***Original Research Article***

# Evaluation of carbon stock across different forest physiognomy in a tropical rainforest ecosystem at Obafemi Awolowo University Ile-Ife, Nigeria


## Abstract

This study investigated carbon stock in above-ground biomass across different physiognomies in Obafemi Awolowo University tropical rainforest ecosystem. This was with a view of increasing the understanding of carbon cycle in tropical rainforest in Nigeria.

Two 20 m x 20 m plots were marked out in the secondary forest, *Tectona grandis* and riparian vegetations. Total enumeration was carried out for the living tree, the Diameter at Breast Height (DBH) of trees ≥10 cm were measured at 1.3 m above the ground and height was also determined using a ranging pole and Haga altimeter.

Aboveground carbon stocks in standing trees ranged from 218.24 to 318.92 C t ha$^{-1}$ with the highest value in *Tectona grandis* plantation. Trees with DBH size class 11-20 cm contributed more to Carbon stock in secondary forest and *Tectona grandis* plantation, while size class ≥60 cm contributed more in the riparian vegetation. Tectona grandis plantation proved to be better in mitigating carbon in our environment and this result will enhance better estimates of local and regional carbon stock which is crucial to addressing the problems of climate change.


Keywords: Allometric, Atmosphere, Climate, Human, Plantation, Sequestration

## Introduction

Tropical rainforest and plantation ecosystems sequester carbon in terrestrial ecosystems and therefore serve as an important natural brake on climate change (Gibbs et al. 2007). These ecosystems are unique environmental resources that provide numerous global benefits and play crucial role with respect to global carbon pools and fluxes as they store about half of the world's biomass (Brown and Lugo, 1992). It has been previously reported that they represent important pools of biological, ecological and economic resources (Sheikh et al. 2012), which greatly influence the lives of other organisms as well as human societies (Komiyama et al. 2008). The tropical forest and plantation ecosystems are long-lived dynamic systems that are involved in climate regulation (Egbe and Tabot, 2011); as well as prominent sites for the study of climate change in terms of total net carbon emission and global storage capacity (Terakunpisut et al. 2007).

The main carbon pools in tropical forest and plantation ecosystems are the living biomass of trees, understorey vegetations, mass of litters, woody debris and soil organic matter (Ludang and Jaya, 2007). The carbon stored in the aboveground living biomass of trees is typically the largest and the most directly impacted upon by human disturbances (Gibbs et al. 2007). Stable tropical forest and plantation ecosystems with less disturbances are important as carbon sinks and are currently sequestering carbon dioxide ($CO_2$) from the atmosphere which are critical to future climate stabilization (Stephens et al. 2007) and this can be strengthened by increasing the density of vegetations cover in currently vegetated areas or increasing the areas covered by vegetations (Karjalainen et al. 2002).

Forest and plantation ecosystems management practices can play a significant role in climate change mitigation by sequestering carbon through photosynthesis (Strassburg et al. 2009). Knowledge of the aboveground living biomass density is useful in determining the amount of carbon stored through photosynthesis in the forest stands. Forest also releases carbon to the atmosphere through plant respiration and organic material decomposition, although the loss of carbon into the atmosphere is usually less than the gain (Fonseca et al. 2011).

The issue of aboveground biomass and carbon stock has received tremendous attention across the world; however, little information is available in Nigeria. This study is focusing on carbon sequestration specifically in terms of aboveground biomass and carbon stock. The estimates of carbon stock are important for scientific and management issues such as forest productivity and nutrient cycling. In addition, aboveground biomass is a key variable in the annual and long term changes in the global terrestrial carbon cycle and other earth system interactions. Hence, a study on evaluation of carbon stock in the aboveground biomass of tropical rainforest and plantation ecosystem was conducted in Obafemi Awolowo University estate, Ile-Ife, with the aim of providing information on carbon stock across different forest vegetations that is critical to better understanding of the issues of global climate change. The specific objective of this study was to estimate carbon stock in aboveground biomass across different vegetations (secondary forest, *Tectona grandis* plantation and riparian vegetation) based on allometric models.

