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STAND VOLUME AND ABOVEGROUND BIOMASS ESTIMATION IN SELECTED TROPICAL RAINFOREST RESERVES OF CROSS RIVER STATE, NIGERIA

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Abstract

This research was conducted with the view to estimate stand volume and aboveground biomass in selected tropical rainforest reserves, Cross River State. Agoi-Ibami, Afi-River and Okpon River are the three tropical rainforest reserves selected for this study. Systematic line transect was used to lay sample plots across the three selected reserves. Two transects of 1500m in length with a distance of at least 500m between the two parallel transects were used for each study site. Sample plots of 50m X 50m in size were laid in alternate along each transect at 100m interval and thus, summing up to 10 sample plots per 1500m transect and a total of 20 sample plots in each forest reserve. A total of 1368, 1277 and 110 individual trees were identified and measured in Afi River, Agoi-Ibami, and Okpon Forest Reserves respectively. A sum total of 3745 individual trees spread across twenty eight (28) tree families within the three selected forest reserves were identified and measured for diameter at breast height (dbh ≥ 5cm), diameters at the base, middle and top and also for total height. In Okpon Forest Reserve, mean diameter at breast height and total height of 28.8cm and 18.6m were obtained. Mean basal area of 50.29 m^2 ha^{-1} was obtained with a mean volume of 271.249 m^3 ha^{-1}. Meanwhile, green biomass (ton ha^{-1}), Dry biomass (ton ha^{-1}), Carbon stock (ton ha^{-1}) and Carbon-dioxide emission (ton ha^{-1}) recorded 271.249, 460.867, 334.128, 167.064 and 613.12 respectively. Afi River Forest Reserve, mean diameter at breast height (dbh) and total height of 25.8cm and 18.5m were respectively obtained while12.01 m^3 and 80.72 kg were obtained for average tree volume and biomass respectively. At stand level, mean basal area of 48.95m^2ha^{-1} was obtained with a mean volume of 244.561m^3 $ha^{-1}$and mean green biomass was 448.860ton $ha^{-1}$with a dry biomass of 325.423ton ha^{-1}. Agoi-Ibami Forest Reserve recorded an average dbh of 26.04 cm total height of 15.9m and mean basal area of 50.21m^2ha^{-1}. Mean stand volume, aboveground green biomass, dry biomass and carbon stock and carbon dioxide emission of 263.194 m^3 ha^{-1}, 459.6653 t ha^{-1}, 333.2569 t ha^{-1}, 166.6281 t ha^{-1} and 611.5267t ha^{-1}respectively were obtained.

Keywords: Aboveground biomass, Dry biomass, Stand volume, Tropical rainforest and Reserve

1. Introduction

Forest carbon stocks are generally stored in the form of biomass, which includes the above- and below- ground biomass (AGB and BGB), such as trees, shrubs, vines, roots, and the dead mass of fine and coarse litter associated with the soil. Forest aboveground biomass (hereafter biomass) can be converted into carbon stocks. It is an important component in temperate and tropical forest ecosystems, and is a relatively smaller part in boreal forest ecosystems (Malhi and Grace, 2008). Anthropogenic disturbance and management, including deforestation and forest degradation from management manipulations, have led to changes in biomass and thus the carbon budget (Houghton *et al.,* 2012). Yet the loss of carbon from forest disturbance and the gain from post-disturbance recovery have not been well assessed. Accurate surface measures of spatial and temporal variations in biomass change will support climate treaty frameworks such as Reduced Emissions from Deforestation and Forest Degradation Plus (REDD+).

Deforestation, forest degradation and land use change are the main sources of carbon emissions from developing countries, accounting for 15–20% of global carbon emissions (Angelsen and Warts-K, 2008, UNFCCC, 2009, Kanninen *et al.,* 2010). The increase in the concentrations of carbon-dioxide (CO_2) and other greenhouse gases (GHG) in the atmosphere are the main drivers of the changes in the Earth's environmental conditions and global climate (IPCC, 1990). Since the early 1990s, there is increasing effort from the international community to combat global climate change through mitigation and adaptation. Mitigation actions are those actions that are aimed at a reduction of the carbon-dioxide and other GHG concentrations in the atmosphere, whereas adaptation efforts are those actions that are geared towards the reduction of the vulnerability or the enhancement of the resilience of the environment to cope with future global climatic conditions (Kanninen, 2012).

Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity and carbon budgets (Bassey and Ajayi, 2020). Biomass analysis is an important element in the carbon cycle especially, carbon sequestration. Recently, biomass is increasingly used to help quantify pools and fluxes of greenhouse gases (GHG) from terrestrial biosphere associated with land use and land cover changes (Cairns *et al.,* 2003). The importance of terrestrial vegetation and soil as significant sinks of atmospheric CO_2 and its other derivatives is highlighted under Kyoto Protocol (Wani *et al*. 2010). Vegetation especially, forest ecosystems store carbon in the biomass through photosynthetic process, thereby sequestering carbon dioxide that would otherwise be present in the atmosphere. Undisturbed forest ecosystems are generally highly productive and accumulate more biomass and carbon per unit area compared to other land use systems like agriculture. A recent estimate indicates that tropical forests account for 247metric tons vegetation carbon, of which 193 billion tons is stored above ground (Saatchi *et al*. 2011).

The tropical rainforest is one of the major vegetation types of the globe (Richards, 1996; Whitmore, 1998). It occupies a total area of 1818.43 million hectares, representing 47% of the total land area occupied by all forest types of the world (FAO, 2005). According to Turner (2001), the tropical rainforest is the most diverse of all terrestrial ecosystems, containing more plant and animal species than any other biome. In spite of this diversity, most species are locally endemic or rare and patchily distributed (Richardson, *et al.,* 2002). Thus, the overall timber value per unit area is generally low, thereby necessitating logging activities over large areas in order to meet the ever increasing demand. The FAO (2005) estimated that tropical countries are losing 127,300 km^2 of forest annually. In view of the great value of the tropical rainforest and the grave consequences of losing it to unregulated logging activities and over-exploitation, it has become the focus of increasing public attention in recent years.

Estimating tree volume is important for forest management purposes such as assessment of growing stock, timber valuation, selection of forest areas for harvests, and for growth and yield studies (FAO, 2005). Again, explicit estimates of biomass and other forest structures are required to understand how forest will respond to climate change. Estimating aboveground biomass is therefore a critical step in quantifying and monitoring the change in tropical forests. It is therefore upon this background that this research focused on the estimating stand level volume and aboveground biomass in selected tropical rainforest reserves of Cross River State Nigeria.

2. Methodology

2.1 Study Area

Cross River State is situated between Latitudes 5° 32'N and 4° 27'N and Longitudes 7° 50’E and 9° 28'E and occupies about 20,156 km^2 (Olofsson *et al.,* 2014). Cross River State is bounded to the north by Benue State, to the west by Enugu and Abia States, and to the east by the Republic of Cameroon, with Akwa Ibom state and the Atlantic Ocean to the south (Olofsson *et al.,* 2014). The ecological zones present in Cross River State as documented by Oyebo *et al.,* (2010) include: lowland rainforest, freshwater swamp forest, the mangrove vegetation, coastal vegetation, montane vegetation, savanna-like vegetation, and wetlands for the purpose of management of the forest land of Cross River State may be classified into three (3) types namely; mangrove and swamp, tropical rainforest and savannah forest (Oyebo *et al.,* 2010).

The forests of Cross River State represent the largest block of relatively undisturbed tropical moist forest remaining in Nigeria today. The forests of Cross River once formed part of one of the lowland rainforest refugia of equatorial Africa during the Pleistocene era, and this has resulted in high levels of biological diversity and endemism (Agnew, 1992). Although significant areas have been converted into agricultural farmlands and natural forests have been disturbed by indiscriminate felling and wood removal, the State is still home to the largest contiguous and well-preserved fragments of natural forest in Nigeria. This research therefore was conducted in Okpon River, Agoi-ibami and Afi River forest reserves of Cross River State, Nigeria.

