
Biomass and Carbon Stocks Estimation of Lowland Dipterocarp, Riparian and Hill Dipterocarp Forests in Pahang National Park, Malaysia

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Abstract

Forest biomass estimation at local or global scale is very crucial and served as an important indicator for monitoring and estimating the forest carbon ecosystem especially in the context of climate change. Pahang National Park (PNP) is considered as a primary forest, and therefore, it is expected that more carbon can be absorbed and stored by forest biomass. Despite the multifunctional roles of forest biomass, lack of research had been done with regard to the extent of above-ground biomass (AGB) and below-ground biomass (BGB) in lowland dipterocarp (LDF), riparian (RF) and hill dipterocarp forests (HDF). Therefore, this study was conducted to provide an estimation of the AGB, BGB and carbon stocks with respect to different localities in PNP. A total of 60 plots were randomly set up and each forest type contains 20 plots measuring 20 × 20 m. The diameter at breast height (DBH) and height (H) were used to calculate the AGB and BGB, and the carbon conversion coefficient of 0.50 was used to calculate the carbon stocks. Based on the results, the estimation of biomass within LDF, RF and HDF not greatly varies between different species with the mean total tree biomass (TTB) values of 415.11, 323.33 and 579.05 t/ha, respectively. The estimation of carbon storage demonstrated that HDF attained the highest carbon stocks in TTB with the value of 289.52 t/ha. The information from this study is expected to provide baseline information and an understanding on the role of trees in the natural forest in sequestering carbon.

Keywords: above ground biomass, below ground biomass, carbon stocks, forest biomass, natural forests, Pahang National Park

1. Introduction

Tree biomass is a product from photosynthesis as a result of carbon sequestration by tree. A tree can absorb approximately 23 kg of carbon per year. Indeed, a tree can increase biomass as an effect of tree growth and loss biomass through mortality that is due to natural death or logging. Tree biomass can be divided into above (AGB) and below ground biomass (BGB) in which the AGB includes the stem, leaves and branch biomass whereas the BGB is the biomass of tree roots. Each component of the AGB varies in biomass density. The estimation of biomass is significantly important for the environment which is a critical aspect of studies of carbon stocks and the effects of carbon sequestration on the global carbon balance. In recent years, carbon dioxide (CO₂) has received much attention from the world because its concentration in the atmosphere has risen to approximately 30% above natural background levels [1]. The need for biomass and carbon stocks estimation is critical and can be measured using destructive or non-destructive sampling method. That is why a field inventory is conducted where the measurement of tree diameter is recorded to estimate the biomass of tree and later the carbon stocks. According to Brown [2], for closed forest such as Pahang National Park (PNP), a minimum diameter of tree to be measured is greater than or equal to 10 cm. However, for open or secondary forest, a smaller minimum diameter should be chosen [2, 3].

Most of the researches focus on the estimation of the AGB rather than BGB because the process to estimate the AGB is easier and less complicated as compared to BGB. In addition, the above ground tree components are the largest contributor of biomass from the total tree biomass (TTB) whereas the BGB only constitutes a small portion of the TTB. Lajuni and Latiff [4] reported the BGB value in their study plots at Khao Chong forest was one tenth of the AGB. Besides, a study conducted by Mohamad [5] in Kenaboi Forest Reserve, Negeri Sembilan found that root biomass in his study plots was six times smaller than the AGB with values of 463.81 and 73.57 t/ha for AGB and BGB, respectively.

Tree biomass and carbon stocks also varied in accordance to forest types and geographical regions. As such, forest biomass and carbon stocks in tropical forest are higher than temperate forest. This might be due to the different in tree species and climatic condition between both forests. Furthermore, in any forest types, tree biomass and carbon stocks in primary forest are higher than secondary forest. Secondary forest is a forest that has been logged or naturally disturbed whereas primary forest is a forest that has never been logged and free from anthropogenic disturbance. In this case, PNP is considered as a primary forest since anthropogenic activities such as logging have never occurred in this forest. Therefore, it is expected that more carbon can be stored by forest biomass in PNP.

Despite the multi-functional roles of forest biomass, lack of research had been conducted with regards to the extent of AGB, BGB and carbon stocks in lowland dipterocarp (LDF), riparian (RF) and hill dipterocarp forests (HDF) in PNP. In addition, information on biomass estimation and carbon stocks from tree inventory data is currently unavailable for protected forest of PNP. Therefore, this study was conducted to provide the estimation of the AGB, BGB and carbon stocks with respect to different localities in PNP. Considering the fact that biomass represents the role of tree as a key indicator of carbon source and sink, the information from

this study is expected to provide baseline information and an understanding on the role of trees in sequestering carbon. This study aims to estimate the AGB and BGB as well as the TTB of LDF, RF, and HDF in PNP. This study also aims to estimate the carbon stocks of LDF, RF, and HDF in PNP, and to investigate the interaction between forest and five similar family and five similar species in the study areas.

2. Materials and methods

2.1. Study area and field data collection

This study was conducted in PNP in the state of Pahang. PNP has a tropical climate with an annual rainfall of about 2,260 mm and rich in forest vegetation such as trees, climbers, shrubs, epiphytes and palms. Average temperature throughout the year ranges from 20 to 35°C with more than 80% humidity [6]. There are differences in the soil series in the LDF, RF and HDF mainly due to the variations of parent material between localities [7].

