Spatial and Temporal Evolution of Forest Carbon Stocks in Fujian Province from 2000 to 2020

Rui Lin

Guangdong University of Finance & Economics, Guangzhou, China

Email: 1969400706@qq.com

Abstract. Forests are important carbon sinks in ecosystems. The process of converting forests to other land-use types will lead to a decrease in the carbon sink potential of ecosystems. It is of research significance to explore the mechanism of the impact of land use change on the spatial and temporal evolution of forest carbon stocks. In this paper, we analyzed the land use change and its spatial distribution pattern based on the land use data of Fujian Province. We then used the inVEST model to estimate the impact of land use change on the carbon stock in Fujian Province. The results show that the proportion of forested land in Fujian Province from 2000 to 2020 is 35.02%. Moreover, the area of forested land is mainly shifted to cropland and artificial land, which have a lower carbon sink potential than that of forested land. The top three carbon stocks in Fujian Province in 2000 and 2020 for each land-use type are forested land, cropland, and artificial land in that order. The most important source of carbon stock in Fujian Province is forest land (84.01%). It is followed by cultivated land (12.84%). The carbon stock in the inland area (high carbon stock) and the coastal area (low carbon stock) of Fujian Province had a decreasing and increasing trend, respectively. The transfer of forest land to cropland dominated the decrease of carbon stock in seven cities of Fuzhou, Sanming, Quanzhou, Zhangzhou, Ningde, Longyan, Nanping, and Ningde in Fujian Province. In comparison, the transfer of cropland to cultivated land dominated the decrease of carbon stock in the two cities of Xiamen and Putian in Fujian Province.

Keywords: Forest carbon stock, Fujian Province, Spatial and temporal evolution, inVEST model

1 Introduction

Environmental issues have always been a topic of global concern and heated debate. Climate change caused by greenhouse gas emissions is one of the main manifestations of global environmental problems. In September 2020, China proposed in the 75th United Nations General Assembly to realize the "carbon peak" by 2030 and "carbon neutral" by 2060 to effectively mitigate global warming caused by carbon emissions. In September 2020, China proposed at the 75th United Nations General Assembly to

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achieve "carbon peaking" by 2030 and "carbon neutrality" by 2060 to effectively mitigate the global warming problem caused by carbon emissions. Carbon sinks and neutrality are closely related (Park et al., 2022) [1]. Carbon neutrality refers to the offsetting of carbon emissions from social activities through afforestation. In contrast, carbon sinks include but are not limited to, the process, activity, or mechanism of utilizing plant photosynthesis to absorb atmospheric carbon dioxide and fix it in vegetation and soil through afforestation (Park et al., 2022)[1], forest management (Xu and Yi, 2022) [2], vegetation restoration (Xiao et al., 2011) [3], etc. Thus, the concentration of greenhouse gases (GHGs) in the atmosphere through processes, activities, or mechanisms can be reduced. Carbon stock refers to the amount of carbon retained in an ecosystem, and when carbon stock is in the process of increasing, it is called a carbon sink (Park et al., 2022) [1].

Land use and land cover change (LUCC) refers to the changes in land cover caused by human changes in land use and management. LUCC is closely related to changes in ecosystem carbon stocks. Due to the variability of carbon density in different land classes, the shift of forests to other land classes caused by LUCC is one of the main factors affecting the change of carbon stock in forest ecosystems (Sun et al., 2017) [4]. Nearly 80% of the aboveground carbon in forest ecosystems globally plays an important role in maintaining carbon balance (Streck and Scholz, 2006) [5] and mitigating climate change (Whitehead, 2011) [6]. Forest ecosystems play a dominant role in the global carbon balance (Chen et al., 2015) [7]. Hence, in regions where forests are the dominant land class, forest area change will dominate the change of carbon stock. The change of forest land area is mainly caused by land use change and deforestation.

