ABOVEGROUND BIOMASS AND CARBON STOCK ESTIMATION IN LOGGED-OVER LOWLAND TROPICAL FOREST IN MALAYSIA

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ABSTRACT

Forest plays a vital role in controlling the capacity of atmosphere CO_2. Known as a 'carbon sinker', they manage to capture carbon and store them as biomass. Tropical forest ecosystem is believed to comprise a large number of carbon (C) compared to other natural ecosystem where the majority of C stored in the aboveground vegetation. Estimating carbon is a comprehensive approach to mitigate climate change. However, accurate information on aboveground carbon storage is still not enough. Lacking of standard conversion equation of the aboveground biomass (AGB) to carbon estimation in Malaysia contributes to the problem. Difficulties in the methodology plus the high density of plant species has made it tough to be executed. The study has taken place in a tropical lowland forest which is Bubu Forest Reserve (FR). Summarized inventory data were used with a modified equation to estimate total AGB and carbon stock. All selected tree were harvested and samples from different component (main stem, branches, twigs, leaves) were taken for further analysis. As a result, two allometric equation were formulated for two different groups based on the wood density from the sampled tree which is high wood density class (AGB= 0.05633 x $DBH^{2.75756}$) and medium wood density class (AGB= 0.00023 x $DBH^{3.75745}$). Carbon density of most trees sampled in this area was between 45% and 47%. The total aboveground biomass and carbon stock for Bubu FR are 501.74 t ha^{-1} and 225.55 t C ha^{-1}. In this study, allometric equation with wood specific gravity as a predictor variable can yielded more accurate predictions, even when based on lower sample size than the equation that didn't include wood specific gravity.

Key words: lowland tropical rainforest, Bubu Forest Reserve, aboveground biomass, carbon stock, allometic equations.

Introduction

Global climate change is a fluctuation in the average global temperature, commonly known as 'global warming'. It is one of the most pressing environmental concerns of the humanity in this 21st century. According to Schimel *et al.* (1996), the emission of greenhouse gasses (GHG) especially carbon dioxide (CO_2) has caused the rising of the global temperature. Forests play an important role in controlling the quantity of atmospheric CO_2. It also help slow down the process of climate change, by absorbing CO_2 during the process of photosynthesis. In addition to trees which approximately compose 50% of carbon based on oven dry weight (Brown, 1997).Since the pioneer studies on forest biomass by Kira (1976) and Kato *et al.* (1978), many studies have been conducted to test various methods to estimate biomass of tropical forest (Yamakura *et al.*, 1986; Brown *et al.*, 1989; Brown, 1997; Chambers *et al.*, 2001; Chave *et al.*, 2005; Hoshizaki *et al.*, 2004; Okuda *et al.*, 2004). However, there are still limited data on C densities of natural tropical forest in specificly Southeast Asia countries as the forest conditions changing rapidly from time to time.

Forest carbon stock for particular area maybe overestimated or underestimated. Differences in several forest activities such as the management regimes, environmental factors and human impacts can reflect the forest heterogeneity which also limits the information on the standing biomass. Nabuurs *et al.* (2008) stated that the inventory-based methodology is substantial and realiable in biomass estimations and so does in C stocking application. Along with other tropical rainforest countries, Malaysia has become the focus of climate change mitigation for developing countries in REDD (Reducing Emission from deforestation and forest degradation) (UNFCCC, 2009). According to Department of Statistical Malaysia (2010), Malaysia still own 18, 242, 922 hectares (ha) of forest land and 55.3% green cover.

Malaysia has intensified researches on C stocks and new data have been generated. Many studies have been carried out to determine the allometric equation for biomass estimation such as Kato *et al.* (1978) and Kenzo *et al.* (2009). However, extrapolating the result to an entire country is difficult and only few had really developed new function based on actual dataset. A comparison of approaches for estimating biomass in every area revealed not only a wide range of estimations (lowest and highest estimation), but also difficulty in finding an agreement on which estimation is the best (Houghton *et al.*, 2001). Malaysia is still absence of important data on basic measurement for wood density, carbon content, biomass distribution and allometric equations. Even though there is availability of forest inventory data, lack of standard model for converting tree measurements to aboveground biomass estimation hampers carbon sequestration estimations. This is shown by only few available studies on aboveground biomass in Malaysia (Table 1.0). Therefore, there is a need to conduct more research to obtain this information for estimating biomass and carbon stock.With these information, an important opportunity and risk can be identified and decision can be made to support decisions on where and how to manage the ecosystem for carbon. It will also help the government to address the co-benefit in the planning and implementation of climate change mitigation measure. Thus, it could concurrently combat climate change, protect other ecosystem goods and services and conserve biodiversity. The overall goal of this study were to examine the tree species and family dominance in lowland forest and to develop allometric equations to predict biomass and carbon stock estimation of different components for logged-over tropical lowland forests.

Table 1.0: Aboveground biomass estimations (t ha^{-1}) in Malaysia from 1969-2012**.**

