CARBON SEQUESTRATION OF ABOVE GROUND TREE BIOMASS IN TROPICAL HIGH FORESTS AND MONOPLANTATIONS IN OKPON RIVER FOREST RESERVE, CROSS RIVER STATE, NIGERIA

*[1]Donatus A. Adie and [2]Samuel Ajayi,

[1]Department of Forestry and Wildlife Resources Management, University of Calabar, Calabar, Cross River State, Nigeria.
[2]Department of Forestry and Wildlife Management, University of Cross River State (Okuku Campus), Cross River State, Nigeria.
*Corresponding author's email: *adiedonatusalada@gmail.com*, +2349091269644,

ABSTRACT
This study assessed the above-ground biomass (AGB) of Tropical High Forests (THF) and a 20-35-year-old teak plantation in the Okpon River Forest Reserve, Cross River State, Nigeria. The research used a simple random sampling technique with 26 nested plots in THF and 10 in the teak plantation. A total of 610 trees (435 in THF and 175 in the plantation) were measured for diameter at breast height (dbh ≥5cm). These measurements, along with wood species density, were input into allometric equations to calculate above-ground green biomass, dry biomass, and carbon stock.Results revealed a mean dbh of 42.3 cm in THF and 24.2 cm in the plantation. The THF had a mean basal area of 38.51 m²/ha, compared to 29.06 m²/ha in the plantation. Average stand volume in the THF was 212.6 m³/ha, higher than the 155.95 m³/ha in the plantation. The tropical high forest had significantly higher biomass and carbon stock, with 423.74 t/ha of green biomass, 307.21 t/ha of dry biomass, and 153.61 t/ha of carbon, compared to the plantation's 164.36 t/ha, 119.16 t/ha, and 59.58 t/ha, respectively. The plantation's high tree density suggests overcrowding, indicating a need for thinning to promote growth. Conversely, the THF's stand density indicates limited anthropogenic disturbance and efficient nutrient uptake. To improve forest productivity, it is recommended to implement better management practices such as boundary cleaning and enrichment planting.

Keywords: Carbon stock, tropical high forest, mono-plantation, green biomass, tree biomass

INTRODUCTION

Forests are very important ecosystems, delivering several benefits that go far beyond the supply of timber, including fuel wood, fodder, food, bamboos, Non-Timber Forest Products-NTFPs, carbon sequestration, climate amelioration, soil and water conservation as well as tourism/recreation. Furthermore, forests play a key role in maintaining water quality, clean air, and help in regulating climate, floods, pollination and biological control of diseases thus providing various regulatory services (Shahid and Joshi, (2015). Estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest. It also gives us an idea of the potential amount of carbon that can be emitted in the form of carbon dioxide when forests are being cleared or burned. Biomass estimation of the forest ecosystem enables us to estimate the amount of carbon dioxide that can be sequestered from the atmosphere by the forest. The accurate assessment of biomass estimates of a forest is important for many applications like timber extraction, tracking changes in the carbon stocks of forest and global carbon cycle. Tropical forests store 25% of the global carbon and harbour 96% of the world's tree species, thus depicting the importance of forest in carbon sequestration (UN-REDD+, 2015).

A rapidly expanding interest in the ability of trees to sequester carbon has spawned numerous initiatives for forest conservation, regeneration and improved management (Shahid and Joshi, 2015; Ajayi and Bassey, 2024). In terrestrial ecosystem, forest stores most of the carbon while the high amount of the carbon sequestrated by the forest is held in woody biomass (Tian*et al.,* 2014). Carbon is retained by tree foliage and stored as carbon-rich organic compounds such as cellulose and hemicelluloses, lignin, starch, lipid and waxes, mostly in secondary woody tissues in tree boles and in large roots, as well as in foliage, branches and fine roots (Unwin and Kriedemenn, 2000).

Global emission of carbon dioxide has increased by 18% and is damaging the environment by reaching to the highest level after 1750 (Chavan and Rasal, 2012). In the past two decades, tropical land-use change, especially deforestation and forest degradation, has accounted for 12–20% of global anthropogenic greenhouse gas (GHG) emissions (Chave*et al.,*2014). Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide, and on measuring carbon absorbed by and stored in forests, soils, and oceans (Gorte, 2009). Carbon sequestration, and the extent to which it can be counted as a reduction in a nation's carbon emissions, have been the focus of substantial controversy in international negotiations subsequent to the Kyoto Protocol.

Cross River State is facing rapid tropical deforestation processes as its forest is cleared regularly and extensively for the establishment of food crops and cash crops such as cocoa, oil palm, banana and plantain and traditional method of burning most tree-cover during crops farming, while which the remaining litters/biomass decay. During these processes, carbon dioxide is released into the atmosphere from both the biomass and soil, hence increasing the carbon flux.

