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Biomass and carbon stocks in *Schima superba* dominated subtropical forests of eastern China

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ABSTRACT: Quantitative relationships between stand indices and carbon dioxide (CO_2) stocking are missing in the evergreen broadleaved forests (EBLFs) in eastern China and this hinders to estimate carbon (C) budget in the subtropical region. We determined the vegetation-soil C pool and CO_2 stocking using stand indices [diameter at breast height (DBH), total height (H) and wood density] in *Schima superba* dominated EBLFs in the Tiantong National Forest Park in eastern China. Vegetation biomass was determined by a non-destructive method using the tree volume and wood density approach while soil C concentration was determined using the oil bath-K_2CrO_7 titration method. Finally, multiple regression and one-way ANOVA with LSD test were used for data analysis. Results showed that total C stocks in the vegetation and the 0–20 cm surface soil were 90.53 $t \cdot ha^{-1}$ and 116.24 $t \cdot ha^{-1}$, respectively. The study revealed that the total amount of CO_2 stocks in the studied forest is 331.87 $t \cdot ha^{-1}$. One-way ANOVA with LSD test showed that CO_2 stocks varied significantly ($P < 0.05$) between the tree growth stages. There was a significant variation in CO_2 stocking capacity within sapling and pole growth stages but no significant variation within standard stage. The stepwise multiple regression analysis showed that DBH, BA and H were related to the C stocking while wood density had no significant effect. The significant amount of C stocking in EBLFs in the Tiantong National Forest Park of eastern China showed the potential and significant C stocks by trees. As the C pool structure changes due to a change in the forest type and location, therefore this study is important to estimate C stocks and predict CO_2 stocks from stand indices in EBLFs which serve as a scientific basis for sustainable forestry operations, rational utilization of forest resources and global warming reduction in EBLFs in subtropical regions of China.

Keywords: carbon stocks; evergreen broadleaved forest; forest inventory-based approaches; tree growth; wood density

The increase of carbon dioxide (CO_2) in the atmosphere is becoming a global issue. Carbon (C) is sequestered by the plant photosynthesis and stored as biomass in different components of the tree. During photosynthesis, trees act as a sink for CO_2 by fixing C and sequester excess C as biomass in different tree organs. The net long-term CO_2 sequestration of forest changes through the life span as trees grow up, die and decay (Nowak, Crane 2002). Trees absorb CO_2 from the atmosphere by getting an increase in their biomass through growth and sequester it in the plant tissues (Mathew et al. 2000) resulting in development of different tree components. As the tree biomass performs growth, the C held by the tree also increases the CO_2 stock (Tagupa et al. 2010). The CO_2 sequestration rate depends on the growth (diameter) characteristics of the tree species (Huy, Anh 2008). The plant having a higher quantity of biomass reflects the higher CO_2 sequestration in the whole tree as well as in tree components (overbark stem, branches and leaves) (Jana et al. 2011). Forest trees are recognized as very important in the global C cycling, because the amount of C stored in plant biomass globally exceeds that of atmospheric CO_2, and nearly 90% of the plant biomass C is stored in tree biomass (Mooney et al. 2001). The quantification of forest biomass has a long history and has received renewed attention in the last decades because forest biomass represents about 44% of the

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globe forest C pool (Pan et al. 2011) and therefore plays a crucial role in climate change mitigation. Furthermore, sequestration of CO_2 among forests depends on forest type, dominant tree species and forest stand age (Huy, Anh 2008). This highlights the need to precisely determine the amount of C stored and CO_2 sequestrated in each of specific forest ecosystems.

For estimating C stocks, forest inventory-based approaches have been used all over the world (Kurz, Apps 1999; Liski et al. 2002; Nizami 2012). The output variables of traditional forest inventories are tree height and diameter which can later be converted into tree volume, biomass and C stocks. Stand-level biomass is an aggregation of single-tree biomass. In various process models the relative proportion of biomass components in trees changes after canopy closure (Berninger, Nikinmaa 1997), which is the time point-based variable as light conditions change considerably during forest development (Oliver, Larson 1996). For example, the relative proportion of foliage biomass decreases, while the relative biomass of stems continues to increase through the tree ontogenetic growth (Satoo, Madgwick 1982). Therefore, the stand-level biomass cannot be measured directly. Instead, an estimation for each tree can be done and then summed to give the total stand estimation (Zianis et al. 2005). Estimations of tree biomass can be measured directly by using harvesting methods, but estimation is preferred to avoid damaging the forests (Montès et al. 2000). Using allometric equations (species-specific or generalized; Chave et al. 2005) or general volume equation (Brown, Lugo 1992; Nizami et al. 2009; Nizami 2012) is a non-destructive approach to calculate total tree biomass. Then the estimation of C stocks can be derived from the biomass using an international standard conversion factor (0.5) and assuming that 50% of the tree biomass has elemental C (Dixon et al. 1994; Nizami et al. 2009). After that the ratio of CO_2 to C, i.e. 3.6663, can be used to calculate CO_2 stocks from total C stocks (Anh 2007; Tagupa et al. 2010).

