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TREE BIOMASS CARBON OF EVERGREEN BROAD-LEAVED FOREST IN THE MIDDLE SUBTROPICS OF CHINA

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Abstract

Biomass carbon of tree layer in the three successional stages of *Pinus massoniana* forest (PMF), *Pinus massoniana*and broad-leaved mixed forest (PBF) and evergreen broad-leaved forest (EBF) was studied. The results showed that the biomass carbon storage of tree layer was the highest in EBF（129.34 t/hm^2, followed by PBF and PMF with 95.83 and 85.27 t/hm^2, respectively. Biomass carbon of various tree components showed the trend as stem> root> branch > leaf >bark. With the succession, the proportion of the stem accounted for the tree biomass carbon reduced, and the root of the proportion had increased. Tree biomass carbon is mainly concentrated in the 20-30cm diameter at breast height (DBH), or more than 30cm DBH.

Introduction

China's terrestrial ecosystem was a net carbon sink of 0.19-0.26 Pg per year in the 1980s and 1990s (Piao *et al.* 2009). South China's forests account for more than 65% of the carbon pool, which can be attributed to the large-scale forestry restoration projects since the 1980s (Piao *et al.* 2009), such as the project of returning farmland to forests, the project of Yangtze River shelterbelt, the project of closing mountains for afforestation and the protection of public welfare forest. Large amounts of carbon have been captured from atmosphere during the process of forest restoration and succession (Zeng *et al.* 2013). With the increase of the age of forests, the carbon storage of forest ecosystems includes not only the increase of forest biomass, but also soil organic carbon (Zhou *et al.* 2006, Yang *et al.* 2010).

In recent decades, secondary forests in Hunan Province are in the process of restoration and succession, and its main species is masson pine that plays an important role in carbon sequestration (Kong and Mo 2002, Zheng *et al.* 2008, Zeng *et al.* 2013). Forest biomass is the basis of forest carbon sequestration capacity research, which is affected by many factors such as forest ecosystem structure, restoration and successional stage, forest age, regional location and so on (Yang *et al*. 2010). By comparison, there are a few studies on the changes of biomass carbon storage caused by different forests succession in southern China (Zheng *et al*. 2008). However, the impact of forest succession on forest biomass carbon reserves cannot be ignored (Fang *et al*. 2003, Zeng *et al.* 2013).

In this study, the distribution of tree layer biomass affected by tree species, diameter steps, tree components and other factors among *Pinus massoniana* forest (PMF), *Pinus massoniana* and

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broad-leaved mixed forest (PBF) and evergreen broad-leaved forest (EBF) was measured and compared with the field survey method of replacing space with time. The aim was to quantify changes in forest biomass carbon stock during the forest succession (Zeng *et al*. 2013).

Materials and Methods

The study area is located in the Yingzuijie nature reserve (26°46′ - 26°59′N, 109°49′ - 109°58′E) of Hunan Province. The climate of the region is humid subtropical monsoon, with an annual average precipitation of 1450 mm, of which about 69% occur between April and September, with an annual average temperature of 15.6℃ (Zeng *et al*. 2013). The parent material of soil formation is slate and shale, and classified as a Ultisols under the USDA taxonomy (Typic Paleudults) (Wang *et al*. 2009).

Table 1. The stand characteristics under different successional stages of the evergreen broad-leaved forest. (mean ±SE, n=3).

Forest type	Stand age (a)	Average DBH (cm)	Average height (m)	Wood plant density (plant/hm^2)	Slope aspect	Slope gradient/ (°)	Bulk density of soil (g/cm^2)
PMF*	30~35	16.35 ± 0.51	13.5 ± 0.31	1100 ± 51	Southeast	15	1.36 ± 0.04
PBF	45~50	17.23 ± 0.45	13.9 ± 0.25	1325 ± 55	Southeast	15	1.32 ± 0.03
EBF	65~70	19.2 ± 0.68	14.8 ± 0.32	1150 ± 52	Southeast	15	1.29 ± 0.04

*PMF: *Pinus massoniana* forest, PBF: Pine and broadleaf mixed forest , EBF: Evergreen broadleaf forest.

There are three forest types in different successional stages in the reserve (Zeng *et al.* 2015): PMF with age from 25 to 30 years; PBF with age from 45 to 50 years; EBF with age from 65 to 70 years (Table 1) (Zeng *et al*. 2013).