Region	Area /Types	Total (t ha^{-1})	Source
Peninsular Malaysia	All types (average)	271	Aman and Parlan, 2009
	Undisturbed mix dipterocarp forest	360	Abu Bakar, 2000
	Disturbed forest	230	
Perlis	Mata Ayer Forest Reserve	402.6	Hikmat, 2005
Kedah	Langkawi (mangrove forest)	115.56	Norhayati and Latiff, 2001
	Mt.Mat Chinchang	527.94	Raffae, 2002
Negeri Sembilan	Pasoh Forest Reserve	475	Kato *et al.*, 1978
	Tanjung Tuan	234.20	Mat Salleh *et al.*, 2003
Selangor	Ayer Hitam Forest Reserve	209-222	Ismariah and Fadli, 2007
		355	Lepun 2002
		278	Lim and Tagat, 1983
		83.7-232.4	Kueh and Lim, 1999
	Bangi Forest Reserve	200.6	Norashidah, 1993
	(Logged over forest)	362.32	Lajuni, 1996
Pahang	Cameron Highlands	288	Kira, 1969
	Tasik Chini Forest Reserve	425.43	Norwahidah, 2005
	Taman Negara (Merapoh)	453.14	Norziana, 2003
	Bukit Rengit (Krau)	574	Fakhrul Hatta, 2003
	Perlok	419	Fakhrul Hatta, 2003
	Lesong Virgin Jungle Reserve	955.61	Suhaili , 2004
	Tersang Forest Reserve	383.05	Mohd Ridza, 2004
	Lepar Forest Reserve	399.01	Mohd Ridza, 2004
	Fraser Hill	306.40	Shamsul, 2002
Terengganu	Bukit Bauk Forest Reserve	551.2	Hikmat, 2005
Johor	Mt. West Janing	305.07	Soepadmoe, 1987
	Ulu Endau	210.10	
	Endau- Rompin	167.49	
	Mt. Pulai	320.6	Hikmat, 2005
Sarawak	Lambir Forest Reserve	502	Yamakura *et al.*, 1986
		497	Chave *et al.*, 2008
	Mt.Mulu	280-330	Proctor *et al.*, 1983
Sabah	Ulu Segama	261	Pinard and Putz, 1996
	Deramakot Forest Reserve: Primary Forest	482-522	Seino *et al.*, 2005
	Old Logged Forest	483-596	
	Malua Forest Reserve	323	Saner *et al.*, 2012
	East Coast Sabah	493	Kira, 1969

Malaysia forests have carbon density ranging from 89 to 276 Mg C ha^{-1} in vegetations (FAO, 2005). This wide range of values shows high variation of carbon density within Malaysian forest. Cairns *et al.* (1997) stated that mature lowland forest have approximately 216 Mg C ha^{-1} while Ismariah and Ahmad Fadli (2007) estimated carbon density for logged over forest ranging from 104 Mg C ha^{-1} to 111 Mg C ha^{-1}. Table 2.0 shows values of carbon density done on Malaysia available in literature.

Table 2.0: Carbon density values in Malaysia

Location	Forest type	Carbon density (t ha^{-1})	Source
Peninsular Malaysia	Superior	260	Abu Bakar, 2000
	Good	220	
	Moderate	190	
	Partly exploited	160	
	Disturbed	130	
	Poor edaphic and upper hill	130	

	Swamp	100	
	Mangrove	130	
Peninsular Malaysia	Average	135.51	Aman and Parlan, 2009
MataAyer, Perlis	Primary	201.3	Hikmat, 2005
Bukit Bauk, Terengganu	Primary	275.6	Hikmat, 2005
Mt. Pulai, Johor	Primary	160.3	Hikmat, 2005
Ayer Hitam, Selangor	Logged over	89.57	Kueh and Lim, 1999
	Logged over	104-111	Ismariah and Ahmad Fadli, 2007
Langkawi	Mangrove	115.56	Norhayati and Latiff, 2001

Methodology

Study Area

The study area is located in Bubu Forest Reserve (FR), Beruas, Perak. It is located within latitudes 4° 42'00" N and longitudes 100° 49'00" E , ± 87 a.s.l. It is categorized as lowland forest with dipterocarps as the main species. The size of this forest reserve is 6567.14 ha (Figure 1a). The study site is located in Compartment 63 comprises of 80 ha of logging area (Figure 1b). The climate of Perak is equatorial. The salient feature is low seasonal variation in incoming solar radiation, in both duration and intensity (Ainuddin, 1998). According to Köppen Climatic Zone, Beruas is in Af tropical wet zone (humid > 0.65P/PET). The maximum temperature is 28.2 ºC (May) and the minimum temperature is 27.2ºC (December).Beruas got 1344.5 mm average of rainfall per month. It is classified as a tropical wet with a moist forest. Its' landscape or geographical condition mostly covered with mosaic vegetation. The soil type in the study area is from Rengam-Bukit Temiang series which contain red-yellow Podzolic soil with reddish-brown lateritic. It is from residual material ranging to from acid to intermediate igneous rocks, arenaceous, argillaceous and mixed with sediment.

Figure 1a: Bubu Forest Reserve, Beruas, Perak

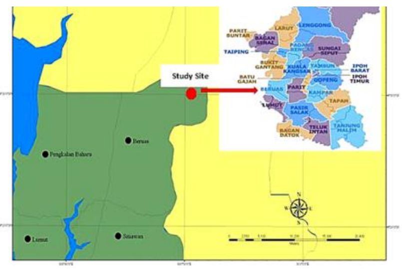
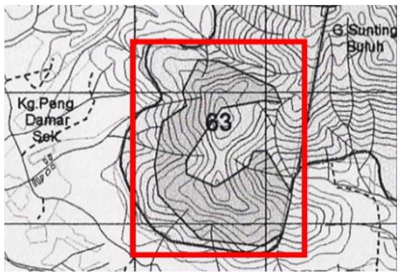


Figure 1b: Location of Compartment 63, Bubu Forest Reserve



Vegetation Analysis

In Bubu Forest Reserve, Perak, all tree species greater than 10cm in diameter were identified, labeled and measured in ten 20mx 50m (0.1ha) plot. Important Value Index (IVI) is used to identify the tree with dominant density. The selected trees will be cut down for biomass assessment according to compartment (leaves, twig, braches and stem). A total of 458 tree species were found in Bubu Forest Reserve plot. Table 3 show the variety of aboveground biomass allometric equation been done in the tropical region. For this study, 14 trees ranging from 10 to 133 cm DBH in Bubu Forest Reserve were selected to be harvested for allometric model development and carbon content analysis.The fresh and dry weight ratios of these samples were used to determine total dry weight of each tree component. The weight and measurement were consequently used to fit allometric equation of aboveground biomass. This method gives the most accurate estimate of woody and non-woody biomass stock at the time of harvest (Losi *et al.*, 2003; Lamlom and Savidge, 2003; van Breugel *et al.*, 2011).Using linear regression gives an advantage over other estimation. It can create a best fitted line and minimize the sum of the square error. It also can provide a single slope or trend and consistent. The fit of the data should be unbiased as well.