## Materials And Methods

*Study area*

The study was conducted at the Obafemi Awolowo University, Ile-Ife, Osun state, Nigeria. Ile-Ife is located on Latitude N 07° 31' and Longitude E 04° 30' and the elevation of Ife ranges from 215 m to 457 m above sea level (Hall, 1969). The study sites lies between Latitude N 07° 032' and Longitude E 04° 031' while the elevation ranges from 243 m to 274 m above the sea level. The climate of the area is a tropical type with two prominent seasons, the rainy and the dry season. The dry season is short, usually lasting 4 months from November to March and the longer rainy season prevails during the remaining months. The annual rainfall average 1400 mm $yr^{-1}$ (Oke and Isichei, 1997) and it showed two peaks, one in July and the other in September, the mean annual temperature range from 27° C to 34° C (Oke and Isichei, 1997).

The soil of the area is derived from material of old basement complex which is made up of granitic metamorphosed sedimentary rock (Hall, 1969). Five major soil types have been recognized in this area: inselberg soils, Hill creep soils, and sedimentary non-skeletal soils, drift soils, alluvial deposits (Hall, 1969). The soil has been classified as lixisols and utisols (FAO/UNESCO, 1974). The original vegetation of Ile-Ife is lowland rainforest as climax vegetation (Keay, 1959). White (1983) described the vegetation as the Guinea-Congolian drier forest type. Most of the original lowland rain forests have been massively destroyed leaving remnant of secondary forest scattered around. Tree crops plantations like *Theobroma cacao, Cola nitida*, *Tectona grandis*, and *Elaeis guineensis* are now common around the area.

*Sampling procedure*

Two samples plots, each of 20 × 20 m were marked out within the secondary forest, *Tectona grandis* plantation and riparian vegetation in the Obafemi Awolwo University community. The secondary forest is 29 years old having been last disturbed by ground fire that engulfed the forest in 1983. It is located within the Biological Garden and lies within latitude 07° 32' 23.11"N and longitude 04° 31' 23.09"E. Some of the dominant species present in the secondary forest in the area includes: *Celtis zenkeri*, *Funtumia elastica*, *Newbouldia laevis* and *Trichilia prieuriana*. The *Tectona grandis* plantation is 38 years old going by the time of its establishment in the year 1967, it was last harvested in 1975. It is a monoculture of *Tectona grandis* trees lying within latitude 07° 32' 26.08"N and longitude 04° 31' 25.19" and the Riparian vegetation whose age cannot be less than 40 years old, though the actual age cannot be ascertained due to unavailable statistics, is located on latitude 07° 32' 30.06"N and longitude 04° 31' 31.11"E. Some of the dominant species encountered in the riparian vegetation includes: *Celtis mildbredii, Funtumia elastica, Pycnanthus angolensis* and *Sterculia tragacantha.*

*Estimation of aboveground biomass and carbon stock*

Aboveground biomass and carbon stock were estimated in each plot across the different physiognomy. The girth size of all the trees (GBH-1.3 m) greater than or equal to 10 cm in height were enumerated, measured with a tape rule and identified to species level and converted to DBH using the equation

$$DBH = GBH/\pi \qquad 1$$

Where: DBH = Diameter at Breast Height, GBH = Girth at Breast Height. $\pi = 22/7$

All identified trees were marked to avoid double enumeration. Tree heights in the secondary forest were measured using a 4m range pole and estimated by the ruler method as stated by Egbe and Tabot (2011). This method was preferred to the altimeter-based measurement because of the closed canopy in the secondary forest. Tree heights in the *Tectona grandis* plantation and the Riparian vegetation were measured using Haga altimeter. The heights of trees and the GBH of all the trees were measured and grouped into different size classes in all the sample plots. Aboveground biomass was calculated using site-specific generated allometric equations developed from measurements such as DBH and tree total height as predictors for the various studied sites.

The site-specific generated equations were developed by plotting DBH as the independent variable against total height, the dependent variable using scattered plot line. The biomass regression equations used for the estimation of the tree species biomass in the secondary forest, *Tectona grandis* plantation and riparian vegetation were developed from the data obtained from these vegetations using the DBH and the height of the tree species as predictors. A total number of 65 trees in the secondary forest with a DBH ranging from 3 to 37 cm, 87 trees with a DBH ranging from 3 to 34 cm in the plantation and riparian vegetation having 49 trees with a DBH between 3 and 79 cm were used for the development of individual allometric equations used in the estimation of aboveground biomass in each of these vegetations. The carbon stock was estimated by multiplying the aboveground biomass by a factor of 0.5 (carbon fraction) (IPCC 2003).

