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BIOMASS ESTIMATION, CARBON STORAGE AND ENERGY CONTENT OF THREE VIRGIN JUNGLE RESERVES IN PENINSULAR MALAYSIA

(*Perkiraan Biomasa, Penyimpanan Carbon dan Kandungan Energi dari Tiga* Virgin Jungle Reserve *di Semenanjung Malaysia*)

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ABSTRAK

Suatu kajian terhadap biomasa, penyimpanan Carbon dan kandungan energi telah dilakukan di tiga Virgin Jungle Reserve (VJR) yang mewakili zona geografi yang berbeda, yaitu Mata Ayer VJR, Perlis, Bukit Bauk VJR, Terengganu dan Gunung Pulai VJR, Johor, Semenanjung Malaysia. Plot tunggal seluas 2 hektar (100 m x 200 m) telah dibuat di masing-masing VJR. Plot kemudian dibagi menjadi 50 subplot seluas 20 x 20 m^2. Semua pohon $\geq$ 5 cm setinggi dada, telah ditandakan dengan alumunium bernomor, diukur dan spesimen voucher dikumpulkan. Hasilnya menunjukkan kepadatan pohon di Mata Ayer VJR sebanyak 1171 individu/ha, Bukit Bauk VJR sebanyak 1351 individu/ha dan Gunung Pulai VJR sebanyak 1035 individu/ha. Jumlah biomasa di atas tanah, Mata Ayer VJR = 402.6 t/h, Bukit Bauk VJR = 551.2 t/ha dan Gunung Pulai VJR = 320.6 t/ha. Sedangkan jumlah penyimpanan Carbon di atas tanah untuk Mata Ayer VJR = 201.3 t/h, Bukit Bauk VJR = 250.6 t/h dan Gunung Pulai VJR = 160.3 t/ha. Kandungan energi di atas tanah untuk Mata Ayer VJR = 154.97 toe, Bukit Bauk VJR=212.17 toe, dan Gunung Pulai VJR = 123.41toe.

Kata kunci : Biomasa, Carbon, *Virgin Jungle Reserve*, Semenanjung Malaysia

INTRODUCTION

The establishment of Virgin Jungle Reserves (VJRs) within the timber production areas in Peninsular Malaysia was initiated in 1950's to serve as: (1) permanent nature reserves and natural arboreta; (2) control for exploited and silviculturally treated forest; and (3) undisturbed natural areas for general ecological and botanical studies of fundamental importance (Putz 1978).

Forests have been perceived as a source of timber, wood and other extractive such as medicinal and ornamental plants. This perspective has changed considerably due to international and local initiatives that view forests as ecosystems that render both productive and service functions. The later include soil conservation/regeneration, water flow regulation/storage/cycling, and recreational and biodiversity reserve service (Ramirez 2000).

The international community too has at last recognized the problem of global warming and the latter has become the subject of a global accord, following the signing of the United Nations Framework Convention on Climate Cange and the Kyoto Protocol. The UN Framework Convention recognizes that world's forests will have an important role to play in implementing a global strategy for reining in the global emissions of carbon, which is the main factor in global warming (Dore & Guevara 2000).

By using information on biomass, the content of carbon, energy and nutrient can be estimated rapidly. Trees and other plants capture CO^2 from the atmosphere through photosynthesis, fixing carbon in their biomass and releasing oxygen (O2) (Ramirez 2000). The quantity of biomass in a forest is a result of the difference between production through photosynthesis and consumption by respiration and harvest processes. Thus it is a useful measure for assessing changes in forest structure. Changes in forest biomass density are brought about by natural succession; human activities such as silviculture and functional attributes of forest ecosystem across a wide range of environmental conditions (Brown 1997). Tree biomass is the organic matter fixed by the trees. Therefore, biomass helps to determine energy fixation efficiency of a forest ecosystem (Whittaker 1975). Biomass can also help to quantify the amount of nutrients in the ecosystem. Hence, these elucidate the nutrient cycling processes (Baker *et al*. 1984; Goley *et al*. 1975; Long & Turner 1974; Lim 1988).

