Research paper

Estimation of the Aboveground Biomass in a *Dillenia suffruticosa* Stand, Malaysia

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【Summary】

The natural regeneration of forests is an important part of the recovery of former shifting-cultivation areas. Regenerating secondary forests are reported to have the potential to assimilate and store large quantities of carbon. However, there is a lack of information on biomass accumulation by pioneer species that dominate early successional processes, especially in tropical Asia. This information would help quantify their role in carbon storage and sequestration. The objectives of this study were to estimate the biomass accumulation and develop a biomass estimation model for a *Dillenia suffruticosa* stand. Six 10 x 10-m plots were established in a *D. suffruticosa* stand. A destructive harvesting method was used to estimate the total and tree component (stem, branches, and leaves) biomass values. An analysis showed that the biomass relationship for each tree component using diameter at breast height (dbh) as an independent variable in a log relationship accounted for 63~89% of the variations at $p \leq 0.01$. The estimated total aboveground biomass of the *D. suffruticosa* stand was 5.2 t ha^{-1}. The high variability of the estimated total biomass in each study plot indicated that the stand was at different stages of succession, but the low biomass accumulation is a reflection of severely degraded conditions and may require a longer period for recovery. However, the natural regeneration of *D. suffruticosa* has contributed to biomass and carbon accumulation in a former shifting-cultivation area.

Key words: aboveground biomass, biomass model, carbon sequestration.

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研究報告

馬來西亞*Dillenia suffruticosa*次生林地上生物量之推估

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摘 要

森林之天然更新，在以前遊牧開墾地區是很重要的。雖然有報導次生林具有吸收和儲存大量碳之潛能，但欠缺那些在演替階段初期先驅樹種之生物量累積之資料。此等資料有助於評估次生林在碳吸存方面之貢獻。本研究之目的為，對*Dillenia suffruticosa*林分進行生物量推估和發展生物量推估模式。在*D. suffruticosa*林分內設置6個每個面積為10 x 10 m 之樣區。於樣區內進行整株林木和各別部分(樹幹。枝條和葉)生物量推算。研究結果顯示林木各部位生物量和與胸高直徑關係之對數回歸式，具有63~89%之變異之解釋力($p \leq 0.01$)。*D. suffruticosa*林分每公頃地上總生物量為5.2噸。樣區間地上總生物量之高度差異顯示林分內各樣區正處在不同之演化階段，但低生物量反映出此林分處於嚴重劣化，或許需要更久之時間來回復。然而*D. suffruticosa*林分之天然更新的確對遊牧開墾地區生物量和碳之累積有所貢獻。

關鍵詞：地上生物量、生物量模式、碳吸存。

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INTRODUCTION

Secondary forests are forests which have developed by natural secondary succession on land abandoned after shifting agriculture and logging activities (Chai 1997). The natural regeneration of forests is an important part of the recovery of former shifting-cultivation areas. Shifting cultivation was reported to have contributed 25% to the carbon emissions in Asia over the past 150 years (Houghton and Hackler 1999). In 2005, the UN's Food and Agricultural Organization (FAO) reported that about 60% of the world's remaining tropical forests are secondary or degraded forests (FAO 2005) compared to 31% as reported by Brown and Lugo (1990) in the 1980s. These figures indicate the increasing and significant role of secondary forests in tropical landscapes. The roles of secondary forests were discussed in detail by Brown and Lugo (1990), who stated that secondary forests (i) are an important source of timber and non-timber products, (ii) are a source of medicinal plants, (iii) provide wildlife habitats, (iv) act as reservoirs for biodiversity, and (v) provide ecological services and products to mankind.

The recent Copenhagen Climate Change Summit 2009 reinforced commitments by signatory countries towards the *Kyoto Protocol* and Reducing Emissions from Deforestation and Forest Degradation (REDD) scheme as one of the initiatives to mitigate climate change. Such interest is amplified, as it was reported that 52% of the world's forests are found in the tropical region where deforestation rates are highest (Brown et al. 1996). Therefore, degradation and loss of tropical forests have significant impacts on the global carbon cycle (Silver et al. 2000). Under the REDD initiative, countries are required to report their carbon storage and changes. Therefore, the above- and belowground biomass, litter, dead wood, and soil organic carbon must be monitored (Philip and Haron 2010). Among the methods to determine forest biomass are use of information from forest inventories with regression models and remote-sensing techniques (Brown 2002, Houghton 2005).

