# COMPARISON OF CARBON STOCK ESTIMATION METHODS AND CARBON STORAGE IN A NIGERIAN STRICT NATURE RESERVE AND ENRICHMENT PLANTING FOREST

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## ABSTRACT

Forest ecosystem is a major biological scrubber of atmospheric carbon dioxide. Deforestation and forest degradation could lead to the depletion of the ozone layer by greenhouse gasses. Unfortunately, research efforts to estimate carbon stock potential in natural forest and forest regenerated through enrichment planting in Nigeria have not been intensified. More so, researches on the evaluation of non-destructive carbon stock estimation methods are scarce. In this study, systematic line transect was employed in the laying of the plots. A total of 8 sample plots under each of the selected forest types were used. For above-ground biomass estimation, two non-destructive methods were used. The amount of carbon stock obtained using model and denisity method was significantly higher in strict nature reserve (21,112.50 ton/ha, 161.93 ton/ha) than the forest established through enrichment planting (3,018.07 ton/ha, 88.96 ton/ha). Findings from this study revealed that the total above-ground life carbon stock obtained using model was significantly higher in the strict nature reserve and enrichment planted Forest than the total above-ground life carbon stock obtained using density method. Since the estimated carbon stock using density method is closer to the average aboveground biomass carbon estimated around 248 tC ha$^{-1}$ for tropical rainforest, it was considered more appropriate for non-destructive carbon stock estimation and therefore recommended.

**Keywords:** Above-ground biomass, Soil carbon, Carbon sequestration, Enrichment planting and Natural Forest.

## INTRODUCTION

Forest ecosystem is a major biological scrubber of atmospheric carbon dioxide. Absorbing carbon dioxide from the atmosphere and moving into the physiological system and biomass of the plants, and finally into the soil is the only practical way of removing large volumes of the major greenhouse gas ($CO_2$) from the atmosphere into the biological system. Thus, carbon is sequestered into the plants and then from the plants to the animals. Eventually, after the death of the animals, the detritus decomposes into the soil organic carbon by microbial activities. These sequestered carbons finally act as ‘sinks’ in the forest lands. Free-air $CO_2$ enrichment experiments suggest that tree growth rates may increase with increasing levels of atmospheric $CO_2$, but these effects are expected to saturate over time as tree communities adjust to increased $CO_2$ levels (IPCC 2006). Climate change effects that influence tree growth will also alter the rates of carbon storage (or sequestration) in trees and soils. Increased carbon sequestration would remove more $CO_2$ from the atmosphere (negative feedback that lessens climate change), whereas carbon losses through forest disturbances would result in more $CO_2$ entering the atmosphere (positive feedback that strengthening climate change).

Clearing and burning of forest estates for agricultural purposes could lead to the depletion of the ozone layer by greenhouse gasses. Greenhouse gases play an important role on Earth’s climate (IPCC 2007). These greenhouse gasses include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3). When sunlight reaches the surface of the Earth, some are absorbed and warm the Earth. In turn, the Earth emits longwave radiation towards the atmosphere, a fraction of which is absorbed by the greenhouse gasses. The Greenhouse gasses then emits longwave radiation both towards space and back to the Earth. The energy emitted downward further warms the surface of the Earth. When the concentration of greenhouse gasses in the atmosphere increased, the temperature at the Earth's surface is also expected to increase (IPCC 2001). Carbon dioxide ($CO_2$) is one of the most abundant greenhouse gases and a primary agent of global warming. It constitutes 72% of the total anthropogenic greenhouse gases, causing between 9-26% of the greenhouse effect (Kiehl and Trenberth, 1997). IPCC (2007) reported that the amount of $CO_2$ in the atmosphere has increased from 280 ppm in the pre-industrial era (1750) to 379 ppm in 2005, and is increasing by 1.5ppm per year. The dramatic rise of $CO_2$ concentration is attributed largely to human activities. Over the last 20 years, majority of the emission is attributed to the burning of fossil fuel, while 10-30% is attributed to land-use change and deforestation (IPCC 2001). Increase in $CO_2$ concentration, along with other greenhouse gases (GHG), as a result of deforestation raised concerns over global warming and climate changes.

While conservationists value tropical forests for their diversity, nutrient cycling, watershed protection, and role in regulating climate, these values rarely translate into financial benefits for landowners in forested regions. Rather, the financial return from converting tropical forest land to agriculture is often less than that of maintaining forest cover (Cardille and Foley 2003; Geist and Lambin 2002). One strategy for enhancing the value of forests is to increase the concentration of economically important, indigenous tree species by planting seeds or seedlings (enrichment planting) for future harvest (Brown *et. al.* 2003). This can be accomplished with enrichment planting (EP).

