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Structural development and carbon dynamics of Moso bamboo forests in Zhejiang Province, China

Lin Xu[a,b,c,d,1], Yongjun Shi[a,b,c,d,1], Guomo Zhou[a,b,c,d,*], Xiaojun Xu[a,b,c,d], Enbing Liu[a,b,c,d], Yufeng Zhou[a,b,c,d], Feng Zhang[e], Chong Li[a,b,c,d], Huiyun Fang[a,b,c,d], Liang Chen[a,b,c,d]

[a] State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Lin'an 311300, Zhejiang, China
[b] Zhejiang Provincial Collaborative Innovation Center for Bamboo Resources and High-efficiency Utilization, Zhejiang A&F University, Lin'an 311300, Zhejiang, China
[c] Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon Sequestration of Zhejiang Province, Zhejiang A&F University, Lin'an 311300, Zhejiang, China
[d] School of Environmental and Resources Science, Zhejiang A&F University, Lin'an 311300, Zhejiang, China
[e] Forest Resources Monitoring Center of Zhejiang Province, Hangzhou 310000, Zhejiang, China

A R T I C L E I N F O

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A B S T R A C T

Moso bamboo (*Phyllostachys pubescens*) is widely distributed in subtropical China and plays an important role in terrestrial carbon cycling. However, the capacity of Moso bamboo forests to sequester carbon and their long-term structural development in large regions remain poorly quantified. We used the national forest continuous inventory data to measure and quantify the carbon stock and structure change from 2004 to 2014. The results of kernel density estimation showed that the culm density and average DBH (diameter at breast height) of Moso bamboo forests had a tendency to increase in Zhejiang Province. However, the culm structure of the Moso bamboo forests in Zhejiang Province was not optimal for high bamboo productivity. The aboveground culm carbon stock increased from 2004 to 2014, indicating that the Moso bamboo forests acted as a carbon sink. The average change in the aboveground carbon stock over the study period was 0.94 Mg C ha^{-1} yr^{-1}, smaller than the corresponding value for different forest types in the same region and for the Moso bamboo forests managed by farmers in the lower mountain areas of central Taiwan (8.13 Mg C ha^{-1} yr^{-1}), indicating that Moso bamboo forests have a large carbon sequestration potential. Furthermore, age classes 2–4 contributed positively to changes in the total aboveground culm carbon stock by 23.07%, 36.35%, and 50.17%, respectively. The change in the carbon stock was not correlated with any environmental factors, but the carbon stock increased with increasing culm density, average DBH (diameter at breast height), and culm age. Our results suggest that the Moso bamboo forests of Zhejiang Province have a large carbon sequestration potential if the structure and management strategies of the forests are optimized. This study improves our understanding of the carbon dynamics and structural development in Moso bamboo forests, which could help guide the future forest management strategies.

1. Introduction

Increasing atmospheric carbon dioxide (CO_2) concentrations are considered one of the main drivers of global climate change (IPCC, 2014). Forests play an important role in the global terrestrial carbon cycle and their potential to sequester additional atmospheric carbon dioxide (CO_2) is considered a mitigation strategy to reduce global climate warming (Luyssaert et al., 2007; Pan et al., 2011; Xu et al., 2016a). Therefore, an accurate investigation of the structural development of forests and estimation of carbon sequestration by forests at the regional and even at the global scale is important for improving the understanding of forest carbon dynamics and the potential of forest ecosystems to mitigate future climate change. However, forests biomass is highly heterogeneous in space and time, and its dynamics are determined by different factors at different scales (Pan et al., 2013; Xu et al., 2016a). Thus, long-term and large-scale field measurements should be prioritized to better understand global carbon sequestration.

Bamboo belongs to the subfamily *Bambusoideae* in the family *Gramineae*, which has about 1500 species worldwide (Li and Kobayashi, 2004; Gratani et al., 2008). Bamboo forests are widely distributed in the subtropical regions of Asia, Africa, and Latin America, with a total area of 31.5 Mha globally, accounting for about 0.8% of the world's total

* Corresponding author at: State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Lin'an 311300, Zhejiang, China.
E-mail address: zhougm@zafu.edu.cn (G. Zhou).
[1] The authors contributed equally to this study.

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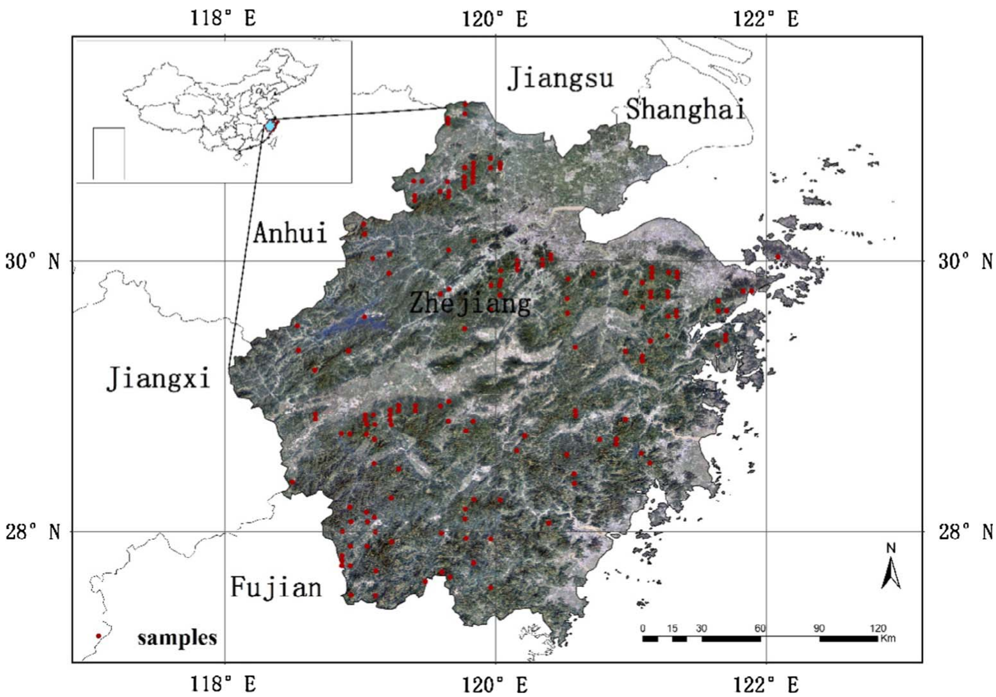