Development of localized regression models is more accurate but such models are rather limited in tropical regions (Chave et al. 2005, Kenzo et al. 2009a, Van Breugel et al. 2011). In Malaysia, the Pasoh model (Kato et al. 1978) for primary forests has been widely used, while Kenzo et al. (2009a, b) developed a biomass model for logged-over forests. However, localized models should be given consideration as studies conducted by Kenzo et al. (2009a) in a secondary forest of Sarawak, Malaysia found biomass estimates vary between those equations developed for primary forests and early successional secondary forests. This is due to different growth forms and wood densities with different forest structures and floristic compositions (Kenzo et al. 2009a, b).

Tropical forests are known to play an important role in carbon sequestration because of their high carbon storage (Lal and Augustin 2012). Furthermore, regenerating secondary forests were reported to have the potential to assimilate and store large quantities of carbon. This is primarily due to the higher recruitment and growth rate of tree species in these forests compared to primary forest tree species (Whitmore 1986, Swaine and Agyeman 2008). Therefore, communities of pioneer species could significantly contribute to carbon sequestration during the early stages of forest recovery. The shift from a secondary forest of pioneers to a primary forest of climax species is termed succession. The successional process has 4 stages: pioneer, young secondary, old secondary, and primary (Kruk et al. 1988).

Dillenia suffruticosa or simpoh air (Dilleniaceae) was selected for this study because it is commonly found in pioneer species communities. The presence of this species is also a sign of forest degradation. *Dillenia suffruticosa* was found to be growing with *Trichospermum kurzii*, *Gochidion lutescens*, *Macaranga* spp., *Pithecellobium jiringa*, and *Vitex pubescens* (Chai 1997), whereas on degraded lands in Singapore, *D. suffruticosa* was found growing with *Adinandra dumosa*, *Fagraea fragrans*, *Myrica esculenta*, *Ploiarium alternifolium*, *Rhodamnia cinerea*, and *Rhodomyrtus tomentosa* (Corlett 1991). Hattori et al. (2005) reported that *Dillenia* species were found growing with *Macaranga* spp., *Ficus* spp., *Glochidion* sp., *Callicarp*a sp., and *Artocarpus* sp. in a regenerating secondary forest in Sarawak. The species is distributed in Malaysia, Indonesia (Sumatra and Java), and Sri Lanka (Staples et al. 2000). Among the uses of this species are (i) wrapping food by using the large leaves, (ii) indicating the presence of groundwater due to the deep tap roots, (iii) formulating traditional medications for wounds, and (iv) using the fruit pulp as hair shampoo. It is a medium-sized tree (Ng 1983), but the timber is not useful because it is twisted and very hard (Corner 1997).

The lack of information on the biomass of early successional forests in this region, particularly in Sarawak, limits our understanding of the role of pioneer species as carbon sources and sinks. Several researchers, such as Ewel et al. (1983), reported the biomass of 4.5- and 9.5-yr-old secondary forests in Sabal Forest Reserve, Sarawak, Malaysia, while Chai (1997) reported on 10- and 14-yr-old secondary forests in Semengok, Sarawak, Malaysia. Lim and Basri (1985) reported on the biomass of a naturally regenerating secondary forest in Sibu, Sarawak, Malaysia. Kenzo et al. (2009a, b, 2010) reported on the biomass of a logged-over forest in Sarawak, Malaysia. With insufficient biomass information on *D. suffruticosa* and no localized biomass estimation model, this research is important for gathering information that can facilitate the quantification of the role of this species in carbon sequestration and its contribution to mitigating climate change. The objectives of this study were to estimate the aboveground biomass of a *D. suffruticosa* stand and develop a biomass estimation model.

MATERIALS AND METHODS

This study was conducted in 2008 at a secondary forest on the Univ. Putra Malaysia Bintulu Sarawak Campus, Sarawak, Malaysia (3°12'N, 113°3'E). Shifting cultivation was formerly practiced in the area, and it has been naturally regenerating since 1987. Climatic information for a 6-yr period (2006~2011) was obtained from the Bintulu Meteorological Station, Malaysia. The average monthly rainfall recorded at the Bintulu Meteorological Station was 193.2 mm, while the average monthly relative humidity was 86.5%. The average annual recorded rainfall over 6 yr was 2318.7 mm. The area receives the highest rainfall in October to January. The average monthly air temperature was 27.5℃. The mean relative humidity is also consistent throughout the year (82.8~86.7%). Soils of the study sites are Ultisols (Nyalau and Bekenu Series) and are well drained.

Six research plots (10 x 10 m) were established in a *D. suffruticosa* stand. Small-sized plots were used as there are restrictions on felling trees. The small study plots also represented different successional stages. Van Breugel et al. (2011) suggested that small plots at various successional stages in secondary forests would be more representative and better reflect the variability of the biomass stock in the overall forest area. All stands in all study plots were enumerated. The distribution of the diameter size class was right-skewed which indicated that the study plots were in an early stage of forest recovery (Fig. 1).

