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Assessment of Above-Ground Biomass (AGB) and Tree Diversity across Rainforest Ecosystems in Nigeria

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Abstract
The tropical rainforest ecosystem in Nigeria is very rich in species diversity and plays a significant role in conserving biodiversity resources and supporting livelihood. However, these ecosystems are characterized by inadequate information on the species diversity and biomass carbon accumulation This study investigated the above-ground biomass (AGB) and tree diversity across the tropical rainforest ecosystem of Nigeria. Data on variables such as Diameter at the breast height and total tree height of the trees were collected from seven forest reserves located in the tropical rainforest area. The diversity index was computed, the generalized pan-tropical aboveground biomass equation was used to estimate the tree biomass. The results revealed that the Shannon diversity index ranged from 1.876 to 2.933 across the forest ecosystem, Shaha forest reserves recorded the highest species diversity. The Ekuri forest reserves had the least AGB values with 110.4 Mg/ha while Ago Owu and Akure forest reserves indicated the highest AGB values of 861.3 and 828.3 Mg/ha respectively. This study has provided empirical evidence that there are high biomass density and species diversity across the tropical forest ecosystem in Nigeria. The results indicated that there are dissimilarities in the species diversity across the seven forest reserves. The study revealed that a significant relationship exists between species diversity and the AGB across forest ecosystems and the ecosystem could hold great potential for biodiversity conservation in the area. It is therefore recommended that requisite silvicultural practices such as enrichment planting that could enhance the diversity of the forests be taken seriously.

Keywords: Rainforest, Ecosystem, Diversity, Biomass, Vegetation.

Introduction

Africa is undoubtedly facing critical challenges of biodiversity loss (Borokini *et al.*, 2013; Onefeli *et al.*, 2013; Onefeli, 2016; Onefeli, 2018; Leishra *et al.*, 2020) and climate change (Serdeczny *et al.*, 2017). These challenges have been majorly linked to unsustainable forest management practices in tropical countries. Tropical forests are the highest biomass accumulator of the world's terrestrial ecosystems (Philips *et al.* 1998; Pan *et al.*, 2011; Urbazeav *et al.*, 2018; Jegede *et al.,* 2020). It accounted for over 40% of total global biomass and carbon sequestration (Day *et al.,* 2013). This large amount of biomass accumulation in tropical forests has been attributed to the high level of tree species diversity (Mensah *et al.*, 2016; Lawal *et al.*, 2020; Onefeli, 2021). However, tropical forests have been subjected to a high level of deforestation and degradation thereby contributing to the global challenges of biodiversity loss and climate change (Strassburg *et al.* 2010; Talbot, 2010; Day *et al.*, 2013; Onefeli *et al.* 2014). Relationships and interactions between forest biodiversity and biomass accumulation have been receiving attention in the last couple of decades from researchers, Non-Governmental Organizations (NGOs), policymakers, and other stakeholders on climate change (Midgley *et al.* 2010). This is because forest-based mitigation and adaptive strategies are significant components of the Paris climate agreement (Grassii *et al.,* 2017). The quantification of biomass and carbon sequestration is required for forest-based protocol compliance (Ebeling and Yasue 2008; Vieilledent *et al.*, 2012; Srinivas and Sundarapandian, 2019). It is indispensable in carbon pricing in the Reducing Emission from Deforestation and Degradation (REDD+) initiatives (Köhl *et al.*, 2020). It is vital in the analysis of atmospheric carbon dynamics and carbon stock forecasts (Le Toan *et al.*, 2011; Pan *et al.*, 2011; He *et al.*, 2013; Sharma *et al*., 2020). The measure of forest ecosystem services and forest management sustainability can also be ascertained from forest biomass assessment (Caputo *et al.*, 2016). Therefore, understanding the relationship between biomass and biodiversity will be essential in the implementation of forest-based climate change adaptation and mitigation mechanisms (Midgley *et al.* 2010; Strassburg *et al.* 2010).

There is increasing attention on assessing regional forest biomass and carbon estimates for social economics, ecological and environmental protection (FAO, 2020; Verkerk *et al.*, 2019). Hence, adequate information on forest biomass and carbon stocks that can be used to extrapolate the tree variables are available in some regions of the world (FAO, 2020; Ploton *et al.*, 2020; Verkerk *et al.*, 2019). There is precise information on biomass and carbon pools of tropical forests on a global scale (Srinivas and Sundarapandian, 2019). However, such information is lacking in most countries in West Africa (FAO, 2020). This results in a dearth of information on carbon pools of the forests due to inadequate local and national carbon inventories with the consequences on economics and impediments to the implementation of carbon credit initiatives.

The appropriate technique to evaluate the effects of diversity on biomass accumulation is through experimental designs. This method of biomass accumulation is practicable in grassland ecosystems (Oba *et al.*, 2001). However, the slow growth rate and the complexity of the tropical forest ecosystem impede the use of this experimental manipulation (Li *et al.*, 2018). Hence, tree sampling has gained prominence in tropical countries for biomass estimation (Day *et al.*, 2013; Mensah *et al*, 2016; Lisboa *et al.*, 2018; Sharma *et al*., 2020). Allometric equations for individual trees (Oladoye *et al.*, 2018) and ecosystems using tree diameter and height sampled data are used for biomass estimation (Lisboa *et al.*, 2018). However, inconsistent results have been obtained on the effects of biodiversity on biomass accumulation in the tropics with the quantity of forest biomass attributed to high and low forest tree diversity. For example, Laurin *et al* (2016) established a strong positive correlation between tree diversity and biomass whereas a weak relationship was established between tree diversity and biomass (Sullivan *et al.*, 2017). In contrast, a strong negative correlation between biomass and tree diversity has also been affirmed (Con *et al.*, 2013). High variation exists among tropical forests in biomass accumulation. Lisboa *et al* (2018) reported 291Mg/ha of above-ground biomass whereas 144.2 Mg/ha have also been documented (Sharma *et al.*, 2020). These large variations in biomass resulted from variations in climates, soil, disturbances, evolutionary and geological history (Talbot, 2010), and ecosystems (Lisboa *et al.*, 2018).

Nigeria's tropical rainforest is an important ecosystem with high tree diversity (Onefeli and Stanys, 2019; Akinyele *et al.*, 2020). The ecosystem has been delineated into gazetted forest reserves for biodiversity conservation and sustainable timber production. The ecosystem covers about 11% of Nigeria's landmass (Mfor (Jr) *et al.*, 2014; Usman and Adefalu, 2010). Tropical rainforests also contribute significantly to ecosystem services and carbon sequestration. Their strength of productivity and carbon sequestration is normally assessed through biomass estimation. However, the forests have been fragmented and highly degraded without any concrete policy framework aimed at averting degradation (Saka- Rasaq, 2019). The country once attained 20% forest cover (FORMECU, 1996; Mfor (Jr) *et al.*, 2014). However, the area decreased to 7.2% by 2016 (World Bank, 2021). Hence, the unabated decline in biomass and carbon stocks. The main drivers of forest degradation are anthropogenic forces ((Mfor (Jr) *et al.*, 2014). Forests serve as a source of livelihood for rural dwellers, government depends on forest resources for revenue generation, gazettes of forest land are allocated for industrial and small-scale farming leading to land-use change. These practices have been linked to biodiversity losses and the precursor for carbon sources for global warming (Strassburg *et al.*, 2010; Rodriguez-Echeverry *et al.*, 2018; Karma *et al.*, 2020) and climate change (Lisboa *et al.*, 2018). Sustainable forest management has been identified as key to biodiversity conservation and climate change mitigation and adaptation because of its carbon sequestration and also social, and economic benefits. Though there are shreds of evidence of biodiversity loss in Nigeria's forest ecosystems. However, there are inadequate biomass estimates of the ecosystems. Thus necessitating biomass estimation and establishing the relationship between biomass accumulation and the biodiversity of the ecosystems. The purpose of this study is to establish the dynamics of biodiversity and tree aboveground biomass in selected forest reserves in Nigeria.

