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An Estimate of Forest Biomass in Ayer Hitam Forest Reserve

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ABSTRAK

Daripada inventori yang dijalankan di Hutan Ayer Hitam (AHFR), min dbh berjulat dari 20.6 ke 26.0 cm manakala keluasan pangkal berjulat dari 9.16 ke 21.57 m^2/ha. Modifikasi persamaan regresi biojisim digunakan untuk menanggarkan biojisim. Kepadatan biojisim untuk pokok dbh 10 cm dan ke atas di semua kompartment di AHFR berjulat dari 83.69 ke 232.39 t/ha. Jumlah biojisim di 1248 ha AHFR yang dianggarkan adalah 223,568 t. Variasi dalam kepadatan biojisim antara kompartment menunjukkan peringkat pemulihan yang berbeza atau pada peringkat sasaran yang berbeza. Maklumat biojisim boleh digunakan untuk menanggarkan parameter yang lain seperti kandungan karbon dan kandungan tenaga. Kandungan karbon yang dianggarkan adalah 111,784 t manakala kandungan tenaga dianggarkan adalah 3.74 x 10^{12} kJ. Pengumpulan kandungan karbon tahunan berjulat dari 0.30 ke 0.50 t/ha/yr manakala tenaga yang dihasilkan berjulat dari 1.00 x 10^7 ke 1.67 x 10^7 kJ/ha/yr. Hutan juga memainkan peranan yang penting dalam kitaran karbon dan pengeluaran tenaga. Biojisim adalah bahan organik yang dihasilkan oleh pokok dan ia adalah punca kepada pengeluaran hutan yang lain.

ABSTRACT

From an inventory conducted in Ayer Hitam Forest (AHFR), the average dbh ranged from 20.6 to 26.0 cm while the basal area ranged from 9.16 to 21.57 m^2/ha. Modified biomass regression equation was used in the biomass estimation. The biomass density for trees of 10 cm dbh and above in all the compartments in AHFR ranged from 83.69 to 232.39 t/ha. The total biomass in the 1248 ha of AHFR is estimated at 223,568 t. Variations in biomass density among the compartments indicate the different stages of recovery or different stages of succession. Biomass information was used to estimate other parameters such as carbon content and energy content. The estimated carbon content is 111,784 t while the energy content is 3.74 x 10^{12} kJ. The estimated annual carbon accumulation ranges from 0.30 to 0.50 t/ha/yr while the energy fixed ranges from 1.00 x 10^7 to 1.67 x 10^7 kJ/ha/yr. Forest also plays an important role in carbon cycle and energy production. Biomass is the organic matter fixed by the tree and is the source of all other productivity of the forest.

INTRODUCTION

Tree biomass is defined as the total amount of living organic matter in trees and is expressed as oven-dry biomass per unit area (usually in tonnes/hectare) (Brown 1997). The term has been widely used as a unit of yield since the 1970s as it is a more useful measure than volume as it allows comparisons to be made between different trees as well as among different tree components.

The uses of biomass information are to (i) quantitatively describe ecosystems and indicate the biomass resources available (Young and Tryon 1978 ; Brown 1997), (ii) quantify amount of nutrients in the ecosystem and hence elucidate nutrient cycling (Long and Turner 1974; Golley 1975; Baker *et al.* 1984; Lim 1988), (iii) determine energy fixation in forest ecosystems (Satoo 1968), (iv) provide estimates of the carbon content in forest (Brown and Lugo 1984; Brown *et al.* 1989; Brown 1997), (v) quantify increment in forest yield, growth or productivity (Burkhart and Strub 1973) and (vi) assess changes in forest structure (Brown 1997).

By using information on biomass, content of carbon, energy and nutrient could be estimated rapidly. With this information, detrimental effects of harvesting can be assessed and compensatory programmes for nutrient replacement through fertilization can be considered. This is also important for evaluation and improvement of site and these form the bases for sound forest management (Lim 1993).