To meet the challenge of providing high quality wood for the increasing population and rapid industrialization at sustained production level while preserving our natural heritage for future generation, exotic tree species were introduced into Nigeria and other parts of the world. The Federal and State governments in Nigeria in conjunction with the World Bank have heavily invested in plantation establishment of those exotic species (predominantly Teak *and* Gmelina*)*in most parts of the countryto provide raw materials in the form of poles, timber, veneer, wood particles, pit props, pulp and fuelwood. Vast plantations of these introduced species were to be established almost everywhere including Cross River State. According to International Tropical Timber Organisation – ITTO (2001), these plantations have answers for more than a few global problems. They reduce deforestation, restore degraded land, ameliorate climate change, improve local livelihood, return good profits, create employment and bolster national economies.

There is need for comparison of biomass from tropical high forest and mono-plantations because, in recent pasts, emphasis has been on tropical high forest biomass assessment in Cross River State. It is obvious that the tropical high forest will continue to be under pressure. Therefore, extensive plantation forestry will be the next feasible alternative, hence, the need to be interested in carbon pool of mono-plantations. In fact, there are hundreds of hectares of privately owned teak plantations across the state (located at Obubra, Ikom, Ogoja, Obudu, Akamkpa, andOdukpani) primarily for carbon trade. Forest plantations on non-forested land create a clean and reliable way ofabsorbing the excess CO_2 in the atmosphere which also prevent continuous greenhouse gas emissions and` contributes to benefits such as timber production, environmental protection, biodiversity and land rehabilitation (Unwin and Kriedemenn, 2000).

The objective of this study is to estimate above-ground tree biomass and determine sequestered carbon inthetropical high forest (THF) and Mono-plantation (Teak) in Okpon River Forest Reserve, Cross River State.

METHODOLOGY

Study Area

The research was conducted in the Okpon River Forest Reserve within the Central senatorial district of Cross River State. Tropical High Forest (THF) and Mono-Plantation (Teak) of the selected areas wereconsidered in this research. Okpon River Forest Reserve is located withinObubra, Etung and Yakurr Local Government Areas in Cross River State, Nigeria (Latitudes $5^{o}40^{1}30^{11}$ and $5^{o}57^{1}30^{11}$N and Longitudes$8^{o}12^{1}00^{11}$ and $8^{o}32^{1}00^{11}$ E).

The reserve has a total area of thirty-one thousand, three hundred hectares (31,300 Ha.) in which 22,194.04 hectares is THF while Teak plantation occupies 3,165.694 hectares and other land uses has 5,940.26 hectares (NASDRAand FAO, 2014). The elevation of the study areas ranged between 14 m and 87 m above mean sea level. The study area has a moist tropical maritime climate, with high rainfall concentrated during monsoon period from June to September and high temperature. The mean annual rainfall ranges from 2,500mm in January to 4,000mm in August. The rain is fairly distributed through-out the months of April to October. Mean annual temperature ranges from 27.6^{0} C in August to 33.1^{0} C in February. The strong stormy winds usually accompany the onset of dry season, which is caused by hot and dry North East wind. The mean relative humidity ranges from 71% in February to 90% in August (Ajayi*et al.*, 2006).

Sampling Technique and Data Collection

In this study, simple random sampling technique was used to lay 26 and 10 nested plots (35m x 35m each) in the tropical high forest and mono-plantation respectively. The sampling intensities used in tropical high forest and teak plantation were 0.02%and 0.03% respectively. Each plot consisted of three nests: Small nest (7m x 7m), Medium nest (25m x25m) and large nest (35m x35m) - (Winrock, 1998).

Tree diameters measured in each nest were:

- **i.** 50cm and above dbh in large nest
- **ii.** 20cm – 49cm dbh in medium nest
- **iii.** 5cm – 19cm dbh in small nest

Systematic sampling method was used for identifying the mono-plantation (teak) in the field. At first, the geo-positions of the plantation and THF were determined using GPS. Primarily, the land use of each

intersection point was identified in the field. In the fixed grid lines, tree stems were counted: Diameter tape and Sunto clinometers were used for diameter and height measurements. Diameter at breast

DATA ANALYSIS

Above Ground green tree Biomass Calculation for a Single Tree

It is impossible to estimate biomass of plantation/THF by cutting all the trees due to substantial costissues involved and numerous demerits to the environment. In order to address this, the model developed by Chave*et al.* (2014) was used. This equation is recommended if it is possible to measure height with reasonable confidence. The equation was used in this research as it is one of those developed for the sub-Sahara Africa. The Chave*etal.*(2014) allometric equation for AGB inmoist tropical forest (kg) is of the form:.

