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Research Article

Estimation of total above ground biomass at selected age stands of a rehabilitated forest

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ABSTRACT. Forests have the potential to act as global carbon storage. Due to this, declining forest areas globally elevate the role of remaining natural regenerating and rehabilitated forests. This paper reports an initiative to estimate total above ground biomass distribution and storage at different age stands of a rehabilitated forest. The study site is the UPM-Mitsubishi Forest Rehabilitation Project, Bintulu, Sarawak. 20 x 20 m plots were established at one-, 10- and 19-year-old rehabilitated forests and the adjacent natural regenerating secondary forest. Regression analysis showed that the above ground biomass equations with the function of dbh*H have high adjusted coefficient of determination (r^2)= 0.96-0.99. Results showed the distribution of percentage tree component biomass to total above ground biomass was in the order of main stem > branch > leaf. The total above ground biomass increased significantly with age of the forest which was in the order of Plot 1991 > Plot NF > Plot 1999 > Plot 2008. The total above ground biomass for young rehabilitated forest was estimated at 4.3×10^{-3} t/plot while the 10 and 19-year-old rehabilitated forests stood at 1.5 t/plot and 4.2 t/plot, respectively, whereas the natural regenerating secondary forest was at 3.9 t/plot. All the study plots showed variations in the total above ground biomass which indicated that these forests are in the process of recovery. The older rehabilitated forest showed comparable total above ground biomass recovery and storage to the adjacent natural regenerating secondary forest.This reaffirms the need for human intervention in rehabilitating former shifting cultivation areas to facilitate the recovery of the above ground biomass.

Keywords: Biomass, allometric relationship, rehabilitated forest.

INTRODUCTION

Biomass is defined as the total amount of living organic matter in plants and expressed as oven-dried tonne over a unit area (Avitabile *et al.*, 2008; Brown, 1997; Husch *et al.*,1982). Growing interest in biomass study is primarily due to the recognition of the role of forests as global carbon storage, and the existence of international treaties and policies (such as the Kyoto Protocol and REDD+). Moreover, Malaysia is one of the signatory countries of the Kyoto Protocol. The recent Copenhagen Climate Change Summit 2009 has renewed cumulative international efforts in dealing with climate change and commitment towards

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Kyoto Protocol and REDD+, which requires each signatory country to provide carbon storage information. Hence, accurate methods for estimating above ground biomass especially in logged-over and rehabilitated tropical rainforests are required to estimate the effects of carbon sequestration after logging and rehabilitation activities, as well as to evaluate the baseline for a nation's carbon storage (Angelsen, 2008; Gibbs *et al.*, 2007).

It is also known that the forest plays an important role in carbon sequestration, where it has the capability to remove carbon dioxide from the atmosphere through photosynthesis. However, forest areas are declining globally and it is reported that 13 million hectares of forests globally were converted to other land uses annually from 2000 to 2010. The remaining global forests accounted for 36% of primary forest, 57% of naturally regenerated forest and 7% of planted forest (FAO, 2010). As 52% of the world's forests fall under the tropical forest region which are subject to high rates of deforestation and land use change (Brown *et al.* 1996), these have raised concern on the impact towards issues related to climate change. Large forest areas converted to other land uses and on-going issues on forest degradation have elevated the role of remaining forest categories such as secondary, regenerating (Van Breugel *et al.*, 2011) and rehabilitated forests in providing products and services to mankind.

Secondary forests have the potential to assimilate and store relatively large proportions of biomass and carbon. This is due to high recruitment and growth rate of logged-over tree species (Swaine & Agyeman, 2008; Whitmore, 1984). Several researchers including Montagnini & Porras (1998), Ritcher *et al.* (1999) and Silver *et al.* (2000) have suggested that rehabilitation, reforestation and afforestation activities have the potential to enhance biomass and carbon storage. Such information is rather limited in rehabilitated forests especially in the tropical region. This paper reports on the initiative to estimate the total above ground biomass distribution and storage at selected age stands of a rehabilitated forest.