From May to July 2010, three 20 m × 20 m plots were established for each forest type. The DBH (diameter at breast height at 1.3 m height) and height of all trees in each plot were measured. The biomass of each tree and the biomass of each standby were calculated using the allometric growth equation (Zeng *et al.* 2013).

Carbon content in biomass samples was determined by C/N analyzer (Elementar, Germany). (Wang *et al.* 2009). The quality of carbon stored in the tree was estimated by multiplying biomass by the corresponding content (Mu *et al*. 2013).

SPSS software version 20.0 was used for data analysis. One-way analyses of variance (ANOVA) were used to test the differences of carbon concentration, biomass and carbon storage among different forest types. The least significant difference (LSD) was calculated when the treatment was significantly different. In all statistical analyses, the significance level was set to $\alpha = 0.05$(Zeng *et al*. 2013).

Results and Discussion

In terms of the diameter class distribution of the biomass of PMF, the biomass of trees having DBH range of 20 - 30 cm was largest, accounting for 49.64% of the total biomass (Table 2). There was no significant difference among the biomass of three diameter classes of PBF, among which the biomass of above 30 cm was the highest, making up 37.23% of the total biomass. In terms of the diameter class distribution of the biomass of EBF, the diameter class above 30 cm was the highest, accounting for 50.08% of the total biomass. Comparison of biomass at the diameter class of 5 - 20 cm were, PBF>EBF>PMF; for the comparison of biomass at the diameter of 20 - 30 cm were, EBF>PMF>PBF; and at the diameter above 30 cm were, EBF>PBF>PMF, respectively.

Table 2. Diameter distribution in relation to biomass in tree layer at different successional stagees (t/hm^2).

Diameter (cm)	PMF*	PBF	EBF
5-20	36.87 (2.1)c	62.38 (3.5)a	48.59 (2.8)b
20-30	85.26 (3.4)b	67.45 (2.9)c	97.42 (3.8)a
Above 30	49.63 (2.6)c	77.01 (4.2)b	146.50 (8.5)a
Total	171.76 (8.2)c	206.85 (10.9)b	292.51 (13.7)a

*PMF: *Pinus massoniana* forest, PBF: Pine and broadleaf mixed forest, EBF: Evergreen broadleaf forest. Values with the different letters denote significant difference among forests at $\alpha = 0.05$ based on the least-significant-difference tests.

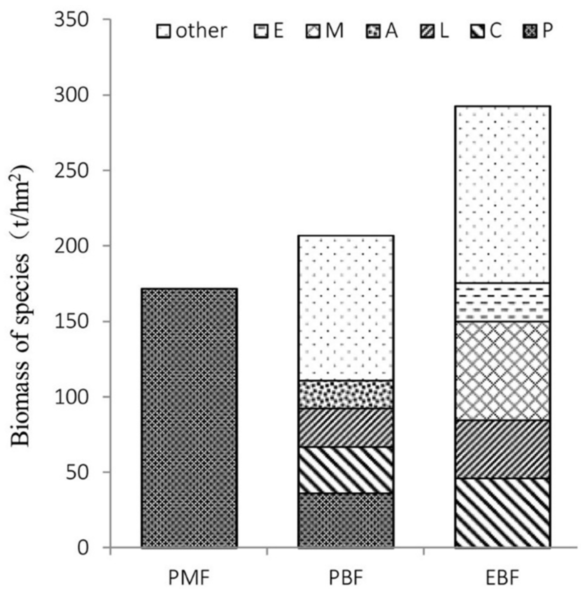

Fig. 1. Biomass of tree species at different successional stages. PMF : *Pinus massoniana* forest, PBF: Pine and broadleaf mixed forest, EBF: Evergreen broadleaf forest. P: *Pinus massoniana,* C: *Castanopsis fargesii,* L: *Liquidambar formosana,* A: *Alnuscrema stogyne* andE: *Elaeocarpus decipiens.*

Considering the dominant tree species distribution of the biomass in the tree layer in PBF, the biomass of four species, namely *Pinus massoniana*, *Castanopsis fargesii*, *Liquidambar formosana* and *Alnuscrema stogyne* was largest with storage of 110.73 t/hm^2, accounting for 53.53% of the total biomass; in EBF, the biomass of *Machilus pauhoi*, *Castanopsis fargesii*, *Liquidambar formosana* and *Elaeocarpus decipiens* accounted for the largest proportion of 59.98% (Fig. 1).

