

CARBON STOCK OF THE ECOSYSTEM OF LOWER SUBTROPICAL BROADLEAVED EVERGREEN FORESTS OF DIFFERENT AGES IN PEARL RIVER DELTA, CHINA

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SUN L & GUAN DS. 2014. Carbon stock of the ecosystem of lower subtropical broadleaved evergreen forests of different ages in Pearl River Delta, China. This research analysed the carbon stocks and distribution characteristics of the ecosystems of lower subtropical broadleaved evergreen forests of different ages (young, middle-aged and mature) in the Pearl River Delta. Forest age significantly affected carbon stocks of a forest ecosystem. Carbon stocks ranged from 125.23 to 125.23 t C ha⁻¹ in the forest ecosystem, 40.17 to 154.05 t C ha⁻¹ in the arbor layer and 72.12 to 105.73 t C ha⁻¹ in the soil. Secondary biomass carbon was an important carbon pool, which accounted for about 7–10% of the ecosystem carbon stock with ranges from 12.94 to 22.18 t C ha⁻¹. Ecosystems with different forest ages showed significant differences in carbon stock distribution characteristics. The soil contributed 56.55% carbon stock to young forests; arbor layer and secondary biomass contributed less with 31.50 and 10.33% respectively. However, in middle-aged and mature forests, the arbor layer contributed the most carbon stock. Soil and secondary biomass contributed less. In the secondary biomass stock, understorey vegetation provided the most carbon stock for young and middle-aged forests with 61.51 and 55.36% respectively. Coarse woody debris provided the most carbon stock (51.26%) for mature forests.

Keywords: Forest age, secondary biomass carbon

INTRODUCTION

After the Kyoto Protocol, the expansion of forest areas to increase carbon-absorbing capacity became a widely accepted measure for reducing carbon emission by countries worldwide (Yu et al. 2003). The cultivation of fast-growing trees also receives significant attention (Xu et al. 2012, Zhang et al. 2012). However, minimal attention has been directed towards the recovery of zonal vegetation, especially in terms of carbon stock distribution characteristics and variation pattern during recovery. The study of ecosystem carbon stock under zonal vegetation would provide baseline data for the regional forest ecosystem carbon stock (Ravindranath & Ostwald 2008). Such baseline data may also be of use to climate modellers who study the dynamics of global carbon cycle (Houghton et al. 2009, Scholes et al. 2009, Smith & Fang 2010)

The Pearl River Delta (PRD) is the most economically developed zone in South China.

However, rapid social and economic development destroyed almost all native zonal vegetation. Lower subtropical evergreen broadleaved forests were destroyed and only a few naturally mature, secondary, evergreen broadleaved forests were preserved in several natural reserves or geomantic forests. Over the past three decades, the destroyed lower subtropical evergreen broadleaved forests gradually recovered due to increasing environmental awareness and governmental protection. According to the fourth, fifth and sixth national forest inventory data from 1989 till 2004, the lower subtropical evergreen broadleaved forest area in PRD has increased annually. During the sixth national forests inventory, its area accounted for 18.86% of the region's total forest area. However, the area still focuses on middle-aged and young forests. Forest deterioration (Körner 2003, Pregitzer & Euskirchen 2004) and the growth period after

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destruction (forest age) are decisive factors in organic carbon stock accumulation and can enrich carbon cycle cognition by providing a deeper understanding of the impact of forest age on carbon stocks (Pregitzer & Euskirchen 2004, Wang et al. 2011).

The current studies on the carbon stock of lower subtropical evergreen broadleaved forests attach much importance on the climax community (Tang et al. 2003), ecosystem and its component under different succession stages (Tang & Zhou 2005, Zhou et al. 2005). However, these studies often neglected the impact of understorey vegetation, coarse woody debris (CWD), litter as well as other components of carbon stocks. The studies seldom involved discussion about the impact of forest age on carbon stocks of lower subtropical evergreen broadleaved forests and their distribution characteristics. The understorey vegetation, CWD, litter as well as other components of carbon stocks significantly contributed to an ecosystem (Pregitzer & Euskirchen 2004, Peichl & Arain 2006, Zhou et al. 2008). The carbon stocks of an ecosystem would be underestimated if these components were neglected (Clark et al. 2001). Therefore, based on the PRD data, this study selected samples from young, middle-aged and mature forests to determine the amount and distribution characteristics of carbon stocks present in the lower subtropical evergreen broadleaved forest ecosystem. This paper provides baseline data for the carbon stock of regional forest ecosystem.