Forest can be a carbon source and sink. Therefore, the management of the forests can affect the global carbon cycle and climate change. In a review by Brown (1997), approximately fifty percent of the biomass is carbon. This represents the potential amount of carbon that can be added to the atmosphere as CO_2 when the forest is cleared (Brown 1997). Tipper (1998) estimated that deforestation contributes about 1.8 Gigatonne Carbon (Gt C) per year. However, forests can also remove CO_2 from the atmosphere through photosynthesis. It is estimated that between 1.1 and 1.8 Gt C per year can be sequestered in 50 years (Makundi *et al.* 1998).

There are efforts to reduce fossil fuel use to more friendly energy sources such as solar, wind, hydropower and biomass. Biomass energy is considered low tech and suitable. Tree biomass can also be an energy source to substitute the use of CO_2-emitting fossil fuel. Renewably grown biomass is a carbon-neutral fuel with a low sulphur content and can be converted to electricity, heat, liquid and gaseous fuel. Plant biomass energy can contribute up to 45 million tonnes oil equivalent (Mtoe) per year. This renewable carbon-neutral biomass energy could reduce CO_2 emission by 50 million tonnes (Mt) of carbon per year (Hall 1998).

This paper will highlight the total above ground biomass estimates using a modified biomass equation. Comparisons of total biomass estimates between compartments are made. In addition, estimates of total carbon and energy content are also presented.

MATERIALS AND METHODS

Summarized inventory data of the area were used with a modified equation to estimate the total biomass in all the compartments. All trees data of 10 cm dbh and above were used in the calculation.

Many biomass estimates are based on the Kato's *et al.* (1978) equations (e.g. Soepadmo 1987; Philip 1999). However, these equations are difficult to use as they involve sequential estimates using a number of equations. The different equations used are shown below.

Stem weight-DBH regression

The stem biomass (W_S) is related to the product of the square of Dbh and tree height. The regression equation is:

$$W_s = 0.313*(Dbh^2H)^{0.9733}$$

where:
W_S = Stem biomass (kg)
Dbh = Diameter breast height (dm)
H = Height (dm)

Branch weight-DBH regression

The branch biomass is estimated from the equation

$$W_B = 0.0390*(Dbh^2H)^{1.041}$$

where:
W_B = Branch biomass (kg)

Leaf weight-Stem weight allometry

The leaf biomass is related to the stem weight by the following equation

$$1/W_L = 1/0.124*(W_S^{0.794}) + 1/125$$

where:
W_L = Leaf biomass (kg)
W_S = Stem biomass (kg)

Estimation of tree biomass

Given the value of Dbh of a tree, it is possible to estimate the total biomass (W_T). This is done by the summation of stem biomass (W_S), branch biomass (W_B) and leaf biomass (W_L) estimated from the above equations.

$$W_T = W_S + W_B + W_L$$

where:
W_T = Total biomass (kg)
W_S = Stem biomass (kg)
W_B = Branch biomass (kg)
W_L = Leaf biomass (kg)

Many other studies use a simple allometric equation of the form $Y = a(Dbh)^b$ (Satoo and

Madgwick 1982). Estimates from the Kato *et al.* (1978) equations above were used to develop a regression of the form $Y = a\ (Dbh)^b$. Estimates from *Acacia mangium* stands (AM86, AM88) (Lim 1986, 1988) and modified Kato *et al.* (1978) were incorporated to derive the modified equation. The derived biomass equation is $Y= 0.0921*(Dbh)^{2.5899}$. The list of the equations are as shown in Table 1.

TABLE 1
Summary of the biomass equations

Source	Equations
Modified Kato *et al.* (1978)	$Y = 0.2544*(Dbh)^{2.3684}$
Lim (1986)	$Y = 0.0843*(Dbh)^{2.5201}$
Lim (1988)	$Y = 0.0380*(Dbh)^{2.8320}$
Modified	$Y= 0.0921*(Dbh)^{2.5899}$

Note: Modified Kato *et al.* (1978) equation denotes as Modified Kato
Lim (1986) equation is denoted as AM86
Lim (1988) equation is denoted as AM88
Modified is denoted as derived equation from AM86, AM88 and Modified Kato

where:
Y = Biomass (kg)
Dbh = Diameter breast height (cm)