Estimation of woody biomass is essential for determining the status and flux for biological materials in an ecosystem and for understanding the dynamics of the ecosystem (Anderson 1970; Lodhiyal & Lodhiyal 1997). Swank and Schreuder (1974) have explained that quantity of tree biomass per unit area of land constitutes the primary data needed to understand the flow of materials and water through forest ecosystem. The rising demands for energy from renewable sources has generated new ideas and turned attention to woody biomass production system.

The study was aimed to estimate the biomass of trees of three VJRs in the relation to the carbon storage and energy content of the forests ecosystem.

METHODS

Study Site

A study was simultaneously conducted in three Virgin Jungle Reserves (VJRs) of Peninsular Malaysia, in period 2001-2003. These VJRs were arbitrarily chosen to represent the three different geographical zones, namely: Mata Ayer VJR, Compartment 24, Perlis for the northern zone; Bukit Bauk VJR, Comparment 8B, Terengganu for the middle and eastern zone and Gunung Pulai VJR, Compartment 16, Johor for the southern zone (Figure 1). Details of these VJRs are as follows:

Study Site 1: Mata Ayer VJR, Compartment 24. Altitude: 92-160 m above sea level; Slope: 0-40^{0}; Geographical Position: 06^{0}39'41 N and 100^{0}15'24 E; Total Area of Mata Ayer VJR: 55 hectares; Annual rainfall: 1728 mm.

Study Site 2: Bukit Bauk VJR, Compartment 8B. Altitude: 110-220 m above sea level; Slope: 0-40^{0}; Geographical Position: 04^{0}41'12 N and 103^{0}24'22 E; Total of Bukit Bauk VJR: 28 hectares; Annual rainfall: 2700 mm.

Study Site 3: Gunung Pulai VJR, Compartment 16. Altitude: 88-152 m above sea level; Slope: 0-50^{0}; Geographical Position: 01^{0}37'29 N and 103^{0}32'52 E; Total Area of Gunung Pulai VJR: 111.27 hectares; Annual rainfal: 2457 mm.