MATERIALS AND METHODS

Study Area

This study was carried out in six forest reserves in the tropical rainforest ecosystem in Nigeria, the reserves were purposively selected because they are known to harbour large populations of trees and play a fundamental role in improving rural livelihood rural, contributing significantly to economic development in sub-Sahara region benefits. The reserves include Ago-Owu, Akure, Cross River South (CRSFR), Ekuri, Ikrigon, Oluwa and Shasha (figure 1). The reserves contain relics of tropical rainforest characterised by multi-layer, multispecies indeterminate age compositions.

Ago Owu Forest Reserve is located in Isokan local government of Osun State, Nigeria, the area has Latitude: 7.046E, 7.252N and Longitude: 4.066N and 4.387E. The vegetation of the area is classified as a tropical Lowland Rain Forest (Keay, 1959). Akure Forest Reserve is a tropical rainforest ecosystem, which has an undisturbed segment popularly known as 'Queen's plot that covers an area of about 32 hectares (Akinbowale *et al.*, 2020). According to Akinbowale *et al.* (2020), it is located in Ondo State at latitude 06.59718ºN and longitude 004.49199ºE having a mean annual rainfall of around 1700mm and the temperature ranges from about 20.6 º C to 33.5º. Ekuri Community Forest is located in Akamkpa Local Government Area of Cross River State, the area lies between latitude 05º33ˡ00” N and 05º38ˡ00” N and longitude 08º7ˡ00” E and 08º37ˡ00” E. The area is characterised by seasonal mean annual rainfall ranging from 2,314 mm to 3,500 mm. Cross River South Forest Reserve (CRS FR) lies between latitude 5°50.978′ to 5°51.029′ N and longitude 8°29.833′ to 8°29.424′ E and occupies an area of 80,534.07 ha. Ikrigon Forest Reserve lies between latitude 6°17.597′ to 6°17.862′ N and longitude 8°35.597′ to 8°35.276′ E and occupies an area of 542.7 ha (Ogana, 2019). Oluwa Forest Reserve is located between latitudes 6°38' and 6°59'N and longitudes 4° 23' and4° 46'E. The reserve consists of both natural forest and Plantations. The natural forest is a tropical rainforest and it is characterized by emergent trees with multiple canopies and lianas (Orimoogunje, 2014). Shasha Forest Reserve is located in Ife south Local government Area of Osun state, Nigeria, the vegetation encompasses a tropical rainforest ecosystem in Southwest and lies between latitude 7°8'and 7°10' N and longitude 4°20' and 4°40' E.

Field Data Collection Procedures and Analysis

The dataset consists of diameter at breast height (1.3 m above the ground, *d*) and total tree height (*h*) of 3,276 individual trees representing more than one hundred and fifty species measured from 93 plots. The plot sizes ranged from 0.062 – 0.25 ha, and only trees with dbh ≥ 10.0 cm were considered in this study. All the trees within each plot were identified up to the species level and enumerated.

In each plot, both stand variables and diversity indices were computed. Important stand variables such as density (number of trees per ha i.e., the observed frequency of trees divided by plot size; *N* trees/ha), basal area per ha (sum of cross sectional area divide by plot size, *G* m^2/ha) and quadratic mean diameter (*Dg*, cm) (equation [1]) were calculated.

$$D_g = \left(\sqrt{\frac{4G}{\pi N}}\right) \times 100 \qquad [1]$$

where *Dg* is the quadratic mean diameter (in cm), *G* is basal area per ha, *N* represents density that is number of trees per ha and π is pi. Pielou's species evenness, Shannon-Weiner index and Simpson index of dominance were the diversity measures computed for each plot. Furthermore, the generalised pan tropical aboveground biomass equation (Chave et al., 2014) was used to estimate the tree biomass. The biomass equation requires diameter (*d*), height (*h*) and wood density (ρ) as input variables (equation [2]). Wood density of individual tree species was retrieved from the global wood density database (Zanne et al., 2009). For those unidentified species, an average of 0.5 g cm^{-3} was used. The same average value was used by Ogana (2019) in the rainforest zone. Reyes *et al*. (1992) also found an average of 0.5 g cm^{-3} for the wood density of trees in tropical Africa.

$$AGB_{est} = 0.0673 \times (\rho d^2 h)^{0.976} \qquad [2]$$

where AGB_{est} is the estimated aboveground biomass (in Mg); *d* is diameter at breast height (in cm); *h* is tree height (in m) and ρ represents wood density (in g cm^{-3}). The individual AGB was summed for each plot and then divided by the plot size to obtain the AGB per ha (Mg/ha).