*Data analysis*

The data were first tested for normality and homogeneity in order to satisfy assumptions of Analysis of variance (ANOVA). One way analysis of variance was employed to test for significant difference between carbon stock in aboveground biomass, soil across the different vegetations. Descriptive statistics was also employed in presenting some of the results. Means of the main effects were compared using Least Significant Difference (LSD) test, using SPSS 17.0 software package.

## Results

*Aboveground biomass across the different physiognomies*

Relationships between biomass of trees in kg, DBH in cm and height in m of the tree species employed in the estimation of the biomass of the vegetations studied are shown in figure 1 to 3. The $R^2$-values of the allometric equations explain the relationship between the outcome (biomass) and the values of the DBH and height used for predicting the biomass. It is a measure of how well the allometric equation appropriates the real data points. The $R^2$-value indicates a positive, nonlinear relationship between the biomass; DBH and height in all the vegetations (Figure 1-3).

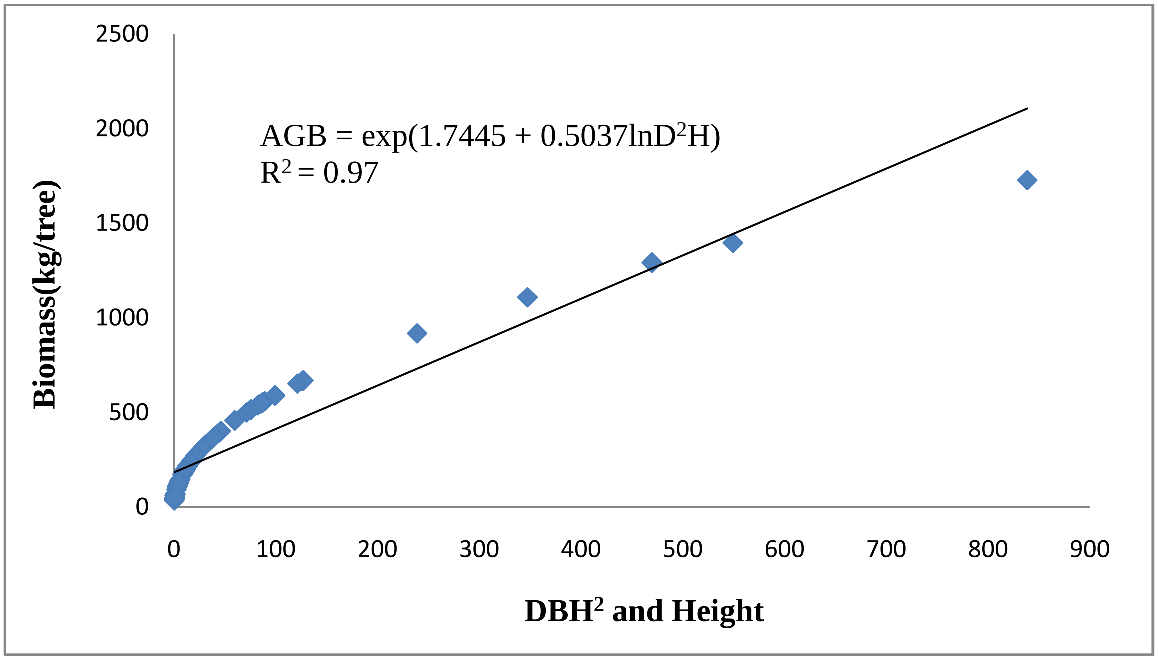


Figure 1: Allometric relationship in the secondary forest; Allometric relationship between aboveground biomass (kg), diameter (cm) and height (m) for tree species in the secondary forest.