MATERIALS AND METHODS

Study area

PRD is located in the south central region of Guangdong Province. The geographic coordinates of PRD are 21° 31'–23°10' N and 112° 45'–113° 50' E. PRD lies at the border near South China Sea (Figure 1). Mountains and hills lie in the west, north and east areas of PRD, whereas plains are mainly in the centre. Several estuaries lie in its south, including Guangzhou, Shenzhen, Zhuhai, Dongguan, Zhongshan, Jiangmen, Foshan, Huizhou and Zhaoqing. PRD is the largest alluvial plain in the lower subtropical zone of China. PRD is classified as having typical monsoon climate but has evident characteristics of monsoon tropics and the oceanic climate of the subtropics. The annual average temperature is 21 to 23 °C, with the coolest month being January and the hottest, July. The average coldest temperature for years has been 13 to 15 °C and the average hottest temperature, 28 °C. PRD is hot and moist in summer but warm and dry in winter, showing a clear division of dry and wet seasons. The annual average rainfall exceeds 1600 mm. The zonal vegetation of PRD is classified as lower subtropical evergreen broadleaved forest with a variety of natural vegetation such as Lauraceae, Fagaceae, Myrtaceae, Moraceae, Theaceae, Euphorbiaceae, Rubiaceae, Papilionaceae, Caesalpiniaceae, Rutaceae, Sterculiaceae, Elaeocarpaceae, Myrsinaceae, Aquifoliaceae, Palmae and Symplocaceae. The current evergreen

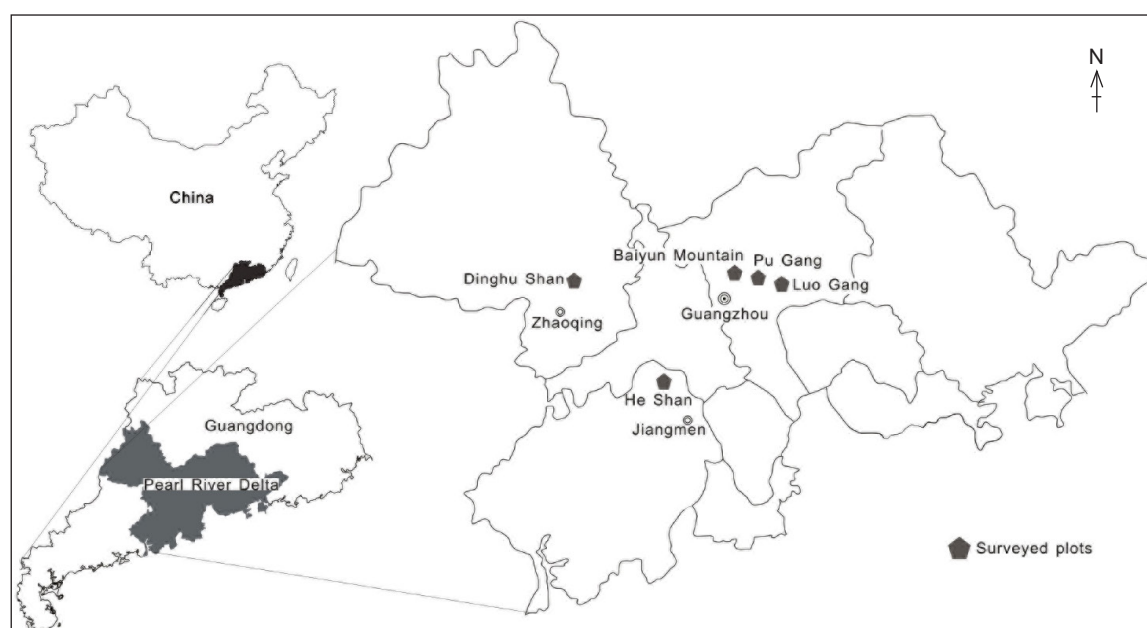


Figure 1 Location of Pearl River Delta in China

broadleaved forests in PRD are secondary forests because of human interference and destruction; most of these forests are young and middle-aged. The zonal soil in PRD is latosolic red soil.