This study was conducted in three types of forests of LDF, RF and HDF of PNP and the location of study area are shown in **Figure 1**. The description for each location is summarized in **Table 1**. A total of 60 plots were set up in which each forest contains 20 plots measuring at 20 × 20 m (0.04 ha). Study plots for LDF were located in Kuala Keniam while plots for RF were scattered; 10 plots were located along Keniam River while another 10 plots were located along Tembeling River near to Kampung Pagi. As for the HDF, data collection was conducted in the Teresek Hill at an elevation around 330 m above sea level.

For the field measurement, diameter at breast height (DBH) tape was used to measure the diameter of sampled trees with DBH ≥ 10 cm which is 1.3 m up from the ground [8]. In the case of big buttressed stems, the tree height was measured just above the upper end of plank buttress [9]. Each tree was permanently tagged using laminated label. Tree height was measured using a clinometer, a device that can be used to measure the slope to points on a tree, which can subsequently be used to determine the tree height. The sampled trees were identified to species level and for unknown species, the botanical specimens (e.g. leaves, flower or fruit) were collected for species identification at herbarium laboratories of Universiti Kebangsaan Malaysia (UKM) and Forest Research Institute Malaysia (FRIM).

2.2. Data analysis of tree biomass

Throughout this study, AGB was estimated using Kato et al.'s function [9] (Eqs. (1)–(4)) while BGB using a function from Niyama et al. [10] (Eq. (5)). According to reference [10], the total root biomass is the summation of coarse and fine roots in which fine root is defined as root with diameter less than 5 mm. The TTB is the summation of AGB and BGB. From the values of measured DBH and tree height; the dry mass of stem, branch and leaves of sample trees were estimated. The equations used to estimate these components are as follows:

$$M_s = 0.0313 (D^2 H)^{0.9733} \quad (1)$$

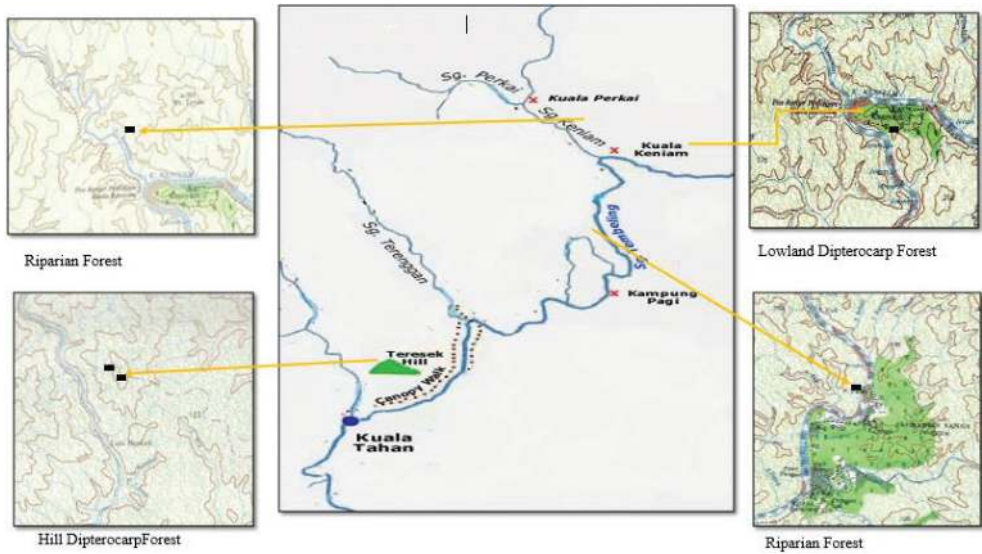


Figure 1. Study areas of LDF, RF and HDF in PNP.

Study area	Forest types	Locality	Coordinates	Slope	Elevation	Soil series
1	Lowland dipterocarp	Kuala Keniam	04° 31.148' N, 102° 28.100' E to 04° 31.058' N, 102° 27.934' E	0–56°	133–139 m above sea level	Telemong
2	Riparian	Along Keniam and Tembeling River	04° 31.507' N, 102° 28.130' E to 04° 27.690' N, 102° 29.196' E	0–40°	102–115 m above sea level	Telemong and Pagi
3	Hill dipterocarp	Teresek Hill	04° 23.888' N, 102° 24.469' E to 04° 23.872' N, 102° 24.534' E	30–79°	292–340 m above sea level	Gol and Tahan

Table 1. Study area, forest types, locality, coordinates, slope, elevation and soil series in PNP.

$$M_B = 0.136 (M_s)^{1.070} \tag{2}$$

$$\frac{1}{M_L} = \frac{1}{0.124(M_s^{0.794})} + \frac{1}{125} \tag{3}$$

$$AGB = M_s + M_B + M_L \tag{4}$$

$$BGB = 0.0262 \times D^{2.497} \tag{5}$$

$$TTB = AGB + BGB \quad (6)$$

Where, M_s , M_b , M_L were denoted as dry mass of stem, branch and leaves in kg, respectively (Eqs. (1)–(4)). The AGB was computed from the summation of these components as in Eq. (4). The biomass functions developed by Kato et al. [9] can be applied irrespective of tree species since these equations were developed without taking regards of tree species in the study area of Pasoh Forest Reserve [9, 11]. In this study, the dry mass of the tree biomass components was presented in t/ha. The dry mass (kg) for each component was converted into tonne by dividing the values with 1000 then divided with 0.04 ha which is the size of each plot. For an estimation of carbon storage, the biomass value was divided with 0.8 ha which is the total size for each study area. The carbon storage in the forests was calculated in accordance to method from Brown [2] whereby 50% of the biomass in the forest is assumed as carbon.