$$AGBest = 0.0673 \times (\rho \times D^2 \times H0.976) \quad - \quad - \quad - \quad - \quad - \quad \text{Eq. 1}$$

where**:**

AGBest = above ground biomass (kg)

ρ = species specific wood density (g/cm^3)

D = diameter at breast height (cm)

H = total tree height (m)

Above-ground green Biomass Calculation for Sample Plot

In each Sample plot, variable estimates for all trees were added together to

height (1.3 m above ground) and Height were measured for all trees of the plot while density of each of the trees measured was determined from the default values of the Pan tropical table (Chudnoff, 1984) and Wood densities for tropical tree species (Gisel*et al.*, 1992). The obtained values were used to estimate the biomass of each tree within the sample plots in the tropical high forest and plantation.

obtain an estimate of the total AGB for each sample plot.

Above-ground green Biomass Calculation per Hectare

AGB is always reported on a per hectare basis hence, the formula for converting from a per plot estimate (in kg) to a per hectare estimate (in kilogram per hectare) is as follows:-

$$AGB_h = (A_h/A_p) \times AGB_p \quad - \quad - \quad - \quad - \quad - \quad \text{Eq 2}$$

where**:**

AGB_h= Above-ground green biomass (Kgha^{-1})

A_h = area of one hectare in m^2

A_p = area of the plot in sqm^2

AGB_p = the plot level estimate of above-ground biomass (in kg)

Above-ground Dry Biomass Calculation per Hectare

Above ground dry biomass is calculated from:

$$W = \frac{AGB_h \ X\ 0.725}{1000} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad \text{Eq 3}$$

where:

W= above-ground dry biomass (Metric tonsha^{-1}),

AGB_h = Above-ground green biomass (kgha^{-1})

Note that average tree is 72.5% dry matter and 27.5% moisture (Chavan and

Rasal, 2010) and 1000 kg is equal to 1 metric ton.

Carbon Sequestration

The content of carbon in woody biomass of any forest is generally 50% of the tree's total volume. Therefore, the weight of carbon in the tree was calculated by multiplying the dry weight of the tree by 50% (Eneji*et al*., 2014)

The equation for the measurement of Carbon sequestered per hectare is given as:

$$S_c = W \times 0.5 \qquad \text{Eq 4}$$

where:

S_c= Sequestered carbon (tha^{-1})

W= above-ground dry biomass (tha^{-1}) (IPCC, 2006; Bassey and Ajayi, 2020)

RESULTS

Summary of characteristics data for THF and mono-plantation (Teak)

In Table 1, a total of 435 trees were measured for diameter at breast height (dbh) in the 26 plots of THF while 175 trees were measured in the 10 plots of the mono-plantation. Average dbh of 42.3cm and 24.2 cm were obtained for THF and mono-plantation respectively. Mean basal area of 38.51 $m^2ha^{-1}$was determined for the THF and 29.06$m^2ha^{-1}$for mono-plantation.

The result also indicates that the 20–35-year-old plantation has average stocking of 1068 stemsha^{-1}and basal area of 29.06m^2ha^{-1}.

Average stand volume in the THF was 212.588m^3ha^{-1} as against 155.954m^3Ha in the plantation.

For the THF, a total of 68 trees species belonging to 37 families were identified. *Leguminosae Moraceae*, *Meliaceae* and *Sterculiaceae* the dominant in the study area with the family Leguminosae accounting for 24 individual tree species, followed by Moraceae with 10 individual tree species. Meliaceae and Sterculiaceae had 5 individual trees species each. Predominant species include *Albizia Spp.*, *Pterocarpus osun*, *Piptadenistrum africanum*, *Daniella ogea, Brachystegia eurycoma, Ficus experata*, *Treculia africana*, *Antiaris africana, Carapaprocera*, *Khaya ivorensis, Pterogota Spp., Sterculia Spp.* and *Triplochyton sclroxylon.* Other families had fewer individual tree species represented.