A destructive harvesting method was used, as such a protocol has been widely used by many researchers such as Kenzo et al. (2009a, b) and Basuki et al. (2009) to estimate the total biomass. From a field survey, all trees (n = 27) in the study plots were harvested, and their biomass was measured. The harvested trees ranged 5.0~9.1 cm in diameter and 8.3~13.7 m in height. After felling, all trees were divided into main stem, branches, and leaves in the field. The fresh weight of

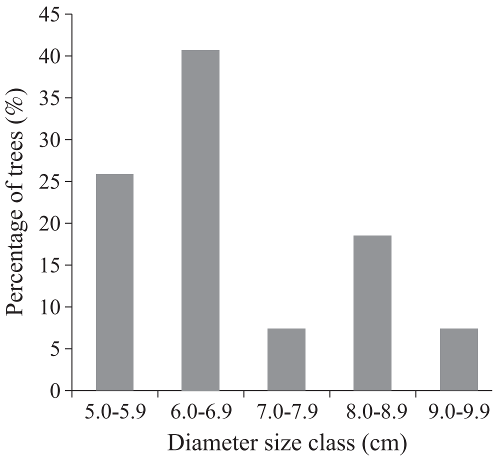

Fig. 1. Distribution of diameter size classes in the study plots.

each of the tree components was measured in the field, and then representative samples were dried at 105℃ in an oven until they reached a constant weight.

In the regression analysis, the diameter at breast height (dbh and dbh^2) was tested as an independent variable. Power functions from a linear regression of log-transformed data using the model of Log(y) = Log(a) + bLog(x) was developed. Y is the biomass (kg), x is the dbh, and a and b are regression constants. Data were analyzed using SPSS 16.0 for Windows (SPSS, Chicago, IL, USA). Back-transformed biomass estimates were multiplied by a correction factor (CF) = $e^{0.5*MSE}$, where MSE is the mean squared error of the regression model (Sprugel 1983).

RESULTS

Biomass allometric model

When correlated to the dbh on a log-log basis, the biomass of the tree components and of the entire tree gave regressions with adjusted correlation coefficients (adjusted r^2) of 0.63~0.89 compared to dbh^2 as an independent variable with adjusted r^2 of 0.68~0.85 (Table 1). Both models showed lower r^2 values of 0.632 and 0.678 for the leaf component compared to the main stem (r^2 of 0.749 and 0.804) and branch components (r^2 of 0.758 and 0.828). Both intercepts and constants were highly significant at 0.01% (*n* = 27). The MSE improved in the dbh variable model that ranged 0.002~0.013 compared to the dbh^2 variable model that ranged 0.003~0.018. The CF was included in both models with a range of 1.001~1.007 to improve the model reliability.

Aboveground biomass estimation

The estimated aboveground biomass showed wide variations among the study plots, ranging 8.3~105.3 kg with basal areas that ranged 0.28 x 10^{-2}~3.48 x 10^{-2} m^2. The total aboveground biomass was 5.2 t ha^{-1}, while the basal area was 1.7 m^2 ha^{-1} (Table 2). The distribution of total biomass among the diameter size classes showed high variability. Of the total biomass, 35 and 23% were respectively contributed by the diameter size classes of 6.0~6.9 and 8.0~8.9 cm (Fig. 2). The contributions of the tree component biomass to the total biomass were in the order of main stem > branches > leaves. A high proportion of wood partitioning (90.1%) was found in

Table 1. Results of regression analyses [Log(Y) = Log(a) + bLog(X)] for predicting the biomass of various plant parts from the diameter at breast height (dbh) using data from all felled trees

Y	X	No. of trees	a (±SE)	b (±SE)	Adjusted r^2	MSE	CF
Stem	dbh	27	-1.658**±0.234	2.952**±0.284	0.805	0.013	1.007
biomass (kg)	dbh^2	27	-1.604**±0.209	1.447**±0.163	0.749	0.018	1.001
Branch	dbh	27	-0.362**±0.082	1.120**±0.100	0.828	0.002	1.001
biomass (kg)	dbh^2	27	-0.393**±0.063	0.576**±0.105	0.758	0.003	1.002
Leaf biomass	dbh	27	-1.032**±0.150	1.227**±0.182	0.632	0.006	1.003
(kg)	dbh^2	27	-1.306**±0.135	0.611**±0.082	0.678	0.004	1.002
Total	dbh	27	-0.695**±0.121	2.097**±0.147	0.886	0.004	1.002
biomass (kg)	dbh^2	27	-0.754**±0.145	1.085**±0.088	0.853	0.005	1.003

r^2, coefficient of determination; SE, standard error; MSE, mean squared error; CF, correction factor.
* $p \leq 0.05$, ** $p \leq 0.01$.

