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Original paper

Above-ground Biomass of Subtropical Evergreen Broadleaf Forests in Longwangtan, Guangdong, China

Fang Zhang [a], Guangyi Zhou [b], Motoshi Hiratsuka [c],
Kazuo Tanaka [a] and Yasushi Morikawa [a]
([a]Graduate School of Human Sciences, Waseda University
[b] Institute of Tropical Forest of China
[c] Mitsubishi UFJ Research & Consulting Co. Ltd.)
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Abstract

Although some allometric equations could be used to accurately estimate biomass or carbon stock in tropical forests, the reliability of these estimations will be questionable due to the local site specific conditions such as forest type and wood specific gravity of each tree species. In this study, twenty-one individuals from 16 tree species were harvested to measure the above-ground biomass, which consist of each organ of trunks, branches and leaves. The coefficients of correlation between tree diameter at breast high (DBH) and each organ showed high values, ranging from R^2=0.894 to 0.973. It was also found a relatively high correlation between DBH and total above-ground, of which the coefficient is 0.978. The allometric equation: Biomass=$0.1378DBH^{2.3142}$ was compared with other equations of similar subtropical forest conditions. There was small difference among our curve and the other three curves in the range of DBH of 3-34cm. In addition, for the purpose of confirmation, we calculated above-ground biomass 60.1 Mg ha^{-1} based on the equation of this study which is similar with other above-ground biomass determined by different authors for secondary subtropical forest. Therefore, the equation of this study could be applied to the large scale estimation of above-ground biomass in Longwangtan. Meanwhile, considering the time and labor consuming, it is not necessary to measure tree height for biomass estimation after testing the allometric relation of $(DBH)^2 \times H$ (Height) and biomass of sample trees. Moreover, another estimating method of above-ground biomass with the relation between the basal area (BA) and biomass of sample trees was inspected

Key Words：Above-ground biomass, Subtropical Forest, Allometric equation, Basal area, tal policy

Introduction

Forests of southern China are distributed widely in tropical and subtropical areas. The forest biomes are mainly rainforest, monsoon and evergreen-broadleaf forests. The species composition of them is complicated and there are a lot of precious tree species and fast growing ones which have already been introduced well as artificial forest. In the aspect of diameter, most of trees are median and small-diameter trees [1]. At one time, a large scale of forests in southern China was destroyed by artificial disturbances, the main reason of which had been usage of fuel wood by local people and wood industry. Once vegetation was damaged, the landscape would be changed to devastate due to the degradation of surface soil [2]. Chinese government has realized the seriousness of forest loss and carried out a large number of afforestation and/or reforestation programs, such as the protective forest program on the middle upper basin of the Changjiang River and so on. Recent years, the intensive afforestation and /or reforestation are also conducted widely in southern China. Some of the reforestation conservation of natural forests and restoration of degraded land projects have been focused on ecological services of forest, such as the function of carbon sequestration of forests that is a governmental issue based on the 12th Five-Year Plan of China.

There is less information on carbon stock in Chinese forests and the general method to evaluate the carbon stock has been required. Usually, in order to estimate the carbon sequestration or biomass in each target site, destructive sampling method, harvesting and weighing of sample trees, might be needed. If the general allometric relations, diameter at breast height (DBH) and tree biomass, to regional forests could be available, it would not be necessary to cut down sample trees in various areas.

In this study, the allometric equation of natural forest in Longwangtan was compared with other six allometric equations from the various ones in the tropics by putting the tree census data into equations. The allometric equations in this study might be applicable to the natural forests in Southern China. Another approach to estimate the stand biomass, which is by using the relationship between stand basal area (BA) and biomass, is discussed from the view point of nondestructive methods.