The biomass of the tree layer in different types of forests was dvaried from 171.76 t/hm^2 in PMF to 292.51 t/hm^2 in EBF (Table 3). The biomass of each organ in the tree layer at the same successional stage showed the trend of biomass contents were trunks > roots > branches > leaves >bark; the biomass of each organ in different successional stages in descending order was EBF>PBF>PMF. With the positive progression of succession, the proportion of trunk biomass decreased, and the proportion of other organs increased to varying degrees. In short, during the succession of PMF to EBF, the mode of distribution of biomass was changed, and the biomass was distributed to the vegetative organs such as roots and leaves, which was more conducive to the growth of trees and the accumulation of biomass.

Table 3. Different organs' biomass in tree layer at different successional stage（t/hm^2).

Organ	PMF	PBF	EBF
Trunk	98.39 (1.1)c	108.69 (5.9)b	136.59 (3.1)a
Bark	9.76 (0.7)c	17.19 (1.0)b	25.48 (0.6)a
Branch	23.47 (0.7)c	29.09 (1.1)b	49.56 (1.7)a
Leaf	15.23 (0.5)c	18.72 (0.4)b	26.74 (0.9)a
Root	24.91 (1.3)c	33.18 (1.3)b	54.13 (2.8)a
Total	171.76 (10.9)c	206.87 (12.8)b	292.51(18.7)a

PMF: *Pinus massoniana* forest, PBF: Pine and broadleaf mixed forest, EBF: Evergreen broadleaf forest.Values with the different letters denote significant difference among forests at α = 0.05 based on the least-significant-difference tests.

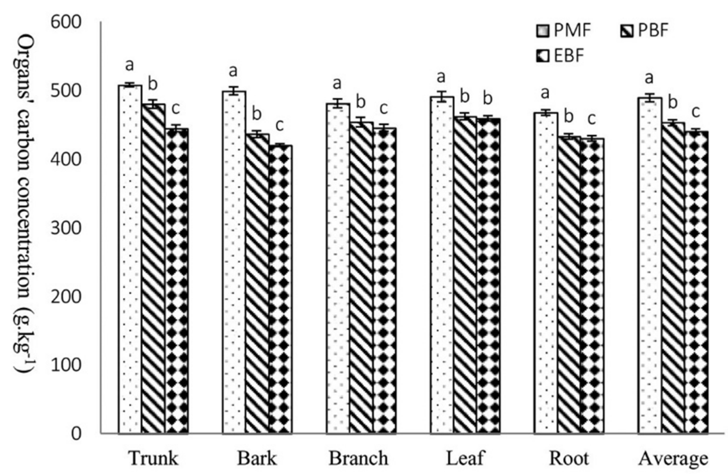

Fig. 2.Different organs' carbon concentration in tree layer of succession (g/kg). PMF: *Pinus massoniana* forest , PBF: Pine and broadleaf mixed forest, EBF: Evergreen broadleaf forest. Values with the different letters denote significant difference among forests at α = 0.05 based on the least-significant-difference tests.

Sequence of organic carbon content in each organ of tree layer was PMF＞PBF＞EBF, and they were 489.22, 452.77 and 439.68 g/kg, respectively (Fig. 2).

Organic carbon content showed the trend of trunk > bark > leaf > branch > root in PMF, trunk > leaf > branch > bark > root in PBF, leaf > branch > trunk > root > bark in EBF.

The sequence of carbon reserve in each organ at tree layer of three kinds of forests was trunk>root>branch>leaf>bark. The sequence of carbon reserve in each organ was EBF>PBF >PMF (Fig. 3).

Carbon reserve at tree layer of EBF was 129.34 t/hm^2, which was the highest, followed by PBF (95.83 t/hm^2), and PMF (85.27 t/hm^2). It showed the trend of EBF >PBF >PMF.