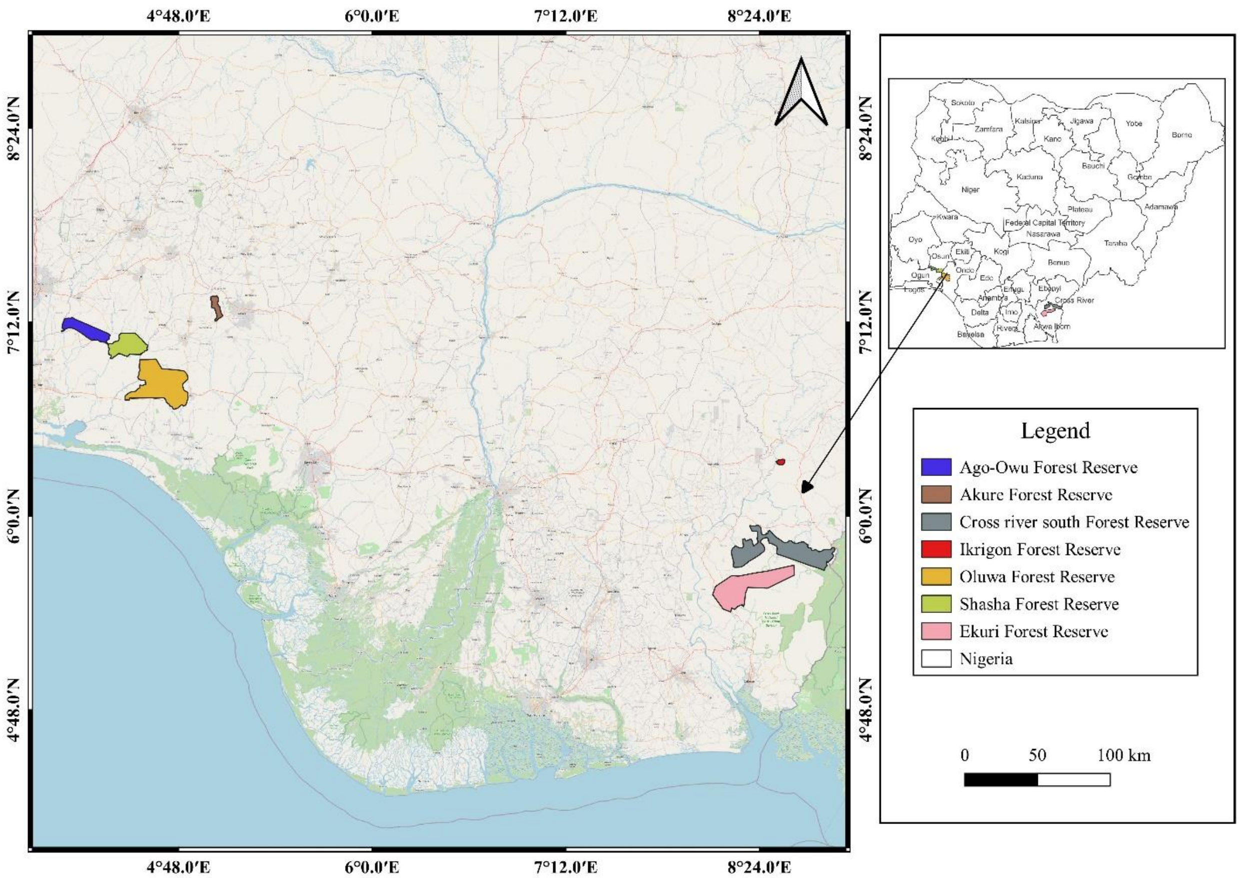

Figure 1: Map showing the location of the study site in the tropical rainforest of Nigeria.

A correlation analysis was used to explain the interaction of species diversity and aboveground biomass production in the tropical rainforest ecosystems. A Pearson correlation analysis (equation [3]) was applied because of the nature of the data set (continuous). The range of the value of correlation (r_{xy}) is between -1 and +1 i.e., -1 < r < 1. The higher the value the stronger the linear association between the species diversity and aboveground biomass. The level of significance of the correlation was tested at 5 %.

$$r_{xy} = \frac{SS_{xy}}{\sqrt{SS_x \times SS_y}} = \frac{\sum xy - \frac{(\sum X)(\sum Y)}{n}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{n}\right)\left(\sum Y^2 - \frac{(\sum Y)^2}{n}\right)}} \quad [3]$$

where SS_{xy} is the sum of square of the cross-product X (species diversity) and Y (AGB in Mg/ha) variables; SS_x is the sum of square of X variable (species diversity); SS_y represents sum of square of Y variable (AGB in Mg/ha) and the *n* is the number of inventoried plot (93 plots).

The variability of species diversity in the seven forests was compared using one-way analysis of variance (ANOVA) at 5%. Duncan Multiple Range Test (DMRT) was used to separate forests that were significantly different at 5 %.

The AGB composition across selected families common to the seven forests was analysed. The families selected were Fabaceae, Malvaceae, Meliaceae, Moraceae and Myristicaceae. Meliaceae and Moraceae contain important timber species like the mahogany. For each selected family, the variability of AGB was compared across Ago-Owu, Akure, CRSFR, Ekuri, Ikrigon, Oluwa and Shasha forests using ANOVA at 5 % level of significance. Further DMRT was used to separate forests whose AGB were significantly different. All statistical analyses were carried out using R (R Core Team, 2020).

RESULTS

Tree variables and Species diversity in the tropical forest ecosystem

The mean and standard deviation (SD) of the stand variables for the tropical forest is presented in Table 1. The quadratic mean for the diameter at breast height varied from 20.7 cm (Shasha) to 106.1 cm (Akure). The diameter and height distributions of the trees across the forests are shown in figure 2 and 3 respectively. Meanwhile, the basal area for the trees encountered in Akure was the highest (119.5 m2/ha) while Ekuri was the least (9.3 m2/ha). In terms of the number of trees existing in a forest, value ranged between approximately 65 (Ekuri) to 622 trees on a hectare basis. Similarly, among the forests, Ekuri had the least above-ground biomass of 110.4 Mg/ha and Ago Owu had maximum value (861.3 Mg/ha).

Variation in diversity indices of the tropical forest ecosystem

Considering the diversity indices among the forests, Ikrigon possessed the least values for evenness and Shannon, which are respectively 0.410 and 1.876 while Akure (0.975) and Oluwa (2.971) were the least (Table 1). Dominance ranged between Oluwa (0.066) and Ikrigon (0.305). All the forests were found to be significantly different ($p<0.05$) based on the diversity indices (Figure 5). Hence, the forests were categorized into three groups according to the indices except for the species evenness, in which Ikrigon was significantly different from the rest six forests (Figure 5).

Table 1: Mean and standard deviation (SD) of the stand variables and diversity indices for the tropical forest data

Variable	Statistics	Ago_Owu Np = 4	Akure Np = 15	CRSFR Np = 10	Ekuri Np = 32	Ikrigon Np = 10	Oluwa Np = 7	Shasha Np = 15
Dg (cm)	Mean	54.9	106.1	30.4	42.2	33.8	29.9	20.7
	SD	15.8	15.5	5.9	6.9	3.5	2.4	3.3
G (m^2/ha)	Mean	73.8	119.5	12.5	9.3	28.0	19.8	21.5
	SD	65.8	29.2	5.4	3.4	9.3	6.5	10.6
N (trees/ha)	Mean	247.0	135.6	175.2	65.3	310.4	277.7	621.5
	SD	157.9	23.3	69.9	11.9	72.8	56.8	196.5
AGB (Mg/ha)	Mean	861.3	829.3	154.5	110.4	253.0	158.8	142.5
	SD	743.5	300.6	79.1	42.7	70.4	75.4	85.8
Dominance	Mean	0.087	0.140	0.193	0.125	0.305	0.066	0.075
	SD	0.031	0.016	0.288	0.038	0.153	0.010	0.019
Evenness	Mean	0.923	0.975	0.745	0.880	0.410	0.754	0.738
	SD	0.102	0.029	0.156	0.066	0.146	0.064	0.079
Shannon	Mean	2.602	1.989	2.526	2.271	1.876	2.971	2.933
	SD	0.423	0.093	1.013	0.252	0.477	0.067	0.228
Simpson	Mean	0.913	0.858	0.807	0.875	0.695	0.934	0.925
	SD	0.030	0.016	0.288	0.038	0.153	0.010	0.019

Np: number of plot; *Dg*: quadratic mean diameter; *G*: basal area per ha; *N*: number of trees per ha

Correlation between diversity indices and above-ground biomass

Evenness correlated significantly ($p<0.05$) with the above-ground biomass (AGB) of the species (Figure 4). Therefore, increment in the AGB tends to be associated with a rise in the evenness. Conversely, species dominance and Shannon diversity index had a positive insignificant correlation with the AGB.

Variation in the above-ground biomass of selected economic familiar taxa of the tropical ecosystem

All the forests were significantly different ($p<0.05$) based on the above-ground biomass (AGB) of the trees within each of the selected families (Figure 6). Akure and Shasha

respectively had the highest and least AGB except only for Moraceae where the Cross River State Forest Reserve (CRSFR) happened to have the least AGB (Figure 6).
Therefore, according to the affinity of the forests concerning their AGB, two clusters were formed for Malvaceae, Meliaceae, Moraceae and Myristicaceae. Specifically, within Malvaceae, Ekuri, Oluwa, Ikrigon, CRSFR and Shasha, which were insignificantly different were distinguished from Akure and Ago Owu (Figure 6). In Meliaceae, Moraceae and Myristicaceae, only Akure formed a cluster, which was significantly different from the remaining forests as another cluster. In Fabaceae however, three clusters were formed comprising of Akure; Ekuri and Ago Owu; CRSFR, Oluwa, Ikrigon and Shasha.