Materials and methods

Study site

This study was carried out in a subtropical forest in the Longwangtan Forest Reserve (25°13′N, 113°27′E) in Longwangtan, Guangdong, China. The climate of the area is subtropical monsoon. Average annual temperature is around 19.6℃. The rainfall is around 1,500mm. The soil is classified as laterite. Parent rocks are composed of weathering stuff derived from limestone, sand shale, and granite. The soil is relatively high nutrient and clay content. The forest is a secondary natural forest and is protected well recently, though it has undergone selective logging in the past several years. The forest mainly consists of pioneer and late-succession tree species such as *Castanopsis fissa* Rehder & E.H.Wilson, *Manglietia chingii* Dandy, *Alniphyllum fortunei* Makino and so on. The dominant species is *Castanopsis fabric* Hance and *Castanopsis fissa* Rehd.et Wils in the study site. A permanent plot was set with the area of 200 m^2 (20 ×20m) of equilateral triangle in December, 2009 and the stand density was 3,250 trees ha^{-1}. DBH and tree height (H) were measured in all trees with above 3 cm of DBH in September, 2011.

Biomass measurements and allometric relations

Twelve trees from 7 species (*Castanopsis carlesii* Chun, *Schima superba* Gardner & Champ, *Sapium discolor* Müll.Arg., *Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill, Aleurites montanus E.H.Wilson, *Castanopsis fissa* Rehder & E.H.Wilson and *Cinnamomum commersonii* Lukman., were harvested in Longwantan Forest Reserve in 2009. Another nine trees from 8 species (*Lamont Evergreen* Chinkapin, *Neolitsea levinei* Merr., *Castanopsis fissa* Rehder & E.H.Wilson, *Tsoongiodendron odorum* Chun, *Neolitsea levinei* Merr. *Schima superba* Gardner & Champ., *Pistacia chinensis* Bunge, *Cerbera manghas* L. *and Diospyros morrisiana* Hance) were harvested and measured for above-ground components in the same region on December, 2010. All selected species were typical in the local subtropical evergreen broadleaf forest. In total twenty-one trees were harvested ranged from 4.8 to 34.4

cm in DBH. After being harvested, trees were separated into trunks, branches, and leaves. Total fresh weight of each tree component was measured and then representative samples were dried in the laboratory to determine fresh and dry weight ratio. These samples were oven-dried at 85℃ for three to five days until they reached to a constant weight. Then the conversion rate from fresh weight to dry weight was determined. Total dry weight of each tree component was calculated by multiplication of total fresh weight and the ratio. Finally, a non-linear equation $y = ax^b$ (Table 1) was created by using DBH and dry weight of each tree component, which is known as allometric relations is needed. After that, both of DBH and H as independent variable were used to create the equation again for comparing between the parameter of DBH and DBH-H in allometric relations.

Results and Discussion

The BA was 16.4 m^2 ha^{-1}. Frequency of stems of different DBH class showed relatively small and L-shaped distribution (Fig. 1). Relatively low wood specific gravity of small trees (mainly 1cm ≤ DBH ≤ 10cm) was about 0.6 kg m^{-3}.

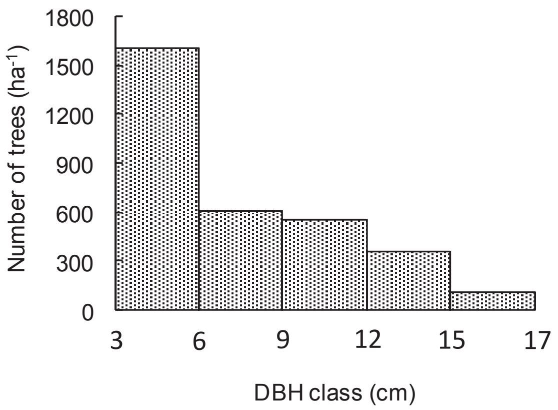

Fig.1 Distribution of DBH in the plot. Intervals of DBH class are 2 cm.

Allometric relation in the study site

The developed allometric equations for above-ground components showed high correlation from 0.894 to 0.978. (Table 1, Fig. 2). These results suggest that the allometric equation $AGB = 0.1378(DBH)^{2.3142}$ (R^2= 0.9776) with the parameter of DBH can be used to estimate above-ground biomass of subtropical secondary forests in Longwangtan, Guangdong, China. On the other hand, allometric relations for leaf biomass showed a relatively lower correlation coefficients, 0.894 compared with biomass of other components (Table 1, Fig. 2). Similar trends have also been reported for leaf biomass in other forest [3, 4]. The main reason of low coefficient might be the loss of leaves from sample tree crown when the sample tree was cut down.