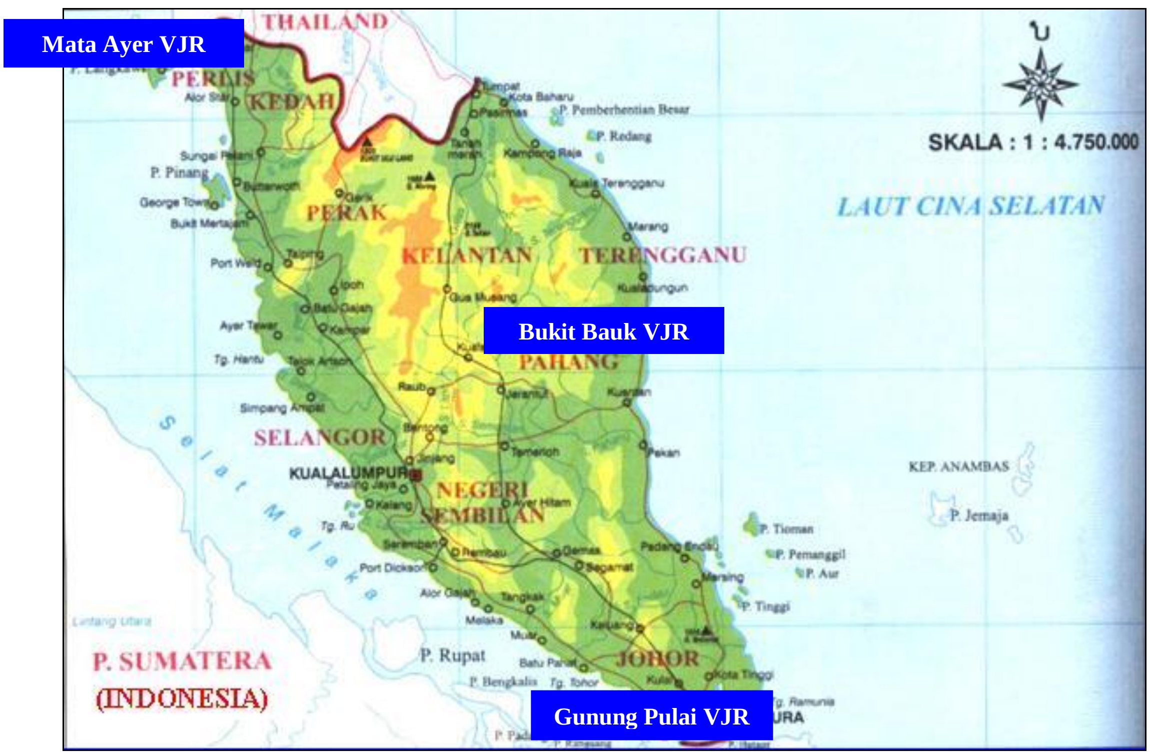

Figure 1. Location of Study Sites

Data Collection

Rectangular plots of 2 hectares (100 m x 200 m) were established in each study. The plot was further divided into contiguous 50 subplots/sampling units each 20 m x 20 m. The rectangular plot were laid out in the representative forest stand with purposive sampling design. The Global Positioning System/GPS (GARMIN Ltd.) was used to seek the plot coordinates (latitude and longitude) in the field.

In the subplot of 20 m x 20 m, all trees (minimum dbh 5 cm) were tagged with an allumunium label, measured and identified. The following data were recorded from all 50 subplots: (1) botanical and local names of trees, (2) number of trees, and (3) diameter at breast height (dbh) or 30 cm above the butresses of trees.

Data Analysis

The above ground biomass on the study sites were estimated by using allometric equations. The equation for biomass estimation was developed by Kato et al. (1978) and modified by Kueh and Lim (1999) as follows :

$$Y = 0.2544 * D^{2.3684}$$

where Y is biomass in kg, and D is diameter breast height in cm.

Carbon storage = Biomass x 0.5 (Brown 1997; Kueh & Lim 1999; Ramirez 2000). Energy fixed was calculated as follow : 1 tonne/ha biomass = 4000 cal/g = 4.0×10^9 cal/t (Kimmins 1997), 1 kcal = 4.184 kJ (Krebs 1994), 1 kJ = 2.3×10^{-8} tonnes oil equivalent (toe) (Jackson & Jackson 1997).

RESULTS AND DISCUSSION

Stand Structure

The structure of stand in the study sites were dominated by trees < 15 cm dbh . In Mata Ayer VJR, the stand density of trees was 2341 stems per 2 ha or 1171 stems per ha, and the proportion of trees < 15 cm dbh was 79.28%. In Bukit Bauk VJR, the stand density was 2702 stems/ 2 ha or 1356 stems/ ha, and the proportion of tree < 15 cm dbh was 72.24%. Whereas, in Gunung Pulai VJR, stand density was 2070 stems/ 2 ha or 1035 stems/ ha, and the proportion of trees < 15 cm dbh was 70.72% (Table 1). These results indicated that the forest has typical diameter-frequency distribution of natural forest with decreasing stems in the higher diameter classes. The diameter distribution of trees is the most simple yet informative for depicting the properties of a stand of trees (Bailey & Dell 1973).

Table 1. Diameter class distribution of trees in the study sites

No.	Diameter class (cm)	Mata Ayer VJR		Bukit Bauk VJR		Gunung Pulai VJR	
		No. Of individual	(%)	No. Of individual	(%)	No. Of individual	(%)
1	5-14	1856	79.28	1952	72.24	1464	70.72
2	15-24	242	10.34	400	14.80	343	16.57
3	25-34	98	4.19	167	6.18	116	5.60
4	35-44	57	2.43	73	2.70	75	3.62
5	45-54	39	1.67	46	1.70	42	2.03
6	55-64	18	0.77	19	0.70	18	0.87
7	65-74	8	0.34	16	0.59	7	0.34
8	75-84	7	0.30	10	0.37	4	0.19
9	85-94	7	0.30	4	0.15	0	0
10	95-104	5	0.21	6	0.22	0	0
11	≥ 105	4	0.17	9	0.33	1	0.05
	Total	2341	100	2702	99.98	2070	100

Biomass

Table 2 shows the total above ground biomass of trees (dbh ≥ 5 cm) in Mata Ayer VJR was 805.2 t/2 ha or 402.6 t/ha, and diameter class 45-54 had proportions higher than others which was 12.67%. The total above ground biomass of trees in Bukit Bauk VJR was 1102.31 t/2 ha or 551.2 t/ha, and the highest proportion of biomass was obtained by diameter class ≥ 105 cm dbh that is 14.96%. The total above ground biomass of trees in Gunung Pulai VJR was 641.13 t/2 ha or 320.6 t/ha, and the highest percentage of biomass was attained by diameter class 35-44 cm dbh, that is 18.16%.