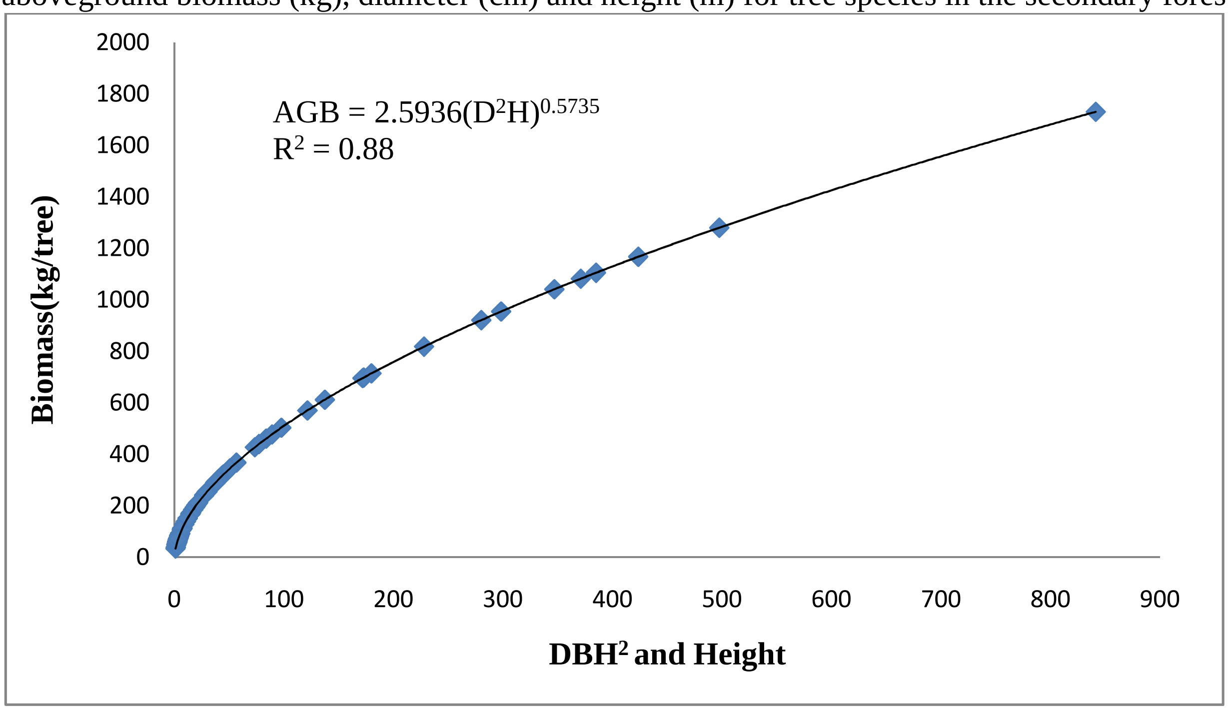

Figure 2: Allometric relationship in the *Tectona grandis* plantation; Allometric relationship between aboveground biomass (kg), diameter (cm) and height (m) for tree species in the *Tectona grandis* plantation.