Table 3: Allometric equations used to determine aboveground biomass of tree components and forests structure in tropical forest

Parameter	Equation: AGB (kg) =	Study location	Source
Tree	Stem = 0.313 x $(DBH^2 \times H)^{0.9773}$	Pasoh, Malaysia	Kato *et al.*, 1978
	Branch = 0.136 x $(Stem)^{1.070}$	Pasoh, Malaysia	Kato *et al.*, 1978
	Leaves = 1.25 x $((0.124 \times (stem^{0.794}))) / (0.124 \times (stem^{0.794})) + 125$	Pasoh, Malaysia	Kato *et al.*, 1978
	exp ((2.62 x ln(DBH))-2.30)	Kalimantan, Indonesia	Yamakura *et al.*, 1986
	exp (-2.409+0.9522 x $\log((DBH^2)$ x H x WSG)	America, Africa, South Asia and Southeast Asia	Brown *et al.*, 1989
	-2.134+2.53 x (ln(DBH))	Latin America and Asia	Brown, 1997
	exp (-0.37 + 0.333*ln(DBH)+ 0.933 x $\ln(DBH)]^2$- 0.122 x $\ln(DBH)^3$)	Amazon, Brazil	Chambers *et al.*, 2001
	exp (-2.207 + 2.62 x ln(DBH) + ln(WSG))	Sumatera, Indonesia	Ketterings *et al.*, 2001[a]
	exp ((2.44 x ln(DBH))-2.51)	Kalimantan, Indonesia	Hashimoto *et al.*,2004
	1.066 x exp(-1.864 + 2.608 x ln(DBH) + ln(WSG)	America, Asia and Oceania	Chave *et al.*, 2005

	1.087 x exp (-2.232 + 2.422 x ln(DBH))	Colombia	Seirra *et al.*, 2007
	exp ((2.196 x ln(DBH))-1.201)	Kalimantan, Indonesia	Basuki *et al.*, 2009
	0.0829 x $DBH^{2.43}$	Sarawak, Malaysia	Kenzo *et al.*, 2009
Palm	10.0 + 6.4 x total height (m)	Puerto Rico	Frangi andLugo,1985
	4.5 + 7.7 x stem height (m)	Puerto Rico	Frangi and Lugo,1985
	exp (-6.3789 -0.877 x ln (1/DBH x 2))+ 2.151 x ln(H)	Colombia and Venezuela	Saldarriaga *et al.*,1988

[a] Coefficients were estimated from the DBH-height relationship of the 244 harveted tree as detailed in Ketterings *et al.*,(2001)
AGB= aboveground biomass, H= height, WSG = wood specific gravity, DBH= diameter breast height,

Sample analysis

Samples were taken to the laboratory for further analysis. All of these samples were oven dried at 70°C for 72 hours and weighed again. The sum of weight of all the components results in the total-oven dried weight of the tree, generally expressed in kilogram (kg). After that, samples were grinded then sieved through 2mm mesh before they were analyzed using CNS-2000 Elemental Analyzer (LECO, USA) to determines carbon (C), Nitrogen (N), and Sulphur (S) in solid samples within the range of 0.01 to 0.05 (according to sample size used) . The samples were weighed into a tare ceramic boat and loaded into the autoloader where it combusts in a furnace at 1350 ^{0}C. Analysis of a certified reference material (Sulfamethazine) is performed each samples to check on instrument accuracy (LECO, 2002). To estimate density, a square sub-sample of dimension 2cm by 2cm by 2cm was extracted from each disk according to heartwood and softwood category. Wood density determination was estimated using water displacement method (Chave *et al.*, 2005). In this method, the mass of the liquid which is displaced by the oven dried sample is determined by using a densimeter.All results from carbon concentration were pooled according to element. The amount of carbon stock per hectare can be obtained by using the equation below where,

$CS = Cc \times DW_T$
CS = carbon stock (ton ha^{-1})
DW_T = Total dry biomass (ton ha^{-1})
Cc = carbon content (%)

Results and discussion
Vegetation Index
Ten plots of 20m x 50m (0.1 ha) each were measured beginning Jun 2008 to November 2009. Based on the density, Most of the tree species here are late successional and pioneer species where they regenerated after logging activities taken place. This species emerges due to canopy opening in the forest area. However, the forest canopy is almost closed because some of the tree has reached heights of approximately 40m. All trees inside the one hectare plot (more than 10cm DBH) were categorized into ten groups based on their diameter. The frequency of individual tree in DBH classes showed the normal inverse J curve distribution (Figure 2). It shows higher density in small trees was observed in this area. These indicate that the forest is in the process of growing and regenerating.

Figure 2. Class distribution of Bubu Forest Reserve.

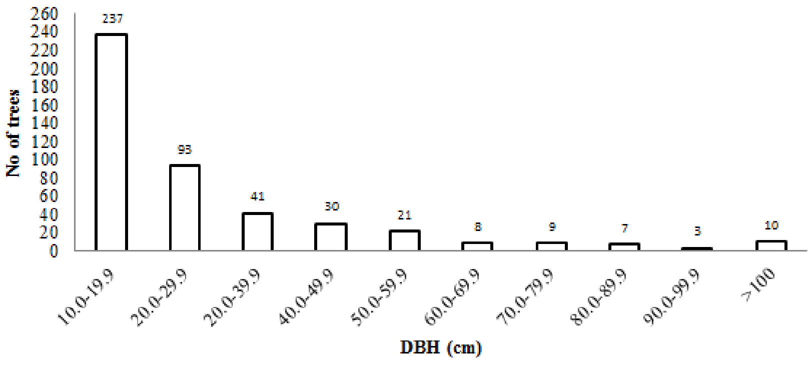
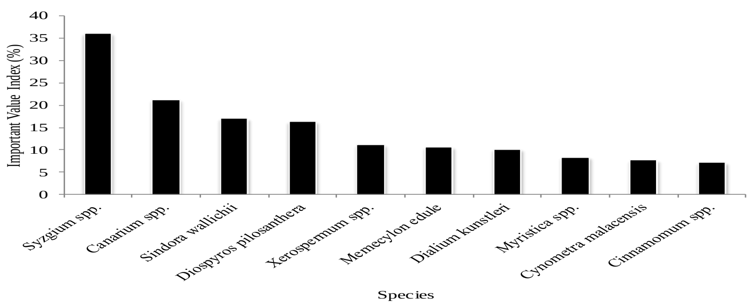