Relevant studies have found that deforestation and other land-use change-induced carbon sources accounted for nearly 33% of carbon emissions caused by human activities over the past 150 years (Houghton et al., 2001; Watson et al., 2000) [8][9]. The large-scale transfer of forested land to other land types is the direct cause of the decrease in carbon stocks in terrestrial ecosystems (Chen and Wei, 2022) [10]. From 2000 to 2018, a large amount of carbon loss (about 29.81 Tg C/year) in China was due to deforestation, while carbon gains occurred in measures such as afforestation (Chang et al., 2022) [11]. Overall, LUCC has a significant effect on carbon stocks in Chinese terrestrial ecosystems. Therefore, the study of forest carbon stock based on LUCC is of great significance.

The total value of forest ecological service functions in Fujian Province is about 13.62% of the national average. The vegetation ecological quality index and ecological civilization index rank first in the country, playing a significant role in regulating the climate and carbon cycle above. The study of the spatial and temporal evolution of forest carbon stocks in Fujian Province is conducive to the prediction of the potential of forest carbon sinks, as well as to the in-depth understanding of the characteristics of forest carbon stocks in Fujian Province. It can serve as a reference for the study of the characteristics of forest carbon stocks in other forested areas in China. Based on the study of the spatial and temporal evolution mechanism of forest carbon stock in Fujian Province, this paper analyzes the relationship between forest carbon stock and land use mode in Fujian. It can provide a reference basis for optimizing the land use mode and

increasing the forest carbon stock in Fujian Province. This further brings out the advantages of carbon stock in Fujian's forested areas.

2 Data and methods

2.1 Generalization of the study area

Fujian (23°33′~28°20′N, 115°50′~120°40′E) is located on the southeastern coast of China (Fig. 1 left). It has a subtropical oceanic monsoon climate. It is close to the Tropic of Cancer and is affected by the monsoon circulation and topography. The cumulative temperature for 70% of the province's area that is ≥ 10 ℃ is 5, 000 to 7, 600℃. With rich rainfall and abundant sunshine, the average annual temperature is 17 to 21. The average rainfall is 1, 400 to 2, 000 millimeters. The highest altitude in Fujian Province is 2031 meters and the lowest altitude is -2 meters (Fig. 1 right). It is one of the richest rainfall provinces in China, with favorable climatic conditions. The land area is 124, 000 square kilometers, interspersed with river valleys and basins, with mountains and hills accounting for more than 80% of the province's total area. The terrain is generally high in the northwest and low in the southeast, with a slightly saddle-shaped cross-section.

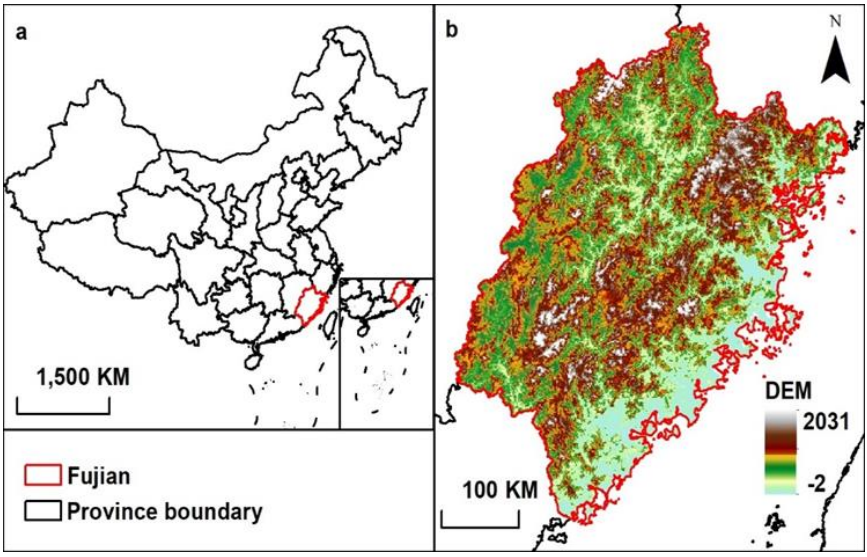

Fig. 1. Study area. (a) Location of Fujian province. (b) Elevation of Fujian province.

2.2 Land use classification

Land use type data were obtained from GlobelLand30 (http://globeland30.org). The spatial resolution is 30 m and includes 10 level 1 types. They are cropland, woodland, grassland, shrubland, wetland, water bodies, tundra, artificial land, bare land, glaciers, and permanent snow. The classification system is shown in the table (Table 1). All data

are in the WGS 1984 World Mercator coordinate system. Among them, the eight level 1 types involved in Fujian Province are cropland, woodland, grassland, shrubland, wetland, water bodies, artificial land, and bare land.