MATERIALS AND METHODS

Study area

Research plots of 20 x 20 m each were established at stands of a 19-year-old (Plot 1991), 10-year-old (Plot 1999) and one-year-old (Plot 2008) at the UPM-Mitsubishi Forest Rehabilitation Project, Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. A plot of 20 x 20 m was also established in a natural regenerating secondary forest at Bukit Nyabau (Plot NF) which is approximately 800 m away from Plot 1991. Generally, soil at the study sites belong to the Nyalau and Bekenu (Ultisols) Series which are acidic and well-drained (Peli *et al.*, 1984). Climate information from 2006 to 2010 was obtained from the Bintulu Meteorological Station at the Bintulu Airport, Malaysia. The average annual total rainfall recorded was 4,552.4 mm while the average annual relative humidity was 83.7%. The average annual air temperature was consistent throughout the year with a range of 23.5–31.5°C.

At the forest rehabilitation project site, the accelerating natural regeneration technique applied was based on the concept of vegetation association and accelerating natural regeneration (Miyawaki, 1999, 2011). High density of three seedlings per meter square was planted with indigenous species mainly from Dipterocarpaceae and Non-Dipterocarpaceae such as Anacardiaceae, Moraceae, Sapindaceae and Myrtaceae. All rehabilitated forest study plots were once shifting cultivation areas with woody species of *Trema orientalis* and grassland dominated by *Ischaemum magnum* and *Miscanthus floridulus* (Yusof & Abas, 1992). Plot NF was an ex-logging area. Since the opening of the campus in 1997, the forest is in a natural regenerating state (± 23-year-old).

The forest inventory shows that most trees are still small (>75%) with less than 10 cm diameter at breast height (dbh). The accelerating natural regeneration technique applied to rehabilitate the degraded forest area had accelerated the structural characteristics performance at the 19-year-old rehabilitated forest compared to the adjacent natural regenerating secondary forest (Roland *et al.*, 2011). Overall, the study plots are at different stages of recovery from the aspect of structural characteristics as reflected by the inverse-J formation (Figure 1). In terms of forest stand development these forests are at an early stage of succession. The key forest structural characteristics are shown in Table 1.

Biomass measurements and allometric relationships

The destructive harvesting method was used to estimate the above ground biomass and develop their allometric relationships. All stands in the study plots were enumerated for their dbh and height. In this study, the selected sample trees have diameter and height within the mean dbh and height for each of the study plots. The mean diameter ranged between 0.8-8.2 cm and mean height ranged between 0.5-9.3 m in the rehabilitated forests while in the natural regenerating secondary forest, it was 3.2 cm and 4.0 m, respectively (Table 2).

It is important to note that only one individual tree was felled at each study plots. Sample tree felling in sufficient numbers is one of the many issues in biomass studies. This was also highlighted by Chave *et al.* (2005) and Van Breugel *et al.* (2011) where they reported the lack in terms of number and size distribution of trees for destructive sampling. However, local developed allometric models are assumed to provide more accurate biomass estimates in a localised situation. In this issue, Van Breugel *et al.* (2011) found that the number trees used for model development has limited effect on biomass estimates at plot level but has very