Table 2. Above ground biomass distribution between diameter class

No.	Diameter class (cm)	Mata Ayer VJR		Bukit Bauk VJR		Gunung Pulai VJR	
		Biomass (t)	Proportion (%)	Biomass (t)	Proportion (%)	Biomass (t)	Proportion (%)
1	5-14	75.07	9.32	89.05	8.08	71.81	11.20
2	15-24	69	8.57	111.11	10.08	93.65	14.61
3	25-34	70.59	8.77	127.56	11.57	88.22	13.76
4	35-44	83.40	10.36	111.51	10.12	116.40	18.16
5	45-54	102.04	12.67	118.73	10.77	109.12	17.02
6	55-64	69.9	8.68	78.55	7.13	71.01	11.08
7	65-74	48.70	6.05	97.17	8.82	41.44	6.46
8	75-84	56.07	6.96	84.10	7.63	32.64	5.09
9	85-94	74.18	9.21	40.23	3.65	0	0
10	95-104	68.77	8.54	79.37	7.20	0	0
11	$\geq$ 105	87.48	10.86	164.93	14.96	16.84	2.63
	Total	805.2	99.99	1102.31	100	641.13	100

The biomass values of the study sites were moderate compared to other biomass studies in Malaysian forests. FAO (1973a) reported that biomass for Mixed Dipterocarpaceae Forest was 280-330 t/ha in Sarawak, 475 t/ha in Pasoh Forest Reserve (Kato *et al*. 1978), 650 t/ha in Gunung Mulu (Proctor *et al*. 1983), 200.6 t/ha in Bangi Forest Reseve (Norashidah 1993), 306.4 t/ha in Fraser Hill lower montane forest (Shamsul 2002), 83.7-232.4 t/ha in Mata Ayer Forest Reserve (Kueh & Lim 1999), 527.94 t/ha in Matchingcang Forest Reserve (Raffae 2002), 234.2 t/ha in Cape Rachado coastal forest (Mat-Salleh *et al*. 2003), and 955.6 t/ha in Lesong VJR (Suhaili 2004).

Brown *et al*. (1989), showed that the total above ground biomass for primary forest moist forest is the highest in Malaysia (255-446 t/ha) followed Cameroon (238-314 t/ha), French Guiana (280-283 t/ha), and Sri Lanka (153-221 t/ha). Above ground biomass estimation of different forest types in Peninsular Malaysia is given in Table 3.

Table 3. Above ground biomass estimation of different forest types in Peninsular Malaysia

Location	Forest type	dbh (cm)	Biomass estimation (t/ha)	Source
Pasoh (2 plot)	Lowland forest Lowland forest	$\geq$ 5 cm $\geq$ 5 cm	655.3 465.1	Kato *et al*. (1978)
G.Janing, Ulu Endau (4 plot)	Hill dipterocarp forest	$\geq$ 5 cm	350.1 210.1 167.5 107.5	Soepadmo (1987)
Bangi	Hill dipterocarp forest	$\geq$ 5 cm	200.6	Norashidah (1993)
Bangi	Lowland dipterocarp forest	$\geq$ 5 cm	362.32	Lajuni (1996)
Ayer Hitam	Lowland dipterocarp forest	> 10 cm	83.7 – 232.4	Kueh & Lim (1999)
Fraser Hill	Lower mountain forest	$\geq$ 5 cm	306.4	Shamsul (2002)
Pulau Langkawi		$\geq$ 5 cm	527.94	Raffae (2003)