Houghton *et. al.* (1997) predicted that carbon dioxide emission to the atmosphere would increase from 7.4 Gigatons (Gt) C per year in 1997 to approximately 26 Gt C per year by 2100. Many scientists agreed that a doubling of atmospheric $CO_2$ could have a variety of serious environmental consequences (Lindzen 1994, Adam *et. al.* 1993). According to Geldemhuys (1995), the loss and fragmentation of forests, due to excessive burning and clearing for subsistence and commercial agriculture, contribute to the loss of the unique habitats, biodiversity and atmospheric deterioration. Unfortunately, research efforts have not been intensified to estimate the carbon stock potential in natural forest and forest regenerated through enrichment planting in Nigeria as it has been reported that carbon dioxide used by trees during photosynthesis varies from species to species (Piraino *et. al*. 2002).

The two methods available for measuring tree biomass are destructive and non-destructive. The destructive method is done by felling the sample tree and then weighing it. However, direct weighing can only be done for small trees, but larger trees, partitioning is necessary so that the partitions can fit into the weighing scale. In other cases, the volume of the stem is measured. Sub-samples are collected, and its fresh weight, dry weight, and volume are measured. The dry weight of the tree (biomass) is calculated based on the ratio of fresh weight (or volume) to the dry weight. Another destructive method recommended by De Gier (2003) uses the principle of randomized branch sampling.

The non-destructive method does not require the trees to be felled. Measurement can be done with spiegel relaskop and the total volume can be computed. Tree density which can be found from literature is used to convert the measured volume into biomass estimate (Aboal *et al.* 2005). Wood specific gravity is an important factor in converting forest volume data to biomass (Fearnside 1997). This approach takes even more time and costs to perform. Another approach is by taking two photographs of the tree at orthogonal angles. Then the scale of the photograph is calculated so that the volume of each tree components (stem, branch, foliage) can be calculated. The density of the different tree components is calculated and used to convert the volumes into biomass (Montes *et al.* 2000). However, the calculated biomass from these procedures can not be validated unless the sample tree is felled and weighed. Once sample tree variables and biomass data are obtained, and the biomass equation is developed by regression analysis, it is then applied to each tree in the sample plots to obtain the plot biomass. Landscape biomass is estimated depending on whether sampling technique or remote sensing method is used. A challenge in biomass assessment of tropical rainforest is cost and accuracy (De Gier 2003). Developing the biomass equation is a laborious process. It requires a crew of two or three people to fell and weighs the sample tree. But once established, it can easily be used to estimate forest biomass. Although several biomass equations have been developed, these are specific to geographic locations (De Gier 2003). More so, researches on the evaluation of non-destructive carbon stock estimation methods are scarce. In this study, tree biomass was estimated using two non-destructive methods - biomass model for carbon-stock prediction in Nigeria and the density method.

## METHODOLOGY

### Study Area

This study was carried out in one of the Nigerian SNRs (SNR 1). It is located within Akure Forest Reserve, Ondo State, Nigeria. This portion of the reserve, that was designated as SNR and the adjoining natural forest regenerated through enrichment planting was used in this present study. Akure Forest Reserve covers an area of 69.93 km$^2$. The reserve is under the management of the Department of Forestry, Ondo State, Nigeria. The reserve lies along Ondo-Akure road at about 20 km south of Akure, the capital city of Ondo State. It is located on Latitude 7$^o$ 18'N and Longitude 5$^o$ 02'E (Figure 1).

The area is gently undulating and lies on a general altitude of 229m above sea level (Jones, 1948). The reserve is well drained due to the presence of Owena River, which flows north to south across the Forest Reserve into the Atlantic Ocean about 160km away. According to a brief geological description of the forest reserve by Jones (1948), and Ola-Adams and Hall (1987), the underlying rock is crystalline, mainly gneissose and referable to the basement complex. As a result of continuous weathering, the ferric luvisol soils which feature abundantly in the typical upland soils in many parts of South-Western Nigeria is also present in Akure Forest Reserve (FAO/UNESCO 1988).

The climate is humid tropical with seasonal variation. The mean annual rainfall is about 4000mm with double maxima in July and September and a short relatively dry period in August. December through to February constitutes the major dry season while January and February are the driest months with each having less than 30mm rainfall (Ola-Adams and Hall 1987). The relative humidity at 15 hours Greenwich Mean Time (GMT) is highest in the maxima months of July and September and lowest in February at about 81% and 44% respectively.