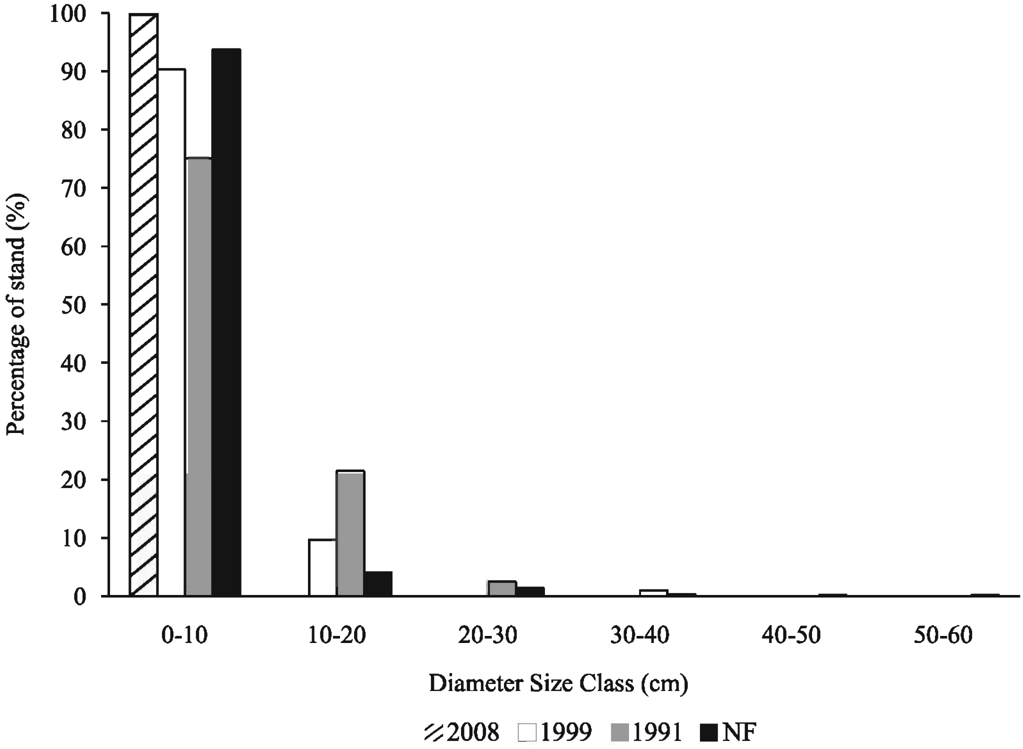

Figure 1. Distribution of the stand percentage in the Diameter Size Class among the study plots (data adapted from Roland *et al.*, 2001).

Table 1. Selected key forest structural characteristics of the study sites.

	Plot 2008	Plot 1999	Plot 1991	Plot NF
Mean Dbh (cm)	0.76*	6.00*	8.16*	3.24*
Mean Height (m)	0.46*	6.15*	9.30*	4.02*
Total Basal area (m^2/0.04ha)	0.02*	0.80*	1.56*	1.64*
No of Trees	321	227	205	546
No of Species	19	19	18	120
No of Family	10	9	5	38
5 most common families	Dipterocarpaceae Meliaceae Clusiaceae Myrtaceae Sapotaceae	Dipterocarpaceae Anacardiaceae Fabaceae Lauraceae Mrytaceae	Dipterocarpaceae Sterculiaceae Bombacaeae Clusiaceae Myrtaceae	Dipterocarpaceae Anacardiaceae Eupborbiaceae Sapotaceae Ixonanthaceae
Common species (%)	*Sandoricum borneense*	*Dryobalanops beccarii*	*Shorea dasyphylla*	*Parishia maingayi*
Importance Value (IV) Index	*Sandoricum borneense*	*Dryobalanops beccarii*	*Shorea dasyphylla*	*Teijsmanniodendron holophyllum*

Note: * indicates data was adapted from Roland *et al.* (2011)

Table 2. Summary of forest stand structural characteristics for biomass study.

	Mean Dbh (cm)	Dbh (cm)	Mean Height (m)	Height (m)
Plot 2008	0.76±0.16 *		0.46 ± 0.15 *	
Sample tree		0.99		0.59
Plot 1999	6.00± 0.20 *		6.15 ± 0.13 *	
Sample tree		6.75		6.91
Plot 1991	8.16 ± 0.38*		9.30 ± 0.24 *	
Sample tree		7.80		10.75
Plot NF	3.24 ± 0.23*		4.02 ± 0.14 *	
Sample tree		2.28		4.19

Note: values are mean ± standard error; * indicates data was adapted from Roland *et al.* (2011)

strong effect on the uncertainties of the overall forest area. Therefore, through the average tree sampling method, sample trees within these sizes should represent the respective study plots.

