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Analysis and Prediction of Forest Carbon Storage and Carbon Sequestration Capacity in China

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Abstract: *In order to cope with the greenhouse effect and achieve the double carbon goal, China has become the key work of continuous promotion. As the largest carbon pool of terrestrial ecosystem, the research on forest carbon sequestration capacity and carbon storage can not be ignored. China has a vast territory, with a national forest area of 22000 hectares, ranking fifth in the world. The research on China's forest carbon sequestration capacity is of great significance to the world's double carbon goal, In this paper, the biomass method will be used to estimate the forest carbon reserves of relevant provinces in China, the remote sensing model will be used to analyze the net primary productivity of China's terrestrial ecosystem, and then estimate the carbon sequestration capacity of China's forests, and then the grey prediction model will be established to predict the changes of China's forest carbon reserves in the next few years, so as to predict the carbon sequestration potential.*

Keywords: *carbon storage, grey prediction model, carbon sequestration capacity*

1. Research background

With the process of human development entering the 21st century of rapid industrialization, it is an indisputable fact that the sharp increase of carbon emissions in various countries leads to the sharp increase of greenhouse gases. Climate change caused by the greenhouse effect will pose a great threat to the survival of life on earth. Under this background, countries all over the world strive to find the most appropriate way to reduce carbon emissions. As the largest carbon market covering carbon dioxide emissions in the world, China, It is incumbent on us to achieve "zero emission" of carbon dioxide. Since then, the implementation of the double carbon goal has become the focus of China's continuous promotion.

As the main body of terrestrial ecosystem, forest is the largest carbon pool. Forest carbon sequestration will be one of the economic and effective ways to deal with climate change and achieve the dual carbon goal. Forest carbon storage has naturally become one of the focuses of our research on carbon balance. China has a vast territory and the forest area ranks fifth in the world, but the carbon storage is not sufficient, and the carbon sequestration capacity still has great potential. This paper will focus on the research of China's carbon storage from a global perspective, which can effectively obtain the forest carbon storage data and its carbon sequestration capacity, and then make a reasonable prediction of the future change of carbon storage [1].

2. Analysis of forest carbon storage and carbon sequestration capacity in China

2.1. Estimation of carbon sequestration by biomass method

Forest carbon storage can be used as an alternative indicator of forest carbon sequestration [2]. The size of carbon storage can directly reflect the size of carbon sequestration, and then reflect the size of forest carbon sequestration capacity. The biomass method is selected in this study, which can be expressed as:

$$\mathrm{FC} = C_t \times A \tag{1}$$

where FC is the carbon sequestration of a certain tree species, C_t is the average carbon density of a tree species. A is the total area of a tree species.

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2.2. Estimation of forest carbon storage

According to the forest resources inventory method recognized by international organizations and countries all over the world, there is a linear relationship between forest biomass (b) and forest volume (V). In this paper, the biomass conversion factor continuous function method suitable for China is selected to estimate the biomass of forest stands in various provinces. Through the data of biomass and stock conversion parameters a and B, the forest carbon reserves are calculated scientifically by biomass method, which can be expressed as:

$$B = aV + b \tag{2}$$

where B is the stand biomass per unit area of a certain tree species (t/hm^2), V is the stand volume per unit area of a tree species (m^3/hm^2). a and b are the conversion parameters of biomass and stock.

By querying the forest resources inventory data compiled by the State Forestry Administration, we can get the relationship between the stand biomass per unit area and the stand volume per unit area of each tree species, so as to calculate the biomass, and then obtain the forest carbon reserves of each province through the biomass. This paper selects some representative tree species: oak forest, Chinese fir forest, larch forest, birch forest, poplar forest, masson pine forest, eucalyptus forest, spruce forest, Yunnan pine forest and cypress forest. The planting range of these tree species covers most of China and can effectively represent China's forests as the research object. The biomass equation of each dominant tree species is shown in table 1.

Table 1: Accumulation biomass equation of dominant tree species in China

Dominant tree species	a	b	Biomass equation
Oak forest	1.1453	8.5473	1.1453V+8.5473A
Chinese fir forest	0.3999	22.5410	0.3999V+22.5410A
Larch forest	0.6096	33.8060	0.6096V+33.8060A
Birch forest	1.0687	10.2370	1.0687V+10.2370A
Poplar forest	0.4754	30.6034	0.4754V+30.6034A
Pinus massoniana	0.5101	1.0451	0.5101V+1.0451A
Eucalyptus forest	0.8873	4.5539	0.8873V+4.5539A
Spruce forest	0.4642	47.4990	0.4642V+47.4990A
Yunnan pine forest	0.5101	1.0451	0.5101V+1.0451A
Cypress forest	0.6129	46.1451	0.6129V+46.1451A

At present, international organizations and countries all over the world generally use the method of calculating forest carbon reserves by directly or indirectly obtaining forest biomass and multiplying it by the content of carbon element in biomass (carbon content coefficient), which can be expressed as:

$$C = B \times C_c \tag{3}$$

where C is carbon storage (t), C_c is the carbon content coefficient.