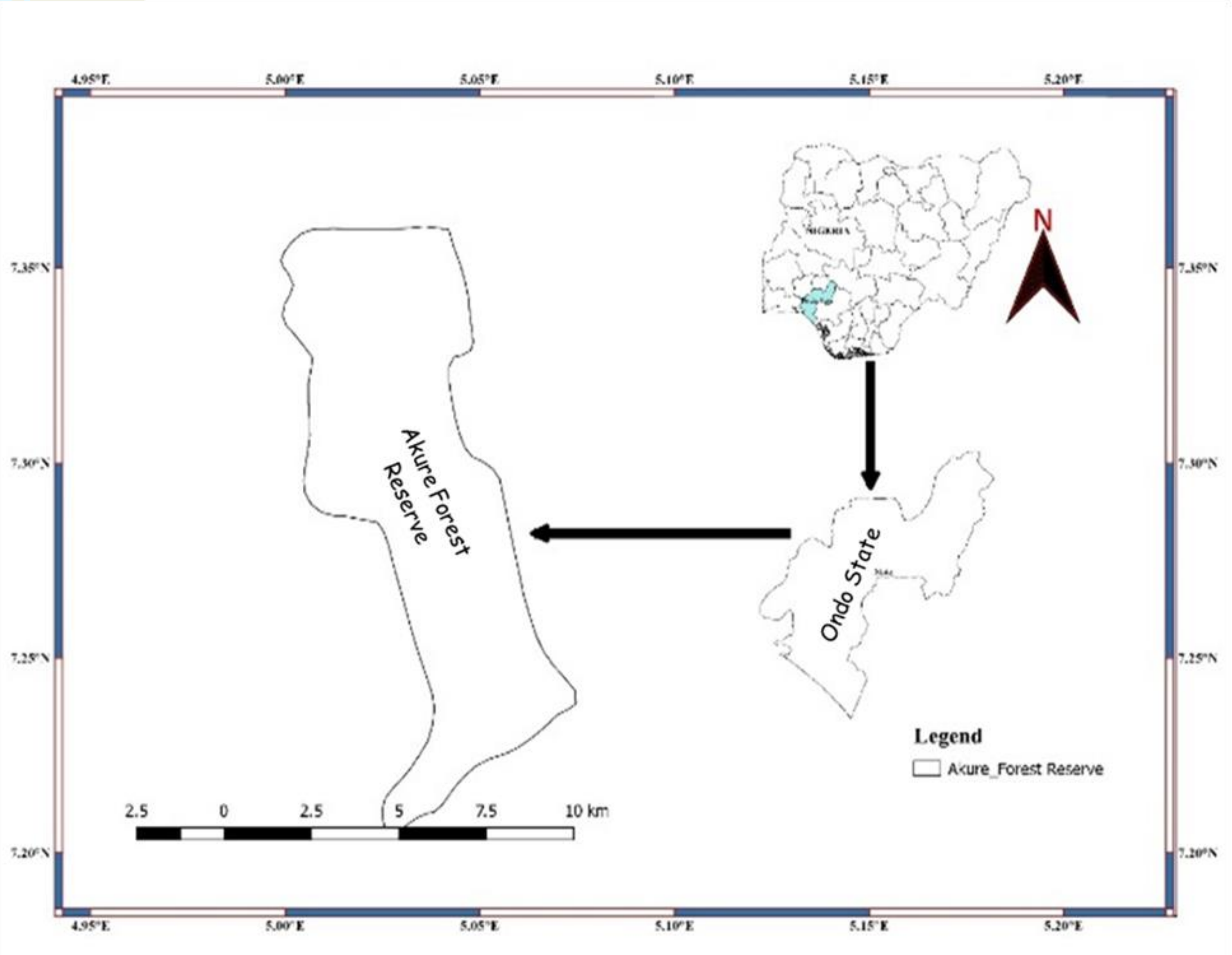


**Figure 1:** **Map of Akure Forest Reserve**

## Sampling Procedure

Systematic line transect was employed in the laying of the plots. Two transects of 1100m in length with a distance of at least 500m between the two parallel transects were used in each of the study sites. Sample plots of 25m x 25m in size were laid in alternate along each transect at 250m interval and thus summing up to 4 sample plots per 1100m transect and a total of 8 sample plots under each of the selected forest types.

## Method of Data Collection

### *Tree Species Identification*

In each plot, all living trees with dbh ≥10cm were identified and measured. The botanical name of every living tree encountered in each sample plot was recorded for each of the study sites. When a tree's botanical name was not known immediately, it was identified by its commercial or local name. Such commercial or local name was translated to correct botanical names using Keay (1989). Each tree was recorded individually in the field and possible effort was made not to omit any eligible stem in a sample plot. This is because any species omitted will indicate the absence of such species in the ecosystem.

## Method of Data Analysis

### *Volume Estimation*

The volume of individual trees was estimated using the formula of Newton (Husch *et. al.* 2003). This equation is expressed as follows:

$$V = \frac{\pi h}{24}(D_b^2 + 4D_m^2 + D_t^2)$$

Where:

$V$ = Volume of the tree ($m^3$)
$D_b$ = Diameter at the base ($m^3$)
$D_m$ = Diameter at the middle ($m^3$)
$D_t$ = Diameter at the top ($m^3$)
$h$ = height (m)

Total plot volume was obtained by adding the volume of individual trees encountered in the plots. Mean volume for sample plots was calculated by dividing the total plot volume by the number of sample plots (8 plots).

Volume per hectare was obtained by multiplying mean volume per plot $\bar{V}_P$ with the number of 25×25m plots in a hectare (16).

$$V_{ha} = \bar{V}_P \text{x} 16$$

### Biomass and Carbon Stock Estimation

Two methods were used namely Biomass equation and use of tree densities. For the biomass equation, the best model predicting the above-ground tree biomass in Nigeria by Aghimien *et al.* (2015) was adopted. The equation is given as:

$$\ln(AGTB) = c + \alpha \text{In}(DBH) + \beta \ln(avgWD)$$

Where AGTB is above-ground tree biomass in kg and DBH is the diameter at breast height in cm, avgWD is average wood density, c, α and β are best-fit parameters.