2.2 Sampling Procedure

Systematic line transect was employed in the laying of plots. Two transects of 1500m in length with a distance of at least 500m between the two parallel transects were used in each of the study site. Sample plots of 50m X 50m in size were laid in alternate along each transect at 100m interval and thus summing up to 10 sample plots per 1500m transect and a total of 20 sample plots under each of the selected forest reserve.

2.3 Methods of Data Collection

In each plot, all living trees with dbh ≥10cm were identified and measured for diameters and tree total height. Spiegel relaskop/girthing tape and sunto clinometers were used for individual tree diameters (diameter at the base, diameter at the middle and diameter at the top) and tree height measurements respectively. For trees growing on a slope, the dbh was measured from the uphill side. Buttresses were considered to be non-commercial. So, when buttresses extending more than 1.30 m above ground surface were encountered, the equivalent of dbh was measured at a height of 20 cm above the upper limit of the buttresses. When knots or localized deformations occurred at breast-height point, a more representative dbh point either above or below the breast-height point was chosen (Adekunle *et al.,* 2010).

3. Data Analysis

The diameter at breast height was used to calculate the basal area.

$$BasalArea(BA) = \frac{\pi D^2}{4} \ldots\ldots\ldots\ldots 1$$

Where: D = diameter at breast height (m)

$\pi = 3.142$

BA = Basal Area (m^2).

D = diameter at breast height (m)

The total Basal Area (BA) for each plot was obtained by adding all trees basal area in the plot while mean basal area for the plot was calculated with the formula:

$$\overline{BA_p} = \frac{\Sigma BA}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

$\overline{\mathrm{BA_p}}$ = Mean basal area per plot and

n = Toatal number all possible samplot plot

Stem Volume Estimation

Individual tree volume was calculated using the Newton's formula of Husch *et al.,* (2003):

$$V = \frac{H}{6}[A_b + 4A_m + A_t] \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where:

V= Volume (m^3)

A_b = Basal area at the base (m^2)

A_m = Mid basal area (m^2)

A_t = Basal area at the top (m^2)

H = height (m)

The plot volumes were obtained by adding the volume of all the trees in the plot while mean plot volume was obtained by dividing the total plot volume by number of sample plots.

Mean volume for the sample plot was calculated thus:

$$\overline{V_p} = \frac{\Sigma V_p}{8} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$\overline{\mathrm{V_p}}$ = Mean plots volume

The volume of trees per hectare (V_{ha}) was subsequently estimated by multiplying the mean per plot by the number of sampling units in a hectare (Adekunle, 2007).

Biomass and Carbon Stock Estimation

Two methods were used, namely; Biomass equation and use of tree densities. To estimate the Above-ground live biomass, the equation of Brown (1997) for mixed tropical climate zone was adopted. The equation is given as

$$Y = 21.297 - 6.952(D) + 0.740(D^2) \ldots 5$$

Where; Y = biomass per tree in kg and D = diameter at breast height (dbh) in cm.

Estimation of the Above-ground live biomass was alsocarried out by multiplying the volume of each tree with its respective wood density. Below ground biomass was estimated as 15% of the above ground biomass (MacDicken, 1997). To estimate the total biomass of each site, the amount of biomass of each species in hectare area in the study sites was summed up and multiplied with the total size of the forest.

3.1 Aboveground Live Green Biomass Estimation per Hectare

The summation of the biomass that was calculated for all trees in a sample produced the total plot biomass (AGBplot). This per plot estimate of aboveground (in kg) was divided by 1000 to express it in metric tons. This was then converted to per hectare estimate (AGBha) by using the equation:

$$AGBper\ ha = \left(\frac{Ah}{Ap}\right) \times AGBplot \ldots\ldots\ldots 6$$

Where: AGBha = aboveground biomass (metric tons per hectare)

Ah= area of one hectare in m^2

Ap= area of the plot (m^2)(Brown, 1997).