The rate of sequestrated and stored CO_2 of a given tree is related to the tree size such as stem basal area (BA) and total tree height (H). At a sapling stage, the biomass and CO_2 stocking varies among tree species but as trees grew bigger and reached the pole and standard stages, no more significant variation existed in terms of their C stocking capacity (Tagupa et al. 2010). During the tree growth, BA and H should allometrically relate to biomass accumulation and CO_2 stocks of a tree. However, the stem wood density might have no significant effect on CO_2 stocks because of a small variation in wood density with the tree growth for a given species (Zhang 1995). If this is true, we thus hypothesized that CO_2 stocks should vary with the tree growth from sapling to standard stage. Rather than wood density, tree CO_2 stocks should be associated with BA, diameter at breast height (DBH) and H, because of the negligible variation in wood density among the growth stages of a tree.

In absolute terms, soil C stocks are much larger than C sequestered in tree biomass (Lal 2004). A recent calculation of C storage values, including soil C stock estimates, revealed significantly higher estimates in nearly all biomes, including an approximately threefold increase in soil organic C stocks estimates for tropical forests (Eglin et al. 2011). The moist tropical or sub-tropical forests contained more than 50% of C stocks in soils and almost less than 50% in the vegetation because the dead biomass rapidly decomposes in the warm, humid conditions and the minerals rapidly leach out of tropical forest soils (Ross 2009).Therefore, the C concentration in soils is highly significant; it is assumed that soils have approximately three times more C than the vegetation and twice more as to that present in the atmosphere (Batjes, Sombroek 1997). However, little is currently understood how C stocks partitioned between vegetation and soil in subtropical forests in eastern China.

Evergreen broadleaved forests (EBLFs) are a zonal vegetation type located in subtropical China (Song,Wang 1995; Feng et al. 1999). In this study, we determined the vegetation-soil C pool and estimated CO_2 stocks in one of the typical EBLFs using different stand indices through forest inventory based approaches. Specifically, we were interested in (1) how the C stock partitions between vegetation and soil pools; (2) whether forest CO_2 stocks relate to the tree growth stage, and (3) whether site indices can be used for predicting CO_2 stocks of trees in EBLFs.

MATERIAL AND METHODS

Study site and plot. The study was conducted in Tiantong National Forest Park (29°48'N, 121°47'E, 200 m a.s.l.), Zhejiang province, China, covering an area of 349 ha. The region has warm and humid subtropical climate with an average annual temperature of 16.2°C, average annual precipitation of 1,374.7 mm (mostly concentrated in the summer), annual average relative humidity is 82 % (shows low intra-annual variability) and mean annual evaporation is 1,320.1 mm (less than annual precipitation). The soil is mostly mountain yellow-red soil, with the parent material mostly including Mesozoic sedimentary rocks, some acidic igneous rocks, and granite residual weathered material (Song, Wang 1995).

The zonal vegetation in this region is subtropical EBLFs. In Tiantong National Forest Park, the majority of the EBLFs are *Schima superba* Gardn. et Champ dominated forests, which are considered as sub-climax monsoon EBLFs and have been severely disturbed in the history with only small tracks (approximate 10 ha) of semi-intact forests left around a Buddhist temple (Yan et al. 2009). Since forest age, community structure and plant species composition are similar in this area (Yan et al. 2013), six square plots, each of 10 × 10 m in size, were established to represent the ranges of both community and environmental properties in this study. The tree stratum is 15 to 18 m high and cover percentage is 80~90%, occupied by evergreen broadleaf species. The shrub stratum is < 4 m in height and coverage is 45–50%. The herb stratum is < 0.5 m in height with coverage being 10 to 30 % and the dominant species are normally ferns. Totally, eighteen woody plant species were found in the studied plots. The species list and their DBH (cm), BA (m^2·ha^{-1}), H (m), stem volume (m^3·ha^{-1}), wood density (g·cm^{-3}) and stem density (trees·ha^{-1}) for each species are shown in detail in Table 1.