Estimation of the Above-ground live biomass was also carried out by multiplying the volume of each tree with its respective wood density. The densities were obtained from the literature (i.e., NCP 1973, Dinwoodie 1981) and the internet. To estimate the total above-ground biomass of each site, the amount of biomass of each species in a hectare area in the study sites was summed up and multiplied with the total size of the forest. Biomass value was converted to carbon stocks using 0.5 carbon fractions as default values (MacDicken 1997, IPCC 2006 and Penman 2003) and expressed in ton/ha. Total carbon dioxide ($CO_2$) sequestered was estimated by multiplying the carbon stock with a constant (3.6663) (Vishnu and Patil 2016).

### Statistical Analysis Methods

Appropriate test statistics (student's t-test) was used to compare the carbon stock in the two forests. The two carbon stock estimation methods used in this study were also compared using the same test statistics. Data from the best carbon stock estimation method was used for correlation analysis.

## RESULTS

Biomass and carbon stock estimated using biomass equation in the two forest types are presented in Table 1. Finding from this study reveals that *Erythrophleum ivorensis* (366,702,638.32kg) had the highest carbon stock per hectare followed by *Brachystegia nigerica* (60,301,328.09kg) and *Erythrophleum suaveolens* (58,172,662.21kg) in SNR while in EPF, *Chrisophylum albidun* (18,311,848.64kg) recorded the highest carbon stock per hectare followed by *Trilepisium madagascariense* (12,998,631.55kg), *Terminalia superba* (12,672,677.14kg) and *Triplochyton schleroxylon* (11,060,659.03kg) as presented in the Table.

Table 2 shows the tree density, biomass and carbon stock estimated in the two forest types. In SNR, the species with the highest carbon stock per hectare was *Triplochyton schleroxylon* (24,381.43kg) followed by *Erythrophyleum ivorensis* (21,063kg) and *Entandrophragma angolense* (18,333.03kg) while in EPF, *Trilepisium madagascariense* had the highest carbon stock per hectare followed by *Cola gigantia* (10,305.64kg) and *Sterculia rhinopetala* (7,707.18kg) as presented in the Table 1.