2.3. Statistical analysis

Means of AGB, BGB and TTB between LDF, RF and HDF of PNP were obtained and analyzed using 3×5 factorial two-way ANOVA. The PROC GLM was applied in Statistical Analysis Software (SAS) version 9.3 to study the interaction between forests and five similar family and species based on the highest AGB in LDF, RF and HDF of PNP. The normality of the dataset is test using frequency distribution or histogram. Based on the analysis, the data distribution is normal and the statistical tests are considered as parametric tests.

3. Results and discussions

3.1. The total AGB, BGB and TTB for different types of forests

The total AGB, BGB and TTB for lowland dipterocarp, riparian and HDF are shown in **Table 2**. From the **Table 2**, it appears that HDF recorded the highest AGB, BGB and TTB among study areas. This is because HDF consists of higher trees ($n = 579$) and number of trees with DBH of more than 80 cm was higher than the other two forests (14 trees/ha) (**Table 3**). Furthermore, dominant family in HDF based on basal area was Dipterocarpaceae with tree count of 58 from 579 trees (**Table 3**). These dipterocarp trees have diameter ranges from 10.8 to 103.5 cm. RF recorded the lowest AGB, BGB and TTB among the three forests as it recorded contains less number of trees ($n = 285$) and most of trees in RF have smaller diameter. Big-sized trees in RF with diameter more than 80 cm was lower than LDF and HDF (3 trees/ha) thus less contributed to tree biomass of RF.

As comparison with the previous studies, Cairns et al. [12] presented the AGB for 195 sampled trees with diameter of more than 10 cm in dry forest of Mexico's Yucatan Peninsula with value of 191.5 t/ha. Hikmat [13] conducted a study in three virgin jungle reserves in Mata Ayer, Bukit Bauk and Gunung Pulai each in 2 ha plot. A total of 2341, 2702 and 2070 trees with diameter greater than 5 cm were enumerated in Mata Ayer, Bukit Bauk and Gunung Pulai, respectively. From this study, he found that the AGB of each forest was 402.6, 551 and 320.57 t/ha, respectively. The BGB in Hikmat's [13] study was computed following method

Study area	AGB (t/ha)	BGB (t/ha)	TTB (t/ha)
Lowland dipterocarp forest (n = 419)	354.01	61.10	415.11
Riparian forest (n = 285)	276.13	47.21	323.33
Hill dipterocarp forest (n = 579)	493.77	85.27	579.05

Table 2. Total AGB, BGB and TTB in LDF, RF and HDF of PNP.

from [14] in which the root biomass was estimated to be one tenth of the AGB. In this case, the BGB values in Mata Ayer, Bukit Bauk and Gunung Pulai were 40.26, 55.12 and 32.06 t/ha, respectively. The summation of AGB and BGB in the three study areas resulted in total tree biomass of 415.11, 323.33 and 579.05 t/ha. A study at Bangi Permanent Forest Reserve by Lajuni and Latiff [4] revealed that the AGB in 1 ha study plot was 362.13 t/ha derived from 1018 trees of more than 5 cm diameter. Most of trees in their study were distributed in class 5.0–14.90 cm (65.71%) causing the biomass value to be quite low than other studies.

3.2. The analysis of mean of AGB, BGB and TTB between forests

Table 4 shows results from the analysis of AGB, BGB and TTB (t/ha) of lowland dipterocarp, riparian and HDF of PNP. Values presented in **Table 4** are mean values of AGB, BGB and TTB per plot. Result from ANOVA revealed that HDF recorded significantly higher mean of AGB, BGB and TTB than LDF and RF with the values of 499.97, 85.27 and 585.25 t/ha, respectively ($p \leq 0.05$). This is because HDF comprises the highest number of tree and basal area compared to LDF and RF. Family Dipterocarpaceae contributed 10% from the total individuals in HDF. Mostly, dipterocarp trees in this forest especially *Shorea curtisii* have tree height ranges from 30 to 45 m and form the emergent layer of the forest. Even though Dipterocarpaceae was not the highest in term of tree density in the forest, they contributed the most in basal area with value of 13.91 m²/ha as these trees have larger diameter and height as compared to the other family. This value was the highest compared to LDF and RF. Therefore, this contributed to the higher values of AGB, BGB and TTB in HDF. Generally, basal area indicates the cross section of tree stem at breast height. Therefore, this value can be assumed as proportional to the stem biomass of a tree which also indicates the productivity of a forest [4]. This was supported by a result from Proctor and Newberry [15] in their study in four types of lowland forest in Gunung Mulu. They reported that TTB values in each forest types were in accordance to the value of mean basal area.