3.2 Aboveground Dry Biomass Estimation

Aboveground dry biomass estimation was calculated from:

$$W = \frac{AGBh \times 0.725}{1000} \text{.....................}7$$

Where: W= aboveground dry biomass (metric tons)

AGB_h = aboveground green biomass (kg ha^{-1}) expressed metric ton (Chaven and Rasal *et al*., (2010)

3.3 Determination of Carbon Sequestration per Reserve

$$Sc = Wx\,0.5 \text{ ....}8$$

Where; Sc = sequestered carbon (tha^{-1})

W= aboveground dry biomass (t ha^{-1}) (MacDicken, 1997; Bassey and Ajayi, 2020) and expressed in t/ha.

3.4 Estimation of Carbon-dioxide Equivalent from Carbon Stock

The content of carbon in woody biomass of any forest is generally 50% of the tree total volume. Hence, to compute the weight of carbon stock of a tree was obtained by multiplying the dry weight of the tree by 50% (Eneji *et al.,* 2014). Therefore the equation for the measurement of carbon-dioxide equivalent was given as:

$$\text{carbon dioxide emission} = Scx\,3.67 \text{.....}9$$

Where: Sc = sequestered carbon (Ajayi and Adie*,* 2019).

4. Results

4.1 Summary of Tree Growth Variables in Selected Rainforest Reserves of Cross River State, Nigeria

The result presented in Table 1 indicates that a total of 3745 individual tree species were botanically identified and measured for diameter at breast height (DBH), diameters at the base middle and top and total height in four selected tropical forest reserves of Cross River State (Afi River, Agoi-Ibami and Okpon Forest Reserves). Twenty systematic sample plots were laid in each of the four forest reserves for inventorization. A total of 1368, 1277 and 1100 individual trees were identified and measured in Afi River, Agoi-Ibami and Okpon Forest Reserves respectively. A sum total of 3745 individual trees spread across twenty eight (28) tree families across the three selected forest reserves were identified and measured for diameter at breast height (dbh ≥ 5cm), diameters at the base, middle and top and also for total height. Afi River Forest recorded an average dbh of 25.82cm, total height of 18.5m and mean basal area of $48.95m^2ha^{-1}$ with an average stand volume of 244.561 m^3 ha^{-1}. Agoi-Ibami Forest Reserve recorded an average dbh of 26.04 cm, total height of 15.9m and mean basal area of $50.21m2ha^{-1}$ with an average stand volume, of 263.194 M^3 ha^{-1}. Finally, Okpon Forest Reserve recorded an average dbh of 28.82 cm, total height of 18.6m and mean basal area 50.29 m^2ha^{-1} also with an average stand volume, 271.249 M^3 ha^{-1}.

Table 1: Summary of Tree Growth Variables in Selected Rainforest Reserves of Cross River State, Nigeria

Plot number	Parameters	Afi River Forest Reserve	Agoi-Ibami Reserve	Okpon Forest Reserve	Pooled
1	No. of sample	20	20	20	60

	plots measured				
3	No of trees measured	1368	1277	1100	3745
4	No of fam. measured	18	16	21	28
5	Number of trees per hectare (N ha^{-1})	365.49	391.54	454.54	-
6	Mean DBH (cm)	25.82	26.04	28.82	30.1
7	Mean height (m)	18.5	15.9	18.6	16.7
8	Mean Basal Area (m^2ha^{-1})	48.95	50.21	49.35	47.52
9	Volume (M^3ha^{-1})	244.561	263.194	271.249	268.01

4.2 Average Stand Volume, Green and Dry Biomasses, Carbon Stock, Carbon Emission in Selected Tropical Rainforest Reserves, Cross River State, Nigeria