**Table 1: Biomass and carbon stock estimated using biomass equation in the two forest types**

| S/N | Species Name | EPF | | | | SNR | | |
|---|---|---|---|---|---|---|---|---|
| | | Wood Density (Kg/m³) | Mean DBH (cm) | Biomass (kg/ha) | Carbon stock (Kg/ha) | Mean DBH (cm) | Biomass (kg/ha) | Carbon stock (Kg/ha) |
| 1 | *Albizia ferugina* | 470 | 14.00 | 732627.90 | 366313.95 | - | - | - |
| 2 | *Alstonia boonei* | 432 | 29.30 | 3615210.12 | 1807605.06 | 23.60 | 2124177.44 | 1062088.72 |
| 3 | *Bacteria fistulosa* | 600 | 12.00 | 945945.52 | 472972.76 | - | - | - |
| 4 | *Brachystegia enricoma* | 600 | 13.50 | 1263568.93 | 631784.47 | - | - | - |
| 5 | *Brachystegia nigerica* | 736 | - | - | - | 69.50 | 120602656.18 | 60301328.09 |
| 6 | *Bridelia micrantha* | 470 | 17.29 | 1230837.40 | 615418.70 | 34.13 | 6548609.56 | 3274304.78 |
| 7 | *Buchholzia coriacea* | 600 | 31.30 | 9983571.09 | 4991785.54 | 30.90 | 9672881.88 | 4836440.94 |
| 8 | *Ceiba Pentandra* | 260 | 17.50 | 272302.62 | 136151.31 | 68.00 | 7655441.30 | 3827720.65 |
| 9 | *Celtis zenkeri* | 832 | 19.09 | 6923369.56 | 3461684.78 | 18.74 | 6615523.24 | 3307761.62 |
| 10 | *Chrisophylum albidum* | 560 | 57.13 | 36623697.27 | 18311848.64 | 38.57 | 13944142.66 | 6972071.33 |
| 11 | *Chrisophylum perpunchrum* | 560 | 19.54 | 2621098.01 | 1310549.00 | 52.80 | 30173393.81 | 15086696.90 |
| 12 | *Cleistopholis patens* | 600 | - | - | - | 72.50 | 78695183.05 | 39347591.53 |
| 13 | *Cola acuminate* | 460 | - | - | - | 15.10 | 834371.88 | 417185.94 |
| 14 | *Cola gigantia* | 460 | 35.18 | 6671582.79 | 3335791.40 | 97.95 | 82665043.05 | 41332521.52 |
| 15 | *Cola millenii* | 460 | 22.90 | 2322253.58 | 1161126.79 | 17.50 | 1199007.07 | 599503.53 |
| 16 | *Cordia millenii* | 340 | 35.53 | 3116882.45 | 1558441.23 | 72.75 | 18144391.05 | 9072195.53 |
| 17 | *Cordia platythyrsa* | 600 | - | - | - | 56.00 | 41714177.58 | 20857088.79 |
| 18 | *Desplatsia subericarpa* | 600 | 13.40 | 1240686.73 | 620343.36 | - | - | - |
| 19 | *Diospyros barteri* | 864 | 16.80 | 5578158.60 | 2789079.30 | - | - | - |
| 20 | *Discoglypremna caloneura* | 600 | 14.16 | 1420862.26 | 710431.13 | - | - | - |
| 21 | *Entandrophragma angolensis* | 592 | 14.17 | 1374547.75 | 687273.88 | 36.51 | 14076683.48 | 7038341.74 |
| 22 | *Erythrophleum ivorense* | 832 | - | - | - | 127.25 | 733405276.64 | 366702638.32 |
| 23 | *Erythrophleum suaveolens* | 600 | - | - | - | 85.00 | 116345324.43 | 58172662.21 |
| 24 | *Ficus exaspirata* | 600 | 18.30 | 2668966.34 | 1334483.17 | 37.00 | 15061826.85 | 7530913.42 |
| 25 | *Funtumia elastica* | 450 | 15.40 | 827104.74 | 413552.37 | 23.64 | 2371700.03 | 1185850.01 |
| 26 | *Hunteria unbelata* | 600 | 11.50 | 851988.91 | 425994.46 | - | - | - |
| 27 | *Khaya grandifolia* | 600 | 13.75 | 1321863.33 | 660931.67 | - | - | - |
| 28 | *Khaya ivorensis* | 530 | 13.40 | 898852.19 | 449426.09 | - | - | - |
| 29 | *Lecaniodiscuss cupanioides* | 600 | 13.50 | 1263568.93 | 631784.47 | - | - | - |
| 30 | *Mansonia altisima* | 672 | 24.11 | 7055900.01 | 3527950.00 | 21.39 | 5257386.05 | 2628693.03 |
| 31 | *Musanga cecropiodes* | 230 | 18.70 | 233084.57 | 116542.29 | 24.00 | 430413.53 | 215206.76 |
| 32 | *Myranthus arboreus* | 600 | 13.00 | 1151625.64 | 575812.82 | 12.05 | 955663.02 | 477831.51 |
| 33 | *Nesogordonia papaverifera* | 784 | 26.23 | 12955451.44 | 6477725.72 | 28.77 | 16259997.21 | 8129998.61 |
| 34 | *Ochroma lagopus* | 600 | 26.83 | 6835773.39 | 3417886.69 | - | - | - |
| 35 | *Pentaclethra macrophylla* | 780 | 14.40 | 2927724.48 | 1463862.24 | - | - | - |
| 36 | *Pterygota macrocarpa* | 592 | 24.38 | 5217004.22 | 2608502.11 | 10.55 | 665652.39 | 332826.20 |
| 37 | *Pycnanthus angolensis* | 544 | 14.50 | 1167684.71 | 583842.35 | 28.50 | 6147396.46 | 3073698.23 |
| 38 | *Ricinodendron heudelotii* | 200 | 29.53 | 498350.35 | 249175.17 | 19.00 | 168579.16 | 84289.58 |
| 39 | *Spathodea compachinata* | 600 | 31.00 | 9750008.25 | 4875004.13 | - | - | - |
| 40 | *Spondia mombin* | 600 | - | - | - | 31.40 | 10062155.06 | 5031077.53 |
| 41 | *Sterculia oblonga* | 816 | 25.42 | 13307840.30 | 6653920.15 | 44.70 | 53289491.31 | 26644745.66 |
| 42 | *Sterculia rhinopetala* | 848 | 19.06 | 7246553.57 | 3623276.79 | 25.67 | 15064613.70 | 7532306.85 |
| 43 | *Sterculia trigacantha* | 600 | - | - | - | 10.00 | 604280.74 | 302140.37 |
| 44 | *Strombosia fasae* | 600 | 12.46 | 1037580.84 | 518790.42 | - | - | - |
| 45 | *Strombosia grandifolia* | 816 | 21.20 | 8517649.49 | 4258824.75 | - | - | - |
| 46 | *Strombosia postulate* | 880 | 16.45 | 5555466.80 | 2777733.40 | 18.25 | 7170820.08 | 3585410.04 |
| 47 | *Terminalia superba* | 464 | 60.00 | 25345354.27 | 12672677.14 | 28.36 | 4017492.14 | 2008746.07 |
| 48 | *Trilepisium* | 600 | 46.20 | 25997263.09 | 12998631.55 | 56.30 | 42265610.45 | 21132805.22 |

| S/N | Species Name | EPF | | | | SNR | | |
|---|---|---|---|---|---|---|---|---|
| | | Wood Density ($Kg/m^3$) | Mean DBH (cm) | Biomass (kg/ha) | Carbon stock (Kg/ha) | Mean DBH (cm) | Biomass (kg/ha) | Carbon stock (Kg/ha) |
| | *madagascariense* | | | | | | | |
| 49 | *Triplochyton schleroxylon* | 384 | 69.34 | 22121318.06 | 11060659.03 | 54.14 | 12040950.41 | 6020475.20 |
| 50 | *Zanthoxylon zanthoxyloides* | 690 | 16.16 | 2826744.65 | 1413372.32 | 12.90 | 1624678.35 | 812339.18 |