Measurements of forest structure and tree biomass. The vegetation C stocks were estimated based on the general volume equation by getting the relationships between tree H, DBH and wood density (Nizami et al. 2009; Tagupa et al. 2010; Nizami 2012). For all woody plants in the studied plot, base diameter and DBH were measured for tall trees, while base diameter and 45 cm diameter (D$_{45}$) were measured for small trees (of less than 1.50 m in height). The H to the top of trees was measured with a telescopic pole for heights up to 15 m, and with a clinometer for heights > 15 m.

The tree individuals of *S. superba* and *Lithocarpus glaber* were classified into three growth stages on the

Table 1. Characteristics of the studied plots in *Schima superba* dominated evergreen broadleaved forest in the Tiantong National Forest Park in eastern China

Species name	DBH (cm)	Height (m)	Basal area (m^2·ha^{-1})	Volume (m^3·ha^{-1})	Wood density (g·cm^{-3})	Stem density (tree·ha^{-1})	Biomass (t·ha^{-1})
Schima superba	14.70 ± 0.56	14.65 ± 0.50	26.95	176.29	0.6	1,063	105.77
Pinus massoniana	33.30 ± 3.20	18 ± 1.32	15.72	121.82	0.5	125	60.91
Lithocarpus glaber	6.81 ± 1.52	7.93 ± 1.73	2.37	15.55	0.5	250	7.77
Rhododendron ovatum	1.39 ± 0.08	2.21 ± 0.06	0.32	0.37	0.6	1,225	0.22
Camellia fraterna	1.03 ± 0.08	1.84 ± 0.10	0.05	0.05	0.6	387	0.027
Eurya muricata	1.30 ± 0.18	2.07 ± 0.19	0.03	0.03	0.6	137	0.019
Eurya rubiginosa var. *attenuata*	1.19 ± 0.07	1.90 ± 0.06	0.14	0.13	0.6	763	0.08
Symplocos stellaris	1.58 ± 0.22	2.32 ± 0.20	0.10	0.14	0.5	275	0.08
Symplocos sumuntia	1.17 ± 0.06	1.73 ± 0.05	0.12	0.10	0.5	725	0.05
Symplocos heishanensis	1.08 ± 0.06	1.80 ± 0.08	0.07	0.06	0.4	513	0.03
Castanopsis fargesii	1.70 ± 0.60	2.09 ± 0.47	0.50	2.57	0.5	362	1.29
Castanopsis sclerophylla	10.55 ± 1.76	9.77 ± 1.75	1.47	6.74	0.5	100	3.37
Loropetalum chinensis	0.84 ± 0.12	1.93 ± 0.13	0.02	0.01	0.7	162	0.009
Vaccinium mandarinorum	1.06 ± 0.16	1.77 ± 0.07	0.02	0.02	0.8	138	0.01
Helicia cochinchinensis	1.32 ± 0.34	1.92 ± 0.18	0.03	0.03	0.7	113	0.02
Myrica rubra	2.75 ± 1.05	2.96 ± 0.70	0.45	1.74	0.8	187	1.39
Syzygium buxifolium	1.20 ± 0.20	2.31 ± 0.18	0.02	0.02	0.7	88	0.01
Castanopsis carlesii	1.003 ± 0.08	1.78 ± 0.07	0.05	0.04	0.5	437	0.02
Grand total				188.34		7,050	181.075

values of diameter at breast height (DBH) and height for each species are mean ± SE while basal area, volume, and biomass for each species are summarized (total) by all individuals for each species in the plot; basal area and volume were estimated by the ratio of the sample plot area to the area of 1 ha (10,000 m^2)

basis of DBH regardless of the age, i.e. sapling stage (< 10 cm DBH), pole stage (10–20 cm DBH) and standard stage (> 20 cm DBH) by following the method standard of Tagupa et al. (2010) while the other species of the study plot could not be classified into growth stages according to the standard criteria.

Aboveground biomass for each individual tree was calculated by a non-destructive method by multiplying the tree volume by the species-specific dry wood density (Brown, Lugo 1992; Nizami et al. 2009; Nizami 2012). The biomass obtained by the volume-density equation was highly consistent (R^2 = 0.87; $P < 0.0001$) with biomass obtained by the site and species-specific allometric equation for *Schima superba* (DBH ranges from 3.5 to 25.5 cm; the number of trees cut = 6; Yang et al. 2010) (Fig. 1). Tree volume per hectare for each species was calculated using general Eq. (1) (Lu et al. 2003):

$$V = 0.42 \times \mathrm{BA} \times \mathrm{H} \qquad (1)$$

where:
V – volume of a tree ($\mathrm{m^3 \cdot ha^{-1}}$),
0.42 – fixed general value used for form factor because it can be used in the absence of local equations to estimate the cubic volume of a standing tree (Mangnussen et al. 2004),
BA – basal area ($\mathrm{m^2 \cdot ha^{-1}}$) using the formula $\mathrm{BA} = \pi (d/2)^2 \times 10^{-4}$ (Small et al. 2004),
H – total tree height (m),
d – DBH for big trees or D_{45} for small trees (cm).