Table 1. Land use type data classification table

Types	Details	Abbreviations
Crop land	Land used for growing crops	Cld
Woodland	Land with tree cover and more than 30% canopy cover	Wld
Grassland	Land covered by natural herbaceous vegetation with over 10% cover	Gld
Shrubland	Woodland consisting of shrub species with greater than or equal to 30% cover	Sld
Wetland	Land located in the border zone between land and water, with shallow standing water or excessively wet soils, where marsh or wet vegetation tends to grow	Wet
Water bodies	Areas covered by land-wide liquid water, including rivers, lakes, reservoirs, pits and ponds	Wtr
Artificial land	Surface formed by artificial construction activities, including towns and other types of residential land, industrial and mining, transportation facilities, etc.	Ald
Bare land	Natural cover land with less than 10% vegetation cover.	Bld

2.3 Carbon stock quantification

inVEST model.

The inVEST model, i.e., Integrated Valuation of Ecosystem Services and Trade-offs, provides a scientific basis for decision-makers to weigh the ecological and economic benefits and impacts of various human activities. It helps them to make effective decisions on natural resource management. Carbon stock calculation based on the inVEST model requires the use of the Carbon module in the model and the estimation of carbon stocks in the current scenario or a time period based on the carbon stocks of four carbon pools. They are above-ground biomass, below-ground biomass, soil, and dead organic matter.

Determination of forest carbon density in Fujian Province.

The inVEST model needs to study the carbon density values of each class in the region. The carbon density data in this paper comes from the results of the 8th National Forest Inventory of Forest Resources in Fujian Province. The study combines the research data of Lin et al. [12], Wu et al. [13][14], and Zheng et al. [15]. The carbon density of the water bodies in Fujian Province is set to 0. Thus, the low-value area is the water bodies area dominated by lakes and rivers. Finally, the carbon density database of Fujian Province is obtained(Table 2).

Table 2. Fujian Province carbon density data

Carbon density	C-above	C-below	C-soil	C-dead

Cropland	14.92	2.98	10.68	0
Woodland	48.88	70.12	11.55	4.71
Grassland	18.24	58.40	11.18	0.24
Shrubland	18.96	5.69	13.62	2.47
Wetland	0.28	1.37	3.03	1.24
Water	0	0	0	0
Artificial land	8.69	1.74	15.88	0
Bare land	19.52	3.9	0.86	0

3 Results and analysis

3.1 Analysis of land use change trends in Fujian Province

In 2020, the proportion of land use area in Fujian Province, in descending order, will be forest land (66.56%), cropland (19.54%), grassland (7.05%), artificial land (4.76%), water bodies (1.57%), shrubland (0.28%), and bare land (0.09%). From 2000 to 2020, forest land, grassland, and artificial land were the three most significant changes in Fujian Province, decreasing from 67.36% to 66.56%, 7.52% to 7.05%, and increasing from 2.68% to 4.76%.

From Fig. 2, it can be seen that the forest land in Fujian Province mainly shifted to grassland and cropland. Grassland, cropland, and bare land, on the other hand, are the main sources of forest land transfer. Among them, 48.89% of the transferred area of forest land is converted to grassland (Fig. 2b). Cropland is mainly converted to artificial land and forest land, with artificial land and forest land accounting for 44.52% and 38.94% of all transferred area of cropland (Fig. 2a). As the top three land use categories in Fujian Province, the main inflow and outflow areas of cropland, forest land, and grassland were transformed among the three. From 2000 to 2020, the areas of cropland transferred to forest land and artificial land were 2253.09 and 2575.92 km^2, respectively, accounting for 15.59% of the original cropland area. The cropland area that remained unchanged was 25183.45 km^2, accounting for 81.31% of the original area. The area of forest land transferred to cropland and grassland was 2793.73 and 3614.43 km^2 (Fig. 2b), accounting for 6.30% of the original forest land area. The area of forest land that remained unchanged was 94359.43 km^2, accounting for 92.73% of the original area. The area of grassland transferred to cropland and forest land was 925.26 and 6342.59 km^2 (Fig. 2c), accounting for 8.14% of the original area. The area of grassland that remained unchanged was 6342.59 km^2, accounting for 55.78% of the original area.