Twelve groups of natural, secondary, evergreen broadleaved forests were selected, including four young forests, five middle-aged forests and three mature forests (Table 1). Four young forests were the *Schima superba* + *Litsea coreana* communities in Baiyun Mountain Scenic Area in Guangzhou, *Dalbergia balansae* + *Dalbergia odorifera* + *Cratoxylum cochinchinense* community in Fenghuang Mountain Forest Park of Baiyun Mountain in Guangzhou, *Symplocos lancifolia* + *Tetradium glabrifolium* community in Pugang Natural Reserve of South China Botanical Garden in Guangzhou and *S. superba* + *Symplocos lancifolia* community of Dinghushan Biosphere Reserve (DHSBR) in Zhaoqing. In these areas, the average plant density, average basal area, average diameter

at breast height (dbh) and average tree height of the arbor layer were 4925 plants ha⁻¹, 21.52 m² ha⁻¹, 5.79 cm and 4.78 m respectively. The samples were less than 40 years old. Five middle-aged forests were the *Pygeum* + *Endospermum* community in the mountain behind Litzhi Village, Luogang District, Guangzhou; *Engelhardtia* + *S. superba* community and *Machilus chinensis* + *Lithocarpus glaber* communities in Pugang Nature Reserve of South China Botanical Garden in Guangzhou City; *S. superba* + *Engelhardtia* community in the main mountain behind the Qingyun Temple in DHSBR in Zhaoqing and *Machilus oculodracontis* + camphor tree community in Heshan City. The average plant density, average basal area, average dbh and average tree height of the arbor layer of these samples were 3558 plants ha⁻¹, 36.78 m² ha⁻¹, 6.86 cm and 6.12 m respectively. The samples were 50–90 years old. The three mature forests were the *M. chinensis* + *Cinnamomum*

Table 1 Outline of the surveyed plots

Period and age class	Community	Location	Biomass (t ha ⁻¹)	Forest age (years)	Origin	Major arbor type
Young (< 40 years)	<i>Schima superba</i> + <i>Litsea coreana</i>	(23° 10' 46.71" N, 113° 21' 30.80" E)	93.18	20–25	Natural secondary forest	<i>Symplocos lancifolia</i> , <i>Acronychia pedunculata</i> , <i>Cryptocarya chingii</i> , <i>Carallia brachiata</i> , <i>Dalbergia balansae</i> , <i>Dalbergia odorifera</i> , <i>Cratoxylum cochinchinense</i> , <i>Syzygium hancei</i> , <i>Cinnamomum busmannii</i> , <i>Schima superba</i>
	<i>Symplocos lancifolia</i> + <i>Tetradium glabrifolium</i>	(23° 10' 35.96" N, 113° 21' 24.64" E)	93.52	20–25		
	<i>Dalbergia balansae</i> + <i>Dalbergia odorifera</i> + <i>Cratoxylum cochinchinense</i>	(23° 13' 54.8" N, 113° 21' 55.0" E)	119.23	35–40		
	<i>Schima superba</i> + <i>Symplocos lancifolia</i>	(23° 09' 40.3" N, 112° 32' 36.7" E)	124.75	35–40		
	<i>Pygeum</i> + <i>Endospermum</i>	(23° 08' 33.66" N, 113° 29' 09.61" E)	190.07	50–60		
Middle-aged (50 to 90 years)	<i>Engelhardtia</i> + <i>Schima superba</i>	(23° 10' 53.54" N, 113° 21' 28.03" E)	229.35	60–70	Natural secondary forest	<i>Prunus topengii</i> , <i>Endospermum chinense</i> , <i>Sterculia lanceolata</i> , <i>Cinnamomum busmannii</i> , <i>Machilus oculodracontis</i> , <i>Cinnamomum camphora</i> , <i>Syzygium hancei</i> , <i>Engelhardtia roxburgiana</i> , <i>Schima superba</i>
	<i>Machilus chinensis</i> + <i>Lithocarpus glaber</i>	(23° 10' 49.09" N, 113° 21' 22.55" E)	233.46	60–70		
	<i>Schima superba</i> + <i>Engelhardtia</i>	(23° 10' 25.0" N, 112° 32' 9.5" E)	282.19	70–80		
	<i>Machilus oculodracontis</i> + camphor tree	(22° 36' 49.19" N, 112° 54' 21.59" E)	287.21	70–80		
	<i>Machilus chinensis</i> + <i>Cinnamomum burmannii</i>	(23° 10' 4 6.03" N, 113° 17' 43.07" E)	342.32	110–120		
Mature (> 100 years)	Chestnut + <i>Engelhardtia</i>	(23° 10' 30.45" N, 113° 29' 14.93" E)	349.11	110–120	Natural secondary forest	<i>Castanea henryi</i> , <i>Engelhardtia roxburgiana</i> , <i>Machilus veluthna</i> , <i>Aporosa dioica</i> , <i>Prunus phaeosticta</i> , <i>Cinnamomum busmannii</i> , <i>Machilus chinensis</i> , <i>Syzygium rehderianum</i> , <i>Acronychia pedunculata</i> , <i>Schima superba</i>
	Chestnut + <i>Engelhardtia</i> + <i>Aporosa</i>	(23° 10' 30.45" N, 113° 29' 14.93" E)	366.80	130–140		

Forest ages were estimated based on interviews with local residents and diameter at breast height of trees for top high layer

burmannii community in the mountain behind the hotel of Baiyun Mountain Scenic Area in Guangzhou; chestnut + *Engelhardtia* community in the mountain behind Dalang Village, Luogang District, Guangzhou and chestnut + *Engelhardtia* + *Aporosa* community in Heshan. The average plant density, average basal area, average dbh and average tree height of the arbor layer of these samples were 2612 plants ha⁻¹, 40.42 m² ha⁻¹, 10.80 cm and 10.80 m respectively. The communities were over 100 years old.