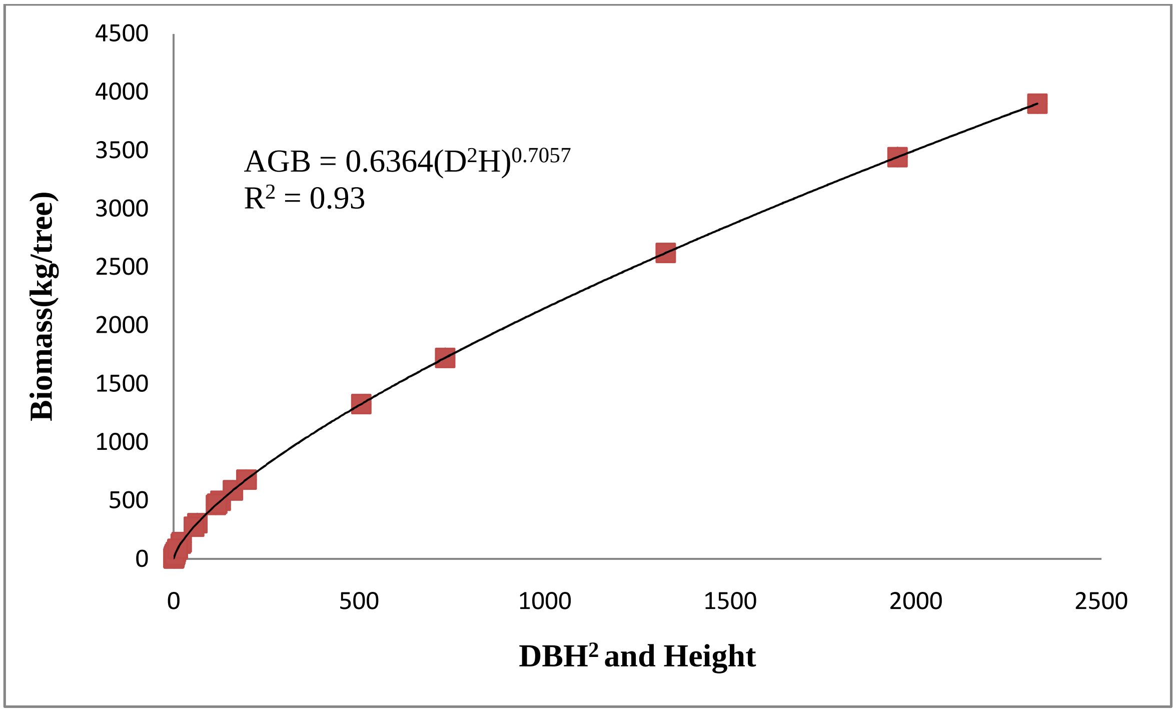


Figure 3: Allometric relationship in the riparian vegetation; Allometric relationship between aboveground biomass (kg), diameter (cm) and height (m) for tree species in the riparian vegetation.

The high $R^2$-values (97% in the secondary forest, 88% in the plantation and 93% in the riparian vegetation) indicate that DBH and tree height are good predictors of forest aboveground biomass and that the allometric equations are reliable for the estimation of forest biomass.

Aboveground biomass accumulation was found to be higher in the *Tectona grandis* plantation followed by secondary forest and the least value was recorded in the riparian vegetation (Table 1). The mean aboveground biomass ranged from 7.49 ± 0.90 in the plantation; 8.27 ± 1.07 in the secondary forest to 8.90 ± 3.02 in the riparian vegetation (Table 1). Across, the three studied sites, there was no significant ($F_{2,198\ (0.05)}$ = 0.202; P = 0.817) difference in the mean aboveground biomass (Table 1).

Table 1: Aboveground biomass (t $ha^{-1}$) across the various study sites

| Name | Maximum | Minimum | Mean ± std error | Total |
|---|---|---|---|---|
| Secondary forest | 43.21 | 0.87 | $8.27 \pm 1.07^{2.46}$ | 537.73 |
| *Tectona grandis* Plantation | 43.28 | 0.83 | $7.49 \pm 0.90^{2.46}$ | 637.83 |
| Riparian vegetation | 97.52 | 0.16 | $8.90 \pm 3.02^{2.46}$ | 436.47 |

*Value in superscript is the LSD value used in comparing the mean difference and mean difference is not significantly different across the column at p=.05.

The distribution of the aboveground biomass across the different tree size classes across the study sites are presented in Table 2. The 11-20 cm size class contributed more to tree aboveground biomass in secondary forest and *Tectona grandis* plantation, while in the riparian vegetation; the above 60 cm size class contributed the most (Table 2). The 31-40 cm size class contributed the least to the aboveground biomass in the secondary forest; the 41-50 cm size class is contributing the least in the *Tectona grandis* plantation and the size class 11-20 cm in the riparian vegetation respectively (Table 2).

Table 2: Size class distribution of tree aboveground biomass (t $ha^{-1}$) recorded across the study sites

| Size class (cm) | Secondary forest | *Tectona grandis* plantation | Riparian vegetation |
|---|---|---|---|
| 0-10 | 100.32 (18.7) | 122.15 (19.2) | 17.51 (4.0) |
| 11-20 | 276.33 (51.4) | 194.88 (30.6) | 11.11 (2.5) |
| 21-30 | 82.96 (15.4) | 175.68 (27.5) | 50.62 (11.6) |
| 31-40 | 78.12 (14.5) | 115.92 (18.2) | 31.75 (7.3) |
| 41-50 | Nil | 29.20 (4.5) | Nil |
| 51-60 | Nil | Nil | 43.10(9.9) |
| Above 60 | Nil | Nil | 282.38(64.7) |

*The percentage contributions of each of the size classes to the tree aboveground biomass are in parenthesis.

The distribution of tree basal area across the study plots are presented in table 3. In the secondary forest, the trees within the 0-10 cm size class had the least basal area and the most was recorded in the 11-20 cm size class (Table 3). Whereas in the *Tectona grandis* plantation, trees within the 41-50 cm size class had the lowest basal area while the highest was recorded in the 11-20 cm size class. In the riparian vegetation, the above 60 cm size class had the highest basal area and the 11-20 cm size class had the lowest basal area (Table 3).