After calculation, the carbon reserves of oak forest, Chinese fir forest, larch forest, birch forest, poplar forest, masson pine forest, eucalyptus forest, spruce forest, Yunnan pine forest and cypress forest in China are shown in table 2. It is concluded that carbon storage is directly and positively affected by forest area and forest accumulation. In addition, the comparison shows that the eucalyptus forest with the largest carbon coefficient has the smallest carbon storage, while the oak forest with the smallest carbon coefficient has the largest carbon storage. Therefore, it is concluded that the carbon coefficient has no significant effect on the carbon storage.

Table 2: Carbon reserves of dominant tree species in China

Dominant tree species	Biomass	Carbon content coefficient	Carbon reserves (100 million tons)
Oak forest	17.6597	0.5004	8.8369
Chinese fir forest	5.97387	0.5201	3.1070
Larch forest	10.5085	0.5211	5.4759
Birch forest	10.9255	0.4914	5.3688
Poplar forest	5.43768	0.4956	2.6949
Pinus massoniana	3.27760	0.4596	1.5064
Eucalyptus forest	2.16226	0.5253	1.1358
Spruce forest	6.66019	0.5208	3.4383
Yunnan pine forest	2.60014	0.5113	1.3295
Cypress forest	3.13325	0.5034	1.5773

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In this study, the carbon storage is calculated, and each tree species is divided into young forest, middle-aged forest, near-aged forest, mature forest and transition forest according to the age group, which makes the data more comprehensive. At the same time, it can also understand the changes of carbon storage during the growth of each tree species through the data. After calculation, the carbon reserves of different age groups of dominant tree species in national natural arbor forest are shown in table 3. This paper reduces the impact of incomplete data on the analysis by comparing the average. The order of carbon storage from large to small is medium-aged forest > mature forest > over mature forest > near mature forest > young forest.

Table 3: Carbon reserves of different age groups of dominant tree species in national natural arbor forest (10000 tons)

Dominant tree species	The forest age group					Total
	Young forest	Middle aged forest	Near mature forest	Mature forest	Over mature forest	
Fir	411.9108	2840.5450	3810.8724	11231.7060	20892.2350	39187.2693
Spruce	1177.8578	4074.9185	5901.3104	12160.2213	8294.7228	31609.0309
Hemlock spruce		26.3277	110.4008	401.9163	1055.7229	1594.3678
Keteleeria	156.4866	241.9462	239.9386	173.4387	19.7720	831.5821
Larch	595.4099	20142.1186	5553.3326	6610.9648	6319.5601	39958.6949
Korean pine		92.4417	30.9493	195.1238.	178.3790	496.8938
Mongolica	195.2976	1217.6782	434.5162	605.3876	286.8569	2739.7365
Red pine	89.7947	222.3347	101.1492	10.6801		423.9587
Chinese pine	172.1813	791.4079	870.7665	486.2879	286.6155	2607.2591
Pinus armandii	110.0656	238.8214	299.9797	327.6543	293.2428	1269.7639
Masson Pine	1182.9052	4788.6930	3607.6412	1773.0756	118.5725	11470.8875
Yunnan Pine	612.2041	2936.8799	3429.1730	3679.7036	1491.3788	12149.3394
Si Maosong	63.2577	313.7996	473.8836	342.7332	105.7973	1299.4714
Other pines	25.6521	58.2174	47.3034	22.4914	58.0275	211.6919
Fir wood	495.4553	1171.9119	394.8140	915.7796	355.4980	3604.0636
Cryptomeria fortunei	13.5798		10.6870			24.2668
Cypress	3029.5732	1293.3731	844.3763	1252.3186	1440.0153	9361.9102
Quercus	16391.033	19103.596	18098.167	2821.532	11142.643	84398.608
Birch	4295.021	11141.546	13601.044	17103.380	8073.262	54214.251
Camphor wood	74.0359	114.2481	35.6462	28.1918		266.2657
Nanmu	124.8331	234.6859	213.2242	87.1790	186.5751	846.4971
Poplar	370.3362	344.5874	499.0019	508.7511	430.4950	2619.3896
Casuarina equisetifolia		1.8544				1.8544
Needle width mixing	8142.538	20260.079	9732.736	8561.853	3351.633	50048.839
Total	37729.429	91652.01	68340.91	69105.25	64381	351235.9
Average	1796.6395	3984.87	2971.344	3290.726	3219.05	14634.83

2.3. Analysis on the relationship between carbon sequestration capacity and carbon storage

China has a vast forest area, large carbon reserves and carbon density, strong carbon sequestration capacity and high carbon sequestration rate. Among them, the size of forest area determines the size of carbon storage, carbon density, carbon sequestration capacity and carbon sequestration rate. The larger the forest area, the greater the carbon storage and carbon density, the stronger the carbon sequestration capacity and the greater the carbon sequestration rate.