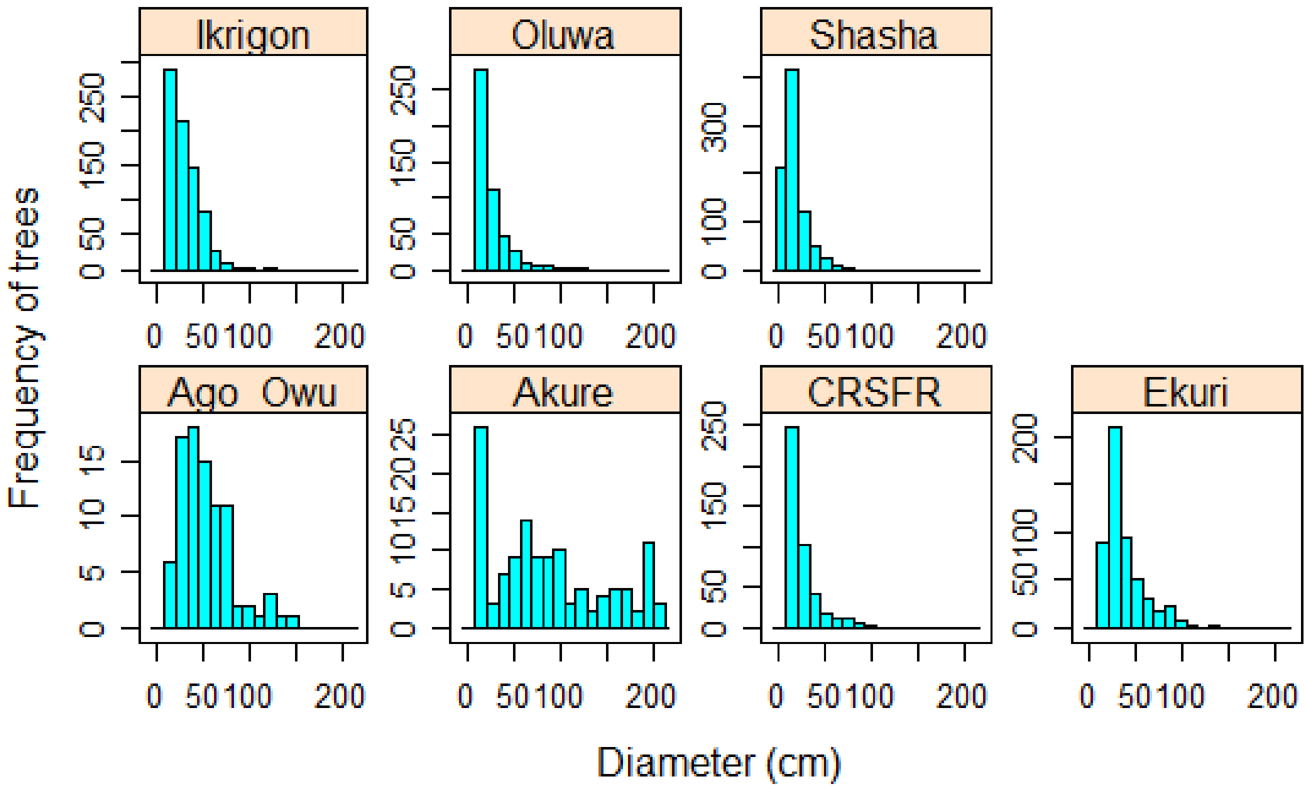

Figure 2: Diameter distributions of tree species

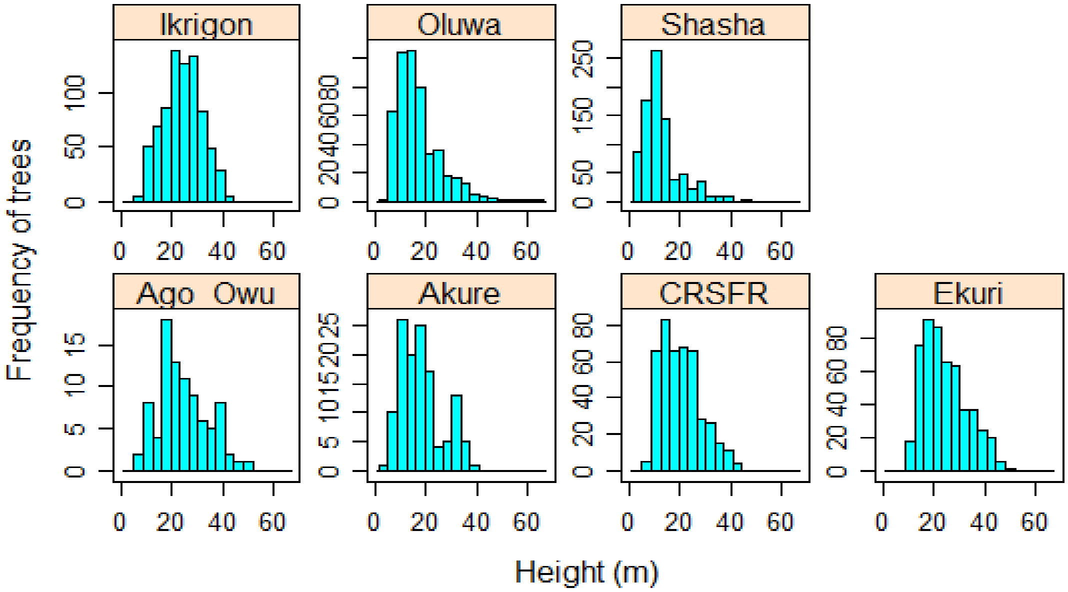

Figure 3: Height distributions of tree species

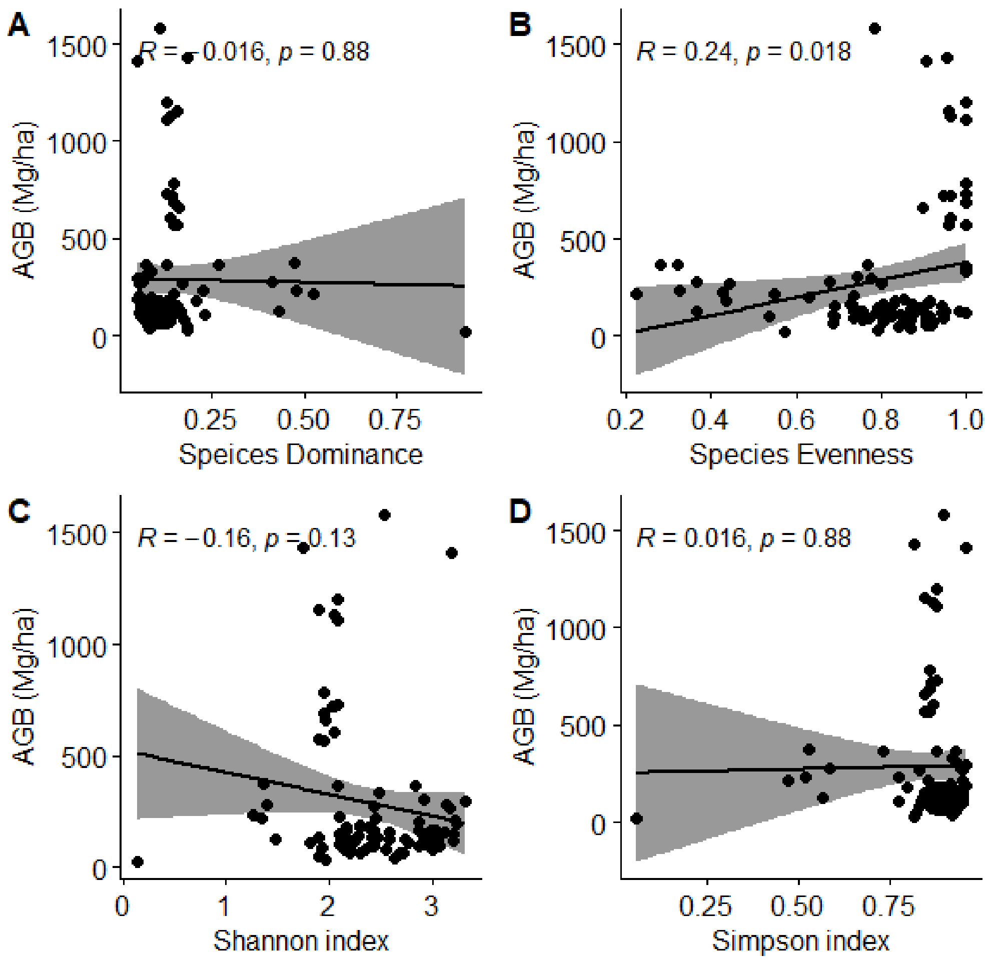

Figure 4: Association of species diversity and aboveground biomass (AGB, Mg/ha)