Selected species were from the dominant species and highest Importance Value (IV) index. The species were *Sandoricum borneense* (Plot 2008), *Dryobalanops beccarii* (Plot 1999), *Shorea dasyphylla* (Plot 1991) and *Teijsmanniodendron holophyllum* (Plot NF). The selection of dominant species using the IV index is one of the ways to achieve representativeness of multispecies in an allometric model. In a review by Van Breugel *et al.* (2011), they found literature that one approach in achieving representativeness of multispecies allometric model is to focus on dominant species since relatively small samples may represent relatively large proportions of biomass stocks in secondary forests. Therefore, choosing dominant species and tree characteristic close to the overall mean plot tree characteristic consider all possibilities in achieving representation for all the study plots, despite the shortcomings.

After harvesting, trees were divided into leaf, branch and main stem components. The fresh weight of each tree components was measured in the field. Sub-samples were taken from each component; where for the main stem, a disc of 5 cm thick was taken from each 1 meter section while for branch and leaf, about 0.5 to 1 kg were collected. These sub-samples were oven-dried at 103°C in an oven to a constant weight. Weighing of oven-dried samples should be carried out as soon as possible after removing them from the oven because they soon absorb moisture from the atmosphere and would gain weight. Weight data of each plant part was correlated with dbh and height on a log-log basisto develop the biomass allometric relationships.The log transformation was applied to data that exhibited heteroscedasticity where the error variance was not constant across all observations (Montagu *et al.*, 2005).

Statistical analysis

In the regression analysis, dbh and height (H) were tested as independent variables. Preliminary assessment suggested that the combination of dbh*h showed better representation in the equation, where it is in the form of Log Y= Log a + bLog(X); where y is biomass (kg), x is the dbh (cm) and H (m), while a and b are regression coefficients. Regression analysis was carried out using SPSS 16.0 for Windows.The back-transformed above ground biomass estimates were multiplied by the Correction Factor (CF) = $e^{0.5*MSE}$ where MSE is the mean squared error of the regression model (Sprugel, 1983).

RESULTS AND DISCUSSION

Biomass allometric relationships

In this study, the biomass components and the whole tree when correlated to the dbh and height on a log-log basis, gives regressions with correlation coefficients.The development and derived equations from the sample trees felled for the biomass estimates as a function of dbh and H (dbh*h) accounted 96-99% of the variations at $p \leqslant 0.01$ for all the plant parts and above ground biomass (Figure 2; Table 3). This means that the biomass of these plant parts proportionately increase with the increase in dbh. Allometry makes use of the fact that there is proportionality between the relative growths of two different parts of the plant (Ong *et al.*, 2004). In a review by Ketterings *et al.* (2001), it was discussed that the commonly used function for allometric equations is the power function which is widely found within biology (Huxley, 1932).

The correction factor (CF) ranging between 1.01-1.03 was included to improve the model reliability. In addition, it has low mean square error (MSE) of 0.01–0.05 for all the tree characteristic which reflects the reliability of the equations (Table 3). The combination of dbh and height as independent variables in the biomass allometric equation was preferred for estimating the tree component biomass and total above ground biomass. Similar trends and consistency were also reported by other researchers in the region. Kenzo *et al.* (2009a) developed allometric equations with combined parameters like dbh^2*H for above ground biomass had adjusted r_2 of 0.99 in a logged-over forest in Sabal Forest Reserve and Balai Ringin Protected Forest, Sarawak, Malaysia.

Allometric relationship for leaf biomass showed relatively lower adjusted coefficient of determination (adjusted $r^2 = 0.96$) compared with other components. Similar observations have been reported for leaf biomass in a logged-over forest in Sarawak (Kenzo *et al.*, 2009a). The large plasticity in the allocation of leaf components with ontogeny and environmental conditions (such as light, soil nutrients and water) may appear as variations of the leaf and branch allometric relationships (Lambers *et al.*, 1998; Kenzo *et al.*, 2009a).