Fig. 2. Land use transfer trend from 2000 to 2020

3.2 Characterization of carbon stock changes under land use change in Fujian Province

In 2000, the carbon stock in Fujian Province was 14387.27×10^5 t. In 2020, it will be 14055.60×10^5 t, with a net decrease of 331.67×10^5 t. Statistics of carbon stock in different land use categories show that the land use categories with the largest net change in carbon stock from 2000 to 2020 are forest land (-417.13×10^5 t), cultivated land (-47.11×10^5 t), and cropland ($+37.14\times10^5$ t), respectively. In 2000, the carbon stocks of forest land, cultivated land, and artificial land in Fujian Province were 13870.16×10^5 t (84.01%), 447.90×10^5 t (12.84%), and 58.36×10^5 t (1.82%). The carbon stocks of forest land, cropland, and artificial land in Fujian Province were 13453.3×10^5 t (84.01%), 447.90×10^5 t (12.84%), and 58.36×10^5 t (1.82%), respectively. In 2020, the carbon stock of forest land, cropland, and artificial land in Fujian Province will be 13453.03×10^5 t (84.56%), 485.04×10^5 t (11.51%), and 11.25×10^5 t (2.56%). In 2000 and 2020, the top three carbon stocks in Fujian Province for each land-use type are consistent with the following: forest land, cropland, and artificial land in the order of forest land, cropland, and artificial land. Compared with 2000, in 2020, the proportion of carbon stock in forest land decreased from 96.41% to 95.71%, cropland increased from 3.11% to 3.45%, and artificial land increased from 0.41% to 0.80%. The proportion of carbon stock in forest land from 2000 to 2010 was 84.01%. In comparison, in 2010-2020, it was 84.56%. The area of forest land decreased from 2000 to 2020. Thus, the carbon stock and total carbon stock of forest land in Fujian Province from 2000 to 2020 are in a decreasing state.

The spatial distribution characteristics of carbon stocks in Fujian Province in 2000 and 2020 (Fig. 3) are calculated. It is found that the spatial distribution characteristics of carbon stocks in Fujian Province are basically the same in 2000 and 2020. In 2000 and 2020, the carbon stocks on the southeast coast of Fujian Province were lower (0-3.62). Most of the inland areas were at the high value (3.62-12.17), and a small portion of the inland areas were at the carbon stock low values (0) and lower values (0-3.62).