Figure 3. Ten most Important Value Index (IVI) for Bubu FR



In this study, the ecological community attributes for Bubu Forest Reserve were obtained using relative density, frequency, dominance and important value index (IVI) (Curtis and McIntosh, 1951). Data collection for Bubu Forest Reserve consists of 459 trees from 72 species and 33 families. Myrtacea family were considered as the most important and ecologically successful species dominating within the plot.The IVI analysis has determined that *Syzygium spp.* give the highest number. All 10 species of tree with high rate in the study area has been listed in Figure 3. From the overall DBH distribution, it is stated that DBH class with 10.00 to 19.99cm has the highest number which is 237trees. All the data for class distribution is shown in Figure 2. Among the 459 tree inventoried, 14 trees from 10 dominance species were selected for destructive sampling. Most of the tree chosen reflected as a representative to the area and contributed to the overall biomass.

Wood density

The differences in equations among forest type related to wood density for each trees species. Many studies reported that higher estimations of biomass equations related to higher wood density where as lower biomass estimations showed forest with lower wood density such as the early successional secondary trees (Nelson *et al.*, 1999; Kettering *et al.*, 2001; Chave *et al.*, 2004; Kenzo *et al.*, 2009). From the analysis, the overall mean of wood density was 0.67g cm^{-3} with the maximum density 0.85g cm^{-3} from *Shorea argentea* and minimum density of 0.48 g cm^{-3} from *Shorea leprosula*. Baker *et al.* (2004) recommended the use of wood density in estimating aboveground biomass. Chave *et al.* (2008) further improved the estimation of the aboveground biomass (AGB) using wood density by categorizing wood density in three major groups which are light, medium and heavy. In this study, the wood densities were categorized into two groups which are medium and heavy wood density. Table 4 shows the average densities achieve from the water displacement method during laboratory work.For the medium wood density category, the mean value for heartwood is 0.50g cm^{-3} and the sapwood is 0.54g cm^{-3}. This may due to a small sample size, species and decay processes that taking place. As for heavy wood density category, the mean value for heartwood is 0.79 g cm^{-3} and higher than the sapwood (0.77 g cm^{-3}).

Table 4: Mean heartwood and sapwood densities according to wood density group and species.

Wood density Group	Tree species	Heartwood (g cm^{-3})	Sapwood (g cm^{-3})	Mean (g cm^{-3})
Medium	*Shorea leprosula*	0.45	0.51	0.48
	Canarium pseudosumatranum	0.47	0.50	0.49
	Cinnamomum spp	0.50	0.52	0.51
	Shorea parvifolia	0.57	0.61	0.59
	Total mean	0.50	0.54	0.52
Heavy	*Sindora spp.*	0.71	0.73	0.72
	Syzgium spp.	0.75	0.72	0.74
	Pometia pinnata	0.77	0.75	0.76
	Diospyros pilosanthera	0.76	0.80	0.78
	Cynometra malacensis	0.84	0.83	0.84
	Shorea argentea	0.90	0.80	0.85
	Total mean	0.79	0.77	0.78

Table 5: Mean and standard deviation of heartwood and sapwood density of harvested tree

Scientific name	Mean heartwood density (g cm^{-3})			Mean sapwood density (g cm^{-3})		
	Base	Middle	Top	Base	Middle	Top
Canarium pseudosumatranum	0.48 (0.04)	0.44 (0.01)	0.48 (0.05)	0.56 (0.05)	0.47 (0.03)	0.47 (0.01)
Cinnamomum spp	0.45 (0.04)	0.47 (0.07)	0.59 (0.04)	0.42 (0.05)	0.55 (0.05)	0.59 (0.02)
Cynometra malacensis	0.90 (0.08)	0.79 (0.05)	0.85 (0.02)	0.81(0.04)	0.82 (0.06)	0.86 (0.06)
Diospyros pilosanthera	0.77 (0.12)	0.73 (0.11)	0.77 (0.07)	0.82 (0.11)	0.79 (0.04)	0.78 (0.06)
Pometia pinnata	0.72 (0.07)	0.73 (0.06)	0.74 (0.03)	0.75 (0.13)	0.73 (0.05)	0.77(0.06)
Shorea argentea	0.82 (0.03)	0.92 (0.08)	0.96 (0.03)	0.80 (0.02)	0.84 (0.07)	0.77 (0.02)
Shorea leprosula	0.51 (0.01)	0.38 (0.03)	0.55 (0.18)	0.51 (0.02)	0.52 (0.01)	0.49 (0.01)
Shorea parvifolia	0.57 (0.02)	0.57 (0.04)	0.56 (0.05)	0.57 (0.08)	0.64 (0.02)	0.64 (0.05)
Sindora spp.	0.67 (0.02)	0.75 (0.07)	0.71 (0.03)	0.72 (0.03)	0.75 (0.02)	0.71 (0.06)
Syzgium spp.	0.77 (0.04)	0.73 (0.12)	0.74 (0.09)	0.74 (0.13)	0.71 (0.03)	0.73 (0.03)

Value are mean ± standard deviation (in parentheses)

The result in Table 5 shows the variation between individuals may be due to the varying needs of trees for structural support under different circumstances. Study by Fearnside (1997) on application of wood density in estimating aboveground biomass showed that the wood density varies according to species, soil, tree growth parameter and condition, and topography.The overall mean wood density value is slightly near to Kettering *et al.* and Basuki *et al.* showed relatively similar wood density (Table 6). According to Chave *et al.* (2005) even though some authors stated site-specific model is not needed, it must be considered for precise estimations of aboveground biomass in tropical rainforest. Through earlier studies, it is reported the importance of site specific model for accuracy in biomass estimation based on application and comparison of the proposed pan-tropic general model by Brown 1997; Chave *et al.*, 2005; Basuki *et al.*, 2009 and Kenzo *et al.*, 2009). This study also supports the site-specific model application for biomass estimation precision. Table 6 shows a summary of average wood density according to forest type.