Biomass partitioning

Results showed wide variations of biomass at each of the tree components in the study plots especially on the branch (3-19%) and leaf (4-15%) components. The contribution of percentage tree component biomass to total

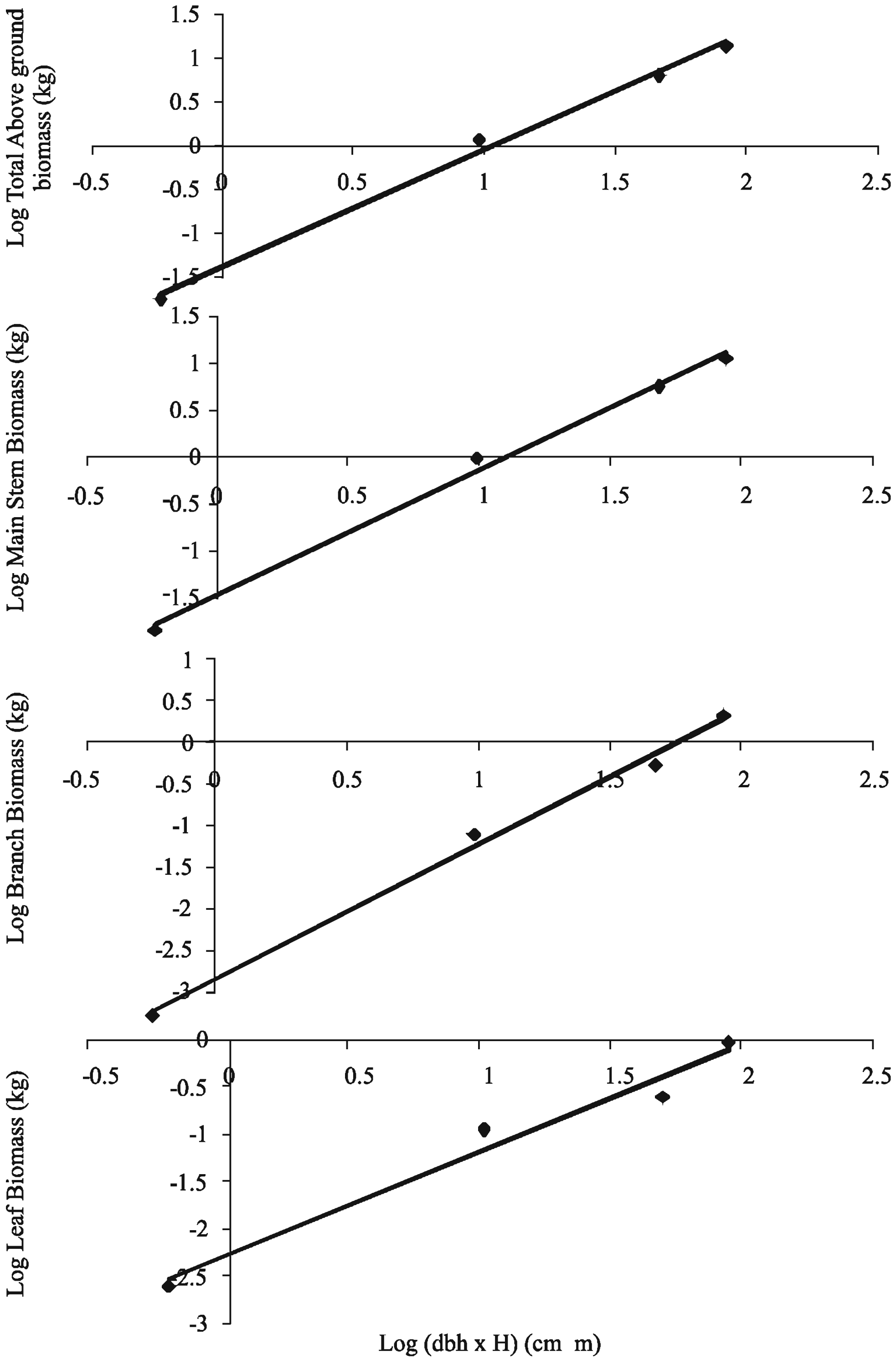

Figure 2. Allometric relationships between above ground biomass (kg) parts and dbh x height (cm, m) in the study plots.

Table 3. Results of regression analyses for predicting biomass of plant parts from dbh and H [Log Y= Log a + bLog(X)] using data from all felled trees.