Measurement of carbon stocks in forests

Carbon stocks of arbor layer

A 40 m × 40 m standard sampling area was set up in each of the 12 selected sites. Within this standard sampling area, the dbh (D) and arbor height (H) of all standing trees higher than 3 m were measured. Basic information on the sample areas was surveyed and recorded including geographic coordinates, orientation, gradient, major vegetation and community structure characteristics. The biomass regression model proposed by Guan (1989) was applied to estimate the aboveground biomass of arbor layer. The underground biomass of arbor layer was calculated based on the ratio between above- and underground biomass (Fang et al. 1996).

Different forest vegetations have varying conversion rates between biomass and carbon stocks because of various factors such as community composition, age structure and stand origins (Zhou et al. 2000). This conversion rate usually ranges from 0.45 to 0.5. This study calculated a conversion rate of 0.5.

Carbon stocks of the understorey vegetation

Carbon stocks of understorey vegetation were measured using the harvest method. In each 40 m × 40 m sampling area, a 2 m × 2 m standard sampling area was set up randomly. All shrubs, ferns and herbaceous plants within the standard sampling area were collected. The shrubs were divided into branch, bole, leaf and root. The herbaceous plants were divided into ground and underground classes. All fresh samples were dried to constant weight in an oven under constant temperature of 65 °C. The biomass of the understorey vegetation was calculated and the carbon contents of the various components of the understorey vegetation were measured.

Carbon stocks of litter and CWD

Litter was obtained using the harvest method. Three to five 1 m × 1 m standard sampling areas were set up randomly in each 40 m × 40 m sampling site. The litter gathered within these areas was weighed and recorded. The litter was mixed evenly and 1 kg of the mixture was brought to the laboratory. The samples were divided into branch, leaf, fruit, etc. The samples were dried to constant weight in an oven under constant temperature of 65 °C. The weight of the dried litter from the sampling area was calculated and carbon content was measured using potassium dichromate outer heating to calculate carbon density.

The carbon stocks of CWD were measured using the definition and five-level classification standard of Tang and Zhou (2005). The carbon stocks of CWD with complete structures were estimated using the regression equation of Wei et al. (1997), whereas carbon stocks of CWD with incomplete structures were converted based on their volume and average carbon content using the cylinder formula. To compare the CWD residue values of forests with different ages, this study adopted the research method of Tang and Zhou (2005). The adopted research method was adjusted appropriately to integrate the decomposition levels as light decomposition (I), moderate decomposition (II and III) and high decomposition (IV and V).

Carbon stocks of soil

Three soil samples were dug randomly in each of the 40 m × 40 m sampling areas. The profiles were divided into seven levels: 0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 75 and 75 to 100 cm. The soil carbon content was measured using potassium dichromate outer heating, and the bulk density and moisture content of each layer of soil were measured simultaneously. Based on the bulk density and moisture content of each layer of soil, the soil carbon stock (SOC_t) was calculated according to the formula:

$$SOC_t = \sum_{i=1}^k C_i \times D_i \times E_i \times (1 - G_i)$$

where C_i = organic carbon proportion of soil (%), D_i = bulk density of the soil (g cm⁻³), E_i = soil thickness (cm), G_i = proportion of gravels (diameter >

2 mm) in the soil volume, k = soil layers and i = strata sequence of the soil.

Data analysis

Carbon density and its distribution pattern between the different forest ages were compared based on the forest area of the unit. Differences in carbon density and carbon components of forests with different ages were compared using analysis of variance through the SPSS16.0 statistical software and least significant difference test.

RESULTS

Carbon stocks of arbor layer

The carbon stocks of young, middle-aged and mature forests were 40.17 ± 3.33 , 98.25 ± 9.03 and 154.05 ± 8.24 t C ha⁻¹ respectively (Table 2). The carbon stocks of the arbor layer increased significantly with forest age.