Biomass was calculated by inputting DBH to the allometric equation as mentioned above. Comparing to biomasses of other secondary evergreen forests with similar basal area [5, 6, 7, 8], there was just small difference among them (Table 2 and Fig. 3). Therefore, the equation in this study will be reliable and could be applied to a large scale estimation of above-ground biomass in Lechang, Nanling Mountain of southern China. Nevertheless, the divergence among the curves presented a tendency to increase with diameter. Moreover, Kettering's and Sierra's allometric relations [6, 7] fit ours better (Fig. 4). Tanaka's

Table 1 Allometric relations for estimating biomass of sample trees

Dependent variable (y)	Independent variable (x)	Allometric equation	Coefficient of correlation (R^2)
Trunks biomass (kg)	DBH (cm)	$Biomass = 0.1225DBH^{2.2687}$	0.973
Branches biomass (kg)	DBH (cm)	$Biomass = 0.0127DBH^{2.4925}$	0.935
leaves biomass (kg)	DBH (cm)	$Biomass = 0.0053DBH^{2.4075}$	0.894
above-ground biomass (kg)	DBH (cm)	$Biomass = 0.1378DBH^{2.3142}$	0.978

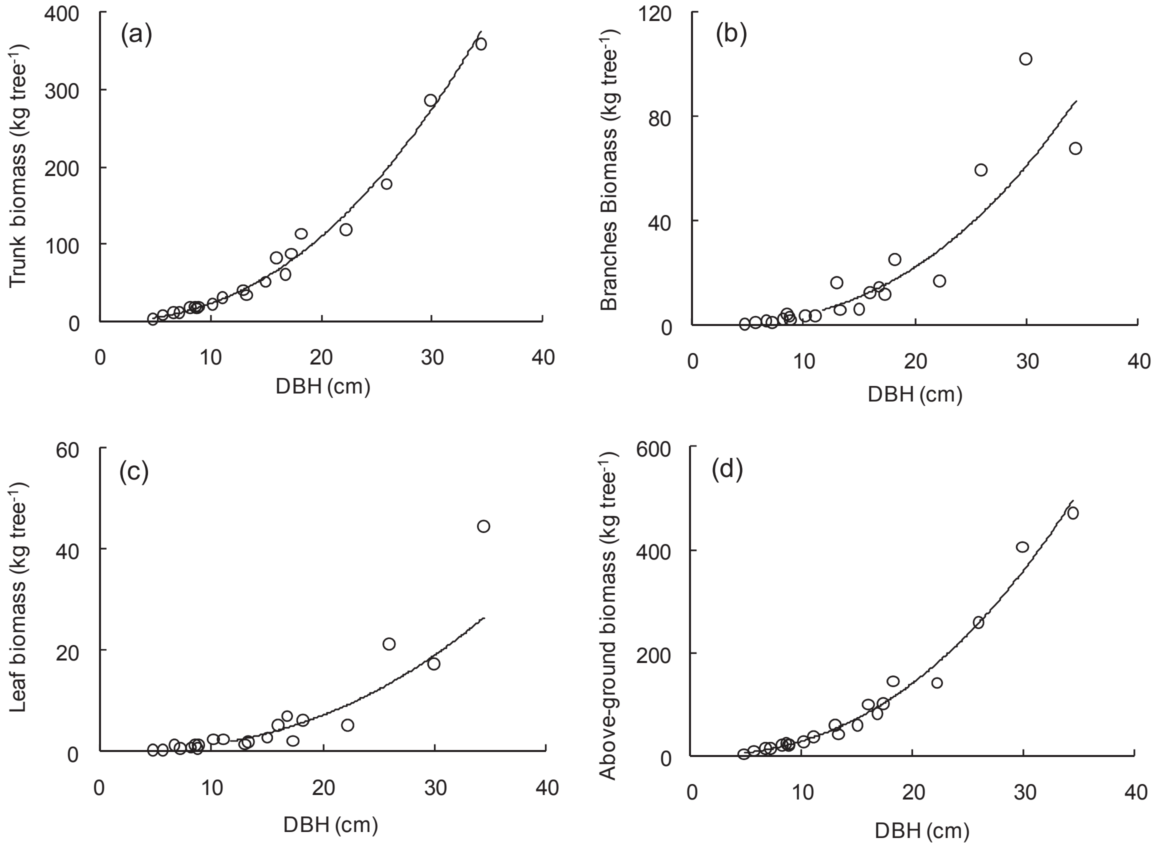