Green and Dry Biomass and Carbon Stocks for Tropical High Forest and mono-plantation

Average above-ground green biomass, dry biomass and carbon stock were423,741.46 kg ha^{-1} (423. 74 t ha^{-1}), 307.21 t ha^{-1}, and 153.61 t ha^{-1}respectively for the tropical high forest (Table 2); while 164,365.0 kg ha^{-1}(164.36t ha^{-1}), 119.16 t ha^{-1}, and 59.58t ha^{-1} respectively were obtained for the mono-plantation (Table 3)

DISCUSSION

The observed stocking density of 1068 stemsha^{-1}in the plantation is high considering the age range of 20 – 35 years. The high density can be attributed to the fact that the stands have not been thinned. High dry biomass yield of 119 t ha^{-1} could be attributed to fast growth rate of the tree species with emphasis on height growth due to high nutrient of the site. Average dbh of 24.2cm and density of 29m^2ha^{-1} in this plantation reflect a degree of crowding. There is urgent need to thin the stands to enhance lateral growth. For the tropical high forest, the stand density of 38.51m^2ha^{-1}

is very high compared with 30 – 35m^{2}ha^{-1} suggested as normal density by Dianyuan (2012), though lower than 49.35m^{2}ha^{-1} obtained for Boshe Forest Reserve in Cross River State (Ajayi and Bassey, 2024).

This can be attributed to high nutrient uptake by the trees (that is, the site is productive). Secondly, it reflects adequate protection and human activities limited encroachment level. However, the stand volume of 212.588m^3 ha^{-1} is slightly short of 250m^{3h}a^{-1} recommended by Dianyuan (2012) as normal for tropical high forest. This shortfall could be as a result of recent isolated cases of human encroachment and disease attack on some stems over the years. Therefore, effort should be made to improve the current density and productivity through good management techniques such as boundary cleaning and enrichment planting. This will guarantee steady forest cover increase, vital for wood production for construction and fuel wood supply, environmental protection and carbon trade.

Above-ground green biomass in THF was423,741.46 kgha^{-1}(423.7 t ha^{-1}) while the plantation had 164,365.0 kgha^{-1} (164.4 t ha^{-1}). These values compare favourably with the findings of Onyekwelu et al., (2004) for *Gmelina arborea* in Omo and Oluwa forest reserves in south-western Nigeria. They observed that total above ground biomass (TAGB) varied from 181.5 t ha^{-1} (10 years) to 392.1t ha^{-1} (25 years) in Oluwa and from 184.4 t ha^{-1} (11 years) to 382.1t ha^{-1} (25 years) in Omo. Similarly, Onyekwelu. (2007) recorded 32.5 - 287.7 t ha^{-1}between ages 5 and 30 years for Opepe (*Nauclea diderrichii*) plantation in Omo forest reserve, a humid tropical rainforest zone of south-western Nigeria. From this result, the THF is more densely stocked with large diameter trees and higher average density than mono-plantation (teak). This accounts for the higher above-ground green biomass in THF than the mono-plantation (teak)

In this study, the carbon stocks were 153.61 t ha^{-1} and 59.58 t ha^{-1} (Table 2) in THF and mono-plantation respectively. Tropical high forest stored more carbon than teak plantation due to composition of trees. For example, THF species has higher proportion of large trees with high Leaf Mass per Area (LMA) and well-developed tissues; hence it is higher tree carbon than in the mono-plantations. This result confirms the assertion that, 'plantations have only about half the amount of carbon in their biomass as compared to natural tropical forest (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; Clark and Kellner, 2012). Globally, there is a growing concern on the sustainability of the forest estate so that the benefit 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.

Conclusion and recommendations

Wood productivity in the tropical high forest of OkponRiver Forest reserve is relatively low. Therefore, effort should be made to improve the current density and productivity through good management approach such as boundary cleaning and enrichment planting. This will guarantee steady forest cover increase for wood production for construction and fuel wood supply, environmental protection and carbon trade. The stocking density of teak plantation in the reserve is high considering the age range; therefore, there is urgent need to thin the stands to enhance lateral growth so as to improve the biomass production.

The principal element for the estimation of forest's carbon stocks is the estimation of forest biomass. Forest biomass estimation is also needed for the sustainable planning of forest resources. The study has provided estimates of above-ground biomass for two different forest types in the study area. This is useful for wood productivity studies, forest conservation and carbon trade. Estimation of forest carbon stocks will enable the assessment of the amount of carbon loss during deforestation or the amount of carbon that the forest can store when such forests are regenerated/managed sustainably.

Based on the findings of this study, the following recommendations were made:

i. Ensure effective monitoring of these forests and humans' activities in the study area to reduce negative impacts on the forest cover (green biomass).

ii. Improve forest carbon stocks through reforestation and forest enrichment planting.

iii. Reduce carbon emission from forest degradation and human induced loss of carbon stocks from forest (through reduction of anthropogenic activities).

For further study, it is recommended that CO_2 emission for these two forest types be determined and biomass equations developed for the tropical high forest and Teak plantation in Okpon River Forest reserve.