The per-hectare volume was estimated by the ratio of the sample plot area to the area of 1 ha.

For measuring wood density, wood samples were taken from the trunk of 7–10 trees of the same species having different DBH using a 5 mm-diameter increment corer. In the laboratory, the length of the tree core was measured with an electronic vernier calliper, and then the volume of the tree core was calculated. Next, core samples were dried at 75°C in an oven for 72 h to determine dry mass used to calculate the wood density (Chave et al. 2006).

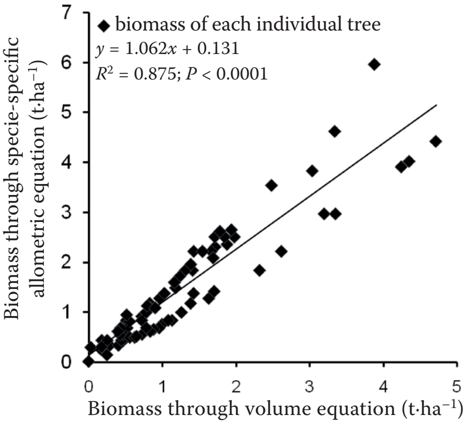

Fig. 1. Comparison of the individual tree biomass of *Schima superba* estimated from the volume equation, i.e. tree biomass = tree volume ($\mathrm{m^3 \cdot ha^{-1}}$) × species-specific wood density ($\mathrm{g \cdot cm^{-3}}$) (Brown, Lugo 1992; Brown, Iverson 1992; Nizami et al. 2009) and species-specified allometric equation for *Schima superba* (Yang et al. 2010)

It should be noted that the studied plots did not include so much deadwood and debris because of clearing by the forest manager every year for a landscape view. Therefore, we decided to take the soil and vegetation as major C pools by ignoring dead woody debris.

Calculation of forest C and CO_2 stocks. Total C stock in each species was determined by multiplying the total tree biomass by a conversion factor (0.5), which is representative of the average C content in tree biomass. This conversion factor shows that 50% of the total tree biomass is equal to elemental C (Brown, Lugo 1982; Dixon et al. 1994; Nizami et al. 2009).

The CO_2 stock in tree was computed using Eq. 2 (Tagupa et al. 2010).

$$CO_{2\ \mathrm{stock}} = C_{\mathrm{veg}} \times 3.6663 \qquad (2)$$

where:
C_{veg} – C stocks in vegetation ($\mathrm{t \cdot ha^{-1}}$),
3.6663 – universal conversion factor of C content values to CO_2 values.

The ratio of CO_2 to C is determined by atomic mass (Anh 2007; CFS 2009; Superak 2010). Furthermore, Anh (2007) also suggested on the basis of an experimental approach that the CO_2 amount which vegetation absorbs and O_2 are harmonized in the atmosphere and can be calculated by means of the chemistry equation, i.e. $CO_2 = C + O_2$ and thus $CO_2 = 3.6663C$.

CO_2 stocks in different tree components for each individual were estimated using tree components specific allometric Eqs. 3–6, developed by Huy and Anh (2008) for *Schima superba* dominated EBLFs in Vietnam:

$$CO_{2\ \mathrm{stem}} = 6.15398 + 1.02468 \times \mathrm{Ln}(V) \qquad (3)$$

$$CO_{2\ \mathrm{bark}} = 4.11447 + 1.06381 \times \mathrm{Ln}(V) \qquad (4)$$

$$CO_{2\ \mathrm{branch}} = -4.11248 + 2.70337 \times \mathrm{Ln}(d) \qquad (5)$$

$$CO_{2\ \mathrm{leaf}} = -2.941 + 1.72414 \times \mathrm{Ln}(d) \qquad (6)$$

where:
CO_2 – stocks in each tree component, converted to $\mathrm{t \cdot ha^{-1}}$;
V – volume of a tree stem ($\mathrm{m^3}$),
d – DBH for big trees or D_{45} for small trees (cm).