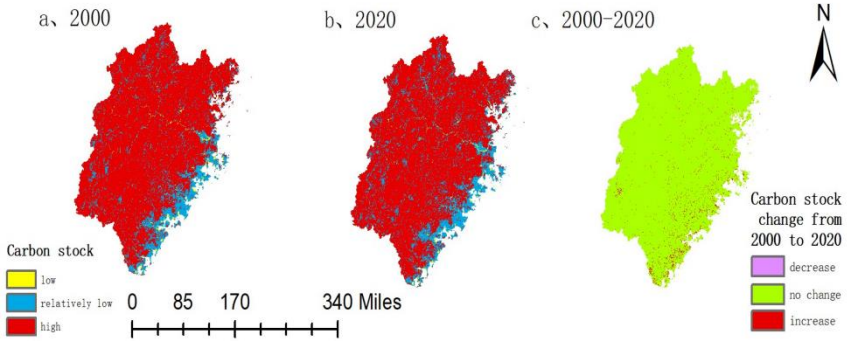

Fig. 3. Changes and distribution of carbon stocks in Fujian from 2000 to 2020

3.3 Trend analysis of carbon stock changes under land use change in Fujian Province

The characteristics of the spatial change of carbon stock in Fujian Province from 2000 to 2020 (Fig. 3) are analyzed. It is found that the carbon stock in Fujian Province is in a decreasing state during the 20 years from 2000 to 2020. Locally, the carbon stock in the inland, northern, southwestern, and part of the western regions remains unchanged. This may be due to the protection of policies in the region, such as forest management. The government enacted the forest law and other measures to limit the harvesting of forests so that the forest land in the region has not been shifted, or on a small scale, to other types of land use with a low potential for carbon sinks. The central part of the southwestern region, as well as a small portion of the southern region and the peripheral regions of Fujian Province, are in a state of decreasing carbon stock. This may be because the proportion of built-up land area in this region has increased over the past 20 years. Moreover, it may also be due to the fact that land use types with high carbon sink potential, such as wooded areas, have shifted to those with low carbon sink potential. Most of the southeastern region, the eastern region, the southern region, and a small part of the western region are in a state of increasing carbon stocks.

During these two decades, the total amount of carbon stock in Fujian Province decreased by 331.67×10^5 t. In general, the decrease in carbon stock was dominated by the transfer of forest land. The spatial change of carbon stock is generally characterized by an increase in the east, a decrease in the west, a high in the south, and a low in the north. The land use change characteristics in Fujian Province mainly show that the proportion of forest land and cultivated land area is decreasing. At the same time, the proportion of built-up land area is increasing, and the total carbon stock of forest land is decreasing. However, the proportion of forest land carbon stock in the total carbon stock is increasing (84.01%-84.56%). In addition, the carbon stock of forest land is becoming more and more important to the overall carbon stock in Fujian. Since the southeast coastal area is mainly an economically developed area with a high urbanization rate and a lot of artificial land, the proportion of forest land and cropland area is lower than that of the inland area. Hence, the carbon stock is at a lower value. Because the inland terrain is complex and difficult to develop, the proportion of artificial land is smaller, and the proportion of land types, mainly forested and cropland, is higher. Therefore, the carbon stock is at a high value.

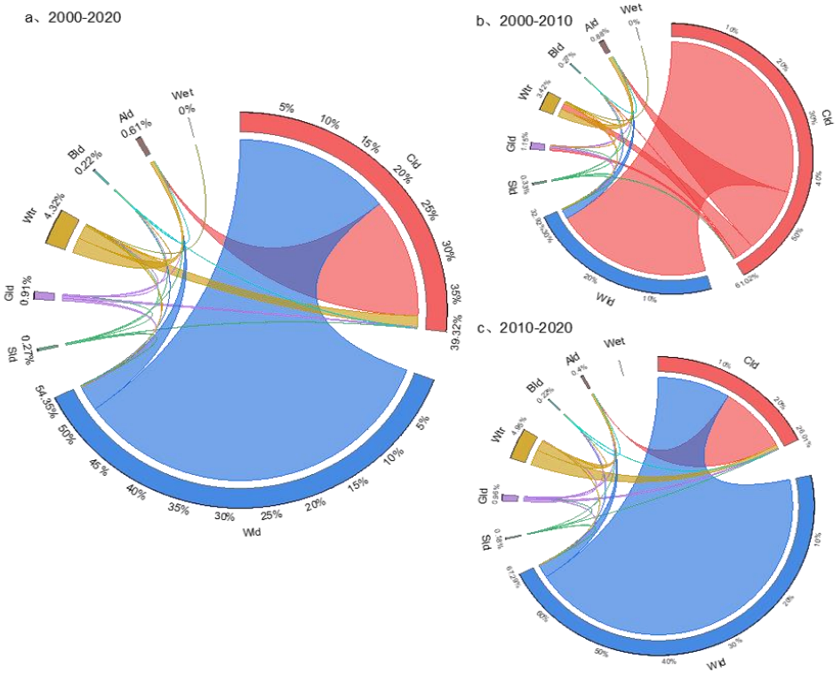

Fig. 4. Land use type changes lead to the changes of carbon stock in Fujian Province from 2000 to 2020

4 Discussion:

During the period from 2000 to 2020, Fujian Province was affected by the urbanization process. The proportion of built-up land area shows a significant upward trend, from 2.68% to 4.76%. Among them, the area of forested land and cultivated land is impacted by the urbanization process. Its area share shows a significant downward trend, with the area share of forested land and cultivated land decreasing from 67.36% to 66.56% and 20.50% to 19.54%, respectively. The increase in carbon stock in Fujian Province is mainly concentrated in the southeastern coastal cities, i.e., Zhangzhou and Quanzhou, as well as Ningde City. Changes in carbon stocks due to land use change in Fujian Province are mainly dominated by the conversion between forest land and cropland.