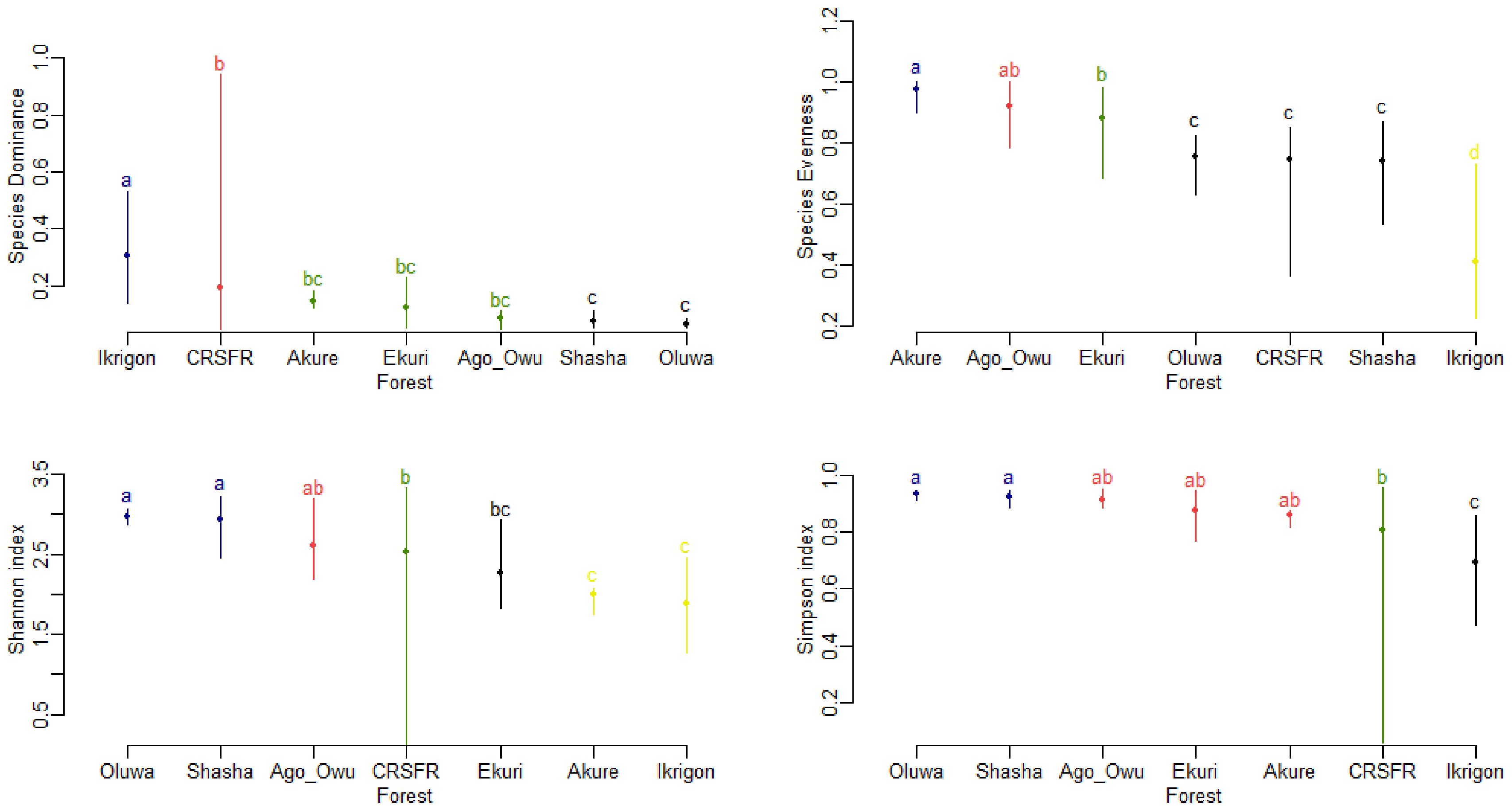

Figure 5: Comparison of diversity indices across the seven forests using Duncan Multiple Range Test (DMRT).
Note: Forests with the same letter are not significantly different at 5 % level.