In terms of forest age, the carbon sequestration capacity of middle-aged forest is the highest, followed by mature forest. The tree species in these two age groups have a strong ability to capture carbon and store it safely, which also replaces the direct emission of carbon dioxide into the atmosphere and plays

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an important role in the improvement of ecological environment and greenhouse effect. In different age groups, the order of carbon sequestration capacity from large to small is medium-aged forest > mature forest > over mature forest > near mature forest > young forest.

3. Carbon storage prediction based on grey GM

The grey prediction model whitens the grey information in the original data through sequence operators such as accumulation generation and subtraction generation, constructs difference and differential equation models, and finally completes the description and prediction of the development trend of system behavior sequence [3].

As an important part of terrestrial ecosystem, forest carbon cycle is of great significance for global carbon cycle and mitigation of global climate change. Based on the data of 9 forest resource inventories in China, this study uses GM (1, 1) model to predict the future forest area and forest carbon storage in China. The main prediction process is as follows:

The grey differential equation model of GM (1,1) is defined as:

$$\mathrm{x}^{(0)}(\mathrm{k})+\frac{1}{2}\mathrm{z}^{(1)}(\mathrm{k})=\mathrm{b} \tag{4}$$

Using least squares estimation:

$$U=\begin{bmatrix}a\\b\end{bmatrix}=(\mathrm{B}^{\mathrm{T}}\mathrm{B})^{-1}\mathrm{B}^{\mathrm{T}}Y \tag{5}$$

The whitening model is determined as:

$$\frac{\mathrm{x}^{(1)}(\mathrm{t})}{dt}+a\mathrm{x}^{(1)}(\mathrm{t})=\mathrm{b} \tag{6}$$

The time response function is:

$$\mathrm{y}\ ^{(1)}(\mathrm{t})=(\mathrm{x}^{(0)}(1)-\frac{b}{a})\mathrm{e}^{-\mathrm{a}(\mathrm{t}-1)}+\frac{b}{a} \tag{7}$$

The predicted value is solved by replacing the time response function:

$$\mathrm{x}\ ^{(0)}(\mathrm{k}+1)=\mathrm{x}\hat{}^{(1)}(\mathrm{k}+1)-\mathrm{x}\hat{}^{(1)}(\mathrm{k}) \tag{8}$$

Test the model results:

The GM (1, 1) model is tested by relative residual test:

$$\varepsilon_k=\mathrm{x}^{(0)}(\mathrm{k})-\mathrm{x}\hat{}^{(0)}(\mathrm{k}) \tag{9}$$

$$\Delta_k=\frac{|\varepsilon_k|}{|\mathrm{x}^{(0)}(\mathrm{k})|} \tag{10}$$

The average relative error of forest carbon storage and forest area is 0.396 and 0.235, both less than 0.05. The results are shown in table 4.

Table 4: Error inspection table

Year	Actual value of forest carbon storage/10^2 TG	Predicted value of forest carbon storage/10^2 TG	Residual (ε_k)	Relative error (ε)
1973-1976	47.44	47.44	0.00	0.00%
1977-1981	49.27	44.51	4.76	9.66%
1984-1988	49.87	48.11	1.76	3.53%
1989-1993	49.59	52.00	-2.41	4.86%
1994-1998	53.52	56.21	-2.69	5.03%
1999-2003	59.17	60.76	-1.59	2.69%
2004-2008	63.47	65.67	-2.20	3.47%
2009-2013	70.20	70.99	-0.79	1.13%
2014-2018	81.03	76.73	4.30	5.31%
Average relative error				3.96%

The GM (1,1) model was tested by mean square deviation ratio:

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$$\overline{X} = \frac{1}{9}\sum_{k=1}^{9} x(k) \tag{11}$$

$$S_1{}^2 = \frac{1}{9}\sum_{k=1}^{9}(x(k) - \overline{x})^2 \tag{12}$$

$$\overline{\varepsilon} = \frac{1}{9}\sum_{k=1}^{9} \varepsilon(k) \tag{13}$$

$$S_2{}^2 = \frac{1}{9}\sum_{k=1}^{9}(\varepsilon(k) - \overline{\varepsilon})^2 \tag{14}$$

$$C = \frac{S_2}{S_1} \tag{15}$$

The small error probability test of GM (1,1) model is carried out:

$$p = P|\varepsilon(k) - \overline{\varepsilon}| < 0.6745\ S_1 = 1 \tag{16}$$

The calculation shows that the small error probability of forest carbon storage and forest area is 1, greater than 0.95, so the small error probability is level I. The results are shown in table 5.