Cape Rachado	Hill dipterocarp forest	≥ 5 cm	234.2	Mat-Salleh *et al*. (2003)
		≥ 5 cm	453.14	Norziana (2003)
Taman Negara, Merapoh	Coastal forest			
Bukit Rengit, Krau		≥ 5 cm	574.0	Fakhrul Hatta (2003)
Perlok, Krau		≥ 5 cm	419.0	Fakhrul Hatta (2003)
Tersang	Lowland dipterocarp forest	≥ 5 cm	383.05	Mohd Ridza (2004)
Lepar	Lowland forest	≥ 5 cm	399.01	Mohd Ridza (2004)
Lesong	Lowland forest	≥ 5 cm	955.61	Suhaili (2004)
Mata Ayer	Lowland forest	≥ 5 cm	402.6	This study
Bukit Bauk	Lowland forest	≥ 5 cm	551.2	This study
Gunung Pulai	Lowland forest	≥ 5 cm	302.6	This study
	Lowland forest			
	Lowland forest			
	Lowland forest			

The total biomass of tree is cumulative between above ground biomass and below ground biomass. Ogawa *et al*. (1965a) estimated the root biomass in the Khao Chong forest at about one-tenth of the above ground biomass. Taking these into consideration, Kato *et al*. (1978) used the value to estimate the below ground biomass of Pasoh Forest. Comparison with plantation forests, e.g. proportion of biomass stored in roots of poplar plantation in the Tarai belt of central Himalayan mountains were found to be 15-18% of the total tree biomass (Lodhiyal & Lodhiyal 1997) ; 10-12% reported for eucalypt forest (Feller 1980); 8-15% for temperate forests (Larsen *et al*. 1976; Whittaker & Woodwell 1971); 43% reported for a eucalypt ecosystem on Stradbroke Island (Westman & Roger 1977). The difference in root biomass estimation in trees may be related to great sampling difficulty (Lodhiyal & Lodhiyal 1997).

In this study, the below ground biomass is estimated to be about 10% of the above ground biomass. Therefore, the below ground biomass of the study sites were 40.26 t/ha (Mata Ayer VJR), 55.12 t/ha (Bukit Bauk VJR) and 32.06 t/ha (Gunung Pulai VJR), and the total biomass were 442.9 t/ha (Mata Ayer VJR), 606.3 t/h (Bukit Bauk VJR), and 352.7 t/h.

Carbon Storage

Total carbon storage in Bukit Bauk VJR was higher than other study sites at 303.16 t/ha. The lowest carbon storage were Gunung Pulai VJR at 352.7 t/ha and respectively (Table 4).

Table 4. Biomass and carbon storage of the forest in the study sites

Item	Mata Ayer VJR		Bukit Bauk VJR		Gunung Pulai VJR	
	Biomass (t/ha)	Carbon (t/ha)	Biomass (t/ha)	Carbon (t/ha)	Biomass (t/ha)	Carbon (t/ha)
Above ground	402.6	201.3	551.2	275.6	320.6	160.3
Below ground	40.26	20.13	55.12	27.56	32,06	16.03
Total	442.86	221.43	606.32	303.16	352.66	176.33

Conversion factor :
Below ground biomass = 0.1 x above ground biomass (Ogawa et al. 1965a)
Carbon storage = 0.5 x biomass (Brown 1997; Kueh & Lim 1999; Ramirez 2000)

Meanwhile, aboveground carbon in Mata Ayer VJR was 201.3 t/ha, in Bukit Bauk VJR was 275.6 t/ha, and in Gunung Pulai VJR was 160.3 t/ha (Table 5.13). Carbon storage in this study was higher than other studies, e.g. Andersen (1996) obtained carbon storage in a matured primary forest, Brazilian-Amazon at 140 t/ha. The above-ground carbon content of tropical forest ecosystems varies between 25 and 250 t/ha (Dore & Guevara 2000). These results confirmed that the above ground carbon content in the study sites are in the range of the above ground carbon mentioned, except in Bukit Bauk VJR that was higher. A comparison of carbon storage in various tropical forest is given in Table 5.