Results in Tables 2, 3 and 4 show volume, aboveground green and dry biomasses, and carbon stock and carbon emission per stand across the four selected tropical rainforest reserves of Cross River State, Nigeria. For Afi River Forest Reserve (Table 2), stand aboveground green biomass ranged from305.6043 t ha^{1} to 552.9221 t ha^{-1}, dry biomass ranged from 221.563 t ha^{-1} to 400.868 t ha^{-1}, carbon stock from 110.781 t ha^{-1} to 200.434 t ha^{-1} and carbon-dioxide emission ranged from 406.568 t $ha^{-1}$to 735.593 t ha^{-1}. More so, stand basal area ranged from 36.6801 m^2 $ha^{-1}$to 58.45645 m^2 ha^{-1} while stand volume ranged from 194.8164 M^3 $ha^{-1}$to 289.7242 M^3 ha^{-1}(see Appendix 3). Average stand volume, aboveground green biomass, dry biomass, carbon stock and carbon dioxide emission obtained were244.561M^3ha^{-1}, 448.86t ha^{-1}, 325.423t ha^{-1}, 162.7112t ha^{-1} and 597.1516t ha^{-1}respectively. Similarly, for Agoi-Ibami Forest Reserve (Table 3), stand aboveground green biomass ranged from380.9338t ha^{-1} to 551.6903t ha^{-1}, dry biomass ranged from 276.177tha^{-1} to 399.975t ha^{-1}, stand carbon stock range from 138.088t ha^{-1} to 199.987t $ha^{-1}$and stand carbon-dioxide emission ranged from 506.784t $ha^{-1}$to 733.954t ha^{-1}. Meanwhile, basal area ranged from 42.3426m^2ha^{-1} to 55.4321m^2ha^{-1} while volume ranged from 235.51468$m^3ha^{-1}$to 304.1706m^3ha^{-1}(see Appendix 4). Average stand volume, aboveground green biomass, dry biomass and carbon stock and carbon dioxide emission obtained were263.194M^3ha^{-1}, 459.6653t ha^{-1}, 333.2569t ha^{-1}, 166.6281t ha^{-1} and 611.5267t ha^{-1}respectively.

Meanwhile, for Okpon Forest Reserve (Table 4), stand aboveground green biomass ranged of 305.773 t ha^{-1} to 565.489t ha^{-1}, dry biomass ranged from221.685 t ha^{-1} to 409.979 t ha^{-1},carbon stock range from 110.842t ha^{-1} to 204.989 t $ha^{-1}$and carbon-dioxide emission ranged from 406.793t $ha^{-1}$to 752.312t ha^{-1}(see

Appendix 1). Meanwhile, stand basal area ranged from 37.2351m^{2}ha^{-1} to 68.4448m^{2}tha^{-1} while volume ranged from 233.0377m^{3}ha^{-1}to 307.7707 m^{3}ha^{-1}. Average stand volume, aboveground green biomass, dry biomass carbon stock and carbon dioxide emission obtained were 271.249M^{3}ha^{-1},460.8677 t ha^{-1}, 334.1286t ha^{-1}, 167.0641 t ha^{-1} and 613.1265t ha^{-1}respectively. Finally, results Table 5 show the summary statistics of volume, green and dry biomass, carbon stock, carbon emission per stand in the selected tropical rainforest reserves.

Table 2: Green and Dry Biomass, Carbon Stock, Carbon Emission per Stand in Afi River Forest Reserve, Cross River State, Nigeria

Plot No	Basal Area (M^{2}ha^{-1})	Volume (M^{3}ha^{-1})	Green Biomass (ton ha^{-1})	Dry Biomass (ton ha^{-1})	Carbon Stock (ton ha^{-1})	Carbondioxide Emission (ton ha^{-1})
1	38.7482	215.1715	482.6361	349.9111	174.955	642.087
2	39.2216	252.7308	512.1911	371.338	185.669	681.406
3	38.1742	194.8164	484.7709	351.458	175.729	644.927
4	37.5370	203.3911	501.9358	363.903	181.951	667.762
5	36.6801	195.549	483.1680	350.296	175.148	642.794
6	42.0937	275.1135	336.9981	244.323	122.161	448.333
7	40.2781	259.1086	431.8447	313.087	156.543	574.515
8	45.9414	262.0678	435.097	315.445	157.722	578.842
9	52.4229	289.7242	552.9221	400.868	200.434	735.593
10	45.9876	245.2843	477.8670	346.453	173.226	635.742
11	43.1123	252.0239	383.3207	277.907	138.953	509.960
12	58.45645	292.9043	443.2513	321.357	160.678	589.690
13	40.4356	256.2135	427.7606	310.126	155.063	569.082
14	48.6432	244.9279	498.0921	361.116	180.558	662.649
15	45.9123	275.9833	305.6043	221.563	110.781	406.568
16	40.7654	224.7129	388.6202	281.749	140.874	517.010
17	39.7312	225.8765	451.9229	327.644	163.822	601.226
18	37.3456	198.0985	409.3462	296.775	148.387	544.583
19	44.0987	248.6563	540.0033	391.502	195.751	718.406
20	43.4672	278.8740	429.8466	311.638	155.819	571.857