However, to avoid the overestimation of the total CO_2 content, the amount of CO_2 in bark and stem was considered as an overall percentage, i.e. CO_2 in overbark stem (Tagupa et al. 2010).

Measurement of soil carbon stock. Ten soil samples were taken with a metal corer from randomly chosen spots in each of the studied plot (0–20 cm soil layer). The litter layer was removed before the soil was taken. The soil bulk density was determined using a steel corer of the known volume. Before weighing, approximately 5 soil cores per plot were placed in a 105°C oven for > 48 hours. Bulk density ($g \cdot cm^{-3}$) was calculated by dividing the oven dry weight (g) of the soil sample by the volume of the soil sample in the steel corer (cm^3). Then the remaining soil samples were air-dried for 30 days, and passed through a 2-mm sieve to determine the total C concentration using the oil bath-K_2CrO_7 titration method (Nelson, Sommers 1975). Finally, C stock in the top 0–20 cm soils was estimated using Batjes (1996) formula.

Data analysis. The data analysis included three steps. The first step was to determine relationships between H, DBH, BA, tree volume and CO_2 stocks of all plant species using linear regression methods. In the second step, one-way ANOVA with the Least Significant Difference (LSD) test was used to find out the significant variance of CO_2 stocks between tree growth stages while regression ANOVA was used to explore the significant variation of CO_2 stocks with the response of DBH in each growth stage of *Schima superba* and *Lithocarpus glaber*. In the third step, the stepwise multiple regression analysis was used to find out whether CO_2 stocks were affected by different tree variables (DBH, H and wood density) of all studied species in the sampling plots. All statistical tests were considered significant at the $P < 0.05$ level.

RESULTS

Forest biomass

H in the studied forest increased with increasing DBH. Among all species, on average basis *Pinus massoniana* had greater H (18 m) and DBH (33.3 cm) than *Schima superba* with 14.65 m H and 14.70 cm DBH (Table 1). For most species, H and DBH showed a positive linear relationship. Stem volume increased linearly with increasing BA ($r = 0.98$) for all species.

Tree biomass was related to BA significantly and linearly for each species (Table 2). Total tree biomass was greater in *Schima superba* (105.77 $t \cdot ha^{-1}$) than in *Pinus massoniana* (60.911 $t \cdot ha^{-1}$). In the studied forest, grand total tree biomass being cal-

Table 2. Linear regression analysis for tree biomass (TB) against basal area (BA)

Species name	Regression equation	R^2	P
Schima superba	TB = –0.151 + 73.356 (BA)	0.875	0.000
Pinus massoniana	TB = –0.578 + 70.697 (BA)	0.904	0.000
Lithocarpus glaber	TB = –0.001 + 54.568 (BA)	0.934	0.000
Rhododendron ovatum	TB = –0.001 + 14.822 (BA)	0.935	0.000
Camellia fraterna	TB = 0.000 + 12.162 (BA)	0.914	0.000
Eurya muricata	TB = 0.000 + 12.535 (BA)	0.939	0.000
Eurya rubiginosa var. *attenuata*	TB = 0.000 + 11.662 (BA)	0.964	0.000
Symplocos stellaris	TB = –0.001 + 15.891 (BA)	0.926	0.000
Symplocos sumuntia	TB = 0.000 + 8.248 (BA)	0.942	0.000
Symplocos heishanensis	TB = –0.00009 + 6.388 (BA)	0.886	0.000
Castanopsis fargesii	TB = –0.009 + 51.722 (BA)	0.979	0.000
Castanopsis sclerophylla	TB = –0.039 + 41.846 (BA)	0.906	0.000
Loropetalum chinensis	TB = 0.000 + 13.022 (BA)	0.935	0.000
Vaccinium mandarinorum	TB = 0.000 + 11.677 (BA)	0.978	0.000
Helicia cochinchinensis	TB = 0.000 + 15.006 (BA)	0.996	0.000
Myrica rubra	TB = –0.006 + 54.293 (BA)	0.997	0.000
Syzygium buxifolium	TB = 0.00004 + 11.230 (BA)	0.947	0.000
Castanopsis carlesii	TB = 0.000 + 8.703 (BA)	0.976	0.000

significant at $P < 0.05$

culated by summating each individual tree of all species was 181.07 $t \cdot ha^{-1}$.