In addition, the changes in forested and cultivated land areas are also related to the local policies of "forest management" and "returning farmland to forest". For example, the southeast coast (Zhangzhou, Quanzhou, Ningde, and Putian cities) has a relatively significant increase. This is caused by the conversion of cultivated land to forest land, thanks to the conversion of cultivated land to forest land. In recent years, policies relating to the protection of forest land on the southeast coast have vigorously developed.

For example, Zhangzhou has actively introduced forestry reform and development policies to accurately improve the quality of forests, thereby strengthening ecosystem protection. Quanzhou has issued a policy to comprehensively strengthen the protection and management of forest resources, realizing a regular regulatory mechanism for forest resources. From the carbon stock transfer matrix (Fig. 4) and the carbon stock change transfer matrix, it can be concluded that the carbon stock loss in Fujian Province is mainly caused by this land use situation of transferring forest land to cropland. 24.35% of the carbon stock loss in forest land is caused by the transfer of forest land to cropland (20%) and bare and artificial land (4.35%). Statistically analyzing nine cities in Fujian Province, the shift of forest land to cropland is the most important reason for carbon stock loss in seven cities, namely Fuzhou (56.79%), Sanming (85.31%), Quanzhou (46.76%), Zhangzhou (60.93%), Ningde (82.35%), Longyan (78.34%), and Nanping (84.03%). Conversion of arable land to artificial land is the main reason for the decrease of carbon stock in two cities, Xiamen (76.00%) and Putian (55.74%). The second reason for the decrease of carbon stock in other cities was the conversion of cultivated land to artificial land. The affected cities and the degree of influence were Fuzhou (32.64%), Quanzhou (46.07%), Zhangzhou (28.38%), Nanping (7.68%), Longyan (12.73%), and Ningde (10.90%), respectively. The next reason for the decrease of carbon stock in Sanming City is the reason for forest land to artificial land conversion, which is affected by 7.54%. The next influencing factor for the decrease of carbon stock in two cities, Xiamen and Putian, was the conversion of forest land to cultivated land.

The carbon stock in Fujian Province is generally in a state of decrease from 2000 to 2020. The central part of the southwestern region, as well as a small part of the southern region and the peripheral region of Fujian Province, are in a state of decreasing carbon stock. This may be affected by urbanization and industrialization, resulting in the transfer of land use types from those with a high potential for carbon sinks (such as forested land) to those with a low potential for carbon sinks (such as artificial land). The carbon stock in the inland region, the northern region, the southwestern region, and part of the western region remain unchanged. This is a situation that may be affected by topographical factors that make it difficult to develop. This could lead to no or small-scale transfer of forest land in the region to other land-use types with low carbon sink potential.

The most important reason for the increase in urban carbon stocks in Fujian Province is the shift in land use type from cropland to forested land, which is the most important reason for the increase in urban carbon stocks in Fujian Province.

5 Conclusion

The carbon stock of forest land is the most important source of carbon stock in Fujian Province, accounting for 84.01% of the carbon stock in the whole Fujian Province. Cropland is the second largest source of carbon stock in Fujian Province, accounting for 12.84% of the total carbon stock in Fujian Province. The third is artificial land, accounting for 1.82% of the carbon stock in Fujian Province.

The spatial distribution of carbon stock in Fujian Province is basically the same in these two decades. Statistically analyzing the net change of carbon stock in each city of Fujian Province from 2000 to 2020, the main reason for the decrease of carbon stock in seven cities of Fujian Province, namely Fuzhou, Sanming, Quanzhou, Zhangzhou, Ningde, Longyan, Nanping, and Ningde, is the transfer of forest land to cropland. The most important reason for the decrease of carbon stock in two cities, Xiamen and Putian in Fujian Province, is the transfer of cropland to artificial land. In addition, there are some shortcomings in the study, such as the data on carbon density in Fujian Province being compiled from other scholars' literature. Hence, the accuracy of the data on carbon density needs to be improved.

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