TABLE 2
The estimated total biomass of different diameter size by using equations by Lim (1986,1988) (AM86, AM88), Modified Kato *et al.* (1978) (Modified Kato) and modified equation (Modified)

Dbh	AM86	AM88	Modified Kato	Modified
10	27.9	25.8	59.4	35.8
20	160.2	183.9	306.8	215.7
30	445.1	579.7	801.6	616.4
40	919.1	1309.3	1584.3	1298.5
50	1612.8	2463.1	2687.6	2314.3
60	2553.4	4127.9	4139.0	3711.0
70	3765.6	6387.3	5962.8	5532.0
80	5272.0	9322.9	8180.8	7817.6
90	7093.9	13014.1	10813.0	10606.0
100	9251.2	17538.8	13877.7	13933.5
110	11762.9	22973.3	17392.1	17834.6

The estimated total biomass by using equations developed by Lim (1986; 1988), modified Kato *et al.* (1978) and the modified equation are as shown in Table 2. The estimated biomass density values were used to estimate carbon and energy content by using conversion factor. The lines of the different equations are shown in *Fig. 1.*

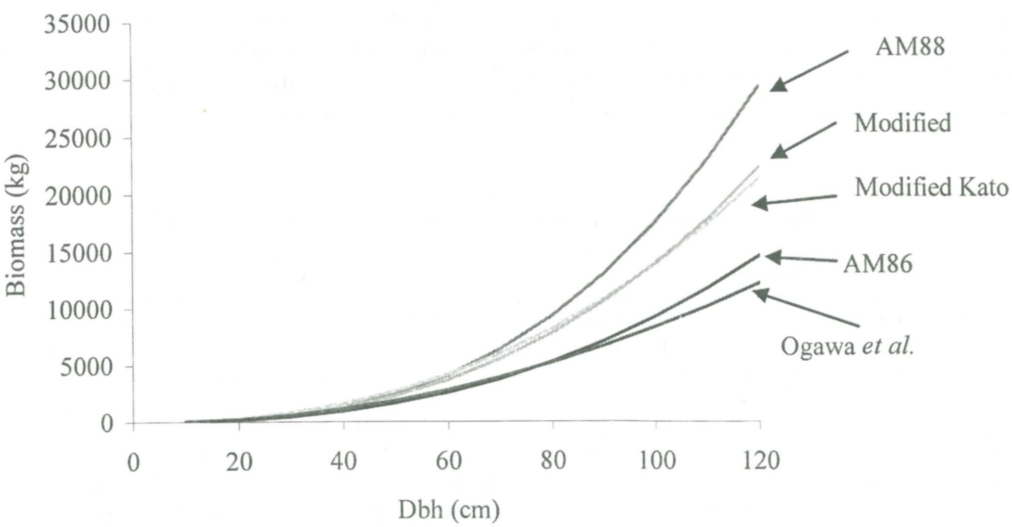

Fig. 1. Biomass regression equations developed by Ogawa et al. (1965), Modified Kato et al. (1978), Lim (1986, 1988) and modification on these equations

RESULTS AND DISCUSSION

The tree densities range from 210 to 366 trees/ha and the basal areas range from 9.16 to 21.57 m^2/ha. The average dbh ranged from 20.6 to 26.0 cm (Table 3). The number of trees in different size classes in most compartments drop rapidly with the increase of size classes (Table 4).

Biomass density is the amount of organic matter expressed in tonne/hectare. It provides a means of comparison between different areas. The estimated biomass density for trees 10 cm dbh and above in Compartment 1 (C1) is 21.57 tonne/hectare (t/ha), Compartment 2 (C2) is 9.16 t/ha, Compartment 12 (C12) is 171.39 t/ha, Compartment 13 (C13) is 149.67 t/ha, Compartment 14 is 232.39 t/ha and Compartment 15 (C15) is 183.28 t/ha (Table 3).