Forest C and CO_2 stocks

Assuming that 50% of the vegetation biomass is C, the greater amount of total C stocks was found in the species *Schima superba* (52.88 $t \cdot ha^{-1}$), followed by *Pinus massoniana* (30.45 $t \cdot ha^{-1}$). Total vegetation C stocks in the studied forest were 90.53 $t \cdot ha^{-1}$ (Table 3). Total soil C stocks at the 0–20 cm surface soil were 116.24 $t \cdot ha^{-1}$ (Fig. 2) having 1.3 ± 0.01 ($g \cdot cm^{-3}$) bulk density. Totally, the overall C stocks on the ecosystem (vegetation + soil) level were 206.77 $t \cdot ha^{-1}$, with 43.79% in vegetation, while with 56.21% in the surface soil (Fig. 2).

The total amount of CO_2 stocks in the studied forest was 331.87 $t \cdot ha^{-1}$. The amount of CO_2 sequestrated among tree components was largest in stems, intermediate in branches, and lowest in leaves (Table 3). Considering particular species, the greater amount of total CO_2 stocks was found in *Schima superba* (193.90 $t \cdot ha^{-1}$) and *Pinus massoniana* (111.66 $t \cdot ha^{-1}$).

Relationship between CO_2 stock capacity and tree growth

To test whether the CO_2 stocking capacity depends on tree ontogeny, the two most abundant species *Schima superba* and *Lithocarpus glaber* were classified into three developmental stages on the basis of DBH; sapling stage (< 10 cm DBH), pole stage (10–20 cm DBH), standard stage (> 20 cm DBH). One-way ANOVA with the LSD test showed that the CO_2 stock varies significantly ($P < 0.05$) between the growth stages (Fig. 3). Furthermore, according to the regression ANOVA result, significant variation in CO_2 stocking capacity with DBH variation exists within sapling stage ($P = 0.037$) and pole stage ($P = 0.00$) while no significant ($P = 0.13$) variation exist within standard stage (Table 4).

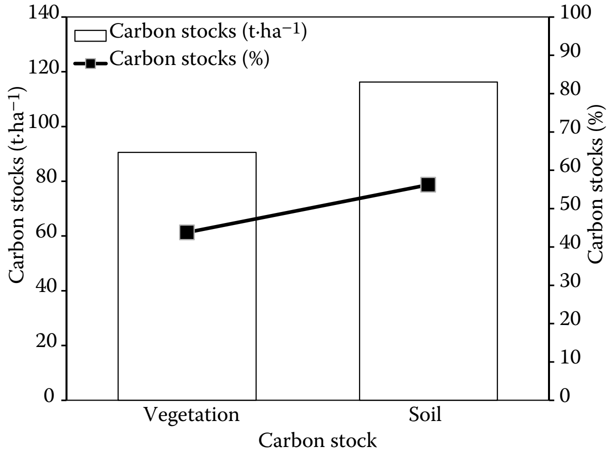

Fig. 2. Carbon stocks in each type of the aboveground vegetation and the 0–20 cm surface soil in *Schima superba* dominated evergreen broadleaved forest in the Tiantong National Forest Park in eastern China

Relationships between CO_2 stocks and stand indices

The regression equation of each species showed that CO_2 stocks increase with the increasing diameter of the tree. Wood density, however, did not affect the C stocks. Also, P-values for each species showed that there was a significant relationship between CO_2 stocks and DBH of trees ($P < 0.05$, Table 5).

In each unit area or each forest stand, it is necessary to calculate CO_2 stocks to find out which stand indices influence the effectiveness of predicting CO_2 stocks. The stepwise regression analysis showed that DBH and H influenced the effectiveness of predicting CO_2 stocks and wood density was excluded from the regression model [i.e. Eq. 7, where $R^2 = 0.80$, $P < 0.001$, DBH – diameter brest hight (cm), H – total tree height (m)].

$$CO_{2\ stock} = -0.27 + 0.35\ DBH - 0.14\ H \qquad (7)$$

DISCUSSION

Effectiveness of stand indices in predicting forest CO_2 stocks

According to Huy and Anh (2008) findings the absorbed CO_2 amount depends on the species, DBH and H but they did not assess the role of wood density and BA in terms of their effect on C stocks for the specific forest type. In this study, wood density and BA were taken as indicators for predicting the CO_2 stocking capacity in EBLFs. The result showed that BA strongly affects the CO_2 stocks because of a change in DBH and stem area occupied by the tree during growth. This result is consistent with the findings of Huy and Anh (2008) that CO_2 has a firm relationship with DBH which has the advantage to identify the CO_2 amount sequestrated in each forest stand. Also, this result was quite close to the finding of Tagupa et al. (2010) that the variation in the amount of CO_2 sequestered and stored in the trees within a forest stand is affected greatly by the stand density of trees. The estimation of per-hectare tree volume using BA as a function is more significant as compared