As for LDF, family Euphorbiaceae recorded the highest density (90 trees/ha), more than the highest family in HDF. However, the basal areas contributed only 3.10 m²/ha, considerably lower than family Dipterocarpaceae from HDF. Euphorbiaceae is known as a pioneer species and commonly have small diameter at the range of 10 to 30 cm in this forest. RF on the other hand, recorded the lowest number of trees compared to the other two forests (285 trees). Family Meliaceae recorded 26% (75 trees) from the total of 285 trees in RF and mostly composed of small trees with diameter 10 to 30 cm and seldom can exceed more than 40 cm, thus causing the tree biomass in RF to be lower than LDF and HDF.

No.	Family	No. of individuals	No. of genera	No. of species
1	Anacardiaceae	25	6	8
2	Annonaceae	12	6	6
3	Apocynaceae	1	1	1
4	Araucariaceae	1	1	1
5	Bombacaceae	3	1	1
6	Burseraceae	43	3	9
7	Celastraceae	4	1	1
8	Chrysobalanaceae	1	1	1
9	Dipterocarpaceae	58	5	12
10	Ebenaceae	3	1	2
11	Elaeocarpaceae	34	1	2
12	Euphorbiaceae	72	7	11
13	Fagaceae	52	2	7
14	Flacourtiaceae	10	3	3
15	Guttiferae	29	5	9
16	Ixonanthaceae	3	1	1
17	Lauraceae	14	6	8
18	Leguminosae	6	4	5
19	Loganiaceae	2	1	1
20	Melastomataceae	9	2	4
21	Meliaceae	4	3	4
22	Moraceae	2	1	1
23	Myristicaceae	23	2	5
24	Myrsinaceae	16	2	2
25	Myrtaceae	64	2	19
26	Olacaceae	1	1	1
27	Polygalaceae	20	1	5
28	Rhizophoraceae	17	2	3
29	Rubiaceae	7	3	3
30	Rutaceae	2	1	1
31	Sapindaceae	4	2	4
32	Sapotaceae	14	2	2

No.	Family	No. of individuals	No. of genera	No. of species
33	Sterculiaceae	7	1	1
34	Theaceae	4	1	2
35	Trigoniaceae	1	1	1
36	Ulmaceae	1	1	1
37	Verbenaceae	10	1	1
	Total	579	85	149

Table 3. Number of families, individuals, genera, and species of HDF in PNP.

Kueh and Lim [16] estimated lower AGB value in comparison with this study. The study was conducted in the logged-over Air Hitam Forest Reserve where the pioneer species such as *Macaranga* spp., *Sapium* spp. and *Endospermum malaccense* were present in high density in the study area with an average DBH of 20.6–25.8 cm. The AGB for Air Hitam Forest Reserve was in the range of 83.69 to 232.39 t/ha. The lower value than the present study might suggest that the forest stand is in an early stage of succession and in the process of recovery after disturbances. Cummings et al. [17] revealed a result from their study in Brazilian Amazon Forest whereby mean of total AGB for open, dense and acetone forests were 313, 377 and 350 t/ha, respectively.

The total AGB of a study from Shanmughavel et al. [18] was 352.5 t/ha while root biomass was 69.9 t/ha. In contrast, Laurance et al. [9] estimated slightly higher AGB at lowland forest of Pasoh Forest Reserve which is 475 t/ha. A review by Malhi et al. [3] on carbon balance of different forest types i.e. Amazonian tropical rainforest, North American deciduous temperate forest and Canadian boreal forest revealed a variation in the AGB value between forests. The AGB value for tropical, temperate and boreal forests were 330–370 t/ha, 155–170 t/ha and 50–60 t/ha, respectively. The heterogeneity in the AGB values between forests was attributed to the climatic factors that affected the soil nutrients in the forest. In this case, due to the seasonality and temperature of boreal forest, nutrient availability is limited by slow decomposition in cold and water-freeze soil. Tropical forest on the other hand, even though has all year warm temperature but have poor soil nutrient and water availability as a result from high soil porosity and heavily leach soil. In general, higher tree biomass is expected on fertile soil simply because there are more resources available for tree growth. According to Laurance et al. [19] a high fraction of forest biomass could be associated with the most fertile soils as well as the tree size. Castilho et al. [20] claimed that texture was strongly associated with the variation in AGB value in their study area at Amazon Forest rather than soil nutrients. Soil texture influences the soil moisture, nutrient availability and nutrient cycling as well.

3.3. The AGB, BGB and TTB distribution according to diameter classes

Figure 2 shows the above ground, below ground and total tree biomass in LDF, RF and HDF of PNP, respectively. Based on **Figure 2**, the total tree biomass in the study areas were not

Biomass (t/ha)	Lowland dipterocarp forest (n = 20)	Riparian forest (n = 20)	Hill dipterocarp forest (n = 20)
Above ground (AGB) (t/ha)	356.79 ± 121.01 ^b	276.12 ± 35.59 ^b	499.97 ± 221.70 ^a
Below ground (BGB) (t/ha)	61.19 ± 586.60 ^b	47.16 ± 24.58 ^b	85.27 ± 160.61 ^a
Total tree (TTB) (t/ha)	417.98 ± 200.54 ^b	323.28 ± 35.89 ^b	585.25 ± 236.06 ^a

Notes: Values are expressed as mean ± standard deviation. Means with same letter indicate no significant different.