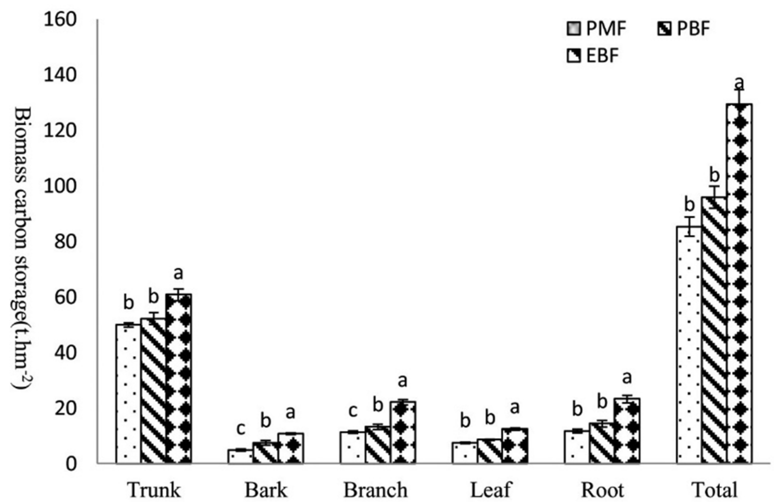

Fig. 3. Different tree organs biomass carbon storage in tree layer（t/hm^2). PMF: *Pinus massoniana* forest, PBF: Pine and broad leaf mixed forest, EBF: Evergreen broadleaf forest. Values with the different letters denote significant difference among forests at $\alpha = 0.05$ based on the LSD.

There are different methods of biomass measurement in China and the rest of the world. Direct harvest method (shrub layer and herb layer) and allometric growth method (arbor layer) are often used to measure the biomass of forest community in China. Generally, more mature stands have higher biomass and closer biomass. The biomass of mature forests at home and abroad is 295.0 - 568.0 t/hm^{-2} and 242.0 - 585.0 t/hm^2 (Liu *et al*. 2002), respectively. In the present work, biomass of EBF was lower than mature forests in China for similar age of stand (Yang *et al*. 2010).

Carbon reserve of tree layer at different successional stages had difference, in which carbon reserve at tree layer of EBF was 129.34 t/hm^2, followed by PBF, (95.83 t/hm^2). The minimum was 85.27 t/hm^2 at tree layer of PMF, showing the trend of EBF >PBF >PMF. Carbon reserve of each organ at tree layer in each stand showed the trend of trunk > root > branch > leaf > bark. The sequence of carbon reserve in the same organ was EBF>PBF>PMF. Compared to average carbon reserve (57.07 t/hm^2) at tree layer of forest vegetation in China (Zhou *et al*. 2000), carbon reserve of tree layer of forest vegetation at successional stage was higher, which was more than national mean.Here, carbon reserve in PMFin Yingzuijie was 85.27 t/hm^2, which was higher than average level of Hunan Province (29.14 t/hm^2) and China (44.19 t/hm^2) (Fang and Chen 2001, Tang *et al*. 2003, Hu *et al*. 2012), the estimated value of overmature forest of *P. massoniana*(62.144 t/hm^2) (Wang and Feng 2000, Li *et al*. 2014), average level of tropical and subtropical coniferous forests (63.17 t/hm^2) (Wang *et al*. 1999, Yang *et al*. 2005) and average level of warm coniferous forest (47.197 t/hm^2) (Zhou *et al*. 2000). Carbon reserve of PBF in Yingzuijie was 95.83 t/hm^2, which was between means of coniferous mixed forest and pine and broadleaf mixed forest (98.187 and 86.185 t/hm^2) by Wang and Feng (2000).

It is clear that carbon reserve was higher in PBF than PMF in Yingzuijie. It might be because of the selected forest was older (30 - 40 years old), while vegetation in the mixed forest was protected well after reserve was established. This shows that besides forest age, invasive broad-leaved species, ecological habits and topographical conditions are also important factors affecting community biomass (Yang *et al*. 2010).

In each stand, diameter distribution of carbon reserve and biomass was basically similar. In PMF, the sequence of carbon reserve was the diameter of 20-30 cm>the diameter more than 30 cm> the diameter of 5 - 20 cm. In PBF, the sequence of carbon reserve was more than 30 cm>the diameter of 20 - 30 cm > the diameter of 5 - 20 cm. In EBF, the sequence of carbon reserve was more than 30 cm > the diameter of 20 - 30 cm > the diameter of 5 - 20 cm.

As the succession progressed, stand became more mature and stable, and proportion of carbon reserve in large-diameter individual to total carbon reserve tended to be larger. When PMF was compared with PBF, PBF tended to be mature, and individual in large diameter was more, and proportion of carbon reserve in large-diameter individual to total carbon reserve was larger. When broad-leaved tree in PBF was compared with broad-leaved evergreen forest, it had small diameter and more individuals, displaying its growth and development characteristics.

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