**Table 2: Wood density, biomass and carbon stock estimation in the two forest types using density method**

| S/N | Species name | Wood density ($kg/m^3$) | EPF | | | SNR | | |
|---|---|---|---|---|---|---|---|---|
| | | | Vol/ha ($m^3$) | Biomass (kg/ha) | Carbon stock (kg/ha) | Vol/ha ($m^3$) | Biomass (kg/ha) | Carbon stock (kg/ha) |
| 1 | *Albizia ferugina* | 470 | 0.21 | 97.02 | 48.51 | - | - | - |
| 2 | *Alstonia boonei* | 432 | 2.66 | 1149.79 | 574.90 | 2.41 | 1040.80 | 520.40 |
| 3 | *Bacteria fistulosa* | 600 | 0.11 | 65.20 | 32.60 | - | - | - |
| 4 | *Brachystegia enricoma* | 600 | 0.59 | 401.40 | 200.70 | - | - | - |
| 5 | *Brachystegia nigerica* | 736 | - | - | - | 29.42 | 21656.40 | 10828.20 |
| 6 | *Bridelia micrantha* | 470 | 78.05 | 745.60 | 372.80 | 6.69 | 3144.77 | 1572.39 |
| 7 | *Buchholzia coriacea* | 600 | 1.52 | 909.82 | 454.91 | 6.62 | 3971.79 | 1985.90 |
| 8 | *Ceiba Pentandra* | 260 | 1.10 | 285.93 | 142.97 | 6.69 | 1740.52 | 870.26 |
| 9 | *Celtis zenkeri* | 832 | 12.37 | 10295.42 | 5147.71 | 11.68 | 9717.96 | 4858.98 |
| 10 | *Chrisophylum albidum* | 560 | 16.29 | 9124.68 | 4562.34 | 20.71 | 11595.05 | 5797.53 |
| 11 | *Chrisophylum perpunchrum* | 560 | 3.69 | 2064.37 | 1032.18 | 7.20 | 4034.41 | 2017.20 |
| 12 | *Cleistopholis patens* | 600 | - | - | - | 9.17 | 5500.51 | 2750.26 |
| 13 | *Cola acuminate* | 460 | - | - | - | 0.46 | 210.50 | 105.25 |
| 14 | *Cola gigantia* | 460 | 44.81 | 20611.28 | 10305.64 | 73.83 | - | - |
| 15 | *Cola millenii* | 460 | 3.15 | 1446.89 | 723.45 | 0.33 | 150.00 | 75.00 |
| 16 | *Cordia millenii* | 340 | 35.02 | 11906.63 | 5953.31 | 15.49 | 5264.98 | 2632.49 |
| 17 | *Cordia platythyrsa* | 600 | - | - | - | 5.72 | 3429.00 | 1714.50 |
| 18 | *Desplatsia subericarpa* | 600 | 0.21 | 123.28 | 61.64 | - | - | - |
| 19 | *Diospyros barteri* | 864 | 0.33 | 282.73 | 141.37 | - | - | - |
| 20 | *Discoglypremna caloneura* | 600 | 0.14 | 84.57 | 42.28 | - | - | - |
| 21 | *Entandrophragma angolensis* | 592 | 1.53 | 902.90 | 451.45 | 61.94 | 36666.06 | 18333.03 |
| 22 | *Erythrophleum ivorense* | 832 | - | - | - | 64.37 | 42125.99 | 21063.00 |
| 23 | *Erythrophleum suaveolens* | 600 | - | - | - | 10.99 | 9145.05 | 4572.53 |
| 24 | *Ficus exaspirata* | 600 | 0.38 | 225.44 | 112.72 | 1.91 | 1144.95 | 572.48 |
| 25 | *Funtumia elastic* | 450 | 0.47 | 210.90 | 105.45 | 6.13 | 2759.76 | 1379.88 |
| 26 | *Hunteria unbelata* | 600 | 0.34 | 204.11 | 102.05 | - | - | - |
| 27 | *Khaya grandifolia* | 600 | 0.50 | 298.20 | 149.10 | - | - | - |
| 28 | *Khaya ivorensis* | 530 | 0.17 | 89.87 | 44.94 | - | - | - |
| 29 | *Lecaniodiscuss cupanioides* | 600 | 0.16 | 97.44 | 48.72 | - | - | - |
| 30 | *Mansonia altisima* | 672 | 15.99 | 10746.53 | 5373.27 | 46.81 | 31454.97 | 15727.49 |
| 31 | *Musanga cecropiodes* | 230 | 0.16 | 37.76 | 18.88 | 0.54 | 123.13 | 61.56 |
| 32 | *Myranthus arboreus* | 600 | 0.17 | 101.58 | 50.79 | 0.34 | 201.58 | 100.79 |
| 33 | *Nesogordonia papaverifera* | 784 | 7.05 | 5530.20 | 2765.10 | 7.48 | 5866.75 | 2933.37 |
| 34 | *Ochroma lagopus* | 600 | 2.38 | 1429.76 | 714.88 | - | - | - |
| 35 | *Pentaclethra macrophylla* | 780 | 0.32 | 247.54 | 123.77 | - | - | - |
| 36 | *Pterygota macrocarpa* | 592 | 25.65 | 15182.38 | 7591.19 | 0.29 | 173.47 | 86.73 |
| 37 | *Pycnanthus angolensis* | 544 | 0.65 | 355.29 | 177.64 | 2.67 | 1454.95 | 727.47 |
| 38 | *Ricinodendron heudelotii* | 200 | 30.14 | 6027.74 | 3013.87 | 0.52 | 103.58 | 51.79 |
| 39 | *Spathodea compachinata* | 600 | 0.98 | 586.44 | 293.22 | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 40 | *Spondia mombin* | 600 | - | - | - | 0.92 | 554.49 | 277.24 |
| 41 | *Sterculia oblonga* | 816 | 9.57 | 7811.40 | 3905.70 | 34.94 | 28507.69 | 14253.85 |
| 42 | *Sterculia rhinopetala* | 848 | 18.18 | 15414.36 | 7707.18 | 11.92 | 10105.75 | 5052.88 |
| 43 | *Sterculia trigacantha* | 600 | - | - | - | 0.09 | 54.04 | 27.02 |
| 44 | *Strombosia fasae* | 600 | 0.60 | 414.76 | 207.38 | - | - | - |
| 45 | *Strombosia grandifolia* | 816 | 0.92 | 752.66 | 376.33 | - | - | - |
| 46 | *Strombosia postulata* | 880 | 3.36 | 2756.56 | 1378.28 | 2.60 | 2291.59 | 1145.79 |
| 47 | *Terminalia superba* | 464 | 14.70 | 6822.66 | 3411.33 | 7.08 | 3286.84 | 1643.42 |
| 48 | *Trilepisium madagascariense* | 600 | 37.65 | 22587.06 | 11293.53 | 15.43 | 9256.28 | 4628.14 |
| 49 | *Triplochyton schleroxylon* | 384 | 49.17 | 18879.90 | 9439.95 | 126.99 | 48762.85 | 24381.43 |
| 50 | *Zanthoxylon zanthoxyloides* | 690 | 1.12 | 773.10 | 386.55 | 0.58 | 398.23 | 199.11 |