The biomass density values of each compartment are related to their corresponding areas to give estimates of the total biomass of each compartment. Thus, the estimated total biomass for this 1248 ha of Ayer Hitam Forest (AHFR) is 223,568 t (Table 3).

Most of the biomass density in each compartment is contributed by the non-dipterocarps species which ranged from 51.02 to 82.36 % of the total biomass density (Table 5).

There are variations in values of biomass density among the compartments. The lowest was obtained in Compartment 2 with biomass density of 83.69 t/ha. Pioneer species such as *Macaranga* spp., *Sapium* spp. and *Endospermum malaccense* from the family Euphorbiaceae are present in high density (13.3 %) in this compartment. The lowest average dbh (20.6 cm) and basal area (9.16 m^2/ha) were recorded in this compartment. This indicates that the forest stand is in an early stage of succession.

The highest biomass density was obtained in Compartment 14 with 232.39 t/ha. High densities of primary species such as *Shorea* spp., *Hopea* spp., *Dipterocarpus* spp., *Syzygium* spp. and *Palaquium* spp. are found. The families of Dipterocarpaceae (31.7 %), Myrtaceae (15.7 %) and Sapotaceae (10.5 %) are dominant. The average dbh is 25.8 cm and the basal area is 20.89 m^2/ha. This suggests that the compartment has recovered quite well from previous disturbances.

Other compartments are in states intermediate between these two compartments. AHFR has a diversity of states of recovery and this suggests a capability to recover after disturbances such as forest harvesting. When compared with other sites, the total biomass estimates obtained from this study show a reasonable value (Table 6).

TABLE 3
Tree density (no./ha), average dbh (cm), basal area (m^2/ha) and biomass density (t/ha) for all the compartments

Compt.	Tree Density (no/ha)	Average DBH (cm)	BA (m^2/ha)	Biomass Density (t/ha)
1	303	26.0	21.57	229.62
2	210	20.6	9.16	83.69
12	246	25.3	16.40	171.39
13	239	24.6	14.89	149.67
14	287	25.8	20.89	232.39
15	366	21.7	18.39	183.28
Average	275	24.0	16.88	175.01

TABLE 4
Contribution of dipterocarps and non-dipterocarps for all the compartments

Compt.	Dipterocarp				Non-Dipterocarp			
	Tree Density	%	Biomass Density (t)	%	Tree Density	%	Biomass Density (t)	%
1	45	14.85	76.70	33.40	258	85.15	152.92	66.60
2	12	5.71	14.76	17.64	198	94.29	68.93	82.36
12	35	14.23	51.58	30.10	211	85.77	119.81	69.90
13	52	21.76	55.33	36.97	187	78.24	94.33	63.03
14	90	31.36	113.83	48.98	197	68.64	118.57	51.02
15	28	7.65	39.83	21.73	338	92.35	143.45	78.27
Average	44	15.93	58.67	31.47	232	84.07	116.34	68.53

TABLE 5
Biomass density (t/ha) in different diameter class sizes, total biomass (t/compartment) and tree density (no./ha) for all the compartments

DBH (cm)	C1	C2	C12	C13	C14	C15	Total	Average
10.0-19.9	145	131	114	124	138	208		143.3
	(12.52 t)	(10.90 t)	(9.58 t)	(11.30 t)	(11.50 t)	(15.60 t)		(11.90 t)
20.0-29.9	54	37	48	36	54	73		50.3
	(20.42 t)	(13.99 t)	(18.51 t)	(12.70 t)	(21.72 t)	(26.62 t)		(18.99 t)
30.0-39.9	50	24	51	38	48	48		43.2
	(44.99 t)	(20.72 t)	(45.65 t)	(34.29 t)	(42.71 t)	(43.17 t)		(38.59 t)
40.0-49.9	29	13	19	27	19	28		22.5
	(51.40 t)	(23.18 t)	(33.87 t)	(45.18 t)	(31.76 t)	(47.34 t)		(38.79 t)
50.0-59.9	11	4	6	11	18	5		9.2
	(32.14 t)	(10.80 t)	(16.08 t)	(31.80 t)	(47.33 t)	(14.33 t)		(25.41 t)
60.0-69.9	10	1	5	2	4	1		3.8
	(41.87 t)	(4.10 t)	(22.05 t)	(8.30 t)	(16.36 t)	(3.72 t)		(16.07 t)
70.0-79.9	4	0	2	1	2	2		1.8
	(26.28 t)	(13.44 t)	(6.10 t)	(6.10 t)	(11.63 t)	(13.73 t)		(11.86 t)
80.0-89.9	0	0	0	0	1	0		0.2
					(8.52 t)			(1.42 t)
90.0-99.9	0	0	1	0	2	0		0.5
			(12.21 t)		(21.96)			(5.69 t)
100.0-119.9	0	0	0	0	1	1		0.3
					(18.90 t)	(18.77 t)		(6.28 t)
Biomass Density (t/ha)	229.62	83.69	171.39	149.67	232.39	183.28		175.01
Compartment Size (ha)	126	156	220	195	279	272	1248	
Total Biomass (t/compartment)	28,932.12	13,055.64	37,705.80	29,185.65	64,836.81	49,852.16	223,568.18	