Fig.2 Allometric relations between above-ground biomass and DBH (a) Trunk biomass, (b) Branch biomass, (c) Leaf biomass, (d) Total above-ground biomass. The coefficient of correlation was shown in Table 1.

Table 2 Regression of above-ground biomass (AGB), species used for regressions, mean annual precipitation (MAP) and temperature (MAT) for different tropical areas and forest types.

Site	Forest type	Species	MAP (mm)	MAT (℃)	Allometric relations	Wood density	Reference
Guangdong, China	MSF	Mixed species	1500	20	$AGB= 0.1378\times DBH^{2.3142}$	0.6	This study
Sumatra, Indonesia	MSF	Mixed species	3000	27	$AGB=0.066\times DBH^{2.59}$	0.6	[5]
Kalimantan, Indonesia	ESF	Mixed species	1800	28	$Ln^{(AGB)}=2.44\times Ln^{(DBH)}-2.51$	0.29-0.47	[3]
Sarawak, Malaysia	ESF	Mixed species	2600	27	$AGB=0.0829\times DBH^{2.43}$	0.35	[13]
Colombia	PR+SF	Mixed species	2078	23	$Ln^{(AGB)}=2.422\times Ln^{(DBH)}-2.323$	-	[10]

Units are kg for AGB and cm for DBH. Forest type: MSF mixed secondary forest, ESF early successional secondary forest. PR primary rain forest, SF secondary forest

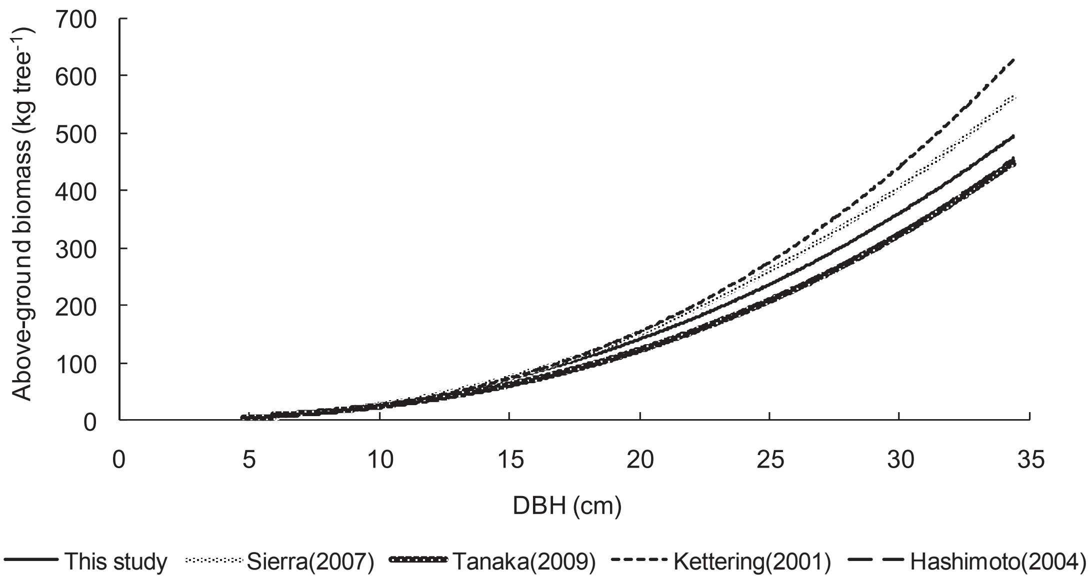

Fig.3 Comparison with previously reported relations between above-ground biomass and DBH of subtropical forest trees. Model variables and site index are shown in Table 2.