Carbon stocks of understorey vegetation

The carbon stocks of understorey vegetation were in the order: middle-aged forest > mature forest > young forest, with values of 10.17 ± 0.88 , 8.17 ± 1.92 and 7.96 ± 0.59 t C ha⁻¹ respectively (Table 2). Understorey vegetation decreased its contribution to secondary biomass carbon with

increasing forest age: young forest > middle-aged forest > mature forest (61.51, 55.36 and 36.84% respectively) (Figure 2). Shrubs and herbs exhibited a different order of carbon stock contribution with increasing forest age. The former was in the order: middle-aged forest > mature forest > young forest (9.37 ± 0.60 , 7.42 ± 2.07 and 6.57 ± 0.77 t C ha⁻¹ respectively) (Table 2). The latter was in the order: young forest > middle-aged forest > mature forest (1.39 ± 0.63 , 0.80 ± 0.33 and 0.74 ± 0.15 t C ha⁻¹ respectively) (Table 2).

Carbon stocks of CWD and litter

The carbon stocks of CWD increased with increasing forest age: young forest < middle-aged forest < mature forest, with values of 2.86 ± 0.48 , 5.75 ± 1.65 and 11.37 ± 0.20 t C ha⁻¹ respectively (Table 2). The contributions of CWD to secondary biomass carbon increased with forest age: young forest < middle-aged forest < mature forest, with values of 22.10, 31.30 and 51.26% respectively (Figure 2). Logs provided the most significant contribution to carbon stocks of CWD in young, middle-aged and mature forests, contributing 84.23, 88.12 and 78.56% respectively (Figure 3). Their corresponding snags contributed 15.77, 11.88 and 21.44% respectively (Figure 3). Analysis of variance indicated that logs and snags provided similar contributions to carbon stocks of

Table 2 Ecosystem carbon stock of forests with different ages

Parameter		Young		Middle-aged		Mature	
Age class (years)		< 40		< 50–90		>100	
Arbor layer (t C ha ⁻¹)		40.17 ± 3.33 a		98.25 ± 9.03 b		154.05 ± 8.24 c	
Understorey (t C ha ⁻¹)		7.96 ± 0.59 a		10.17 ± 0.88 a		8.17 ± 1.92 a	
		Shrub	Herb	Shrub	Herb	Shrub	Herb
		6.57 ± 0.77	1.39 ± 0.63	9.37 ± 0.60	0.80 ± 0.33	7.42 ± 2.07	0.74 ± 0.15
Litter (t C ha ⁻¹)		2.12 ± 0.26 a		2.45 ± 0.30 a		2.64 ± 0.31 a	
CWD (t C ha ⁻¹)	Snags	0.92 ± 0.60 a		0.63 ± 0.17 a		2.39 ± 0.15 a	
	Logs	1.97 ± 0.80 a		5.12 ± 1.56 a		8.97 ± 2.60 a	
Total CWD (t C ha ⁻¹)		2.89 ± 0.48 a		5.75 ± 1.65 a		11.36 ± 0.20 b	
Secondary biomass (t C ha ⁻¹)		12.94 ± 1.02 a		18.37 ± 1.03 b		22.18 ± 2.03 b	
Soil (t C ha ⁻¹)		72.12 ± 5.39 a		87.69 ± 6.80 a		105.73 ± 8.52 b	
Ecosystem (t C ha ⁻¹)		125.23 ± 8.26 a		207.14 ± 11.05 b		288.88 ± 14.76 c	

Values are means \pm standard deviations; different letters indicate significant differences ($p < 0.05$) between ecosystem carbon stock of different ages according to least significant difference test; CWD = coarse woody debris

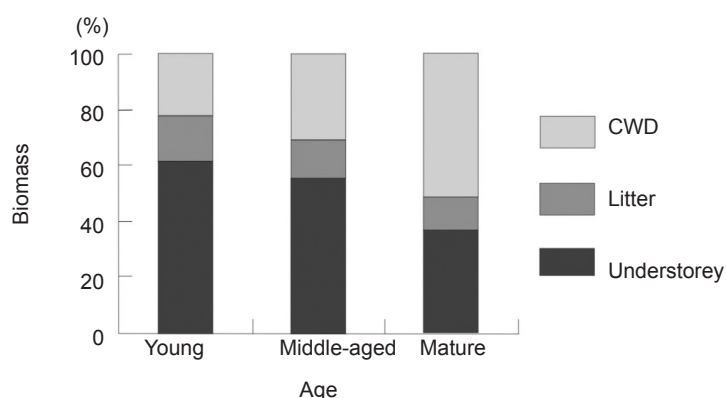


Figure 2 Distribution of secondary biomass carbon stock with different ages; CWD = coarse woody debris

CWD in young, middle-aged and mature forests (Figure 3). With regard to different decomposition levels, young and middle-aged forests exhibited moderate decomposition of CWD, occupying up to 89.80 and 82.55% of the total stocks respectively. Mature forests exhibited high decomposition of CWD (72.21%), allowing little room for slight decomposition of CWD (only 0.21% of the total average stocks) and moderate decomposition of 27.59% (Figure 4).