The results of the t-test for comparing tree volume, biomass and carbon stock using the model developed by Aghimien, *et al.* (2015) and wood density is presented in Table 3. The result revealed a significant difference between the volumes obtained in the two forest types and that the biomass and carbon stock was significantly higher in Strict Nature Reserve (SNR) than in the Enrichment Planting Forest (EPF) when wood density was used. A similar trend was observed for biomass and carbon stock in the two forest types when the biomass equation was used. The result of comparing the two methods of $CO_2$ estimation in the two forests is presented in Table 4. A statistically significant difference was recorded between the two methods. Carbon dioxide ($CO_2$) estimated using the model was statistically higher than the $CO_2$ estimated using the density method in both forests.

The correlation matrix for wood density, volume, biomass and carbon stock in SNR and EPF is presented in Table 5. In SNR, very high strength of the relationship (94.7%) was recorded for volume and biomass. Volume was also strongly correlated (94.7%) with carbon stock. Intermediate relationships were found to exist between volume and biomass (60.6%), volume and carbon stock (60.6%) in EPF as presented in Table 5.

**Table 3: Comparison of biomass and biomass stock of the two forest types.**

| | | ***Estimate from density*** | | **Estimate from model** | |
|---|---|---|---|---|---|
| | Volume ($m^3$/ha) | Biomass (kg/ha) | Carbon Stock (Ton/ha) | Biomass (kg/ha) | **Carbon Stock (Ton/ha)** |
| **SNR** | $600.96^{a}$ | $323855^{a}$ | $161.93^{a}$ | $42,224,999.74^{a}$ | $21,112.50^{a}$ |
| **EPF** | $345.76^{b}$ | $177913.60^{b}$ | $88.96^{b}$ | $6,036,141.08^{b}$ | $3,018.07^{b}$ |

***Means with the same letter along the columns are not significantly different ($p<0.05$)***

**Table 4: Comparison of the two methods of carbon estimation in the two forest types**

| | ***Estimate from density*** | **Estimate from model** |
|---|---|---|
| | $CO_2$ (Ton/ha) | $CO_2$ (Ton/ha) |
| **SNR** | $593.68^{b}$ | $77,404.76^{a}$ |
| **EPF** | $326.14^{b}$ | $11,065.15^{a}$ |