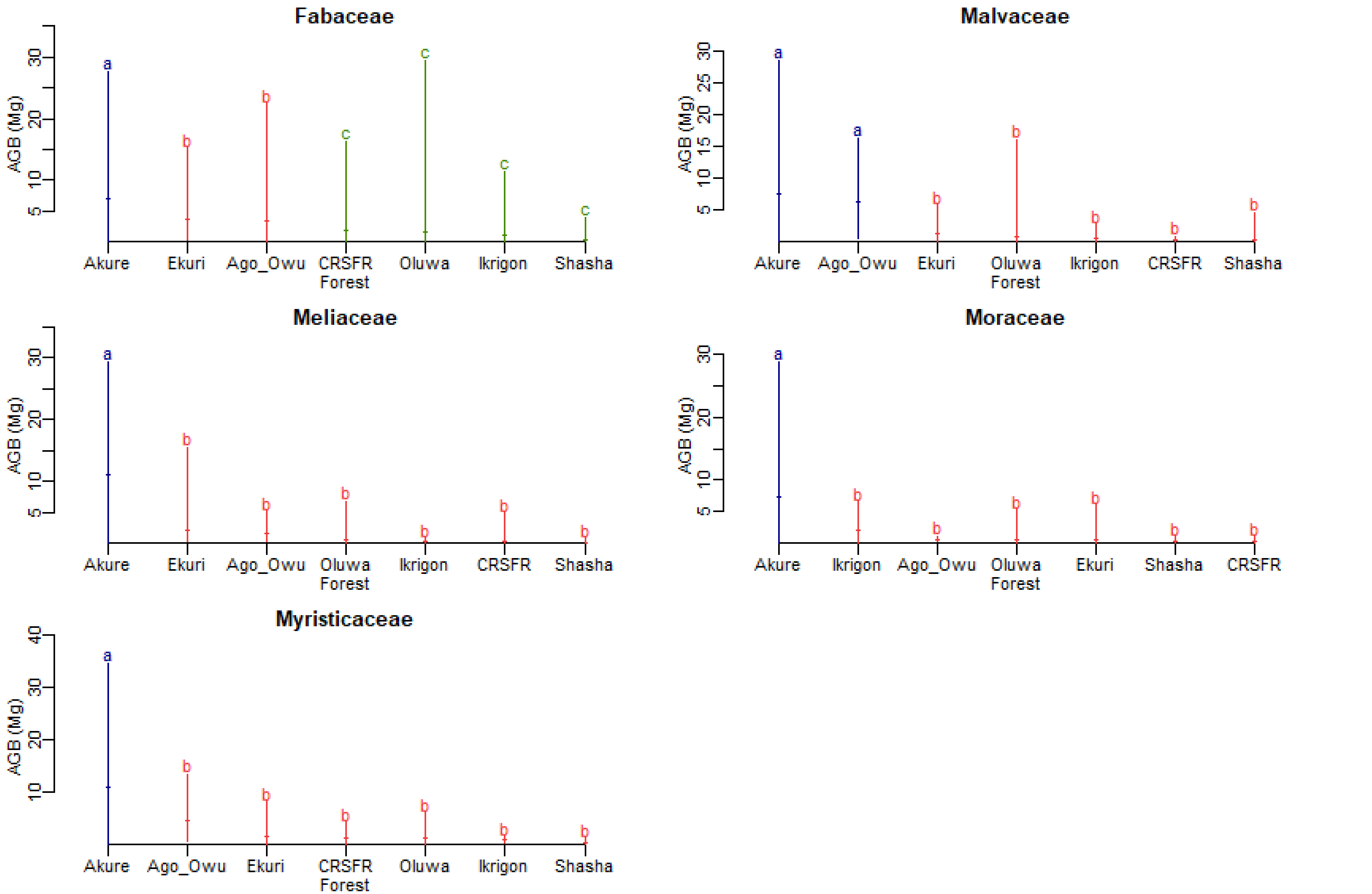

Figure 6: Comparison of AGB of selected families across the forests using DMRT. Note: Forests with the same letter are not significantly different at 5 % level.

Discussion

This study has provided important information on the peculiarity of natural forest ecosystems in biomass accumulation, the results revealed that tropical forest ecosystems have high above-ground biomass (AGB) density as the biomass ranges from 110.4 to 861.3 Mg ha in the seven natural forest ecosystem investigated. The results are in the same range as reported by Sierra *et al.* (2007), that in primary forests of Porce region, Colombia, total aboveground biomass was estimated as 247.8- 40.5 Mg ha. The results are corroborated as reported by Dimobe et al. 2019, which reported high carbon stock across vegetation types in W National Park, Burkina Faso. The results of the study are in agreement with several other studies in tropical regions, they reported higher biomass in primary forest areas (Goussanou *et al.* 2018; Lindner, *et al.* 2012; Lin *et al.* 2015). The study revealed that biomass density is higher in Ago Owu and Akure forest reserve compared to other forests investigated. This could be as a result of the high influences of anthropogenic activities such as logging, extraction of plant materials by herbal collectors, and other forms of illegal encroachment in the forest reserves. The report of Dimobe et al. (2019) that encounter high carbon density in the woodlands and gallery forests of Burkina Faso is similar to this study. They reported high values of carbon stock which could be explained by the abundance of woody trees and reduction in anthropogenic influences. The result is also in the same direction as reported by Qasim et al. 2016, which documents high biomass in the wildlife reserve of Bontioli and Nazinga Game Ranch located in Burkina Faso. Our results revealed that a disturbed forest area has very low forest and biomass less disturbed area accommodates high biomass density, the results are similar to a previous study that reported highest carbon stocks were encounter in non-disturbed areas namely protected areas (Balima et al. 2020; Dayamba et al., 2016; Islam et al., 2017).

The diameter distribution from the seven natural forests assessed across the tropical region in Nigeria show the expected bell shape form for a natural forest except for Akure forest, this revealed that the species distribution is normally distributed across the vegetation. The stem diameter distribution of all the species in the forest is the predominance of adult individuals. This shows a strong indication that the forest is threatened and the species are characterized by aging trees and revealed a declining trend and lack of adequate management practices. The result is similar as reported by Ouédraogo (2006). Only Ikrigo and Ekuri forest reserves showed the height distribution close to normal distribution. Most of the studied forest ecosystems showed the expected normal distribution, except for Akure forest that revealed an unstable tree demographic pattern, which indicated a threat to the forest reserve. The result is in accordance as reported by Traoré et al. (2012) that reported the species population in both protected and unprotected forests in the North Sudanian of Burkina Faso showed a normal distribution in population structure The results revealed that the natural forest ecosystem has high diversity indices in all the diversity indices assessed in the study. The result is similar as reported by Nacoulma et al., (2011), which reported that protected areas had highlighted diversity indices and the ecosystem holds great potential for biodiversity conservation in the area.

The study showed that the evenness of the species in the forest significantly correlated with the above-ground biomass (AGB) of the species (Figure 3), the results corroborate with the report of Balima et al. (2020), that stated carbon storage in tree aboveground biomass was influenced by both stand composition and structure. Dayamba *et al*., (2016) and Islam et al., (2017) had also reported similar results in their previous studies. In Burkina Faso, Dimobe et al. (2019), reported that stand composition and ecological conditions significantly influence carbon storage in the area. Day et al. (2013) documented a complex and highly variable relationship between species diversity and biomass density in Central African rainforests. They further reported positive correlations between biomass and species diversity in the plots. The results corroborate with the findings of this study that revealed Shannon diversity index and species dominance had a positive correlation with the above-ground biomass.

Conclusion

This study has provided important information on species diversity and biomass in tropical forest ecosystem in Nigeria. The studied revealed a positive relationship between the species diversity indices and biomass density in the reserves. It was evident in the study that anthropogenic influences have negative impact on the biomass, species distribution and diversity. The relationships and interactions between forest biodiversity and biomass accumulation could be a useful tool for the policymakers and stakeholders in developing a road map toward climate change mitigation and adaptation. It is therefore recommended that requisite silvicultural practices such as enrichment planting that could enhance the diversity of the forests be taken seriously.

References

Akinbowale, A.S., Adeyekun, O.J. and Adekunle, V.A.J. 2020. Logging impacts on volume yield of tropical rainforest ecosystem in Ondo State, Nigeria. Research Journal of Agriculture and Forestry Sciences 8(3): 17-23.

Akinyele, A.O., Onefeli, A.O. and Fabowale, G. 2020. Comparative morphology of the leaf epidermis in four species of Meliaceae L. family. Environmental Sciences Proceedings. https://sciforum.net/paper/view/conference/8032

Balima, L.H., Nacoulma, B.M.I., Bayen, P., Kouam´e, N.F. and Thiombiano, A., 2020. Agricultural land uses reduce plant biodiversity and carbon storage in tropical West African savanna ecosystems: implications for sustainability. Glob. Ecol. Conserv. 21, e00885. https://doi.org/10.1016/j.gecco.2019.e00875.

Borokini T. I., Onefeli, A.O., Babalola F. D. 2013. Inventory Analysis of Milicia excelsa (Welw C.C. Berg.) in Ibadan (Ibadan Metropolis and University of Ibadan), Nigeria. Journal of Plant Studies 2 (1): 97-109.