The carbon stocks of litter increased with increasing forest age: young forest < middle-aged forest < mature forest, with values of 2.12 ± 0.26 , 2.45 ± 0.30 and 2.64 ± 0.31 t C ha⁻¹ respectively (Table 2). The contributions of litter to secondary biomass carbon decreased with increasing forest age: young forest > middle-aged forest > mature forest, with values of 16.38, 13.34 and 11.90% respectively (Figure 2).

Carbon stocks of soil

Analysis of variance revealed that soil carbon stocks varied significantly between the three forest ages. Carbon stocks increased rapidly with increasing forest age, with values of 72.12 ± 5.39 t C ha⁻¹ (young forest), 87.69 ± 6.08 t C ha⁻¹ (middle-aged forest) and 105.73 ± 8.52 t C ha⁻¹ (mature forest) (Table 2).

Carbon stocks of ecosystem

Young, middle-aged and mature forests exhibited significantly different total carbon stocks, which increased with increasing forest age, with values of 125.23 ± 8.26 , 207.14 ± 11.05 and 288.88 ± 14.76 t C ha⁻¹ respectively (Table 2). With increasing forest age, the arbor layer provided increasing contributions to the carbon stocks of

the ecosystem: 32.08, 47.43 and 53.33% for young, middle-aged and mature forests respectively. However, soil provided decreasing contributions: 57.59, 42.33 and 36.60% for young, middle-aged and mature forests respectively. The secondary biomass carbon also produced decreasing contributions: 10.33, 8.87 and 7.68% for young, middle-aged and mature forests respectively (Table 2).

DISCUSSION

Carbon stocks of the ecosystem in the lower subtropical broadleaved evergreen forests of different ages increased rapidly with increasing forest age. The carbon stocks ranged from 125.23 ± 8.26 to 288.88 ± 14.76 t C ha⁻¹. The mature forests achieved as high as 288.88 ± 14.76 t C ha⁻¹, which was 2.30 and 1.39 times those of young and middle-aged forests respectively. This indicates that the forest ecosystems in the current young and middle-aged forests can deposit carbon when they become mature forests. The carbon stocks of arbor layer ranged from 40.17 ± 3.33 to 154.05 ± 8.24 t C ha⁻¹. The mature forests achieved as high as 154.05 ± 8.24 t C ha⁻¹, which was 3.83 and 1.57 times that of young and middle-aged forests respectively. The carbon stock values of the arbor layer in this study were higher than the carbon stocks of *Coniferous* forest, *Theropencedrymion* and artificial vegetation within the same climatic zone (Fang et al. 2003, Tang & Zhou 2005, Zhang et al. 2012) but lower than the monsoon evergreen broadleaved forest in DHSBR (Fang et al. 2003). However, the values here were equivalent to the tropical forest arbor layer carbon stock of Xishuangbanna in western China (Tang et al. 2012), far higher than the average carbon stocks of vegetation of similar



Figure 3 Distribution of carbon stock among the various components of CWD (coarse woody debris) with different ages

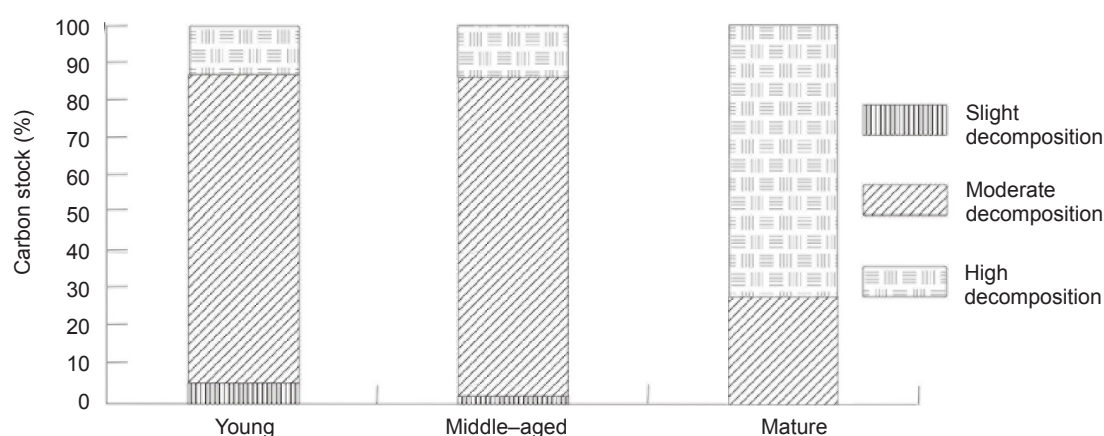


Figure 4 Distribution of CWD (coarse woody debris) carbon stock in the decay class of evergreen broadleaved forests with different ages