Table 4. Analysis of AGB, BGB and TTB between LDF, RF and HDF of PNP.

uniformly increased according to diameter class. HDF attained the highest total tree biomass for most diameter class except for diameter class 40.0–69.9 cm. RF achieved the lowest total tree biomass except for diameter class 50.0–69.9 cm whereas LDF only obtained the highest total tree biomass for diameter class 40.0–49.9 cm. With respect to **Figure 2**, lowland dipterocarp, riparian and HDF acquire highest biomass for diameter class of more than 70 cm with biomass value of 83.39, 70.58 and 202.72 t/ha, respectively. The biomass value for class >70 cm dominated 34, 38 and 35% of the total tree biomass in lowland dipterocarp, riparian and HDF, respectively. This indicates that tree diameter is a deciding factor for producing high biomass value in a forest.

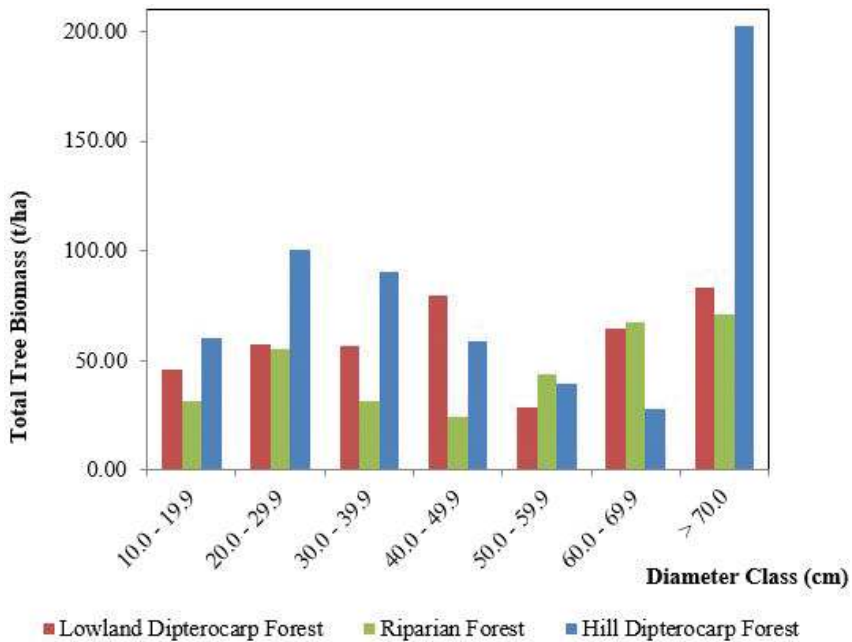


Figure 2. TTB by diameter classes in LDF, RF and HDF of PNP.

As comparison between diameter class, sample trees at class 10.0–19.9 cm recorded the highest number of trees which is 256, 157 and 344 trees in lowland dipterocarp, riparian and HDF, respectively. However, this diameter class recorded lower biomass even though the number of trees was high. Diameter class >70.0 cm recorded the highest biomass though the number of trees was lower which are 5, 6 and 14 sample trees in lowland dipterocarp, riparian and HDF, respectively. Higher biomass value in diameter class >70.0 cm in HDF was due to large trees from family Dipterocarpaceae that constitute 11 trees of the total 14 trees from this diameter class.

A comparison with other studies indicated a similar result whereby a larger diameter class achieved a higher biomass in the study area. For example, a study from Kusin [21] at Jengka Forest Reserve found that trees at diameter class >65 cm dominated 36.64% of the total tree biomass in the study area with the biomass value of 247.12 t/ha. This diameter class comprised of 36 large trees from family Dipterocarpaceae. A study by [13] also obtained a result where large diameter class (≥ 75 cm) contained higher proportion of AGB in three virgin jungle reserves (VJR) in Peninsular Malaysia. The AGB values for diameter class ≥ 75 cm in Mata Ayer VJR, Bukit Bauk VJR and Gunung Pulai VJR were 143.21, 184.32 and 24.74 t/ha, respectively. Most of AGB values from his study were higher than the present study because trees with diameter ≥ 75 cm in his study areas were higher of which more than 20 trees.

In contrast, Ewel et al. [22] reported a different result in hill forest of Ibam Forest Reserve, Pahang. The highest AGB value was recorded by diameter class 30.1–35.0 cm (30.51 t/ha), slightly lower than diameter class >70 cm (30.17 t/ha) in his study. The lower AGB value than the present study might be due to the lower number of trees in >70 cm diameter class. Similarly, Kueh and Lim [16] revealed that diameter class of 30.0–39.9 cm recorded the highest TTB in Air Hitam Forest Reserve. The TTB value of diameter class 30.0–39.9 cm was 232.73 t/ha whereas for diameter class >70 cm was 151.54 t/ha. The differences of TTB values between diameter classes in their study were due to the different in tree density. Furthermore, the TTB value in their study for five compartments was higher than LDF and RF from the present study because higher number of trees at diameter > 70 cm (15 trees) compared to this study (five trees). A study by [18] at tropical seasonal rainforest in Xishuangbanna, China found that TTB value for diameter class >70 cm was 115.01 t/ha. This value was higher than LDF and RF but lower than HDF in this study. This might be attributed to the different forest type and environmental factor that cause the biomass to be higher.