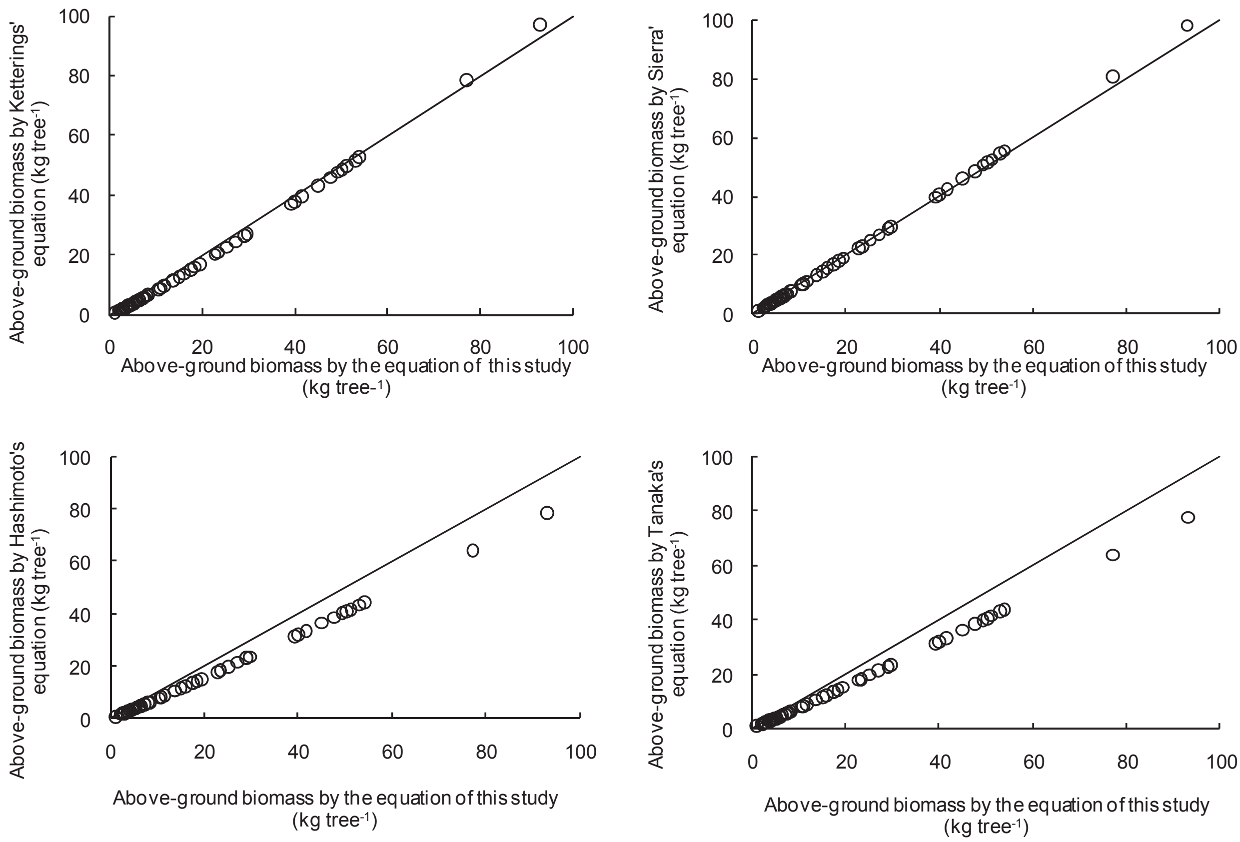

Fig.4 Comparison between this study and either of four allometric relations

and Hashimoto's allometric relations [5, 8] were a little lower than ours. The reason might be depending on the low wood density of Hashimoto and Tanaka's ones which are secondary forests with fast growing species (Table 2).