Caputo, J., Beier, C. M., Groffman, P. M., Burns, D. A., Beall, F. D., Hazlett, P. W and Yorks, T. E. and 2016. Effects of harvesting forest biomass on water and climate regulation services: a synthesis of long-term ecosystem experiments in Eastern North America. *Ecosystems* 19: 271–283 doi: 10.1007/s10021-015-9928-z.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., Henry, M., Martínez-Yrízar, A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E.M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan, C.M., Saldarriaga, J.G. and Vieilledent, G. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Glob. Chang. Biol*. **20**: 3177-3190

Con, T.V., Thang, N.T., Ha, D.T.T., Khiem, C.C., Quy, T.H., Lam, V.T., Van, D.T. and Sato, T. 2013. Relationship between Aboveground Biomass and Measures of Structure and Species Diversity in Tropical Forests of Vietnam. Forest Ecology and Management, 310, 213-218. http://dx.doi.org/10.1016/j.foreco.2013.08.034

Day, M., Baldauf, C., Rutishauser, E and Sunderland, T. C. H. 2013. Relationships between tree species iversity and above-ground biomass in Central African rainforests: implications for REDD *Environmental Conservation* 41(1): 64–72.

Dayamba, S.D., Djoudi, H., Zida, M., Sawadogo, L., Verchot, L., 2016. Biodiversity and carbon stocks in different land use types in the Sudanian Zone of forest biomass to better understand the terrestrial carbon cycle. *Remote Sensing and Environment* 115:2850–2860.https://doi.org/10.1016/j.rse.2011.03.020.

Dimobe, K., Kuyah S., Dabré Z., Ouédraogo A., Thiombiano A. 2019. Diversity-carbon stock relationship across vegetation types in W National park in Burkina Faso.

Forest Ecology and Management 438: 243–254. https://doi.org/10.1016/j.foreco.2019.02.027. diversity and structures forest. Forests. 7. 79: doi: 10.3390/f7040079.

Ebeling, J., and Yasué, M. 2008. Generating carbon finance through avoided deforestation and its potential to create climatic, conservation and human development benefits. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 363: 1917–1924.

FAO, 2020. Global Forest Resources Assessment 2020 Canada (www.google.com. Accessed 15/01/2021).

FORMECU, 1996. Statistics of forest reserves in Nigeria. Forestry Management, Evaluation and Coordinating Unit, Nigeria.

Goussanou, C.A.; Guendehou, S.; Assogbadjo, A.E. and Sinsin, B. 2018. Application of site-specific biomass models to quantify spatial distribution of stocks and historical emissions from deforestation in a tropical forest ecosystem. Journal Forestry Resource 29: 205–213.

Grassi, G., House, J., Dentener, F., Federici, S., den Elzen, M., and Penman, J. 2017. The key role of forests in meeting climate targets requires science for credible mitigation. Nature *Climate Change,* 7(3): 220–226. doi:10.1038/nclimate3227.

He, Q., Chen, E, An, R., and Li, Y. 2013. Above-ground biomass and biomass components estimation using LiDAR data in a coniferous forest. *Forests* 4: 984–1002. https://doi.org/10.3390/f4040984.

Islam, M., Deb, G.P., and Rahman, M., 2017. Forest fragmentation reduced carbon storage in a moist tropical forest in Bangladesh: implications for policy development. Land Use Policy 65, 15e25. https://doi.org/10.1016/j.landusepol.2017.03.025.

Jegede, O.C., Onefeli A.O., Gbadebo, J.O. and Adeniji, I. 2020. Biomass Accumulation of selected Indigenous Species under Flood condition. Journal of Forestry Research and Management 17(3): 14-21.

Keay, R. W. (1959). An Outline of the Nigerian Vegetation. Lagos: Federal Department of Forest Research, Federal Ministry of Information.

Köhl, Michael & Neupane, Prem Raj & Mundhenk, and Philip, 2020. "REDD+ measurement, reporting and verification – A cost trap. Implications for financing REDD+MRV costs by result-based payments," Ecological Economics, Elsevier 168 DOI: 10.1016/j.ecolecon.2019.106513

Laurin, G. V., Puletti, N., Chen G.I., Corona, P., Papale, D and Valentini, R 2016 Above ground biomass and tree species richness estimation with airborne lidar in tropical Ghana forests. *International Journal of Applied Earth Observation and Geoinformation* 52: 371–379. doi.org/10.1016/j.jag.2016.07.008.

Lawal, M.F., Alarape, A.A., Adeyanju, T.E., Onefeli, A.O. and Adeyanju, A.T. 2020. Contributions of University of Ibadan Botanical Gardens to Avifauna diversity Conservation. Ethiopian Journal of Environmental Studies & Management 13 (1): 61-73, 2020.

Le Toan T, Quegan S, Davidson MWJ 2011. The BIOMASS mission: Mapping global on biodiversity and ecosystem services in the Chilean temperate forests. *Landscapes Ecology* 33: 439–453. doi.org/10.1007/s10980-018-0612-5.

Leishera, C., Robinson, N., Browna, M., Kujirakwinja, D.,Schmitza, M .C., Wielandd, M and Wilkied D 2020. BioRXIV. Preprints. doi.org/10.1101/2020.07.22.175513

Li, S., Lang X., Liu, W., Ou, G., Xu, H., Su, J 2018. The relationship between species richness and aboveground biomass in a primary *Pinus kesiya* forest of Yunnan, southwestern China. PLoS ONE 13.1: e0191140. doi.org/10.1371/journal.pone.0191140

Lin, D.; Lai, J.; Yang, B.; Song, P.; Li, N.; Ren, H.; Ma, K. Forest biomass recovery after different anthropogenic disturbances:

Relative importance of changes in stand structure and wood density. Eur. J. For. Res. 134: 769–780.

Lindner, A.; Sattler, D. 2012. Biomass estimations in forests of different disturbance history in the Atlantic Forest of Rio de Janeiro, Brazil. New For. 43: 287–301.

Lisboa, S. A., Guedes, B. S., Ribeiro N and Sitoe, A 2018. Biomass allometric equation and expansion factor for a mountain moist evergreen forest in Mozambique. Carbon Balance Management 13:23. doi.org/10.1186/s13021-018-0111-7.

Mensah, S., Veldtman, R., Toit, B. D, Kakaï, R. G and Seifert, T. 2016. Aboveground biomass and carbon in a South African mist belt forest and the relationships with tree Species Diversity and Forest Structures. Forests 7(4): 79; https://doi.org/10.3390/f7040079

Mfon (Jr), P., Akintoye, O. O., Mfon, G., Olorundami, T., Ukata, U. K and Taiwo Akintoye, A 2014: Challenges of Deforestation in Nigeria and the Millennium Development Goals. International Journal of Environment and Bioenergy. 9(2): 76-94.

Midgley, G.F., Bond, W.J., Kapos, V.K., Ravilious, C., Scharlemann, J.P.W and Woodward, F.I. 2010. Terrestrial carbon stocks and biodiversity: key knowledge gaps and some policy implications. Current Opinion in Environmental Sustainability 2: 264–270.

Nacoulma, B.M.I., Schumann, K., Traore, S., Bernhardt-R omermann, M., Hahn, K., Wittig, R., Thiombiano, A., 2011. Impacts of land-use on West African € Savanna vegetation: a comparison between protected and communal area in Burkina Faso. Biodivers. Conserv. 20 (14): 3341e3362. https://doi.org/10. 1007/s10531-011-0114-0

Oba, G., Vetaas, O. R and Stenseth, N. C 2001. Relationships between biomass and plant species richness in arid-zone grazing lands. *Journal of Applied Ecology* 38:836-845.

Ogana, F.N. 2019. Tree height prediction models for two forest reserves in Nigeria using mixed- effects approach. Tropical plant Research 6(1): 119–128.