3.4. A comparison of similar tree families between forests

In factorial ANOVA experiment, forest and families are considered as two types of treatments. In each treatment, forest for example, consist of three levels; lowland dipterocarp, riparian and HDF while family has five levels; Anacardiaceae, Burseraceae, Dipterocarpaceae, Euphorbiaceae and Leguminosae. Therefore, in this study, the factorial design is 3×5 factorial.

Table 5 presents a result of comparison of five similar families based on AGB between lowland dipterocarp, riparian and HDF of PNP. From analysis of variance, there are no significant differences in the mean of AGB values among the forest types ($p > 0.05$) but

Forest (t/ha)	Anacardiaceae	Burseraceae	Dipterocarpaceae	Euphorbiaceae	Leguminosae
Lowland dipterocarp	1.90 ± 2.98 (n = 11)	1.04 ± 1.63 (n = 28)	2.572 ± 5.76 (n = 17)	0.56 ± 0.99 (n = 78)	0.73 ± 0.92 (n = 22)
Riparian	2.51 ± 2.16 (n = 3)	1.83 ± 1.49 (n = 2)	2.96 ± 3.31 (n = 6)	0.60 ± 0.90 (n = 47)	1.15 ± 2.26 (n = 30)
Hill dipterocarp	1.20 ± 2.55 (n = 25)	0.64 ± 0.98 (n = 43)	3.61 ± 4.81 (n = 58)	0.37 ± 0.69 (n = 72)	0.3823 ± 0.33 (n = 6)

Table 5. Means AGB of similar families in LDF, RF and HDF of PNP.

statistically significant in the mean of AGB among families ($p \leq 0.05$). This result indicated that there were no significant main effects of forest types on the values of AGB. There were, however, significant main effects of families on the AGB values, suggesting that families influence the AGB in any forest type in this study.

The non-significant interaction between forest types and tree families is shown graphically in **Figure 3** which indicated by parallel line trend of mean of AGB distribution among families in each forest ($P > 0.05$). This indicates that the five families in the forest types in this study respond similarly towards the forest types.

From **Table 5**, the significantly different value of AGB between families ($p \leq 0.05$) might due to the unbalanced sample trees in each family. Euphorbiaceae dominated the AGB among the five families in lowland dipterocarp, riparian and HDF. This is in agreement with the study by Ewel et al. [23] whereby Euphorbiaceae was the dominant species in alluvium, upland poor soil and intermediate quality soil forests in three young second growth forests in Sarawak.

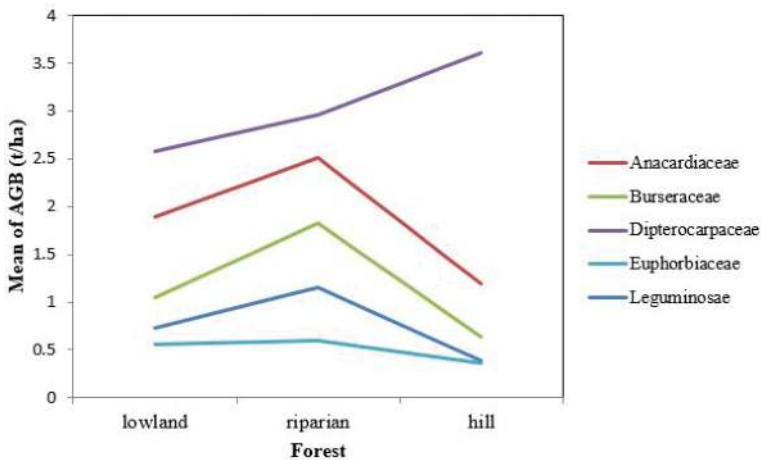


Figure 3. Action between forest types and similar tree families in LDF, RF and HDF of PNP.

Since Euphorbiaceae was a fast-growing pioneer species, therefore most of the biomass in their study was recorded by species in this family.

Zani and Suratman [24] attained a similar result in which there was no significant different detected in the mean of AGB between five transect lines (20 × 100 m) in LDF of Kuala Keniam at PNP. In another study, Rayachhetry et al. [25] observed a similar result in a study to quantify the dry weight of the above ground components of *Melaleuca quinquenervia* trees in three different localities (dry, seasonally flooded, and permanently flooded) at southern Florida. From their study, the effects of locality on the above ground components (total wood, trunk, branch, leaf, seed capsule, and seed) were found to be no significant.

3.5. A comparison of similar tree species between forests

The result of comparison of five similar species between forests namely *Canarium littorale* (Burseraceae), *Elateriospermum tapos* (Euphorbiaceae), *Ochanostachys amentacea* (Olacaceae), *Pimelodendron griffithianum* (Euphorbiaceae) and *Shorea leprosula* (Dipterocarpaceae) based on AGB in lowland dipterocarp, riparian and HDF of PNP is presented in **Figure 4**. **Table 6** shows mean of AGB for five similar species in lowland dipterocarp, riparian and HDF of PNP. From analysis of variance, there are statistically significant differences in the mean of AGB values both in the forest types and species ($p \leq 0.05$). This result indicated there were significant main effects of forests types and species on the AGB value suggesting that the AGB was influenced by the forest types and families.