Table 6: Forest type and wood density from the model comparison

Forest Type	Wood Density (g cm^{-3})	Reference
Moist Tropical	0.71	Brown (1997)
Primary Rain Forest	0.60	Basuki *et al.* (2009)
Primary Rain Forest	0.36-0.81	Yakamura *et al.* (1986)
Mixed Secondary Forest	0.60	Kettering *et al.* (2001)
Early Succesional Secondary Forest	0.29-0.47	Hashimoto *et al.* (2004)
Early Succesional Secondary Forest	0.35	Kenzo *et al.* (2009)
Logged-over lowland forest (30 year)	0.67	Present study (2012)

Allometric equation

Allometric equation is a relationship between two parameters such as DBH and height where DBH is uses as a predictor for volume or biomass. Wood density is also been use as a predictor for biomass. Adding the wood density in the model is very important to estimates biomass for mixed species and big trees as biomass estimates for larger DBH trees are more variable and contribute more toward forest biomass. In recent years, wood density or wood specific gravity has become the domain of ecologist exploring the variability of plant traits (Brown *et al.*, 1989: Chave *et al.*, 2005). It is the primary variable in the estimation of the biomass to assess global carbon stocks.

Diameter at breast height (DBH) and tree height (H) were verified as independent variables. Preliminary analysis of alternative equations point out that the allometric equations $y = ax^b$ (where *y* is biomass (kg), *x* is DBH (cm) or H (m) or DBH^2 x H (cm^2 or m), and *a* and *b* are coefficient estimated by regression best fitted the data. All regressions were carried out using statistical package of social science software (SPSS) and Statistical analysis software SAS software.The scattergram (Figure 4) show a variation of wood density and their relationship with tree diameter. It is be group into two categories. The first one has a range of medium wood density (0.40 to 0.70 g cm^{-3}) while the other group has a range of high or heavy wood density (0.70 to 0.90 g cm^{-3}). The allometric models for the medium wood density is ABG = 0.00023DBH $^{3.75745}$ with R^2 = 0.993 and heavy wood density is AGB = 0.05633DBH $^{2.75756}$ with R^2 = 0.997, where AGB is in kilogram (kg) and DBH is in centimeter (cm) (Figure 5a and 5b). Figure 6 show the comparison of relationship between AGB and DBH (5 -120 cm) from different model

Figure 4: Wood density and DBH of the selected tree

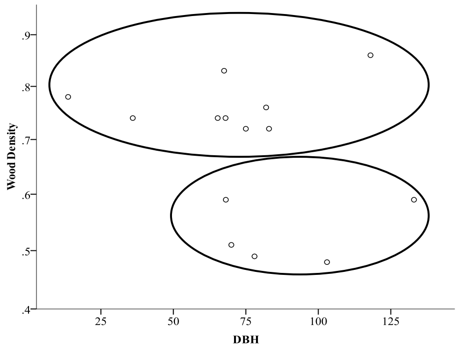
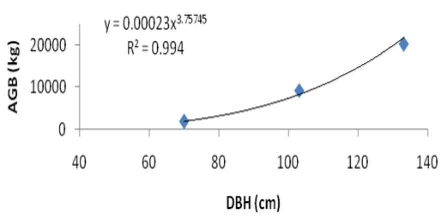
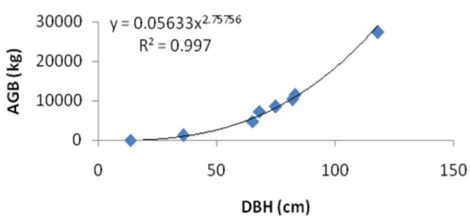


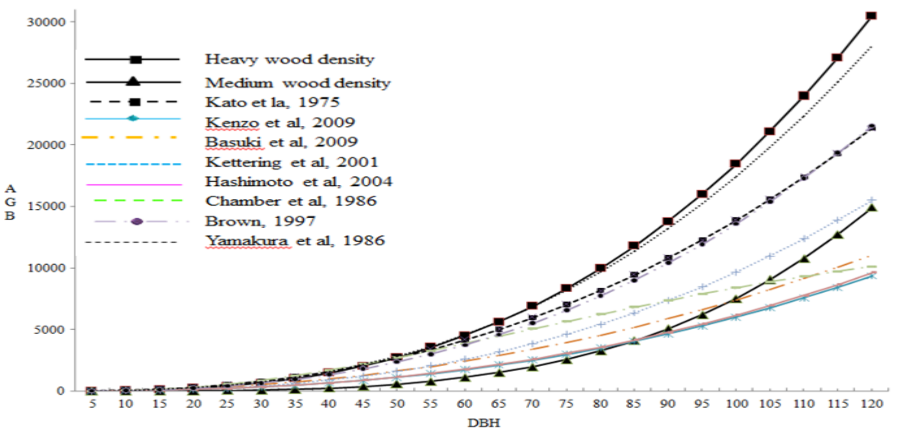
Figure 4a and 4b : Relationship between AGB versus DBH biomass for medium wood density (4a) and heavy wood density (4b)





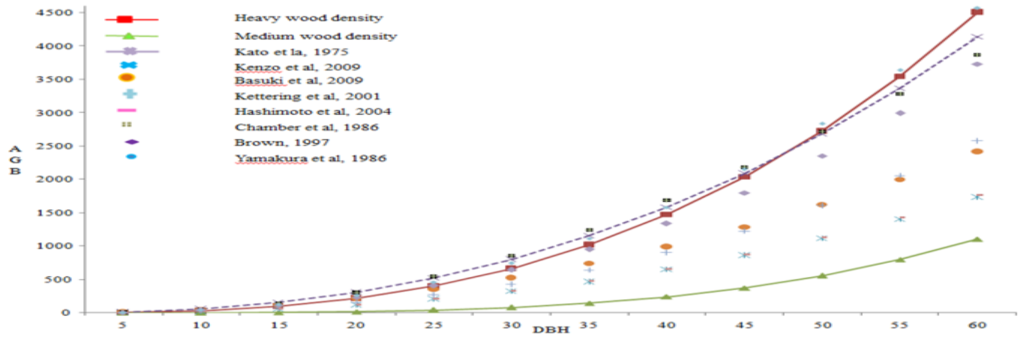
5a **5b**

Figure 6: A comparison of relationships between aboveground biomass and DBH from different model (5-120 cm)