REFERENCES

Ajayi, S. & Bassey, S. E. (2024) Non-Linear Models for Individual Tree Volume and Aboveground Biomass Estimation in Boshi Forest Reserve, Cross River State, *Nigeria. Journal of Contemporary Research* (JOCRES). 3(3):128-141. ISSN: 2814-2241

Ajayi, S., Osho, J. S. A. & Ijomah, J.U. (2006). The use of DBH and Stem Height to Determine Tree Volume Equation for *Gmelina arborea* (ROXB) Plantations in Okpon River Forest Reserve, Cross River State, Nigeria. *Global Journal of Agricultural Sciences*. 5(2): 141 – 146. (http//www.inasp.info/ajol).

Akindele, S.O., Dyck. J., Akindunmi, F. F.,Papka, P. M. & Olaleye, O.A. (2001). Estimate of Nigeria`s Timber Resources. In L. Popoola, J. E. Abu & P.I Oni (Eds.) *Proceedings of the 27th Annual Conference of the Forestry Association of Nigeria*, Abuja FCT. Pp1-11.

Baccini, A., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D., & Hackler, J. (2012). Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. *Nature Climate Change*, 2: 182-185.

Bassey S. E. & Ajayi, S. (2020). Modeling of

Aboveground Tree Stand-Level Biomass in Erukot Forest of Oban Division, Cross River National Park, Nigeria. *Journal of Agriculture, Forestry and the Social Sciences (JOAFSS).* Vol. 18. No 1, 2020. ISSN: 1597-0906

Chavan, B. L.& Rasal, G. B. (2012). Total Sequestered Carbon Stock of *Magnifera indica*. *Journal of Environment and Earth Science*. 2(1):1-37. www.iiste.org ISSN 2224-3216 (Paper) ISSN 2225-0948

Chave J., Rejou-Mechain M. Burquez., A, Chidumayo, E.N.,Colgan M, Delitti W, Duque A. J, Welington D, Fearnside P. M, Goodman R, Henry M, Martínez-Yrízar A, Mugasha W, Muller-Landau H, Mencuccini M, Nelson B, Ngomanda A, Nogueira E, Ortiz Malavassi E, Pélissier R, Ploton P, Ryan C, S J. G. & Vieilledent, G. (2014). Improved PantropicalAllometric Models to Estimate the Above Ground Biomass of Tropical Forests.*Glob Change Biol* 20: 3177–3190.

Chudnoff, Martin. (1984). *Tropical Timbers of the World. Agric. Handb*. 607. Washington, DC: U.S Department of Agriculture. 464 Pp. 8

Clark, D. & Kellner, J. R. (2012). Tropical Forest Biomass Estimation and the Fallacy of Misplaced concreteness – *Journal of Vegetation Science*. 23(1): 1191-1196.

Dianyuan, Han (2012). Standing Tree Volume Measurement Technology Based on Digital Image Processing, *International conference on Automatic control and Artificial Intelligence* (ACAI,2012), pp1922-1923.

Eneji, I.S; Obinna, O. & Azuaet, E. T. (2014). Sequestration and Carbon Storage Potential of Tropical Forest Reserve and Trees Species Located within Benue State of Nigeria. *Journal of Geoscience and Environmental Protection* 2:157 – 166.

FAO.(1996). *Forest Resources Assessment 1990. Survey of Tropical Forest Cover and Study of Clunge Processes Based on Multi-Date High-Resolution Satellite Data Forestry* Paper 130-Rome: FAO, Pp. 152.

Gisel Reyes, Sandra Brown, Jonathan Chapman & Ariel E. Lugo (1992). *Wood densities of tropical species*. US Department of Agriculture (Forest Service).Southern Forest Experiment Station. New Orleans, Louisiana. *General Technical Report* SO – 88, February, 1992. 18 pp

Gorte Ross W. (2009).Carbon Sequestration in Forests.*CRS Report for Confrence*. August 6, 2009.Pp 15-27

Hall, R. J., Skakun, R. S., Arsenault, E. J. & Case, B. S. (2006). Modelling Forest Stand Structure Attributes Using Landsat ETM+ data: Application to Mapping of Above-ground Biomass and Stand Volume: *Forest Ecology and Management*. 225(1-3): 378-

ITTO (2001) Plantations on the March. Tropical Forestry Update Vol. 11, No. 3.www.itto.or.ip and tfu@itto.or.ip

IPCC (2006).2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme (eds Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K.).*Institute for Global Environmental Strategies, Japan*

NASDRA & FAO (2014).Deforestation and Forest Degradation.Forest Survey.http://www.youtube.com/watch?v=TMV4HhFM118.