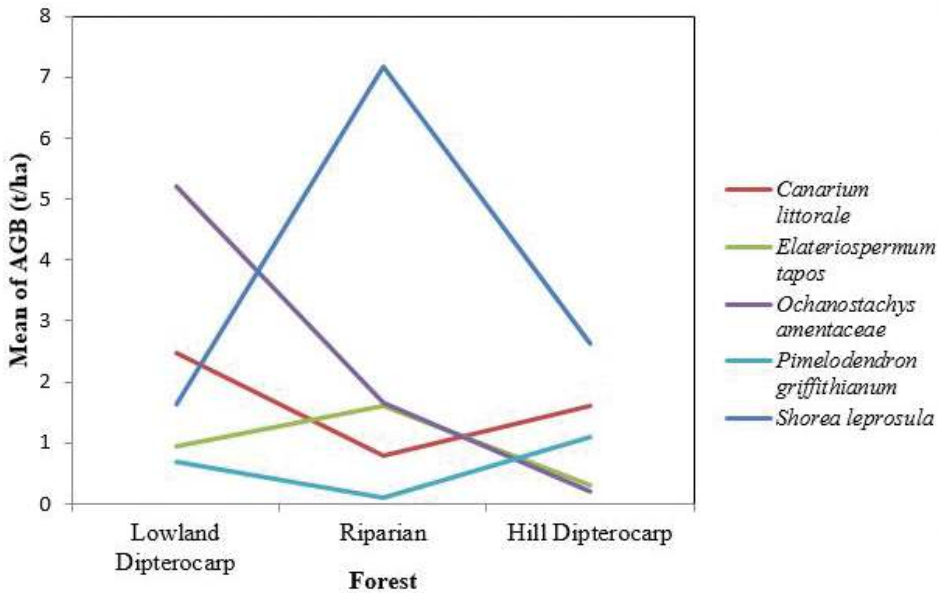


Figure 4. Interaction between forest types and similar tree species in LDF, RF and HDF of PNP.

Forest	<i>Canarium littorale</i>	<i>Elateriospermum tapos</i>	<i>Ochanostachys amentacea</i>	<i>Pimelodendron griffithianum</i>	<i>Shorea leprosula</i>
Lowland dipterocarp	2.4779 ± 3.05 (n = 5)	0.9387 ± 1.51 (n = 26)	1.6559 ± 1.84 (n = 7)	0.6214 ± 2.15 (n = 4)	0.6894 ± 0.85 (n = 11)
Riparian	0.7770 (n = 1)	1.6045 ± 1.08 (n = 3)	5.2016(n = 1)	0.0908 (n = 1)	7.1628 ± 0.2 (n = 2)
Hill dipterocarp	1.6048 ± 2.52 (n = 3)	0.2989 ± 0.42 (n = 25)	0.1998 (n = 1)	1.1029 ± 1.72 (n = 8)	2.6389 ± 1.87 (n = 6)

Table 6. Biomass and carbon stocks of LDF, RF and HDF of PNP.

Based on **Figure 4**, there was significant interaction between forest and species ($p \leq 0.05$). This indicates that there is a variation in the AGB value among species. That is to say, species behaves differently in different forest types.

Based on **Table 6**, *Shorea leprosula* from family Dipterocarpaceae appeared as the species with the higher AGB value among the five-similar species in lowland dipterocarp, riparian and HDF with the AGB of 0.69, 7.16 and 2.64 t/ha, respectively. Even though the presence of *Shorea leprosula* in each forest was not the highest, *Shorea leprosula* managed to attain higher AGB value due to the large DBH of sample trees. The presence of big trees with diameter of more than 80 cm contributed to the higher AGB values especially in the HDF. The mean AGB of *Shorea leprosula* in RF was higher than LDF and HDF because this forest consists of only two sample trees of *Shorea leprosula* therefore, mean AGB value per tree was higher. In fact, both sample trees of *Shorea leprosula* in this forest have large diameter of 69.0 and 69.1 cm that caused of higher AGB values for *Shorea leprosula* in RF. The higher AGB of *Shorea leprosula* in the RF is anticipated because the species is most common in lowland forest. That is to say, *Shorea leprosula* found in RF might be located at the continuum between lowland and RF. That is why only two trees of *Shorea leprosula* with large diameter were found in the RF plots.

Among the five species, *Elateriospermum tapos* recorded the highest number of trees in LDF and HDF but greatly lower in RF. Based on this result, it might suggest that *Elateriospermum tapos* grows abundantly in LDF and HDF rather than RF. However, mean AGB in RF was significantly higher than HDF ($p \leq 0.05$) but not significant to LDF. This is due to similar reason as stated in the case of *Shorea leprosula*.

The AGB values and tree density varies among five similar species between lowland dipterocarp, riparian and HDF might be due to the environmental factors in the study areas (e.g., soil nutrient, topography, water, light). Each species adapts and respond differently to the limiting factors in the area Shono et al. [26]. For example, *Elateriospermum tapos* favors forest soil that is dry and less preferable on soil that often wet. This might be the reason the tree density of *Elateriospermum tapos* in RF was lower than the other two forests.