Table 2. Biomass distributions among the study plots

Plot	*n*	Total biomass (kg)	Mean±SE (kg)	Basal area (m^2)	Mean±SE (m^2)
1	2	17.7	8.8±1.2	0.54 x 10^{-2}	0.27 x 10^{-2}±0.05 x 10^{-3}
2	1	8.3	8.3±0.0	0.28 x 10^{-2}	0.28 x 10^{-2}±0.0
3	8	85.2	10.6±1.8	2.62 x 10^{-2}	0.33 x 10^{-2}±0.45 x 10^{-3}
4	3	60.4	20.1±0.5	1.89 x 10^{-2}	0.63 x 10^{-2}±0.19 x 10^{-3}
5	3	34.6	11.5±2.1	1.14 x 10^{-2}	0.38 x 10^{-2}±0.79 x 10^{-3}
6	10	105.3	10.5±1.0	3.48 x 10^{-2}	0.35 x 10^{-2}±0.36 x 10^{-3}
Total (kg 0.06 ha^{-1})	27	311.5	Total (m^2 0.06 ha^{-1})	9.96 x 10^{-2}	
Total (t ha^{-1})		5.2	Total (m^2 ha^{-1})	1.65	

SE, standard error; *n*, number of trees sampled.

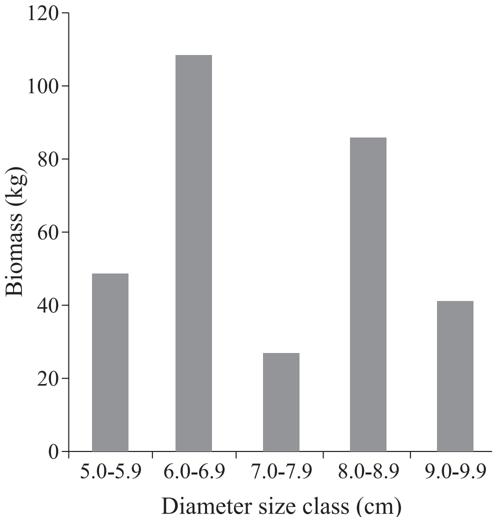

Fig. 2. Distribution of biomass values among different diameter size classes.

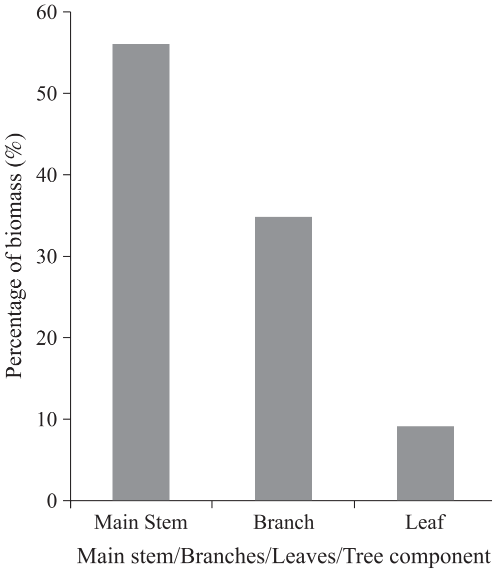

Fig. 3. Proportions of biomass values among the different tree components.

this species compared to the leaf component (Fig. 3).

DISCUSSION

In this study, we found it was possible to develop a biomass allometric model based on the dbh as the independent variable. The dbh variable model exhibited higher regression coefficients compared to the dbh^2 variable model. In addition, the former model had lower MSEs of 0.002~0.013 which indicated a more-reliable model compared to the latter model. Hence, the single independent variable of dbh would preferably be used to estimate the biomass in this study. The use of dbh as an independent variable is especially easy for estimating tree characteristics in the field. This simple model was used by several researchers such as Hashimoto et al. (2004) and Heryati et al. (2011). A single variable (dbh only) used in developing the allometric model is more practical, simple, and economic (Onyekwelu 2007).