Fig. 1. Study area in Zhejiang Province, China. Permanent sample plot locations are denoted by red circles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

forests area (FAO, 2010). The area of bamboo forests has gradually increased in many countries because of their asexual reproduction and high economic value (Guo et al., 2005). China, with over 500 bamboo species of 39 genera, is known as the “Kingdom of Bamboo” (Chen et al., 2009). During the past 30 yr, the bamboo industry has rapidly developed under China’s economic reforms (Mao et al., 2016). The area of bamboo forests has reached approximately 6.01 Mha, 73.8% of which is covered by Moso bamboo (*Phyllostachys pubescens*) (SFAPRC, 2015).

Moso bamboo is a major bamboo species, widely distributed in the tropical and subtropical regions of eastern and southeastern Asia, with 4.43 Mha of the Moso bamboo forests located in China (accounting for 84.02% of the species' global distribution) (Song et al., 2011; SFAPRC, 2015). Moso bamboo has a strong regeneration ability; with the increase in bamboo culms, the productivity of bamboo forests increases gradually and bamboo culms are roughly homogenized by age distribution (Nie, 1994). Yen (2015) also found that the structure of Moso bamboo culms were homogeneously distributed with age in Moso bamboo forests under intensive management. Moso bamboo grows rapidly; it accumulates three-fourths of their biomass for the entire yield period in only 40 d, suggesting that biomass accumulation and carbon storage mainly occurs in the initial growth stage for individual culms (Yen, 2016). At the growth stage of Moso bamboo forests, carbon content increased progressively and fixed carbon was partitioned into cell wall hemicellulose and cellulose to meet the demand of rapid cell elongation (Xu et al., 2011b).

Based on these strong regeneration and rapid growth abilities, many studies have focused on carbon stock estimations based on remote sensing data (Du et al., 2009, 2012; Xu et al., 2011a, 2016c; Han et al., 2013; Shang et al., 2013; Li et al., 2017b) or carbon flux observations using the eddy covariance technique (Xu et al., 2013, 2016b; Song et al., 2017) to confirm that Moso bamboo forests are important carbon sinks with high carbon sequestration potential (Yen and Lee, 2011; Zhou et al., 2011a, 2011b; Li et al., 2015; Song et al., 2016b). Yen and Lee (2011) compared Moso bamboo and Chinese fir and found that the mean aboveground carbon sequestration of Moso bamboo (8.13 ± 2.15 Mg C ha^{-1} yr^{-1}) was significantly higher than that of Chinese fir (3.35 ± 2.02 Mg C ha^{-1} yr^{-1}). Chen et al. (2009) estimated the change in carbon stocks in bamboo stands in China over the next 100 yr and predicted that the carbon stocks will rise in the next five decades. Liet al. (2015) reported that the carbon stocks of Moso bamboo forests in China could substantially increase under three scenarios. The aboveground carbon stocks of Moso bamboo forests had a moderate spatial dependency, while the spatial autocorrelation of SOC was poor (Fu et al., 2013).

The structural and environmental factors can influence the carbon stocks in Moso bamboo forests. In a close-nature Moso bamboo forests, the nearest culm number of the target bamboo was four; thus, the target bamboo most likely achieved a high production rate (Tang et al., 2011). Altitude, slope, aspect, slope position, and slope degree have significant effects on stand structure and vegetation carbon stocks in Moso bamboo forests (Fang et al., 2013). The number of culms and average stand DBH are also among the main factors affecting the carbon stocks of Moso bamboo forests (Liu et al., 2013). However, the dynamics of carbon stocks and the structural development of Moso bamboo forests over the long term at a regional scale remain poorly understood, limiting our understanding of the important role of Moso bamboo forests in the regional carbon budget and their contribution to climate change mitigation. Therefore, we measured and quantified the carbon stocks and structural change of Moso bamboo forests in Zhejiang Province from 2004 to 2014 using data from the national forests continuous inventory. The specific objectives of our study were (1) to investigate the structural development of Moso bamboo forests; (2) to quantify the changes in carbon dynamics and compare them for different culm age groups; and (3) to identify the regional factors driving the changes in the Moso bamboo forests carbon stock.

2. Materials and methods

2.1. Study site

The study site is located in Zhejiang Province (118°01′–123°10′ E, 27°06′–31°11′ N), on the southeastern coast of China (Fig. 1). The area covers approximately 105,500 km^2; the terrain varies from mountains (with an average altitude of 800 m) in the southwest, to hills in the central area and alluvial plains in the northeast (Mao et al., 2017b). This area is characterized by a subtropical monsoon climate with four distinct seasons. Based on the data collected in the last two decades, the