Meanwhile, it was discussed whether tree height will improve accuracy of biomass estimation, comparing DBH-only equation and DBH-H equation AGB=0.0003(DBH^{2}H)-5.8426 (R^2=0.9843) (Fig. 5). The above-ground biomasses estimated by these two methods were close to each other (Fig. 6). In addition, considering the fact that only 0.68% increase in R^2 by adding H into DBH-only equation, it is not necessary to measure tree height for biomass estimation because of time and labor consuming.

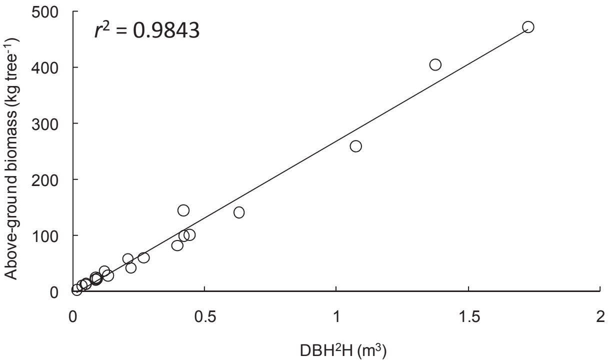

Fig.5 The relation between DBH2H and above-ground biomass

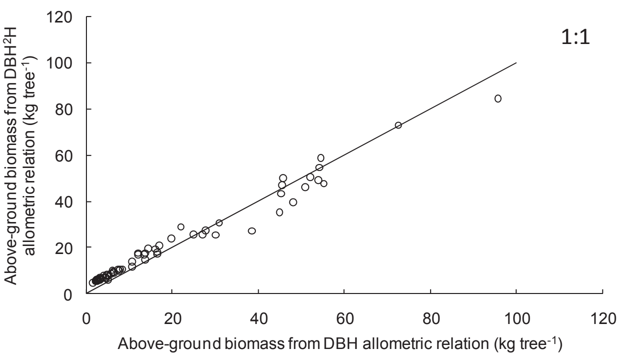

Fig 6 Comparison between DBH and DBH2H methods

Comparison of two methods for estimating biomass

When we would like to estimate the stand biomass from existing tree census data, simple equation might be needed. Ninety data sets of basal area and biomass of tropical and subtropical forests, which are from 23 countries, were selected. (Appendix). Linear relation between stand basal area and biomass was observed (Fig. 7). There was a relatively high relation, coefficient of which was 0.8437. It suggests that if we have a stand DBH data, stand biomass might be approximately calculated by using this equation.

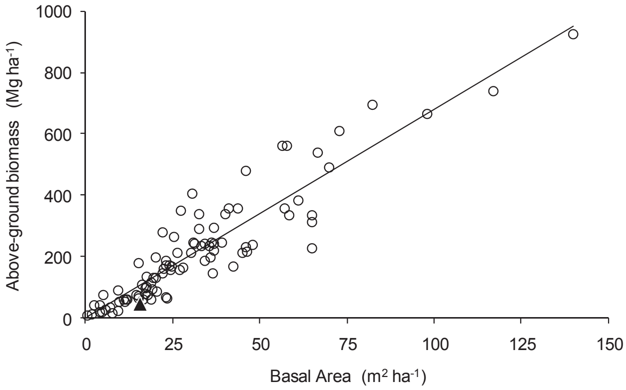

Fig.7 Relation between BA and above-ground biomass: Biomass = 6.7811DBH + 0.7672 (▲: the result of this study)

Above-ground biomass of subtropical secondary forest of Longwangtan would continue to increase, because of the relatively low biomass pointed out in Fig. 7. The above-ground biomass of subtropical secondary forest of Longwangtan presented herein is somehow representing the secondary forest of South China. Comparing to other subtropical secondary forests [9, 10, 11, 12, 13], above-ground biomass is almost the same within 60-70 Mg ha^{-1} due to the similar basal area. The reason that above-ground biomass of tropical forest in Brazil and Bolivia [14] was higher than other sites, is using the indirect method with satellite estimation. That is obviously different from the estimation method of allometric relation. Furthermore, the above-ground biomass in the situation of 21 sample trees did not change a lot compared to the situation of 9 trees (Table 3). It demonstrate a allometric model based on 9 sample trees can accurately predict biomass and there is

Table 3 Above-ground biomass in a 10×20m plot estimated in two different situations by using biomass data of nine and twenty-one trees respectively

Above-ground biomass (Mg ha^{-1})	Allometric relation
Situation of nine sample trees	60.3
Situation of twenty-one sample trees	59.1

no need to cut down more 12 sample trees, which will be obviously take more time and labor.