Table 5: Prediction accuracy level

Prediction accuracy level	P (small error probability)	C (variance ratio)
Good	>0.95	<0.35
Qualified	>0.8	<0.5
Barely qualified	>0.7	<0.65
Unqualified	≤0.7	≥0.65

To sum up, the GM (1,1) model used in this study has a good fitting degree and the prediction results are more reliable, which can be used to predict China's forest area and carbon reserves. Therefore, the prediction results of forest area and carbon storage in China are shown in table 6.

Table 6: Prediction of forest area and forest carbon stocks in China

Year	Actual value of forest area/10^4 ha	Actual value of forest carbon storage/10^2 TG	Percentage of forest cover	GM (1,1) model	
				Predicted value of forest area/10^4 ha	Predicted value of forest carbon storage/10^2 TG
1973-1976	12186.00	47.44	12.70%	12186	47.44
1977-1981	11527.74	49.27	12.00%	11603	44.51
1984-1988	12465.28	49.87	12.98%	12773	48.11
1989-1993	13370.35	49.59	13.92%	14062	52.00
1994-1998	15894.09	53.52	16.55%	15481	56.21
1999-2003	17490.92	59.17	18.21%	17042	60.76
2004-2008	19545.22	63.47	20.36%	18762	65.67
2009-2013	20768.73	70.20	21.63%	20655	70.99
2014-2018	22044.62	81.03	22.96%	22738	76.73
2019-2023				25032	82.94
2024-2028				27558	89.65
2029-2033				30338	96.90
2034-2038				33399	104.74
2039-2043				36769	113.22
2044-2048				40478	122.38
2049-2053				44562	132.28
2054-2058				49058	142.98
2059-2063				54007	154.55
Average relative error				2.35%	3.96%
Mean square deviation ratio				0.1296	0.2485
Small error probability				1	1

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According to the prediction results of GM (1,1) model, under the current conditions, China's forest area and carbon storage are in a state of sustained and stable growth. From 2024 to 2028, China's forest carbon storage and forest area will reach 89.45×10^2 TG、27558×10^4 ha, increased by 10.64% and 25% respectively compared with the ninth forest resources inventory, and the annual average carbon sequestration is 86.2 TG. By 2038, China's carbon reserves will exceed 100×10^2TG, the forest area will reach 33399×10^4ha, with an average annual carbon sequestration of 118.55tg. According to the continuous function equation of biomass conversion factor mentioned above, there is a positive correlation between forest carbon storage and total forest area, and forest area has a significant impact on forest carbon storage. For this reason, due to the continuous growth of forest area, the prediction results show that forest carbon reserves also rise steadily with it. In addition, due to the structural characteristics of China's forests dominated by middle-aged and young forests, improving the level of forest management is of great significance for expanding the supply of forest carbon sink, maximizing the carbon sequestration function of forest ecosystem and improving the sustainable management level of China's forests, which is conducive to China's early realization of the goal of carbon peak and carbon neutralization and high-quality development with minimum carbon emission [4].

4. Conclusion and Recommendations

Through the analysis of the prediction of China's forest carbon reserves, it can be seen that the current policies of our government are conducive to the steady growth of forest carbon reserves. However, compared with the forest carbon sequestration capacity and carbon reserves of other countries in the world, China's forest policies are still lacking. While learning from the policies and management measures of other countries, we should also formulate forest policies reasonably based on China's current national conditions and ecological environment, in order to increase forest carbon reserves in a scientific range. First of all, reducing carbon emissions is an urgent problem to be solved in China. Research shows that China's total carbon emissions in 2020 will be 9719 million tons ~ 10599 million tons. In recent years, due to the emission of residents' life and industry, China's carbon emissions have rebounded after a short decline. Therefore, low-carbon life is a life attitude that the society should vigorously advocate. The top priority is to strengthen the publicity of low-carbon life in the community or mainstream media and strengthen residents' low-carbon awareness. Secondly, improve the forest protection and management system and strictly supervise the deforestation. Scientists envision reducing carbon dioxide emissions by compressing it and storing it in liquid form on the seabed or in geological structures. In addition, afforestation, returning farmland to forests and other measures can also help to increase forest carbon reserves.

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