Table 3. Estimates of C and CO_2 stocks based on tree components in *Schima superba* dominated evergreen broad-leaved forest in the Tiantong National Forest Park in eastern China

Species name	Carbon stock ($t\cdot ha^{-1}$)	CO_2 stock capacity ($t\cdot ha^{-1}$)			
		stems	branches	leaves	total
Schima superba	52.89	139.61	50.41	3.883.87	193.90
Pinus massoniana	30.45	80.4	29.03	2.23	111.66
Lithocarpus glaber	3.89	10.27	3.7	0.29	14.26
Rhododendron ovatum	0.11	0.3	0.1	0.008	0.408
Camellia fraterna	0.01	0.03	0.01	0.001	0.041
Eurya muricata	0.01	0.02	0.008	0.0006	0.0286
Eurya rubiginosa var. *attenuata*	0.04	0.1	0.03	0.002	0.132
Symplocos stellaris	0.04	0.1	0.03	0.002	0.132
Symplocos sumuntia	0.02	0.07	0.02	0.001	0.091
Symplocos heishanensis	0.01	0.03	0.01	0.0008	0.0408
Castanopsis fargesii	0.64	1.7	0.61	0.04	2.35
Castanopsis sclerophylla	1.69	4.44	1.6	0.12	6.16
Loropetalum chinensis	0.004	0.01	0.004	0.0003	0.0143
Vaccinium mandarinorum	0.005	0.01	0.006	0.0004	0.0164
Helicia cochinchinensis	0.01	0.03	0.01	0.0008	0.0408
Myrica rubra	0.70	1.83	0.67	0.05	2.55
Syzygium buxifolium	0.005	0.01	0.005	0.0003	0.0153
Castanopsis carlesii	0.01	0.02	0.01	0.0007	0.0307
Grand total	90.534	238.98	86.263	6.6279	331.8709

C and CO_2 stocks were obtained from the summation of all individuals for each species in the plot

with using DBH only because BA is the area of a given section of land that is occupied by the cross-sections of tree trunks and stems at their base, which can be further applied to more precise estimation of tree biomass and then CO_2 stocks per hectare. In this study, wood density had no significant effect on CO_2 stocks in a mixed forest stand because wood density have a negative correlation with DBH ($r = -0.125$, $P < 0.05$) and H ($r = -0.191$, $P < 0.05$) growth (Rochon et al. 2007), but on the other hand, wood density is a significant parameter for predicting tree biomass and C stocks (Nogueria et al. 2005). Therefore, it is important to mention here that the role of wood density cannot be ignored in tree biomass estimation but it has no significant effect on the CO_2 stocks with tree growth in a mixed forest stand.

Change in CO_2 stocking capacity with tree growth

C sequestration varies from forest type to forest type and for the growth of forest which potentially relies on the tree diameter size class, i.e. growth stages according to DBH (Terakunpisut et al. 2007). The CO_2 stocks were dependent on the amount of biomass of trees, specifically, on the variables trunk diameter and H. This confirmed the result of Terakunpisut et al. (2007) and Tagupa et al. (2010), who mentioned that the C stocking potential in different forest types tends to be correlated with DBH and H. The oneway ANOVA result of *Schima superba* and *Lithocarpus glaber* species showed that the biomass and CO_2 stock varied between growth stages. Furthermore, within sapling and pole stages, CO_2 stocks varied significantly with DBH growth but as trees grow bigger and reach standard sizes,

Table 4. Results of regression ANOVA for the variability of CO_2 stocks induced by individual trees differing in DBH within each growth stage (sapling, pole and standard stages)

Growth stage	CO_2 stock ($t\cdot ha^{-1}$)	F	P
Sapling	6.17	3.328	0.037
Pole	132.17	5.469	0.00
Standard	69.85	76.838	0.13

CO_2 stock data – summation of *Schima superba* and *Lithocarpus glaber*, significant at $P < 0.05$

Table 5. Results of linear regression analysis for CO_2 stocking capacity (Y) against stem diameter at breast height (X) for large trees or diameter at 45 cm height (X) for small trees in *Schima superba* dominated evergreen broadleaved forest in the Tiantong National Forest Park in eastern China