Conclusions

The allometric equation AGB=0.1378 $(DBH)^{2.3142}$ (R^2=0.9776) was developed for estimating above-ground biomass of subtropical evergreen broadleaf forest in Longwangtan, Guangdong, China. Considering the fact that the R^2 was improved only 0.68% even if the value of DBH^2H was used for calculation instead of DBH. It might not be necessary to measure tree height for biomass estimation because of time and labor consuming.

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APPENDIX

Data of basal area and above-ground biomass of tropical and subtropical forests from 90 study sites of 23 countries

No.	Country	Basal Area(m^2 ha^{-1})	Above-ground biomass(t/ha)	References
1	Brazil	30.7	406.3	Cannell (1982)
2	Colombia	20	199.1	Cannell (1982)
3	Ghana	33.3	232.8	Cannell (1982)
4	Guatemala	46	478	Cannell (1982)
		40	338.5	Cannell (1982)
5	India	7.6	15.5	Cannell (1982)
		18.7	59.4	Cannell (1982)
		20.4	88	Cannell (1982)
		46.3	216.6	Cannell (1982)
		58.6	335.9	Cannell (1982)
		66.6	540.2	Cannell (1982)
		18	76.3	Cannell (1982)
6	Ivory coast	15.1	65.9	Cannell (1982)
		31.2	242.5	Cannell (1982)
		65	226.3	Cannell (1982)
7	Jamaica	65	312	Cannell (1982)
		65	333.7	Cannell (1982)
		46	230	Cannell (1982)
		48	238	Cannell (1982)
8	Kampuchea	32.5	339.4	Cannell (1982)
		32.5	291.6	Cannell (1982)
9	Malaysia	27.3	351.3	Cannell (1982)
10	Papua New Guinea	70	489.9	Cannell (1982)
		61	383	Cannell (1982)
		28	166	Cannell (1982)
		27	158	Cannell (1982)
		57	358	Cannell (1982)
		37	218	Cannell (1982)
		117	740	Cannell (1982)
		140	925	Cannell (1982)
		98	665	Cannell (1982)
11	Puerto Rico	39	246.4	Cannell (1982)
		36.5	146.5	Cannell (1982)
		36	198.75	Cannell (1982)
12	Thailand	15.3	71.9	Cannell (1982)
		19.1	92.2	Cannell (1982)
		82.2	695.5	Cannell (1982)
13	Venezuela	36.7	294.8	Cannell (1982)
		72.9	608.7	Cannell (1982)
		34.3	186.3	Cannell (1982)
		34.1	242.6	Cannell (1982)
		16.1	108.5	Cannell (1982)
		25.5	263	Cannell (1982)
14	Zaire	22	144.3	Cannell (1982)