Comparison of allometric equations for total aboveground biomass for various tropical rainforest revealed that the develop equations differed substantially. From the calculation using both models, it is estimated the total AGB in Bubu FR is 491.94 t ha^{-1}. The general equations by Brown, 1997; Kato *et al.*, 1978; Yamakura *et al.*,1986 and Kettering *et al.*, 2001 are in the range between the two new model develop in this study which is model with heavy wood density and the other one with medium wood density. Thus, these models can give estimations values that are close enough to actual number given by the new develop model. Kato *et al.*, (1975) model is overestimate about 20% in 30cm to 45cm DBH and underestimated the value of AGB after that (Figure 7). Chamber *et al.*, (1986) aboveground biomass estimation is higher at the beginning which is approximately 22% overestimated in the case of 35cm DBH but then underestimated 67% at 85cm DBH. Most of the trees in the study area are in 10cm to 20cm DBH classes (Figure 1). This shows that several equations still have limited ability to estimate aboveground biomass precisely.

Figure 7: Comparison of relationships between aboveground biomass and DBH
(5-60 cm)



When the models from others researcher were applied to this data (Figure 7), some of the predicted value are over estimated (e.g. Kato *et al.*,1975 and Yamakura *et al.*, 1986) when it come to certain DBH classes. Hashimoto *et al.*, (2004) and Chamber *et al.*, (1986) equations gives most underestimated values. It apparently can be seen from confidence interval value presented in Table 7. At 95% confidence interval, the upper and lower limit of the mean AGB from Kato *et al.*, (1975) and Yamakura *et al.*, (1986) were a little bit higher than the observed value. The Brown (1997) and Chave *et al.*, (2005) models are the one which have the closest values of upper limit and lower limit to this study through 95% of confidence interval.

Table 7: The confidence interval of the mean from various model compared

	Mean AGB	95% confident interval	
		Lower limit of mean	Upper limit of mean
Present study, 2012	9049.38	4507.64	13591.12
Kato *et al.*, 1975	22446.96	11895.89	32998.03
Brown, 1997	8594.49	4194.61	12994.37
Chave *et al.*, 2005	9618.33	4985.33	14251.33
Ketterings *et al.*, 2001	6101.28	2906.16	9296.40
Hashimoto *et al.*, 2004	3918.01	1980.92	5855.10
Kenzo *et al.*, 2009	3819.04	1938.30	5699.78
Yamakura *et al.*, 1986	10971.40	5161.34	16781.46
Chamber *et al.*, 1986	5697.56	4010.78	7384.34
Basuki *et al.*, 2009	4799.64	2652.31	6946.97

It is likely that different in wood density and trees architecture explains the difference in dry weight of these species. Basuki *et al.* (2009) stated that in the allometric equations, the role of wood density is more prominent for the mixed species than in genera. The deviation of the predicted biomass is much higher than the observed one due to the higher variation of tree features among species and genera. Brown model in 1997 was constricted from a data collected by a number of authors from tropical countries and at a different time. The DBH of trees used to create this equations range from 5 to 148 cm from 170 trees. As for Kato *et al.* (1978), the equation is made up from 156 trees from Pasoh Forest Reserve ranging from 4.5 cm to 101.6 cm in 1971 and 1973 through destructive sampling method. Chave *et al.* (2005) model, the pan-tropic equation used a compilation of data from 27 various tropical forest study site since 1950s. The model develops 2410 sample trees with diameter range from 5cm to 156cm. Meanwhile, for Kettering *et al.* (2001) model, it consists of 29 trees with DBH ranging from 7.6 cm to 48.1 cm from 14 genera. For Basuki *et al.* (2010), the model was developed with Kalimantan, Indonesia as a study site using 205 trees ranging from 6.2cm to 200 cm in diameter.

Bubu forest area is a secondary forest area and usually this type of forest has significantly lower wood density than primary forest trees. Current model from Kenzo *et al.* (2009) and Basuki *et al.* (2009) also lack of data for secondary forest trees which cause model prediction errors for secondary forest trees. However, this estimate cannot be thought as landscape-scale estimation as it results from a single measurement. These differences in equations among forest types may be related to the wood density of each forest's trees. Moreover, the allometric equation of this study is constructed from a limited sample. According to Chave *et al.* (2005), more tropical secondary forest trees dataset might be needed to improve the models, especially correction of equations for wood density.

In the recent study, the samples for wood density or specific gravity analysis were taken from upper, middle and lower of the main trunk. Even so, these data is also used to assess the weight of the big branches that were impossible to weigh. This might cause an over estimation of weight for an individual tree as well. In this study, an accurate allometric relationship for aboveground biomass using both DBH and wood density is developed that include mixed species. Table 8 shows the value of heartwood and sapwood specific gravity for sample trees taken at different level of main trunk. For heartwood, *Shorea argentea* showed the highest value among the samples tree followed by *Pometia pinnata* and *Cynometra malacensis*.

Table 7: Specific gravity for sample trees (heartwood and sapwood)

	Heartwood			Sapwood		
	Trunk (g cm $^{-3}$)			Trunk (g cm $^{-3}$)		
Species	Base	Middle	Top	Base	Middle	Top
Shorea leprosula	0.513	0.385	0.455	0.517	0.523	0.488
Pometia pinnata	0.721	0.838	0.736	0.746	0.733	0.772
Cynometra malacensis	0.905	0.792	0.816	0.808	0.82	0.858
Shorea parvifolia	0.571	0.569	0.561	0.572	0.64	0.616
Canarium pseudosumatranum	0.478	0.436	0.483	0.556	0.472	0.466
Cinnamomum spp	0.454	0.469	0.591	0.418	0.547	0.589
Sindora spp.	0.667	0.752	0.706	0.721	0.747	0.709
Shorea argentea	0.816	0.92	0.957	0.796	0.844	0.772
Syzgium spp.	0.772	0.732	0.744	0.739	0.707	0.728
Diospyros pilosanthera	0.767	0.733	0.77	0.822	0.794	0.775

For the sapwood specific gravity, the values range from 0.42 to 0.86 g cm^{-3} for all level of main trunk. Sapwood is usually less durable and more permeable than heartwood and all samples only has small variations at all tree level. The lowest specific gravity were *Canarium pseudosumatranum* and *Shorea leprosula* with an average 0.498g cm^{-3} and 0.509 g cm^{-3}. In this study, it is confirm that by including data in wood specific gravity in allometric model can improves AGB estimates significantly. Allometric model with wood specific gravity as a predictor variable can yielded more accurate predictions, even when based on considerably lower sample sizes than the model that did not include wood specific gravity. This statement is also support by the research done by van Breugel *et al.*, (2011).