Table 3: Green and Dry Biomass, Carbon Stock, Carbon Emission per Stand in Agoi-Ibami Forest Reserve, Cross River State, Nigeria

Plot No	Basal Area (M^{2}ha^{-1})	Volume (M^{3}ha^{-1})	Green Biomass (ton ha^{-1})	Dry Biomass (ton ha^{-1})	Carbon Stock (ton ha^{-1})	Carbondioxide Emission (ton ha^{-1})
1	48.2345	289.0264	436.8315	316.702	158.351	581.149
2	48.7397	276.1468	437.2631	317.015	158.507	581.723
3	42.3426	235.51468	380.9338	276.177	138.088	506.784
4	55.4354	278.8002	491.2521	356.157	178.078	653.549
5	45.5412	248.2696	520.4011	377.290	188.645	692.328
6	53.3421	294.5842	450.8886	326.894	163.447	599.850

7	55.2364	303.0245	505.3104	366.350	183.175	672.252
8	52.1341	286.8593	414.1813	300.281	150.140	551.016
9	49.0981	251.1472	420.2220	304.660	152.330	559.052
10	54.1325	288.2316	533.8757	387.059	193.529	710.254
11	53.2476	264.6217	451.6152	327.421	163.710	600.817
12	50.6531	260.4160	437.5011	317.188	158.594	582.040
13	43.2416	231.5264	501.8956	363.874	181.937	667.709
14	45.6543	248.2182	475.5490	344.773	172.386	632.658
15	45.2431	278.4321	396.5379	287.489	143.744	527.544
16	49.6543	265.5034	453.6241	328.877	164.438	603.490
17	50.9705	283.9261	551.6903	399.975	199.987	733.954
18	53.6205	256.9455	405.7210	294.147	147.073	539.761
19	52.1788	279.6155	502.4627	364.285	182.142	668.463
20	55.4321	304.1706	425.5498	308.523	154.261	566.140

Table 4: Green and Dry Biomass, Carbon Stock, Carbon Emission per Stand in Okpon Forest Reserve, Cross River State, Nigeria

Plot No	Basal Area (M^2ha^{-1})	Volume (M^3ha^{-1})	Green Biomass (ton ha^{-1})	Dry Biomass (ton ha^{-1})	Carbon Stock (ton ha^{-1})	Carbondioxide Emission (ton ha^{-1})
1	64.5876	272.3685	420.593	304.930	152.465	559.546
2	68.4448	307.7707	549.437	398.342	199.171	730.957
3	58.0987	271.5307	516.814	374.690	187.345	687.556
4	43.2147	209.5298	425.983	308.837	154.418	566.717
5	54.3458	254.7537	565.489	409.979	204.989	752.312
6	48.9876	233.0377	472.015	342.210	171.105	627.956
7	46.3745	254.2633	538.23	390.217	195.108	716.048
8	53.2765	289.5446	305.773	221.685	110.842	406.793
9	47.6426	242.9633	341.972	247.929	123.964	454.951
10	53.1986	270.9717	368.509	267.168	133.584	490.254
11	51.8764	277.073	562.536	407.838	203.919	748.383
12	45.3452	240.5926	405.336	293.868	146.934	539.249
13	37.2351	236.4323	356.097	258.170	129.085	473.742
14	48.4876	297.8624	473.082	342.984	171.492	629.376
15	41.6804	252.0538	536.071	388.651	194.325	713.175
16	56.8652	290.7036	407.745	295.614	147.807	542.453
17	54.0348	270.8640	499.587	362.200	181.100	664.637
18	49.3984	268.2674	435.194	315.515	157.757	578.971
19	43.2654	238.6213	529.825	384.123	192.061	704.866
20	39.5239	254.9712	507.066	367.622	183.811	674.588