forest type throughout the whole country (Zhou et al. 2000) in the different climatic zones. The carbon stocks of soil ranged from 72.12 ± 5.39 to $105.73 \pm 8.52 \text{ t C ha}^{-1}$. The mature forests achieved as high as $105.73 \pm 8.52 \text{ t C ha}^{-1}$, which was 1.47 and 1.21 times those of young and middle-aged forests respectively. Ecosystems in the mature lower subtropical evergreen broadleaved forests exhibited less soil carbon stocks than the zonal mature forests in the cold temperature zone (Guo et al. 2004), three main deciduous broadleaved forests in temperature zone (Fang et al. 2006) and the average soil carbon stock of Chinese broadleaved evergreen forests (Zhou et al. 2000). Their contribution to the ecosystem was less than the global and China's average level (Dixon et al. 1994) (Table 3). Therefore, forest age can exert a significant impact on the total carbon stocks of ecosystems of lower subtropical evergreen broadleaved forests. The carbon stock

of forest ecosystem was higher in mature forest and lower in young and middle-aged forests. Middle-aged and young forest ecosystems in the lower subtropical broadleaved evergreen forest of PRD still possess high carbon sequestration potential. The lower subtropical broadleaved evergreen forest contains relatively lower soil carbon stocks in different climatic zones and possesses relatively higher carbon stocks in the arbor layer.

The secondary biomass carbon stock of the ecosystem in the lower subtropical evergreen broadleaved forest ranged from 12.94 ± 1.02 to $22.18 \pm 2.03 \text{ t C ha}^{-1}$, which was lower than the arbor layer carbon stock and the soil carbon stock. However, it would underestimate about 7–10% of the total carbon stock if the secondary biomass carbon stock of the ecosystem was neglected. The secondary biomass carbon stock of the ecosystem was larger than that of the *Eucalyptus*

carbon stock in the same climatic zone (Zhang et al. 2012), which might be attributed to the fact that the evergreen broadleaved forest provided favourable conditions for understory vegetation growth, whereas planted forests inhibited the growth of understory vegetation because of the self-thinning effect (Ahmed et al. 2008, Fang et al. 2009, Zhang & Fu 2009). Understorey vegetation plays an important function in stabilising the ecosystem and its carbon stock is determined by forest age (Xu et al. 2000). In this study, the contribution of understory vegetation to secondary biomass carbon was in the order of young forest (61.51%) > middle-aged forest (55.36%) > mature forest (36.4%). The shrub layer was the main component of understory vegetation carbon stocks, accounting for over 80% of understory vegetation carbon stocks in all three forest ages (Table 2).

The carbon stocks of CWD and litter increased with increasing forest age. Their contributions to secondary biomass carbon in young, middle-aged and mature forests were 38.72% (16.38% for litter and 22.33% for CWD), 44.64% (13.34% for litter and 31.30% for CWD) and 63.12% (11.90% for litter and 51.22% for CWD) respectively. Mature forests contained 11.36 ± 0.20 t C ha⁻¹ of CWD carbon stocks (2.39 ± 0.15 t C ha⁻¹ from snags and 8.97 ± 2.60 t C ha⁻¹ from logs), higher than those of logs in lowland tropical rainforests of the Australian tropics and the average value of five tropical rainforests in Venezuela, except for

the tropical mountain wet forest and temperate deciduous forest upstream of Great Lakes (Delaney et al. 1998, Grove 2001, Gough et al. 2007). However, the value is lower than that of subtropical evergreen broadleaved forests in Chile and China (Carmona et al. 2002, Yan et al. 2007). This occurrence is attributed to various climatic factors such as temperature and humidity, which can influence the decomposition rate of CWD, thus enabling the CWD carbon stocks to distribute in latitudinal zonality (Woodall & Liknes 2008). The distribution characteristics of the CWD decomposition levels often vary with forest age. This reflects the tree death rate of a forest ecosystem (Bond-Lamberty et al. 2002). The CWD carbon stocks in young and middle-aged forests exhibited moderate decomposition (II and III) higher than 80%, whereas the CWD carbon stocks in mature forests mainly exhibited high decomposition (IV and V) up to 72.21%. This result reflects that young and middle-aged forest ecosystems exhibit low tree death rate, whereas mature forests have high tree death rate. The distribution patterns of the ecosystem carbon stocks vary with forest age (Pregitzer & Euskirchen 2004). The carbon stocks of the arbor layer, soil and secondary biomass in young forests accounted for 32.08, 57.59 and 10.33% of the ecosystem total carbon stocks respectively. Soil organic carbon mainly comes from trees, shrubs, grasses and organic residues in the upper part and root of other plants. Soil organic carbon