Table 3: Size class distribution of tree basal area ($m^2 ha^{-1}$) recorded across the study sites

| Size class (cm) | Secondary forest | *Tectona grandis* plantation | Riparian vegetation |
|---|---|---|---|
| 0-10 | 4.18 | 6.71 | 3.21 |
| 11-20 | 18.16 | 18.38 | 2.25 |
| 21-30 | 7.33 | 15.80 | 10.34 |
| 31-40 | 7.73 | 13.71 | 6.68 |
| 41-50 | Nil | 5.44 | Nil |
| 51-60 | Nil | Nil | 9.32 |
| Above 60 | Nil | Nil | 58.37 |

*Aboveground carbon stock across the different physiognomies*

The estimated amount of carbon accumulated in the trees in the various study sites are presented in Table 4. The estimated carbon stock in the Aboveground carbon stock did not vary significantly ($P < 0.05$) across the various vegetations studied (Table 4).

Table 4. Aboveground carbon stock (t C $ha^{-1}$) across the various vegetations studied

| Name | Maximum | Minimum | Mean ± std error | Total |
|---|---|---|---|---|
| Secondary forest | 21.61 | 0.44 | $4.14 \pm 0.54^{1.23}$ | 268.86 |
| *Tectona grandis* Plantation | 16.01 | 0.42 | $3.66 \pm 0.42^{1.23}$ | 318.92 |
| Riparian vegetation | 48.76 | 0.08 | $4.45 \pm 1.51^{1.23}$ | 218.24 |

*Value in superscript is the LSD value used in comparing the mean difference and mean difference is not significantly different across the column at p=.05.

## Discussion

*Aboveground biomass across the different physiognomies*

Aboveground biomass was estimated at the different forest types in order to indicate the proportion of biomass. Aboveground biomass was highest in the *Tectona grandis* plantation, followed by the secondary forest and the least was recorded in the riparian vegetation. The variation in aboveground biomass from site to site in our study area might be due to different tree growth stages and tree density. The basal area, especially of the biomass of bigger trees has been reported to be the largest component of above ground forest's biomass (Ogawa et al. 1965). The higher aboveground biomass recorded in *Tectona grandis* plantation compared with the estimate in the secondary forest (about 15.6 %) and higher value (about 31.6 %) in secondary forest compared to the riparian vegetation, can be attributed to higher tree density in the *Tectona grandis* plantation (2175 trees $ha^{-1}$) followed by (1625 trees $ha^{-1}$) in the secondary forest and least in riparian vegetation (1225 trees $ha^{-1}$). This observation is consistent with the findings of Egbe and Tabot (2011) in their study in Southwestern Camerooun, where it was reported that pure stands of high density trees are bound to have higher carbon stock resulting from higher aboveground biomass than those in mixed stands of tropical forest. The higher tree density recorded in the *Tectona grandis* plantation might be as a result of high number of tree stands planted or found in the area. The reduction in tree densities in the secondary forest and the riparian vegetation might be as a result of disturbance (fire) that ravaged the secondary forest some 29 years ago and the human disturbances observed in the riparian vegetation respectively.

It should be noted that few studies are available in Nigeria, so our study was compared with the rest of the world. The values of aboveground biomass recorded in our study sites, secondary forest (537.73 t $ha^{-1}$) and in riparian vegetation (436.47 t $ha^{-1}$) are within the range reported by Mohanraj et al. (2011) (597.13 t $ha^{-1}$) in their study of aboveground biomass in Kolli forests in India; Egbe et al. (2012) reported aboveground biomass value that ranged from 496 to 528 t $ha^{-1}$ in Cameroun. A value between 50 to 600 t $ha^{-1}$ was also reported for tropical forests in Asia (Brown et al. 1993, Iverson et al. 1993, Lasco 2002). The total aboveground biomass in tree layers reported by Tang et al. (2010) in Southwestern, China also ranged from 326 to 516 t $ha^{-1}$. However, the results from this study are higher than the result of Odiwe et al. (2012) in Nigeria where aboveground biomass value of 32.38 t $ha^{-1}$ was reported. Sishir and Stephan (2012) reported aboveground biomass for a naturally forested landscape to be 302 t $ha^{-1}$ in Gabon. Brown et al. (1989) estimated aboveground biomass for undisturbed tropical forests in Asia to be 215 Mg $ha^{-1}$; a total aboveground biomass of 98.64 t $ha^{-1}$ and 49.63 t $ha^{-1}$ have been reported in trees in a primary mixed deciduous and secondary mixed deciduous forest in Thailand respectively (Kaewkrom et al. 2011). Aboveground biomass in Nagur rain forest was recorded to be 185.25 t $ha^{-1}$ and in Sonda rain forest to be 263.34 t $ha^{-1}$ (Bhat and Ravindranath 2010) in India.