***Means with the same letter along the rows are not significantly different ($p<0.05$)***

**Table 5: Correlation matrix for wood density, volume, biomas and carbon stock**

| | *Wood density ($kg/m^3$)* | *Vol/ha* | *Biomass (kg/ha)* | *Carbon stock (kg/ha)* |
|---|---|---|---|---|
| **SNR** | | | | |
| Wood density ($kg/m^3$) | 1.000000 | | | |
| Vol/ha | 0.085523 | 1 | | |
| Biomass (kg/ha) | 0.276314 | 0.946863 | 1 | |
| Carbon stock (kg/ha) | 0.276314 | 0.946863 | 1 | 1 |
| **EPF** | | | | |
| Wood density ($kg/m^3$) | 1 | | | |
| Vol/ha | -0.223756688 | 1 | | |
| Biomass (kg/ha) | 0.039704593 | 0.605652 | 1 | |
| Carbon stock (kg/ha) | 0.039704598 | 0.605652 | 1 | 1 |

## DISCUSSION

Nigerian natural forest ecosystem has been under uncontrolled logging and other illegal activities over years. This has led to the loss of biodiversity, reduction in forest area and increasing global temperature (global warming). Intergovernmental Panel on Climate Change (IPCC) reported that average temperatures are increasing globally (IPCC 2013). This climate change is mainly caused by human activities and particularly by carbon dioxide ($CO_2$) emissions (IPCC 2013). Climate progress (2012) revealed the negative effects of the resultant global warming to include the melting of sea ice, landslides and massive dust storms. However, mitigation and adaptation were the two main policies proposed to address these issues (Simonis 2011). Climate mitigation policies aim to reduce GHG emissions (Lutsey and Sperling, 2008), while adaptation policies seek to adapt to the consequences of climate change (Carina and Keskitalo 2010). Given the high rates of deforestation and subsequent depletion of the ozone layer, there are increasing calls to reforest degraded forests.

Sedjo and Sohngen (2012) defined carbon sequestration as the process of capturing and long-term storage of atmospheric $CO_2$. Mandlebaum and Nriagu (2011) opined that the long-term storage of atmospheric $CO_2$ is an important mitigation option to reduce the largest portion of GHG emissions (CO2). Through carbon sequestration, the effects of global warming and the attendant climate change can be reduced (IPCC, 2007). In this study, the amount of biomass and carbon stock obtained using model and densisty method was significantly higher in SNR than the forest established through enrichment planting. Also, volume per hectare was statistically higher in the Strict Nature Reserve (600.96$m^3$) than in forest established through enrichment planting (345.76$m^3$). This is expected as tree harvesting has not been carried out in the SNR since time immemorial and has been strictly protected by the Forestry Research Institute of Nigeria (FRIN). However, the forest established through enrichment planting had been logged but enriched in 2005 by the State Department of Forestry. One of the main reasons for higher carbon stocks in primary forests (SNR) is that most living biomass carbon is found in large, old trees (Stephenson 2014). According to Shearman *et* al. (2012), logged forests have lower carbon densities because they are dominated by regenerating stands of younger and smaller trees.

Luyssaert *et al*. (2008) pointed out that primary forests are rarely sources of $CO_2$. According to Unwin and Kriedemann (2000), tree volumes increase slowly during the first ten years, increasing dramatically during the age range of ten to 40 years, and stabilising after the age of40 years when trees achieve maturity. The relationship between carbon sequestration and tree ages is similar to the relationship between tree volume and tree ages (Unwin and Kriedemann, 2000). According to Leoni *et al.* (2011), the incremental diameter for trees less than ten years of age was 0.4 cm per year and the incremental height of 0.6m per year; for trees aged 11-40 years, the incremental diameter was estimated to be 0.38 cm per year and the incremental height at 1m per year; and finally, for trees more than 40 years old, the tree diameter and height was estimated to remain constant. Therefore, maintaining forests intact is critical for protecting carbon stocks while continuing carbon uptake (Mackey *et al*. 2014). As much as strict nature reserve serves as carbon sink as well as biodiversity conservation area, Natural regeneration and regrowth in logged forests are as well important for carbon sequestration as restoration and reforestation (ISU, 2015). According to ISU (2015), tropical forest regeneration currently sequesters 1.2-1.8 Gt of carbon every year and the rate could be increased significantly if more land is allowed to recover and restoration of tropical forest is prioritized.

Findings from this study revealed that the total above-ground life carbon stock obtained using model was comparatively higher in the strict nature reserve and enrichment planted Forest than density method. For instance, a total of 21,112.50ton/ha was obtained for carbon stock in SNR using model. Whereas, 161.93ton/ha carbon stock was obtained in the same SNR using the density method. Emphatically, the estimated carbon stock using density method in this study was closer to the average aboveground biomass carbon estimated around 248 tC ha-1 for tropical rainforest (Keith *et al.* 2009) than the model. Judging from this, the model method as used in this study overestimated the carbon stock in two forests.

## CONCLUSION AND RECOMMENDATION

This research compared two non-destructive methods of carbon stock estimation, density and biomass equation. We discovered that the density method was more appropriate for non-destructive carbon stock estimation. Carbon stock in SNR was found significantly higher than the carbon stock in EPF. The study indicated the potential of in-situ methods (SNR and Enrichment planting) for high carbon sink. The ability of the tree species to sequester carbon and store in the soil as organic carbon after death and decomposition should be harnessed as this will go a long way to reduce the depletion of the ozone layer and subsequently lessen global warming and its adverse effects.

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