Dependent variable (Y)	Independent variable (X)	No of trees	a (± S.E.)	b (± S.E.)	Adjusted r^2	MSE	CF
Stem	dbh*h	4	-1.46** ± 0.10	1.33** ± 0.07	0.991	0.01	1.01
Branch	dbh*h	4	-2.87** ± 0.12	1.64** ± 0.09	0.991	0.02	1.01
Leaf	dbh*h	4	-2.27** ± 0.19	1.12* ± 0.14	0.956	0.05	1.03
Total	dbh*h	4	-1.38** ± 0.09	1.34** ± 0.07	0.992	0.01	1.01

Note: dbh means diameter breast height in cm; h means height in m; r^2 means coefficient of determination; * and ** indicate significant difference at levels of $p \leq 0.05$ and $p \leq 0.01$; S.E. means standard error; MSE means mean square error; CF means correction factor

above ground biomass was in the order of main stem>branch>leaf (ratio of 81:12:7) (Figure 3). In general, it is crucial to report biomass and carbon inventory. This is to acquire biomass information on the various components of the trees.

Different age stands showed different percentages of biomass distribution among the tree components. Older rehabilitated forests and the natural regenerating secondary forest allocated more biomass on woody components where the main stem was allocated 77-83%

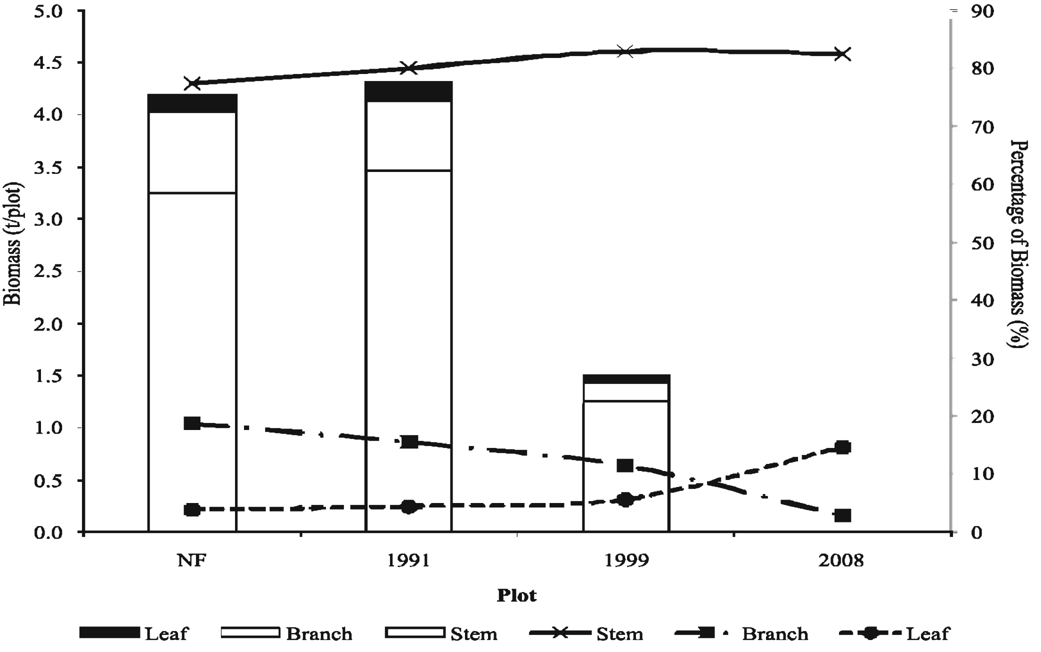

Figure 3. Proportion of biomass partitioning among tree characteristic at the study plots.