15	Zimbabwe	9.2	21.9	Cannell (1982)
		4.9	19.8	Cannell (1982)
		9.8	52.2	Cannell (1982)
		23.3	64.5	Cannell (1982)
16	Indonesia	9.21	89.68	Kusmana (1992)
		3.98	42.94	Kusmana (1992)
		5.01	75.99	Kusmana (1992)
		15.2	178.81	Kusmana (1992)
		22.11	279.03	Kusmana (1992)
		2.5	40.7	Kusmana (1992)
17	Costa Rica	45	211.5	Chaturvedi(1988)
18	Mexico	23	68.6	Castellanos(1991)
19	Colombia, Venezuela	11.17	51.3	Saldarriaga(1988)
		11.52	60.8	Saldarriaga(1988)
		17.31	98.2	Saldarriaga(1988)
		11.12	60.8	Saldarriaga(1988)
		17.5	100	Saldarriaga(1988)
		14.45	73.4	Saldarriaga(1988)
		17.06	79.8	Saldarriaga(1988)
		18.7	116	Saldarriaga(1988)
		11.7	61.9	Saldarriaga(1988)
		19.61	130	Saldarriaga(1988)
		20.07	129	Saldarriaga(1988)
		22.98	186	Saldarriaga(1988)
		17.68	133	Saldarriaga(1988)
		31.04	244	Saldarriaga(1988)
		24.74	169	Saldarriaga(1988)
		22.31	160	Saldarriaga(1988)
		26.44	213	Saldarriaga(1988)
		23.92	173	Saldarriaga(1988)
		23.2	170	Saldarriaga(1988)
		30.45	212.32	Saldarriaga(1988)
		35.62	233.8	Saldarriaga(1988)
		36.21	246	Saldarriaga(1988)
		36.95	242.89	Saldarriaga(1988)
20	Venezuela	0.5	7.08	Uhl.(1987)
		1.8	12.82	Uhl.(1987)
		4	19.95	Uhl.(1987)
		5.7	28.61	Uhl.(1987)
		7	33.86	Uhl.(1987)
21	India	56.4	562	Rana(1989)
		24.3	158	Rana(1989)
		41	357	Rana(1989)
		57.9	561	Rana(1988)
		43.64	356	Rana(1988)
22	USA	42.36	168	Frangi(1985)

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中国南部・南嶺山脈の乐昌地域における亜熱帯常緑広葉樹林の地上部炭素蓄積量

張　　放[a]　周　光　益[b]　平　塚　基　志[c]
田　中　一　生[a]　森　川　　靖[a]

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要　旨

森林の二酸化炭素吸収量は胸高直径や樹高をパラメータとする相対成長式から求める場合が多い。しかし、亜熱帯あるいは熱帯地域でこうした推定式が極めて少ない。本研究では、中国南部の南嶺山脈・乐昌地域における亜熱帯常緑広葉樹林を対象とし、相対成長式を21本の伐倒試料木の器官別重量測定から、幹、枝、葉、地上部のそれぞれについて作成した。胸高直径をパラメータとした器官別の相対成長式の相関係数（r^2）は高く、0.894 から0.973であった。地上部バイオマス（AGB、kg）と胸高直径（DBH、kg）との相対成長式はAGB=0.1378DBH$^{2.3142}$（r^2＝0.978）であった。この相対成長式から求めた調査地のバイオマスは60.1 Mg ha^{-1}であった。同じような直径階を持つ熱帯林の相対成長式と比較した結果、ほぼ同様の相対成長式であることから、本研究で作成した相対成長式は、汎用性が高いと思われる。なお、相対成長式で、一般には胸高直径と樹高（H）の両者をパラメータ（DBH^{2}H）とすることが推奨されているので、検討を加えた結果、直径だけの相対成長式によるバイオマス量と直径及び樹高のそれに大きな違いがなかった。樹高測定は多大の労力と時間を必要とし、また、樹高の測定結果の精度が低いことから、胸高直径をパラメータとする相対成長式で十分な精度でバイオマスを推定できることを提案した。なお、バイオマスの推定で、胸高断面積合計（BA）とバイオマス（t）の比の有効性を、既存の熱帯天然林データから検証した結果、AGB=6.7811BA＋0.7672（r^2＝0.8437）を得た。亜熱帯、熱帯地域の天然林で、直径のセンサスデータがあればバイオマス推定が可能であることを提案できた。

キーワード：地上部バイオマス、亜熱帯林、相対成長、胸高断面積合計

[a] 早稲田大学大学院人間科学研究科（*Graduate School of Human Science, Waseda University*）
[b] 中国林業科学院熱帯林業研究所（*Institute of Tropical Forest of China*）
[c] 三菱 UFJ リサーチ＆コンサルティング（*Mitsubishi UFJ Research & Consulting Co. Ltd.*）