Aboveground biomass and carbon stock

Comparison of the AGB models for various tropical rainforests revealed that this new equations differed substantially from model for primary and secondary forest and even the pan-tropic model. Consequently, when choosing biomass estimations equations for aboveground biomass, it is important to cautiously consider their suitability. Table 9 showed various allometric equations being compared with the model produced in this study. Meanwhile, Table 10 showed the data set of biomass for every tree compartment. From this study, it is found that the trunk or stem contains 50 to 80% of biomass. The leaves biomass associate about 2 to 5% and branches and twigs provide 10 to 18% of biomass. The result is supported by studies from Heriansyah *et al.* (2007) and Pagano *et al.* (2009) which also gave relatively same percentages. Both studies also prove that the stem part contains most biomass in one particular tree followed by branches and twigs as well as leaves.Local model may provide more accurate AGB estimation than imported models, nonetheless it still have a limited effect due the numbers of tree used in the model fitting, different stages of forest growth cycle, habitat and species variability and varying tree density (Terakunpisut *et al.*, 2007; Feeley *et al.*, 2007).

Among the trees analyze using the CNS elemental analyzer, *Syzgium spp.* and *Shorea parvifolia* gives highest percentage in most part of the tree. Giving an average of 43.74% of carbon content of dry matter in all portion, *Pometia pinnata* give the smallest value (Table 11). For the sake of consistency, palm tree also included in this particular assessment even though palm is a bit different from tree. According to Castilho *et al.* (2006), palm represented 1 to 10% of total aboveground biomass and varies from sites (De Walt and Chave, 2004) and forest types (Cummings *et al.*, 2002). *Arenga westerhoutii* has represented the study area for palm and the amount of carbon content in dry matter is 49.28% in average

The average for all samples is 43.80%. The overall result of the abovementioned analysis is that the content of carbon in any component of aboveground biomass tree is on the average of 45% of dry matter quantity. Taking account of the new percentage of the carbon content, the carbon stock of tree for Bubu FR area is 220.95 t C ha^{-1}. Based on ecosystem type (Chan, 1982), Bubu FR is categorized as good dipterocarp forest. The amount of vegetative carbon density in this area is 22 kg m^{-2} respectively. As for the downed woody material and litter, Solehuddin (2009) has already measured and assesses the biomass and carbon stock part. From his study, the biomass estimation for downed woody material is 5.21 t ha^{-1} and the carbon content is about 42% which is 2.17 t C ha^{-1} for the same study area respectively. Meanwhile, for litter biomass, Bubu FR area contains 4.13 t ha^{-1} and 1.72 t C ha^{-1} of carbon substance which is 42% respectively. From this information, it can be determined that the Bubu FR aboveground biomass is 501.74 t ha^{-1} and the carbon stock for this particular study site is 225.55 t C ha^{-1}. Table 12 below shows the value of aboveground biomass from each compartment. Most of the carbon stored in trees (98%) where as downed woody material litter contain 0.96% and 0.76% of carbon. Palms also contribute about 0.28% of carbon to the aboveground biomass assessment.Figure 8 below shows a diagram on percentage of carbon content on each component.

Conclusion and recommendation

Forest can play an important role in climate change mitigation by sequestering carbon through biomass production. This study has attempted to estimate biomass through allometric equations, wood density, inventoried litter and downed woody materials for carbon stock estimations. The overall mean of wood density was 0.67 g cm^{-3} with the maximum density 0.8 g cm^{-3} from *Shorea argentea* and minimum density of 0.48 g cm^{-3} for *Shorea leprosula.* In this study, the wood densities were categorized into two groups which are medium and heavy wood density for aboveground biomass estimation. From the analysis, two allometric equation were formulated for two different group based on the wood density from the tree sampled which is high wood density class ($AGB = 0.05633 \times DBH^{2.75756}$) and medium wood density class ($AGB = 0.00023 \times DBH^{3.7745}$).

Carbon density of most trees sampled in this area was about 45% to 47%. The total aboveground biomass for Bubu Forest Reserve is 501.74 t ha^{-1} and 225.55 t Cha^{-1} for carbon stock value, respectively. This information can help in overall estimation of the carbon stock for lowland forest in Malaysia. Carbon stock in tropical forest can be better understand by collecting additional ground based data and improving sampling design that can be account both forest type and condition. This study also recommends more research be conducted on site-specific and different forest types model development to increase the precision of forest biomass estimate.