while the branch was allocated 3-19% of the total biomass. In the one-year-old rehabilitated forest, vegetative parts were allocated 15% of total biomass while in older rehabilitated forests, this was at a rate of only 4-6%, and in the natural regenerating secondary forest it stood at 4% (Figure 3). This is not unusual as when trees increase in size, a higher allocation of biomass would be on the stem (Montagu *et al.*, 2005; Son *et al.*, 2001). This information also provided an indicator that all the study plots showed variations in physical tree size and different stages of recovery. The mean dbh in Plot 1991 was 8.2 cm compared to 0.8 cm in Plot 2008 (Table 1). Younger stands allocated more masses on the vegetative component to be competitive in the photosynthesizing activities, coupled with available space between trees for rapid rate of canopy development. In addition, this trend was due to the inverse and compensatory relationship between stem and canopy mass. Such observation was reported by Kenzo *et al.* (2009b), who found that leaf biomass to stem biomass decreased significantly with tree diameter in a secondary forest in Sarawak, Malaysia.

Allocation of biomass on the branch component depends on the stand density and the stages of growth related to the age of the forest. Higher stand density as reported at young rehabilitated forest with 301 trees/plot accounted for branch biomass of 3%, compared to 16% and 11% of branch biomass in older rehabilitated forests with stand density of 205 trees/plot and 227 trees/plot in Plot 1991 and 1999, respectively. This was also reported by Tadaki (1977) and Satoo *et al.* (1955) that branches recorded 12% of the woody biomass ata 13-year-old *Pinus densiflora* plantation with stand density of 12,806 trees/ha and 32% at density of 2,462 trees/ha.

High variations and differences recorded in this study could have resulted from the crown competition between adjacent trees. This caused a situation of suppression for smaller trees especially in older rehabilitated and natural regenerating secondary forests. The rehabilitation technique applied in these study plots involved planting of three-seedlings per metre square had created a competitive environment for the seedlings to survive. Lim (1986) also found that high density planting in the *Acacia mangium* plantation resulted in high variability in stand characteristics due to intense competition and growth suppression.

Distribution of total above ground biomass

The total above ground biomass increased significantly with age of the forest which was in the order of Plot 1991>Plot NF>Plot 1999>Plot 2008. The regression equation represented was Ln (Total above ground biomass) = Ln (Age)*2.27-Ln 2.10 (Table 4). The total above ground biomass at the young rehabilitated forest was estimated at 4.3 x10^{-3} t/plot while the 10- and 19-year-old rehabilitated forests were at 1.5 t/plot and 4.2 t/plot, respectively. This was similar with results reported by Silver *et al.* (2000) on tropical reforestation where biomass recovers over time. In comparison, the natural regenerating secondary forest recorded a total above ground biomass of 3.9 t/plot. After 19 years of forest rehabilitation, the rehabilitated forest showed comparable total above ground

Table 4. Results of regression analysis for predicting above ground biomass from age.

Ln (Y)	Ln (X)		Ln a (± S.E.)	Ln b (± S.E.)	Adjusted r^2	MSE	CF
Above ground Biomass	Age	4	-2.10* ± 0.48	2.27** ± 0.20	0.978	0.24	1.13

Note: r^2 means coefficient of determination; * and ** indicate significant difference at levels of $p \leqslant 0.05$ and $p \leqslant 0.01$, respectively; S.E. means standard error; MSE means mean square error; CF means correction factor biomass recovery to the adjacent natural regenerating secondary forest. As the functions of the regression models were based on the dbh and height, the accelerated tree characteristic at the 19-year-old rehabilitation forest contributed to the higher total above ground biomass. These were in consistent with the report by Brown and Lugo (1990) and Silver *et al.* (2000) who suggested that the forest rehabilitation would have higher biomass accumulation rate especially in the first 15-20 years.

Forest rehabilitation using the accelerating natural regeneration technique is to restore the degraded forest by applying high density planting of indigenous species (Miyawaki, 1999, 2011; Miyawaki *et al.*, 1993). The findings suggested that human intervention through the tree planting initiative has the potential to enhance the above ground biomass recovery on former shifting cultivation areas. This was also reported by several researchers including Ritcher *et al.* (1999) and Silver *et al.* (2000) who found that reforestation activities have the potential to enhance carbon storage through biomass and soil carbon accumulation.