Onyekwelu, J. C., Reinhard Mosandl & Berd Stimm (2004). Productivity, site evaluation and state of nutrition of Gmelinaarborea plantations in Oluwa and Omo forest reserves, Nigeria.*Forest Ecology and Management,* 229{2006): 214-227

Onyekwelu, J. C. (2007) Growth, biomass yield and biomass functions for plantation grown Naucleadiderrichii (de wild) in the humid tropicalrainforest zone of south-western Nigeria. *Bioshere Technology,* 98 (2007):2679 – 2687)

Shahid Mohommad & Shambhu Prasad Joshi (2015). An Assessment of Carbon Sequestration Ecosystem Service in the Forests of Doon Valley, Western Himalaya, India.*Global Journal of Science Frontier Research: Environment and Earth Science*. 15(3)

Tian Yi Ma, Sheng Dai, MietecJaroniec& Shi Zhang Qiao (2014). Metal–Organic Framework Derived Hybrid Co_3O_4-Carbon Porous Nanowire Arrays as Reversible Oxygen Evolution Electrodes. *Journal of the American Chemical Society,* I36(39): 13925–13931.

UN-REDD + Programme (2015). Participatory Governance Assessment for REDD+ and Natural Resource Management in Nigeria. *Draft of 7 October*, 2015

Unwin G. L. & Kriedemann, P. E. (2000). Principles and Process of Carbon Sequestration by Trees.Research and Development Division State Forest of New South Wales, Sydney.Page 64.

Winrock International Institute for Agricultural Development (1998).A Guide to Carbon Storage in Forestry and Agroforestry Projects. Forest Carbon Monitoring and Verification Services, Article 566: 504.

Table 1: Summary Data for THF and mono-plantation (Teak)

S/N	Parameters	THF	Mono-plantation
1	Number of sample plots	26	10
2	Number of trees measured	435	175
3	Average number of trees per hectare (N ha^{-1}) for plantation	-	1068
4	Mean dbh/Range (cm)	42.3 (5 -200)	24.2 (5 -39)
5	Mean Basal Area/ Range (m^2 ha^{-1})	38.51 (17.81 – 53.71	29.06 (15.88 – 45.53)
6	Mean Volume/ Range (m^3 ha^{-1}).	212.588 (70.661 - 380.197)	155.954 80.747 – 251.366

Table 2: Biomass and Carbon Stock for T[illegible]l High Forest in Okpon River F[illegible]Reserve

PLOT ID	Basal Area (m^2ha^{-1})	VOLUME (m^3 ha^{-1})	Green Biomass (Kg ha^{-1}.)	Dry Biomass= (Green biomass X 0.725) ÷ 1000 (tha^{-1}.)	Carbon Stock = (Dry biomass X 0.5) (t ha^{-1}.)
THF1	20.9443	104.5722	259780.2	188.34	94.17
THF2	49.5573	299.0935	60349.6	43.75	21.88
THF3	42.9527	244.4625	624071.9	452.45	226.23

THF4	59.1974	380.1969	992265.5	719.39	359.70
THF5	38.9881	201.5732	474562.5	344.06	172.03
THF6	40.8922	216.3386	681752.1	494.27	247.14
THF7	38.4258	218.1614	667390.9	483.86	241.93
THF8	43.8198	267.4509	512477.7	371.55	185.77
THF9	23.5458	70.6607	136034.9	98.63	49.31
THF10	17.8659	88.7529	145896.8	105.78	52.89
THF11	50.7475	311.8572	818225.9	593.21	296.61
THF12	31.4584	166.3836	384057.6	278.44	139.22
THF13	45.4644	256.7699	935029.6	677.90	338.95
THF14	44.3258	258.4801	519122.1	376.36	188.18
THF15	31.6186	167.0006	301789.6	218.80	109.40
THF16	38.7935	194.562	378165.5	274.17	137.08
THF17	41.2778	216.531	426714.8	309.37	154.68
THF18	42.4127	247.9785	123554.5	89.58	44.79
THF19	26.1415	127.5634	158777.5	115.11	57.56
THF20	53.7145	293.1413	390624.5	283.20	141.60
THF21	25.3549	131.3355	189724.7	137.55	68.78
THF22	46.6382	261.6859	397092.3	287.89	143.95
THF23	31.4384	172.75	278229.6	201.72	100.86
THF24	24.5655	136.9454	282622.8	204.90	102.45
THF25	48.073	267.1538	474432.5	343.96	171.98
THF26	42.9293	225.8943	404531.9	293.29	146.64
TOTAL	**1001.143**	**5527.295**	**11017278**	**7987.53**	**3993.76**
AVERAGE	**38.51**	**212.588**	**423,741.46**	**307.21**	**153.61**

10

Table 3: Biomass and Carbon Stocks for [illegible]lantation (Teak) (2.5m x 2.5m)