Oladoye, A., Bello, O.S., Basiru, A. O., Ige, P.O and Ezenwenyi J. U 2018. Above ground biomass and carbon stock of *Nauclea diderrichii* (De Wild. & T. Durand) Merill plantation in Omo Forest Reserve, Nigeria. *Journal of Forestry Research and Management.* 15(2): 95-111.

Onefeli, Alfred O, Opute, O.H. and Oluwayomi, T.L. 2013. Biodiversity Assessment of Okpe Sobo Forest Reserve, Delta State. Proceedings of the 36th Annual Conference of the Forestry Association of Nigeria (FAN) 2: 490-495.

Onefeli, A.O., Oluwayomi, T.L., Isese, M.O.O., Chenge, Iveren B. and Okon, Kufre E. 2014. Environmental Impact Assessment of Selected Sawmills in Ile-Ife, Osun State, Nigeria. 4(2): 217-238.

Onefeli, A.O. (2016). Assessment of Undergrowth Plant Diversity in three different Vegetation at Gambari Forest Reserve, Oyo State. Proceedings of the 1st Commonwealth Forestry Association (CFA) Conference, Nigeria Chapter, 54-60.

Onefeli, A.O. 2018. Taxonomic Rambling of Flora Diversity in Olokemeji Forest Reserve, Nigeria. In Umoh, G.S., Babalola, F.D. and Eniang, E.A. (Eds.). Biodiversity, Conservation and National Development: Potentials and Challenges. Proceedings of 6th Biodiversity Conservation Conference 245–249.

Onefeli, A.O. and Stanys, V. 2019. Phylogenetic Study of African Combretaceae R. Br. Based on rbcL Sequence. Baltic Forestry 22(5): 170-177.

Onefeli, A.O. 2021."Effectiveness of DNA Barcoding in discriminating Daniellia ogea (Harms) Rolfe ex Holland and Daniellia oliveri (Rolfe) Hutch. & Dalziel.," Trees Forest and People (Elsevier) 4, 100067.

Ouédraogo A. 2006. Diversité et dynamique de la végétation ligneuse de la partie orientale du Burkina Faso. Thèse de doctorat de l'Université de Ouagadougou. 2006;195.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz,W.A., Philips, O.L., Schivdenko, A., Lewis, S.L., Canadell, J.G., Ciasis, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S. & Hayes, D 2011. A large and persistent carbon sink in the world's forests. Science 333: 988–993.

Phillips,O.L., Malhi, Y.,Higuchi, N.,Laurance, W.F.,Nunez, P.V., Vasquez, R.M.,Laurance, S.G.,Ferreira, L.V., Stern,M., Brown, S. & Grace, J 1998. Changes in the carbon balance of tropical forest: evidence from long-term plots. Science 282: 439–442.

Ploton, P., Mortier, F., Barbier, N., Cornu, G., Réjou-Méchain, M et al 2020. A map of African humid tropical forest aboveground biomass derived from management inventories. Scientific Data. 7:221. doi.org/10.1038/s41597-020-0561-0.

Qasim, M.; Porembski, S.; Sattler, D.; Stein, K.; Thiombiano, A. 2016. Lindner, A. Vegetation Structure and Carbon Stocks of Two Protected AreasWithin the South-Sudanian Savannas of Burkina Faso,West Africa. Environment 3: 1–16.

Reyes, G., Brown, S., Chapman, J. and Lugo, A.E. 1992. Wood densities of tropical tree species. Gen. Tech. Rep. SO-89 New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station 15pp

R Core Team. 2020 R. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/ (accessed on 13 August 2020)

Rodríguez-Echeverry J, Echeverría C, Oyarzún C, Morales L (2018) Impact of land-use change on biodiversity and ecosystem services in the Chilean temperate forests. Landsc Ecol 33:439–453

Saka-Rasaq, O 2019. Forest Loss in Nigeria, the impact on climate and people from the perspectives of illegal forest activities and government negligence. Degree thesis for Bachelor of Natural Resources Degree programme in Sustainable Coastal Management Raseborg. III+24.

Serdeczny, O., Adams, A., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M, Perrette, M and Reinhard, J 2017. Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*. Vol 15. doi:10.1007/s10113-015- 0910-2.

Sharma, K.., Saikia, A., Goswami, S. and Borthakur, M. 2020. Aboveground biomass estimation and carbon stock assessment along a topographical gradient in the forests of Manipur, Northeast India. *Arabian Journal of Geosciences* 3:443. doi.org/10.1007/s12517-020-05398-4.

Sierra, C.A., Harmon, M.E., Moreno, F.H., Orrego, S.A., del Valle, J.I. 2007. Spatial and temporal variability of net ecosystem production in a tropical forest: testing the hypothesis of a significant carbon sink. Glob. Change Biol. 13: 838–853

Srinivas, K. and Sundarapandian, S. 2019. Biomass and carbon stocks of trees in tropical dry forest of East Godavari region, Andhra Pradesh, India, Geology, Ecology, and Landscapes.3(2): 114-122. 10.1080/24749508.2018.1522837.

Strassburg, B.B.N., Kelly, A., Balmford, A., Davies, R.G., Gibbs, H.K, Lovett, A., Miles, L., David, C., Orme, L., Turner, and K.R Turner, Rodrigues, A.S.L 2010. Global congruence of carbon storage and biodiversity in terrestrial ecosystems.Conservation Letters 3: 98–103.

Sullivan, M. J. P., Talbot1, J., Lewis, S. L., Phillips, O. L., Qie, L et al 2016: Diversity and carbon storage across the tropical forest biome. Scientific Reports. 7:39102 doi: .1038/srep39102.

Talbot, J.D. 2010. Carbon and biodiversity relationships in tropical forests. Multiple Benefits Series 4. Report prepared on behalf of the UN-REDD Programme.School of Geography, University of Leeds, Leeds/UNEP World Conservation Monitoring Centre. Cambridge, UK.

Traoré, L., Sop, T.K., Dayamba, S.D., Traoré, S., Karen, H. and Thiombiano, A. 2012 Do protected areas really work to conserve species? A case study of three vulnerable woody species in the Sudanian zone of Burkina Faso. Environment Development Sustainability 15(3): 663-686.

Usman, B. A. and Adefalu, L.L. 2010. Nigerian forestry, wildlife and protected areas: Status verification A cost trap? Implications for financing REDD+MRV costs by result-based payments. Ecological Economics.168. oi.org/10.1016/j.ecolecon.2019.106513.

Verkerk, P. J., Fitzgerald, J. B., Datta, P., Dees, M., Hengeveld, M. G., Lindner, M and Zudin, S. 2019. Spatial distribution of the potential forest biomass availability in Europe forests *Ecosystems* 6:5. doi.org/10.1186/s40663-019-0163-5.

Vieilledent, G., Vaudry, R., Andriamanohisoa, S. F., Rakotonarivo, O. S., Randrianasolo, H. Z., Razafindrabe, H. N., Rasamoelina, M. 2012. A universal approach to estimate biomass and carbon stock in tropical forests using generic allometric models. *Ecological Applications*. 22(2): 572–583.

World Bank, 2021: Trading Economics (www.google.com accesses 19.01.2021)

Zanne, A.E., Lopez-Gonzalez, G. Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L., Miller, R.B., Swenson N.G., Wiemann, M.C. and Chave, J. 2009. Global wood density database. Dryad. Available at: https://hdl.handle.net/10255/dryad.235 (accessed 1 September 2020)