The aboveground biomass estimated for *Tectona grandis* plantation (637.83 t $ha^{-1}$) in our study was higher compared to other studies from plantations across the world. For instance, Duguma et al. (2001) reported aboveground biomass of 304 t $ha^{-1}$ for cocoa plantation in South Cameroun, Egbe and Tabot 2011, reported aboveground biomass of 600.72 Mg $ha^{-1}$ for a *Ricinodendron heudelotii* and of 494.84 Mg $ha^{-1}$ for *Cola lepidota* plantations in Southwestern Cameroun. Redondo (2007) reported 24.8 to 158.2 t $ha^{-1}$ of aboveground biomass in Costa-Rica. Odiwe *et al*. (2012) also reported aboveground biomass in the *Tectona grandis* plantation to be 38.33 t $ha^{-1}$ in Nigeria. Chittachumnonk et al. (2002) who studied carbon sequestration of *Tectona grandis* plantations (78.15 t $ha^{-1}$) in Thailand. The general differences in aboveground biomass has been reported to be related to factors such as climatic conditions, solar radiation, disturbances, age of forest, species composition and soil characteristics which varies across different regions (Liao et al. 2010). It has also been pointed out that biomass accumulation varies greatly among forest types and ages of forest and that carbon sequestration potential relies on tree size class (Terakunpisut et al. 2007).

The highest stem density in size class 0-10 cm and the lowest contribution to biomass accumulation in the secondary forest in the study sites might have resulted to the lowest stem volume and basal area. The implication of this observation is that this vegetation is recovering from disturbance and its developmental stages might be slow. The size class 11-20 cm, 31-40 cm and 41-50 cm in the riparian vegetation, secondary forest and *Tectona grandis* plantation accumulated the least tree biomass respectively. Their low contributions to aboveground biomass accumulation in this study sites was related to low basal area and low stem density which had resulted from the previous fire disturbances in the secondary forest and human disturbance noticed in the riparian vegetation. The low aboveground biomass in the 41-50 cm size class in the *Tectona grandis* plantation might be as a result of the harvest of trees that was done some years ago (1975).

Comparison of the size class distribution and aboveground biomass showed some evidence of biomass reduction in larger size classes from 31-40 cm to above 60 cm especially in the secondary forest and this might be attributed to the ground fire that ravaged this place sometimes ago (Muoghalu and Odiwe 2001). Ground fire is a threat to tropical forests damaging forest stands especially at the young stage of development preventing these forest stands from developing into larger stands which can accumulate more of the aboveground biomass.

The contribution of large trees (DBH ≥ 60 cm) to aboveground biomass in the riparian vegetation recorded in this study was consistent with the findings of Terakunpisut et al. (2007) in Thailand where most aboveground biomass accumulation was found in trees of higher size classes' ≥ 80 –100 and ≥ 100 cm. This indicates that trees of higher size classes play an important role in the biomass accumulation of tropical forest.

*Aboveground carbon stock across different physiognomies*

Results on carbon sequestration in the different physiognomies showed that the highest amount of carbon was stored in the biomass of trees in the *Tectona grandis* plantation because of the higher tree density encountered in the *Tectona grandis* plantation compared to the secondary forest and riparian vegetation. Hence, calculated carbon stock was higher in the *Tectona grandis* plantation. The aboveground carbon stock of 268.86 Mg C ha$^{-1}$ in secondary forest and 218.24

Mg C ha$^{-1}$ in riparian vegetation recorded in this study are comparable to the value of 7.80-298.56 t C ha$^{-1}$ recorded in a Kolli forest in India (Mohanraj et al. 2011); 25-300 t C ha$^{-1}$ for tropical forests in Asia (Brown et al. 1993, Iverson et al. 1993, Lasco 2002). In other studies, total carbon stock was reported to be 168-258 t C ha$^{-1}$ in a tropical seasonal forest in Southwestern China (Tang et al. 2010); 185.25-263.34 t C ha$^{-1}$ in India in a rain forest (Bhat and Ravindranath 2010).