PLOT ID	Age (Yrs)	Number/ Ha (N ha^{-1})	BA/Ha (m^2 ha^{-1})	Vol./Ha (m^3 ha^{-1})	Green Biomass (Kg ha^{-1})	Dry Biomass = (green biomass X 0.725) ÷ 1000 (t ha^{-1})	(Carbon Stock) = (Dry biomass X 0.5) (t ha^{-1})
TECGRA1	20	1104.33	23.828	134.9564	152523.4	110.58	55.29
TECGRA2	20	1512.49	25.113	140.5602	163052.3	118.21	59.11

TECGRA3	30	1464.49	36.32	178.9048	202192.6	146.59	73.29
TECGRA4	35	1448.49	45.531	251.3659	284085.2	205.96	102.98
TECGRA5	20	788.25	15.88	80.7472	91258.1	66.16	33.08
TECGRA6	25	237.33	27.998	139.9451	158161.5	114.67	57.33
TECGRA7	25	960.33	24.614	140.2642	158522.1	114.93	57.46
TECGRA8	35	1432.49	42.782	238.6286	107586.91	78.00	39.00
TECGRA9	20	960.33	18.797	116.9418	136200.384	98.75	49.37
TECGRA10	25	772.25	29.772	137.2261	190068	137.80	68.90
TOTAL		10680.78	290.635	1559.54	1643650.03	1191.65	595.82
AVERAGE		1068	29.06	155.954	164,365.0	119.16	59.58