Figure 8. Percentage of biomass and carbon content on tree component

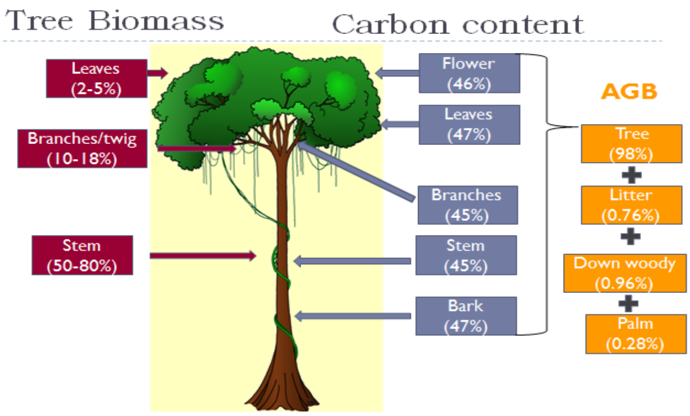


Table 9: Total weight generates from models comparison

Common Name	Weight generate from allometric models (kg)									
	True Weight	Kato *et al.* (1975)	Brown (1997)	Chave *et al.* (2005)	Kenzo *et al.* (2009)	Yamakura *et al.* (1986)	Chamber *et al.* (1986)	Kettering *et al.* (2001)	Basuki *et al.* (2009)	Hashimoto *et al.* (2004)	This Study (2012)
Diospyros pilosanthera	148.0	903.2	88.9	119.7	48.0	95.4	110.6	56.2	94.4	48.3	136.8
Canarium pseudosumatranum	13262.7	23822.6	7248.0	6253.8	3283.6	9086.8	6010.5	5084.1	4304.1	3362.3	13296.2
Shorea leprosula	14263.6	43471.7	14645.2	11747.3	6452.8	18825.9	8680.9	10445.7	7925.7	6625.9	14271.3
Sindora spp. (1)	18198.4	17360.6	8481.7	10693.1	3818.7	10693.2	6587.0	5971.8	4933.4	3912.7	18033.5
Pometia pinnata	13935.4	25592.7	8225.5	10989.3	3707.9	10358.9	6473.0	5787.2	4803.8	3798.6	13670.8
Shorea argentea	37373.7	41570.5	20657.5	28403.6	8979.0	26881.5	9963.3	14854.7	10683.2	9232.4	38112.5
Cynometra malacensis	20862.0	17170.3	5027.5	7620.3	2310.8	6221.6	4763.2	3496.1	3133.3	2362.8	20839.6
Syzgium spp.(1)	2071.6	4393.2	1024.9	1419.9	501.6	1198.5	1326.5	686.3	787.9	509.7	2102.4
Syzgium spp.(2)	12044.0	9956.9	5122.3	6862.3	2352.6	6343.0	4823.2	3563.6	3184.5	2405.7	12037.9
Sindora spp.(2)	13598.0	20279.9	6563.3	8428.7	2985.1	8199.4	5657.9	4593.0	3949.0	3055.4	13643.2
Shorea parvifolia	26774.0	69912.2	27961.5	25298.8	12009.2	36780.2	10972.3	20251.9	13893.9	12362.9	26778.3
Cinnamomum spp	2904.0	15598.8	5512.1	5099.3	2524.3	6843.5	5062.8	3841.4	3393.8	2582.0	2907.6
Sindora spp.(3)	10758.0	13474.6	5141.4	5494.2	2361.0	6367.5	4835.2	3577.2	3194.8	2414.4	10393.7
Syzgium spp.(3)	7986.6	10750.3	4623.2	6226.5	2132.0	5704.2	4499.5	3208.6	2913.4	2179.3	8064.7

Table 10: Dataset for dry weight (kg) of plant parts biomass, total aboveground biomass (AGB), dbh, height and wood density (WD)

Family	Scientific name	DBH (cm)	Height (m)	Leaves (kg)	Branches (kg)	Stem (kg)	AGB (kg)	WD (gcm^{-3})
Ebenaceae	*Diospyros pilosanthera*	13.7	1745	18.08	38.52	91.40	148.00	0.78
Burseraceae	*Canarium pseudosumatranum*	78.0	3712	631.30	5958.70	6672.65	13262.65	0.49
Dipterocarpaceae	*Shorea leprosula*	103.0	4635	542.48	5171.13	8550.00	14263.61	0.48
Leguminosae	*Sindora sp.*	83.0	2177	928.11	7181.89	10088.43	18198.43	0.72
Sapindaceae	*Pometia pinnata*	82.0	3685	449.29	5720.71	7765.40	13935.40	0.76
Dipterocarpaceae	*Shorea argentea*	118.0	3333	1607.04	16856.66	18910.00	37373.70	0.86
Leguminosae	*Cynometra malacensis)*	67.5	3245	556.03	4073.97	16232.00	20862.00	0.83
Myrtaceae	*Syzgium spp.*	36.0	1956	81.50	332.81	1657.24	2071.55	0.74
Myrtaceae	*Syzgium spp.*	68.0	1580	269.22	3750.78	8024.00	12044.00	0.74
Leguminosae	*Sindora sp.*	75.0	3260	381.87	5428.13	7788.00	13598.00	0.72
Dipterocarpaceae	*Shorea parvifolia*	133.0	5140	856.77	12263.23	13654.00	26774.00	0.59
Lauraceae	*Cinnamomum spp*	70.0	2665	232.32	1127.68	1544.00	2904.00	0.51
Leguminosae	*Sindora sp.*	68.1	2330	505.63	3884.37	6368.00	10758.00	0.59
Myrtaceae	*Syzgium spp.*	65.3	1892	183.69	3660.91	4142.00	7986.60	0.74

Table 11: Carbon content in all part of tree (%)

Scientific Name	Branches	Leaves	Stem	Bark(Base)	Bark(Middle)	Bark(Top)	Flower
Pometia pinnata	43.84	45.39	37.45	45.12	45.32	45.93	43.15
Shorea argentea	45.94	51.52	49.40	47.66	48.62	41.64	-
Syzgium spp.	46.68	45.27	49.49	48.59	48.85	49.15	-
Shorea leprosula	43.87	48.47	46.35	47.88	48.76	48.14	48.02
Diospyros pilosanthera	44.94	42.60	47.02	44.36	45.19	45.51	-
Canarium pseudosumatranum	43.79	41.01	47.65	46.55	46.55	45.12	-
Cinnamomum spp	45.25	49.93	48.86	47.38	47.67	48.03	-
Sindora spp.	43.08	49.18	41.37	48.40	48.87	47.44	-
Cynometra malacensis	45.06	44.34	48.31	44.65	44.64	44.61	-
Shorea parvifolia	46.46	53.10	44.62	49.38	48.19	51.52	-
Arenga westerhoutii	-	38.38	48.30	48.84	49.44	50.55	-

Table 12. Aboveground biomass value in Bubu Forest Reserve for each compartment

AGB Compartment	Bubu Forest Reserve	
	Biomass (t/ha)	Carbon (t C/ha)
Tree	491.00	220.95
Palm	1.40	0.71
Down woody	5.21	2.17
Litter	4.13	1.72
Total	501.74	225.55

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