Table 5: Summary Statistics of Volume, Green and Dry Biomass, Carbon Stock, Carbon Emission per Stand in Selected Tropical Rainforest Reserves, Cross River State, Nigeria

S/N	Parameter	Afi Forest Reserve	Agoi-Ibami Forest Reserve	Okpon Forest Reserve
1	Volume (M^3ha^{-1})	244.561	263.194	271.249
2	Green biomass (ton ha^{-1})	448.860	459.665	460.867
3	Dry biomass (ton ha^{-1})	325.423	333.256	334.128
4	Carbon stock (ton ha^{-1})	162.711	166.628	167.064
5	Carbon-dioxide emission (ton ha^{-1})	597.151	611.526	613.126

5. Discussion

The average volume recorded for these selected reserves are far above that reported by Ajayi and Adie, (2018) (212.588m^3h^{-1}), and slightly above the volume of 250 m^3h^{-1} recommended by Dianyuan Han (2012) for a normal tropical high forest. Also, the volume obtained is far higher than that reported by Bassey and Ajayi, (2020) (177.2647m^3h^{-1}). This high volume recorded is an indication that the level of encroachment is relatively low and efforts must be intensified so as to sustain and improve on the reserves especially with the alarming and continuous rate of global warming and climate change. The higher values of volume obtained in this study is an indication that the selected forest reserves are probably some of the richest of the tropical rainforest left in Nigeria, which was also reported by ITTO (2011). Thus, efforts should be made to sustain this level of recommendable management approach through alternative sources of livelihood, integrated management system and time to time anti-poaching patrol.

The amount of aboveground biomass obtained using the equation of Brown (1997) across the three selected forest reserves was not significantly different with each other. Okpon Forest Reserve recorded the highest volume and aboveground biomass across the selected reserves and followed by Agoi-Ibami, Boshi and Afi River Forest Reserves respectively. The mean volume per hectare recorded in this study across reserve is relatively higher than the values reported for tropical rainforest ecosystems in Nigeria by previous researches (Adekunle *et al.,* 2004 who reported 181.36 m^3/ha in Shasa Forest Reserve; 227 m^3/ha in Ala Forest Reserve; 91.71 m^3/ha in Omo Forest Reserve; and Adekunle and Olagoke (2008) who reported 262.36 m^3/ha). The higher values of aboveground biomass obtained in this study is an indication that the selected forest reserves are probably some of the richest of the tropical rainforest left in Nigeria, which was also reported by ITTO (2011).

Similarly, the aboveground green and dry biomasses, carbon stock and carbon dioxide recorded in the selected reserves are higher than that recorded by Ajayi and Adie, (2019).Carbon stock recorded in this study is way too far compare to that reported by Ajayi and Adie, (2019) (59.58 t ha^{-1}) in a mono plantation. This result confirmed the assertion that, ‘plantations have only about half the amount of carbon in their biomass as compared to natural tropical rainforest (FAO, 1996). The plantings of mixed native species usually known as environmental plantings and mono plantations are increasingly being developed for carbon sequestration whilst providing additional environmental benefits such as biodiversity and water quality (ITTO, 2001). Forest biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity and carbon budget (Hall *et al.,* 2006). The potential capacity of forests to sequester carbon will obviously influence the future balance of global carbon flux; however, this potential is largely determined by the rate of carbon sequestration occurring in forests and the calibration will still rely on the accuracy of ground-based carbon storage estimation (Baccini *et al.,* 2012). Globally, there is a growing concern on the sustainability of the forest estate so that the benefits from it can be available in perpetuity (Akindele *et al.,* 2001). This concern needs to be fully expressed in Cross River State to manage the remaining forest resources in the natural and plantation forests, reserves and parks sustainably given that the state is the pilot state in Nigeria for effective implementation of United Nation-Reducing Emission from Deforestation and Forest Degradation (UNREDD+) Program.

6. Recommendations

Permanent sample plots should be established in the study areas to enhance and promote accurate data collection and for informed management decisions.

Government should provide the enclave communities with alternative source(s) of livelihood in order to sustain and improve on the management of the reserves.

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