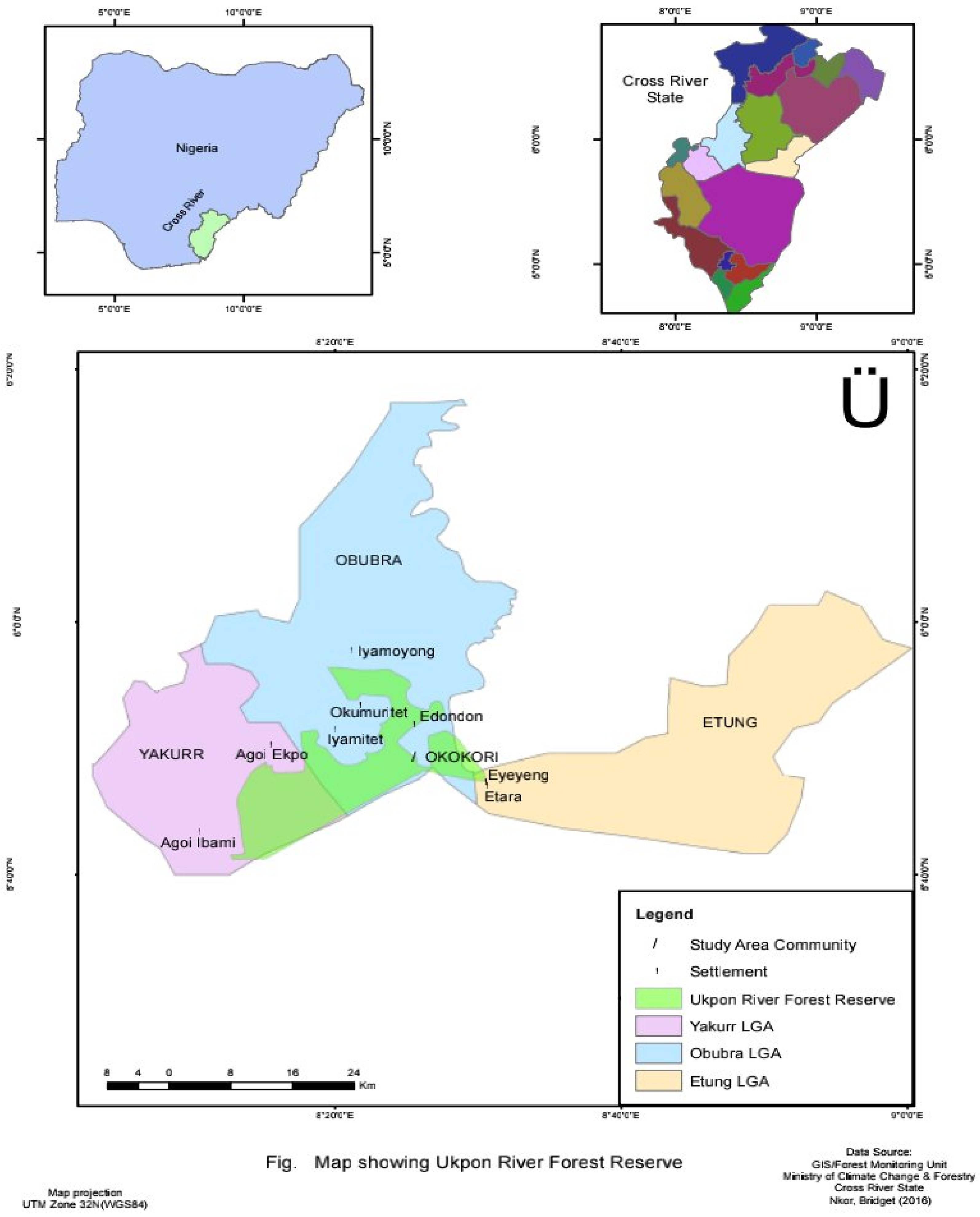

Figure 1: Map of Study Area

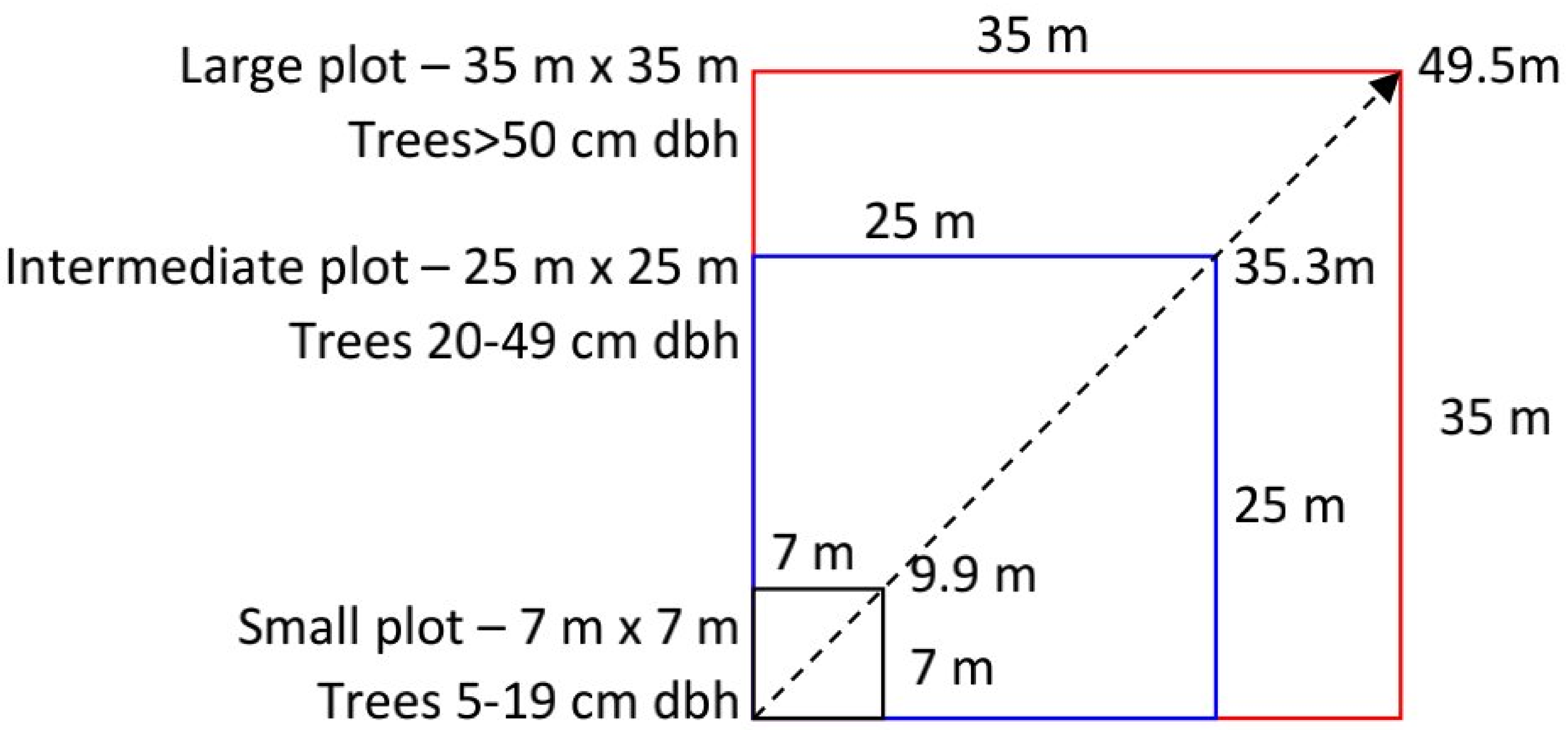

Figure 2: Tree diameter (dbh) class measurements in the three nests of each sample plot.