Species name	Regression equation	R^2	*P*
Schima superba	$Y = -2.550 + 0.329 (X)$	0.819	0.000
Pinus massoniana	$Y = -10.886 + 0.662 (X)$	0.855	0.000
Lithocarpus glaber	$Y = -0.193 + 0.133 (X)$	0.890	0.000
Rhododendron ovatum	$Y = -0.006 + 0.007 (X)$	0.794	0.000
Camellia fraternal	$Y = -0.003 + 0.004 (X)$	0.798	0.000
Eurya muricata	$Y = -0.004 + 0.005 (X)$	0.877	0.000
Eurya rubiginosa var *attenuata*	$Y = -0.004 + 0.005 (X)$	0.877	0.000
Symplocos stellaris	$Y = -0.008 + 0.009 (X)$	0.739	0.000
Symplocos sumuntia	$Y = -0.002 + 0.003 (X)$	0.849	0.000
Symplocos heishanensis	$Y = -0.001 + 0.002 (X)$	0.836	0.000
Castanopsis fargesii	$Y = -0.264 + 0.165(X)$	0.964	0.000
Castanopsis sclerophylla	$Y = -0.417 + 0.109(X)$	0.759	0.005
Loropetalum chinensis	$Y = -0.002 + 0.003(X)$	0.829	0.000
Vaccinium mandarinorum	$Y = -0.002 + 0.004(X)$	0.898	0.000
Helicia cochinchinensis	$Y = -0.007 + 0.009(X)$	0.913	0.000
Myrica rubra	$Y = -0.131 + 0.109(X)$	0.985	0.000
Syzygium buxifolium	$Y = -0.002 + 0.004(X)$	0.970	0.000
Castanopsis carlesii	$Y = -0.002 + 0.003(X)$	0.889	0.000

significant at $P < 0.05$

no significant variation exists any more in terms of their CO_2 stocking because the growth rate (change in DBH) will gradually slow down for mature trees (Terakunpisut et al. 2007). The factors such as wood density, H, BA and DBH may have interplayed, giving complementary effects. The lower wood density values may be compensated by greater H and DBH, and vice versa.

Carbon stock pattern in typical subtropical forest

Estimating C stocks by species is an important trend and should be studied to a greater extent especially when the tree species composition might change in a mixed forest stand (Kellomäki, Kolström 1992). Therefore, the study of C stocks between vegetation and soils is more important to clear the complex relationship for each forest type and location. A linear regression equation was developed for the tree biomass of each species as a function of BA, showing that the tree biomass increases with the increasing stem diameter (Nizami et al. 2009). In this study, the result is quite close to the findings of Yang et al. (2010), who reported that the total biomass in Tiantong *Schima superba* community was 225.3 ± 30.1 t·ha^{-1}. The overall C stock (vegetation plus soil) in subtropical EBLFs was 206.77 t·ha^{-1} which consists of 43.79% in vegetation biomass and 56.21% in the topsoil. Additionally, our results are quite close to the findings of Ross (2009), who reported that the subtropical forest contained more than 50% (i.e. up to 50.5%) C in soil and less than 50% (i.e. up to 49.5%) C in vegetation. The overall C stocks are relatively close to the estimate by Dixon et al. (1994), who reported that the Asian tropical forest holds a C density of 132–174 t·ha^{-1}. Brown and Lugo (1984) estimated that the tropical forests of Bangladesh hold approximately 55–90 t·ha^{-1} of C in forest ecosystems. Overall, soil C stocks are the interactive result of climate, soil properties, litter production by vegetation, and litter quality; the more productive and dense vegetation in the site, the more litter is fed into soil (Liski 1995). In subtropical EBLFs, the C stocks in soils are a little higher than those in vegetation because of the rapid decomposition of dead biomass (Yan et al. 2007), higher litter production due to the dense mixed forest stand (approx; plant to plant and row to row distance was 3 × 3 m, respectively, in the study plot), and moist and humid climate (Yan et al. 2008).

CONCLUSIONS

The significant amount of C stocking in the typical EBLF in the Tiantong National Forest Park of eastern China showed the potential and significant C stocks by trees. Despite of the tree age, the bigger trees, particularly at their standard sizes, have the greatest C stocks, sequestered the greatest amount of CO_2, but have a low ability to sequester more CO_2 from the atmosphere for future because of the slow growth in trunk diameter as compared to the trees of pole and sapling sizes. Assuming that the trees are allowed to grow and are not cut for any purpose at all, they continue to provide the safety C sinks for the adverse effects of climate change. As the C pool structure changes due to a change in the forest type, class and location, therefore this study is important to estimate C stocks and predict CO_2 stocks from stand indices in EBLFs which serve as a scientific basis for sustainable forestry operations, rational utilization of forest resources and global warming reduction in EBLFs in subtropical regions of China.

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