These five-similar species that can be found in all forests in this study were due to the adaptability of these species to the environmental factors in the areas. For example, *Shorea leprosula* is a dipterocarp species that can easily adapt to full sunlight and fast growing once the seeds have been germinated whereas *Canarium littorale* was capable to survive in full sunlight and

water stress [26]. According to Pereira Da Silva et al. [27], many factors influence the tree growth in the forest. Usually, tropical tree species exhibits different behavior under different environmental conditions regardless of species or families. Macdicken and Brewbaker [28] agreed with this finding in which they found a significant different between site location and species interactions which indicate different environmental requirements for each species. In support to these findings, Brackand and Wood [29] provided a fact that tree growth was influenced by the environmental factors in the forest. Factors such as climatic, soil, topographic and competition combine to create a site. Therefore, the biomass value in a forest is indirectly affected by these factors because tree biomass value depends on the tree diameter.

3.6. Carbon stocks

Global climate change is the current major threat to the earth. Due to the rapid deforestation and land clearing and conversion that have been actively taking place since 1850 [3] the emission of CO₂ keeps increasing. Referring to the report from National Research Council [30], these activities contribute 17% from the total CO₂ released to the atmosphere. However, it was reported that forests can remove twice the amount that is lost by deforestation. It was estimated that the total carbon pool in the forest ecosystems approximately 1150 Gt, of which 14% in temperate forests, 37% in tropical forests and 49% is in the boreal forests [3].

Table 7 exhibits the carbon storage of lowland dipterocarp, riparian and HDF in PNP. The estimation of carbon storage within each forest was not greatly varies between different species or tree components. The carbon storage in HDF at 289.52 t/ha was higher than LDF and RF. LDF was 207.88 t/ha whereas the lowest was RF at 161.67 t/ha. Meanwhile, above ground carbon in HDF was 246.89 t/ha, in LDF was 177.29 t/ha while RF was 138.07 t/ha, respectively (see **Table 7**).

The carbon storage in HDF was the highest due to the higher biomass in this forest. This is because the tree density in HDF was higher compared to the other two forests types ($n = 579$).

As comparison to other study, Hikmat [13] found nearly the same result in three virgin jungle reserves (VJR) in Peninsular Malaysia. Carbon storage in Mata Ayer VJR, Bukit Bauk VJR and Gunung Pulai VJR recorded 221.43, 303.16 and 176.33 t/ha, respectively. In another study, [16] estimated carbon storage in Air Hitam Forest Reserve was 89.57 t/ha. This value was considerably lower than the present study because Air Hitam Forest Reserve was recovering from the past disturbances. Therefore, most of the sample trees were composed of small diameter trees with average diameter of 24.0 cm.

Item	Lowland dipterocarp Carbon (t/ha)	Riparian Carbon (t/ha)	Hill dipterocarp Carbon (t/ha)
Above	177.29	138.07	246.88
Below	30.59	23.61	42.64
Total	207.88	161.67	289.52

Table 7. Biomass and carbon stocks of LDF, RF and HDF of PNP.

The differences of estimated carbon storage among tropical forests might be due to some limiting factors such as species composition, soil fertility, disturbance history, successional stage and climate Kang et al. [31]. The AGB in the secondary forest would not be the same as the primary forest. Primary forest contains old-growth and large trees since this forest have never been disturbed whereas secondary forest that had been logged or naturally disturbed contains trees with smaller diameter. Therefore, the tree biomass in secondary forest is less than the primary forest. This was supported by Kang et al. [31] who conducted a study to quantify carbon stocks in primary and secondary forests of Bukit Timah Nature Reserve in Singapore. The result from their study revealed that primary forest obtained higher carbon stock than secondary forest with value of 337 and 274 t/ha, respectively. The values in their study were lower than LDF and HDF but higher than RF from this study.

4. Conclusions

In this chapter, the AGB, BGB and TTB of lowland dipterocarp, riparian and HDF have been estimated. Analysis of AGB, BGB and TTB between forests showed that means of AGB, BGB and TTB values in HDF were significantly higher than LDF and riparian ($p \leq 0.05$). The distribution of AGB, BGB and TTB according to diameter class revealed higher AGB, BGB and TTB values in >70 cm class for all forests. HDF was highest in most diameter class except for 40.0–69.9 cm. LDF obtained highest biomass in 40.0–49.9 cm whereas RF for 50.0–69.9 cm. There was no significant interaction between lowland dipterocarp, riparian and HDF and five similar families (i.e. Anacardiaceae, Burseraceae, Dipterocarpaceae, Euphorbiaceae and Leguminosae) with ($p > 0.05$). However, the interaction between lowland dipterocarp, riparian and HDF and five similar species (i.e. *Canarium littorale* (Burseraceae), *Elateriospermum tapos* (Euphorbiaceae), *Ochanostachys amentacea* (Olacaceae), *Pimelodendron griffithianum* (Euphorbiaceae) and *Shorea leprosula* (Dipterocarpaceae) was significant at ($p \leq 0.05$). The estimation of carbon storage in the study areas demonstrated HDF attained the highest carbon value in above ground, below ground and total tree with value of 246.88, 42.64 and 289.52 t/ha, respectively.

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