The high variations reported for the biomass of each tree component and total biomass indicated that there is great variability in the stem size and also high heterogeneity in the field. The high proportion of wood partitioning (90.1%) showed that this species can provide a sufficient supply of woody materials. Many researchers from other study sites suggested that a higher proportion of biomass was found in stems, and it increased with tree size (Montagu et al. 2005) and age (Son et al. 2001), while stem density would affect the allocation of branch biomass (Munoz et al. 2008). High variations in the leaf biomass are not surprising, as this species is a shrub and has multiple leaders. In addition, a study by Kenzo et al. (2009a) in a Sarawak secondary forest found that large plasticity in the allocation of leaf characters with ontogeny and environmental conditions may appear as variations of leaf allometric relationships. The results of wide variations in total biomass among the study plots indicated that this *D. suffruticosa* stand is at different stages of succession. This is also typical of a regenerating secondary forest which is characterized by a high density of smaller trees with low biomass (Brown and Lugo 1990).

The results obtained in this study were extrapolated to a hectare for the purpose of comparison. The total biomass obtained was 5.2 t ha^{-1}. This value is slightly lower than values reported for secondary forests that ranged 6.2~118.8 t ha^{-1} (Table 3). The lower value suggests that the study area was severely degraded and disturbed. Lim and Basri (1985) found that areas dominated by *Imperata cylindrical* and *Pteridium* spp. had low biomass of 6.2 t ha^{-1} compared to 21 t ha^{-1} in an upland area with high numbers of larger-sized trees. Soils of the study site are Ultisols which are known for their low fertility and high acidity. In addition, they have a sandy loam texture with a low water-holding capacity and high erodibility. Therefore, it is best if the area remains covered by natural vegetation (Paramananthan 2000). The study site is a former shifting-cultivation area, and regenerating *D. suffruticosa* exhibited low biomass accumulation after 20 yr. This suggests that the study site will require a longer period for natural recovery. The period of tropical forest recovery after a disturbance was estimated to be 50~80 (Brown and Lugo 1990), 73 (Hughes et al. 1999), >100 (Kruk et al. 1988), 150~200 yr (Richards 1996), and even centuries (Whitmore 1991).

By making the assumption that 50% of the biomass is carbon (Basuki et al. 2009), the estimated total aboveground carbon accumulated was 2.6 t ha^{-1}. Carbon that accumulated in the *D. suffruticosa* stand was higher compared to that of grassland/fallow land as

Table 3. Distribution of forest biomass estimates among different forest types

No.	Forest type/Location	Total biomass (t ha^{-1})	Reference
1	4.5-yr-old secondary forest, Sarawak, Malaysia	54.0	Ewel et al. (1983)
2	9.5-yr-old secondary forest, Sarawak, Malaysia	39.0	Ewel et al. (1983)
3	Secondary forest, Sibu, Sarawak, Malaysia	6.2	Lim and Mohd. Basri (1985)
4	1-yr-old secondary forest, Sebubu, Kalimantan, Indonesia	8.0~10.0	Hashimoto et al. (2004)
5	10-12-yr-old secondary forest, Sebubu, Kalimantan, Indonesia	45.0~56.0	Hashimoto et al. (2004)
6	4-yr-old secondary forest, Niah Forest Reserve, Sarawak, Malaysia	21.4	Kenzo et al. (2010)
7	17-yr-old secondary forest, Niah Forest Reserve, Sarawak, Malaysia	118.8	Kenzo et al. (2010)
8	*Dillenia suffruticosa* stand, Bintulu, Sarawak, Malaysia	5.2	This study

reported by Hashimoto et al. (2004) where grasslands dominated by alang-alang accumulated biomass of 1.98~5.1 t ha^{-1} which accumulated carbon of about 0.1~2.6 t ha^{-1}. The natural regeneration of this *D. suffruticosa* stand has promoted the recovery of the biomass and carbon-storage capacity in a former shifting-cultivation area. The information from this study provides a reference and understanding of the trends of biomass and carbon recovery and quantifies the role of this species in carbon sequestration which can contribute to mitigating climate change.

CONCLUSIONS

The recovery of woody tree species is important in natural succession. This facilitates aboveground biomass recovery, and hence acts as a carbon sink in a former shifting-cultivation area. *Dillenia suffruticosa* stands could play an important role in carbon storage and sequestration in early successional stages. Long-term monitoring is essential to enhance our understanding of trends and recovery of biomass and carbon accumulation in naturally regenerating forests. It was concluded that it is possible to develop an allometric biomass model for *D. suffruticosa* stands. Different stand biomass values and proportions among the tree components can be used as an indicator to determine the stages of forest recovery. The lower biomass that had accumulated at the study sites indicated that the forest was severely degraded and has yet to recover. Despite this, the natural regeneration of this *D. suffruticosa* stand has contributed to biomass and carbon accumulation in a former shifting-cultivation area.

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