Table 3 Parameter the arbor layer and soil carbon stock of forest ecosystem in different study areas

Layer	Study plot	Forest type	Carbon stock (t C ha ⁻¹)	Reference
Arbor	Pearl River Delta	Lower subtropical broadleaved evergreen forest	154.05	This study
	Dinghushan Nature Reserve	Coniferous forest	71.75	Fang et al. 2003, Tang & Zhou 2005
		<i>Theropencedrymion</i>	150.39	
		Evergreen broadleaved forest	203.9	
	Pearl River Delta	<i>Eucalyptus</i>	93.21	Zhang et al. 2012
		<i>Acacia</i>	76.83	
Soil	China	Evergreen broadleaved forest	73.68	Zhou et al. 2000
	Xishuangbanna	Tropical forest	155.00	Tang et al. 2012
	Honghuerji Desert	<i>Pinus sylvestris</i> in cool temperate zone	195.0	Guo et al. 2004
	Dongling Mountain in Beijing	Three main deciduous broadleaved forest in temperature zone	201–232	Fang et al. 2006
	China	Evergreen broadleaved forest	257.57	Zhou et al. 2000
	Pearl River Delta	Lower subtropical broadleaved evergreen forest	105.73	This study

is formed over a long period (Six et al. 2002), whereas arbor layer carbon stock accumulates more rapidly with increasing forest age. The arbor layer increased its contributions to the ecosystem carbon stock with age, while secondary biomass and soil decreased their contributions gradually, respectively contributing 53.33, 7.68% and 36.60 to the ecosystem total carbon stocks in mature forests.

The distribution patterns of the secondary biomass carbon stocks also varied with increasing forest age. Considering that young and middle-aged forests were inadequately dense, the carbon stocks of understorey vegetation increased with increasing forest age. Furthermore, the forest ecosystem continues to grow vigorously, thus resulting in low tree death rate and less CWD. Understorey vegetation contributed the most to secondary biomass carbon (young forest 61.51% and middle-aged forest 55.36%), followed successively by CWD (young forest 22.34% and middle-aged forest 31.31%) and litter (young forest 16.38% and middle-aged forest 13.34%). When forest density is increased, the understorey vegetation receives less sunshine, thus restricting growth. This could be responsible for the decrease in the carbon stocks of understorey vegetation in mature forests. However, mature forests produced more CWD because of gradual tree deaths or sudden unexpected issues, thus distributing the secondary biomass carbon stocks as CWD (51.22%) > understorey vegetation (36.4%) > litter (11.90%).

Different species of the community may also affect the accumulation of carbon stock of the forest ecosystem. In this study, the high trees play decisive role in carbon stock accumulation because they share the same life form (the sun megaphanerophyte). Carbon stock of ecosystem and its components increase significantly with forest age. Thus, species is not considered a fundamentally influential factor in this study.

CONCLUSIONS

Forest age can exert a significant impact on the total carbon stocks of ecosystems of lower subtropical evergreen broadleaved forests. The carbon stock of forest ecosystem was higher in mature forest while lower in young and middle-aged forests. Middle-aged and young forest ecosystems in the lower subtropical broadleaved evergreen forest of PRD still possessed high

carbon sequestration potential. The lower subtropical broadleaved evergreen forest contained relatively lower soil carbon stocks in the different climatic zones and possessed relatively higher carbon stocks in the arbor layer. Secondary biomass stock of ecosystem was an important component of the ecosystem stock. It could not be neglected in estimation of forest ecosystem carbon stock. The distribution characteristics of the ecosystem carbon stocks varied with increasing forest age. Soil contributed the largest carbon stock in young forests, followed by arbor layer and secondary biomass. However, the arbor layer contributed the largest carbon stock in middle-aged and mature forests, followed successively by soil and secondary biomass. For the distribution characteristic of secondary biomass carbon stock, in young and middle-aged forests, understorey vegetation contributed the most to secondary biomass carbon stock, followed successively by CWD and litter. However, in mature forests, CWD contributed the most to secondary biomass carbon stock, followed successively by understorey vegetation and litter.

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