11th National Forest Inventory (2024-2028) are 2,287,074,0000 tons and 2,592,278,0000 tons, respectively, which indicates that China's forest carbon sinks are becoming more and more abundant.

4.3. Model Testing

The prediction accuracy of the model was tested from three indicators, which were accuracy, variance ratio and small probability error, and the corresponding code was written according to the principle, and Python 3.9 software was used to perform the operation, and the prediction model of forest carbon sinks in the whole country and provinces from 1999 to 2018 was examined, and it was found that the variance ratio of the whole country and provinces was within the range of [0, 0.35], and the small probability error was 1, which were within the range of (0.95, 1] range, and the prediction accuracies are above 90%, indicating that each prediction model is excellent, the prediction data have credibility, and the prediction fit is high.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The forest carbon sinks of 31 provinces (municipalities and districts) in mainland China were measured from 1999 to 2018 using the forest stock method with the province as the research unit. On this basis, the forest carbon sinks of the whole country and provinces were predicted and analyzed by using the grey prediction GM (1, 1) model, and the following conclusions were drawn: the forest carbon sinks of the whole country and the 31 provinces in China showed an increasing trend, and there are differences in forest carbon sinks among different provinces, and provinces of southwest forest area and northeast forest area are very rich in forest carbon sinks, followed by provinces of south forest area, and provinces of other forest areas are the least.

5.2. Recommendations

Based on the above conclusions, the following suggestions are made: in the future, when building and managing forests, the geographic characteristics of different regions in China should be comprehensively combined, the principle of adapting to local conditions should be followed, the forestry development plan of each region should be reasonably formulated, the radiation effect of the Southwest Forestry Region and the Northeast Forestry Region should be played. Eventually, it will make full use of their advanced experience in forest carbon sinks, improve the quality of existing forests, promote the enhancement of the function of forest carbon sinks, effectively drive the development of forest carbon sinks in other regions, and promote the realization of the goal of “double carbon” in China.

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