However, tree aboveground carbon stock in the secondary forest and the riparian vegetation in our study was higher than the results of Hertel et al. (2009), where 120 t C ha$^{-1}$ was reported for aboveground carbon storage in a non-Dipterocarp forest in Indonesia. A carbon pool of 150 to 200 Mg C ha$^{-1}$ has been reported in old-growth forests in South America (Brown and Gaston 1995, Dixon et al. 1994, Houghton et al. 2001, Malhi et al. 2006, Saatchi et al. 2007). Brown and Lugo (1982), also reported total carbon sequestration for tropical forest in three countries; Malaysia, Cameroon and Sri Lanka, to be 76.50 t C ha$^{-1}$ in disturbed tropical rain forest (Sri Lanka) and 223 t C ha$^{-1}$ in relatively undisturbed mature tropical rain forest (Cameroun and Malaysia). The highest value was recorded in Malaysia (112.5-223 t C ha$^{-1}$), followed by Cameroun (119-170.5 t C ha$^{-1}$), and the least in Sri Lanka (76.5-110.5 t C ha$^{-1}$). Likewise, aboveground carbon stock in this study in the secondary forest and riparian vegetation were also found to be higher than the result (188 t C ha$^{-1}$) reported by FAO (2010) in Cote d'Ivoire in Tai National park and the results of Sishir and Stephan (2012), where aboveground carbon stock recorded in a naturally forested landscape was 146 t C ha$^{-1}$ in Gabon. The variation in aboveground carbon stocks generally have been pointed out to depend on a number of factors such as species composition, climate, nutrient conditions, topography, forest age, disturbance and land history management (Vieira et al. 2004, de Castilho et al. 2006, Hertel et al. 2009), and allometric model equation used. All of these factors will influence the development of large-scale policy prescriptions aimed at C-sequestration and that carbon sequestration depended not only on rates of productivity, but also on the size of the trees (Huston and Marland 2003).

The higher carbon sequestration value recorded in the *Tectona grandis* plantation in this study can be attributed to higher tree density in the plantation. The value of aboveground carbon stock (318.92 Mg C $ha^{-1}$) in the plantation was found to be higher than the carbon stock reported by other workers in other places. For instance, Duguma et al. (2001) reported aboveground biomass carbon stock of 152 Mg C $ha^{-1}$ for a cocoa agroforestry in South Cameroun; Egbe et al. (2012) reported carbon stock in oil palm to range from 66 to 88 Mg C $ha^{-1}$ and in rubber to range from 248 to 264 Mg C $ha^{-1}$ in Cameroun. van Vuuren *et al*. (1978) has also reported carbon storage for a 25 years old *Pinus patula* plantation and *Eucalyptus grandis* plantation to be 62.6 and 269.9 Mg C $ha^{-1}$ respectively in South Africa. Chavan and Rasal (2012) reported total standing carbon stock for *Mangifera indica* to be 82.83 t C $ha^{-1}$ in India. Odiwe et al. (2012) reported aboveground carbon stock in *Tectona grandis* plantation to be 38.33 t C $ha^{-1}$ in Nigeria. Chittachumnonk et al. (2002) in their study on carbon sequestration of *Tectona grandis* plantations in Thailand reported aboveground carbon stocks of 78.15 t C $ha^{-1}$. The difference in tree carbon stock estimates in all these study sites is largely as a result of the form of the regression curve for trees in plantation and the high levels of variability in aboveground carbon estimates. This is as a function of different assumed allometric relationships which affects the size of individual tree canopies, tree-management practices, and crown architecture and this differ considerably by forest type (Nair et al. 2009), species-specific allometry is needed to improve the precision of carbon estimates.

## Conclusion

Carbon sequestration varies among different physiognomy and the capacity of a forest to sequester carbon depends on the tree stand density and tree size class. The *Tectona grandis* plantation has the highest potential of sequestering carbon, followed by the secondary forest and the least in the riparian vegetation. The lower size class 11-20 cm had the highest contribution both in the secondary forest and *Tectona grandis* plantation, unlike the riparian vegetation where the above 60 cm size class had the highest contribution. This indicated that the secondary forest and *Tectona grandis* plantation are younger or be relatively disturbed and are just recovering from the disturbance.

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