As for the purpose of comparison with other published literature, the results were extrapolated to a hectare. The rehabilitated forests contain total above ground biomass that ranged between 0.1–104.8 t/ha, in contrast to the natural regenerating secondary forest where the total above ground biomass recorded was 98.6 t/ha. Biomass studies reported from other study sites within Malaysia revealed wide variations. These results fall within the range of total above ground biomass reported for secondary forests that ranged between 6.2–232.4 t/ha. Mature forests recorded high total above ground biomass of at least 320 t/ha (Table 5).

The structural tree characteristic of the rehabilitated forests exhibited smaller mean dbh (0.8-8.2 cm) and shorter mean height (0.5-9.3 m) (Table 2). With intrinsic smaller and shorter trees in the rehabilitated forests, these elucidate the lower total above ground biomass recorded in this study. The physical structural characteristic of the forest affects the biomass stored. This is consistent with other studies such as Brearley *et al.* (2004) who reported that a 55-year-old secondary forest with mean basal area of 6.43 m^2/0.25 ha and mean height of 19.0 m stored 264 t/ha of biomass while a primary forest with a basal area of 7.83 m^2/0.25 ha and mean height of 22.1 m stored 358.4 t/ha of biomass.

The findings of this study showed that rehabilitated forests are still in the recovery process and at the early stage of succession, and additionally that the total above ground biomass accumulation increases with age. After 19 years, the rehabilitated forest has yet to recover from the aspect of the total above ground biomass but is comparable to the adjacent natural regeneration secondary forest. Therefore, this reaffirms the need for human intervention in efforts to rehabilitate degraded forests especially at former shifting cultivation and grassland areas to facilitate the recovery process of the above ground biomass.

CONCLUSION

It can be concluded that in the rehabilitated forest, the total above ground biomass distribution varies among forest stands and its proportion in tree components. This type of information can help forest managers to assess the status of forest recovery. Generally, these forests have yet to recover in the aspect of above ground biomass accumulation and storage. Rehabilitation activities have shown the potential to facilitate the recovery of above ground biomass in severely degraded ex-shifting cultivation areas.

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Table 5. Distribution of total biomass among different forest types.

No	Forest Type/Site	Total Biomass (t/ha)	Source
1	Mixed diptercarp-dense stoking, flat to undulating terrain/Sarawak, Malaysia	325.0 -385.0	FAO (1973)
2	Lowland forest/Pasoh, Negeri Sembilan, Malaysia	475.0	Kato *et al.* (1978)
3	4.5 -year -old secondary forest, Sarawak, Malaysia	54.0	Ewel *et al.* (1983)
4	9.5 -year -old secondary forest, Sarawak, Malaysia	39.0	Ewel *et al.* (1983)
5	Secondary forest/Sabal, Sarawak, Malaysia	53.0	Kamaruzaman *et al.* (1983)
6	Ridge/Mulu, Sarawak, Malaysia	650.0	Proctor *et al.* (1983)
7	Secondary forest/Sibu, Sarawak, Malaysia	6.2	Lim and Mohd. Basri (1985)
8	Secondary forest/Ayer Hitam Forest Reserve, Puchong, Selangor, Malaysia	83.7 -232.4	Roland and Lim (1999)
9	Tanjung Tuan VJR/, Malacca, Malaysia	233.4	Mat -Salleh *et al.* (2003)
10	Bukit Bauk VJR/Terengganu, Malaysia	551.2	Hikmat (2005)
11	Mata Ayer VJR/Perlis, Malaysia	402.6	Hikmat (2005)
12	GunungPulai VJR/Johor, Malaysia	320.6	Hikmat (2005)
13	2008 rehabilitated forest, Bintulu, Sarawak, Malaysia	0.11	This study
14	1999 rehabilitated forest, Bintulu, Sarawak, Malaysia	37.8	This study
15	1991 rehabilitated forest, Bintulu, Sarawak, Malaysia	104.8	This study
16	± 23-year-old natural regenerating secondary forest, Bintulu, Sarawak, Malaysia	98.6	This study

Note: VJR means virgin jungle reserve

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