Table 5. Comparison of carbon storage in tropical forest

Location	Forest type	Carbon (t/ha)	Source
Mata Ayer	Primary forest	201.3	This study
Bukit Bauk	Primary forest	275.6	This study
Gunung Pulai	Primary forest	160.3	This study
Ayer Hitam	Logged forest	89.57	Kueh & Lim (1999)
Brazilian-Amazon	- Mature primary forest	140	Andersen (1996)
	- Intervened forest	55	
Costa Rica	- Primary forest	75.15-127.3	Carranza (1996)
	- Secondary forest	68.4-106.6	

Tropical forests play an important role in the global carbon cycle. Intact un-logged forests provide permanent storage of carbon in their biomass, and secondary forests take up carbon as they grow. When forests are harvested or converted, some portion of the stored carbon is released as carbon dioxide into atmosphere. The extent and timing of the release depend on a variety of factors, such as the fate of the harvested timber and the rate of forest regeneration. The stock of carbon stored in Malaysian forest declined by half between 1971 and 1989 (Economic Planning Unit 1993). Brown *et al*. (1991) found an 18% reduction in forest area in a region of Peninsular Malaysia coincided with a 28% reduction in total biomass. The total loss of biomass was 267.6 Tg C (Tg = 10^6 t), and the total loss of forest area was 1.45 x 10^6 ha. Most of this decrease was due to conversion to agriculture or rubber and palm oil plantations under a programme of planned rural development (FAO 1973b).

Energy of the Forest

Energy content in the study sites indicated that Bukit Bauk VJR was the highest, at 233.39 tonnes oil equivalent (toe). The lowest energy content was in Gunung Pulai VJR at 145.75 tonnes oil equivalent (toe) (Table 6).

Table 6. Biomass and energy content in the study sites

Item	Mata Ayer VJR		Bukit Bauk VJR		Gunung Pulai VJR	
	Biomass (t/ha)	Energy (toe)	Biomass (t/ha)	Energy (toe)	Biomass (t/ha)	Energy (toe)
Above ground	402.6	154.97	551.20	212.17	320.6	123.41
Below ground	40.26	15.5	55.12	21.22	32.06	12.34
TOTAL	442.86	170.47	606.32	233.39	352.66	145.75

Conversion factor :
1 tonne/ha biomass = 4000 cal/g = 4.0 x 10^9 cal/t (Kimmins 1997)
1 kcal = 4.184 kJ (Krebs 1994)
1 kJ = 2.3 x 10^{-8} tonnes oil equivalent (toe) (Jackson & Jackson 1997)

Plant biomass energy can contribute up to 45 million tonne equivalent (Mtoe) per year. This renewable carbon-neutral biomass energy could reduce CO_2 emission by 50 million tones (Mt) of carbon per year (Hall 1998). The lowest and the highest energy content, depend on the biomass content of the forest. As a comparison, Kueh and Lim (1999) estimated that the total carbon content from Ayer Hitam Forest Reserve (1248 ha) was 111,784 t (89.57 t/ha) while the estimated energy content of all biomass was 3.74 x 10^{12} kJ. This energy is equivalent to 8.60 x 10^4 tonnes equivalent oil (toe).

It is estimated that the global energy consumption is 7.0 x 10^9 toe in 1993 (Jackson & Jackson 1997). In developing countries, wood fuel is used for cooking, making charcoal, etc. Nearly half wood consumed in the world is used as fuel wood waste and bioenergy tree plantations as a source of renewable energy in the future (Kimmins 1997). By displacing the use of fossil fuel, fuel wood can make useful contribution by reducing the threat of global climate change caused by release of fossil carbon to the atmosphere.

CONCLUSIONS

The aboveground biomass of trees was the highest in Bukit Bauk VJR that estimated at 551.2 t/ha, and the lowest was in Gunung Pulai VJR, that was 320.6 t/ha, whereas in Mata Ayer VJR was 402.6 t/ha. These biomass value were moderate compared to other biomass studies in Malaysian forests. Meanwhile, above ground carbon in Mata Ayer VJR was 201.3 t/ha, in Bukit Bauk VJR was 275.6 t/ha, and in Gunung Pulai VJR was 160.3 t/ha. Above ground energy in the study sites indicated that in Bukit Bauk VJR was the highest at 212.17 tonnes oil equivalent (toe), followed by Mata Ayer VJR at 154.97 toe. The lowest energy content was in Gunung Pulai VJR at 123.41 toe. This estimate from VJRs suggest that forests can play an important role in biomass produce, carbon storage and energy supply.

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