TABLE 6
Comparisons of total biomass (t/ha) in different study sites

Site	Source	Total Biomass (t/ha)
Mixed dipterocarp-dense stocking, flat to undulating terrain/ Sarawak	FAO (1973)	325.00-385.00
Lowland forest/Pasoh	Kato *et al.* (1978)	475.00
Lowland Dipterocarp forest/Philippines	Kawahara *et al.*(1981)	262.00
Secondary forest/Sabal Forest	Kamaruzaman *et al.* (1983)	53.04
Secondary forest/Sibu	Lim and Mohd. Basri (1985)	6.20
Superior to moderate hill/Peninsular Malaysia	Forestry Department (1987)	245.00-310.00
Ayer Hitam Forest Reserve	Present Study	83.69-232.39

As half of the biomass is carbon, the estimated total carbon content from AHFR is 111,784 t, while the estimated energy content of all the biomass is 3.74×10^{12} kJ. This energy is equivalent to 8.60×10^4 tonne oil equivalent (toe) (Table 7). It is estimated that the global energy consumption is 7.80×10^9 toe. in 1993 (Jackson and Jackson 1997). In developing countries, wood fuel is used for cooking, making charcoal, etc. This estimate from AHFR suggests that forests can play an important role in carbon cycle and energy supply.

TABLE 7
The estimated carbon content (t) and energy content (kJ, toe) in 1248 hectare of Ayer Hitam Forest Reserve

Compt.	Biomass (t/compartment)	Carbon (t)	Energy (kJ)	Energy (toe)
1	28,932.12	14,466.06	4.84×10^{11}	1.11×10^{4}
2	13,055.64	6527.82	2.18×10^{11}	5.01×10^{3}
12	37,705.80	18852.90	6.31×10^{11}	1.45×10^{4}
13	29,185.65	14592.83	4.89×10^{11}	1.13×10^{4}
14	64,836.81	32418.41	1.10×10^{12}	2.53×10^{4}
15	49,852.16	24926.08	8.34×10^{11}	1.92×10^{4}
Total	223,568.18	111,784.09	3.74×10^{12}	8.60×10^{4}

Conversion Factors:
1 tonne/hectare = 4000 cal/g = 4.0×10^{9} cal/t (Kimmins 1997)
1 kcal = 4.184 kJ (Krebs 1994)
1 kJ = 2.3×10^{-8} tonne oil equivalent (toe) (Jackson and Jackson 1997)

From other unpublished studies in AHFR, we estimate that the biomass increment ranges from 0.60 to 1.00 t/ha/yr. Therefore, the annual carbon accumulation ranges from 0.30 to 0.50 t/ha/yr and the annual energy fixed ranges from 1.00×10^{7} to 1.67×10^{7} kJ/ha/yr.

CONCLUSION

AHFR is recovering after disturbances in the past. Forest stands in the different compartments are in different stages of recovery as indicated by different biomass densities. This biomass is the organic matter fixed by the tree and is the source of all other productivity of the forest.

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