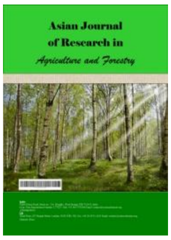

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Diversity, Biomass and Carbon Storage Potential of Some Tree Species in a Nigerian Natural Forest

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study was carried out to assess diversity, biomass and carbon storage potential of some tree species in a Nigerian forest. All trees with Dbh >10cm were enumerated. Tree growth variables, namely the Diameter at the base (Db), Diameter at breast height (Dbh), Diameter at the middle (Dm), Diameter at the top (Dt) and height, were measured for basal area and volume estimation and their frequency of occurrence was ascertained for tree diversity assessment. Fifty-six (56) trees distributed among 21 species and 11 families were enumerated in this study area. Some of these species were *Acacia ataxacantha, Blighia sapida, Alstonia bonnie, Ceiba pentandra, Celtis zenkeri, Khaya ivorensis,* etc. *Funtumia elastica* had the highest frequency of occurrence (11 stems) with a Relative Density of 19.64%. Therefore, it could be regarded as the most abundant tree species in the forest. Shannon Wiener index of 2.62 was recorded for this study with an evenness value of 0.86. *Khaya senegalensis* stored the highest carbon of 4.86 tonnes, and total Above Ground Biomass (ABG) of 53.64 g/m^2, equivalent to 26.82 tonnes of Carbon was obtained for all the tree

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species. The results from this study showed that there is high level of forest degradation in the study area. Though, the forest could only store small amount of carbon but it has been able to reduce the amount of carbon escaping into the atmosphere. Conservative measures must be put in place to protect the forest from further degradation and this will go a long way in mitigating climate change by serving as carbon sinks.

Keywords: Rainforest; sustainability; biodiversity; carbon storage.

1. INTRODUCTION

Tropical rainforest support life because of their richness in plant species composition and fauna diversity [1]. They are mostly dominated by a wide variety of broad-leaved trees, which form a dense canopy and make it one of the most complex ecosystems [2]. The tropical rainforest is a vital ecosystem that provides services, such as raw materials, reservoirs for biodiversity, habitat to diverse animal species, soil protection, sources of timber, medicinal plants, carbon sequestration, watershed protection and also forms the livelihood for many different human settlements, including 60 million indigenous people [3]. Besides, it contains up to 82% of the terrestrial plant biomass, interlinked with atmospheric CO2 levels, through the carbon cycle. Tree species richness is one of the characteristics of the tropical forest and is fundamental for biodiversity conservation [4]. Moreover, the favorable environmental conditions and the tropical rainforest's canopy structure are special features that promote species diversity. About 70–90% of living flora and fauna depend on trees for survival in the rainforest ecosystem [5]. The high tree species diversity of rainforests is partly responsible for the intense pressure on them and therefore have resulted into species extinction, biodiversity reduction, and primary productivity decrease [6].

Carbon sequestration is a way to mitigate the accumulation of greenhouse gases in the atmosphere released by burning fossil fuels and other anthropogenic activities. One of the objectives of Reducing Emissions from Deforestation and Forest Degradation (REDD+) programme is to mitigate climate change through climate-smart forestry and conserve biodiversity. More so, the objective of forest management has been focusing on altering deforestation and forest degradation targeting the enormous benefits of REDD+ programme in climate change response. Biomass assessments are very important for many purposes and are used in the measurement of carbon stock of the forest stands.

The tropical forest ecosystem is an important carbon sink source containing most of the above ground terrestrial organic Carbon. Carbon sequestration is the storage of Carbon to mitigate global warming. The forest ecosystem plays a very important role in the global carbon cycle. Forests are the natural storehouses of biomass and different life form. Thus, the tropical forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural brake on climate change [7]. Forests fix, store and emit Carbon by photosynthesis, respiration, decomposition and disturbances through a series of stages in the life cycle from regeneration to harvest [8]. Human activities are responsible for changing carbon stocks in these pools by changing the land use pattern of the area. Whether and to what degree biodiversity influences carbon stocks in tropical forests is still uncertain. However, experimental work in other ecosystems has shown that biodiversity often promotes stability and primary productivity.

2. METHODOLOGY

This study was carried out at Obanla natural forest, a portion of forest left behind during land clearing for the establishment of the Federal University of Technology, Akure, Ondo State, Nigeria, in 1981. As a result, the forest is rich in tree and animal species diversity. It is used presently as a botanical garden and practical field for dendrology courses by students and staff of the Department of Forestry and Wood Technology, FUTA. This forest was formerly part of the Akure forest reserve located between four towns: Akure, Idanre, Ondo and Ilesa. Specifically, Obanla natural forest is located along Akure-Ilesa road in the North Western part of FUTA on Longitude 050 18'E and Latitude 07°17'N. Generally, the vegetation zone is the tropical humid lowland forest ecosystem. FUTA occupies a total land area of 640 ha. As a result of physical development, the original native vegetation has been removed, leaving behind this small portion.

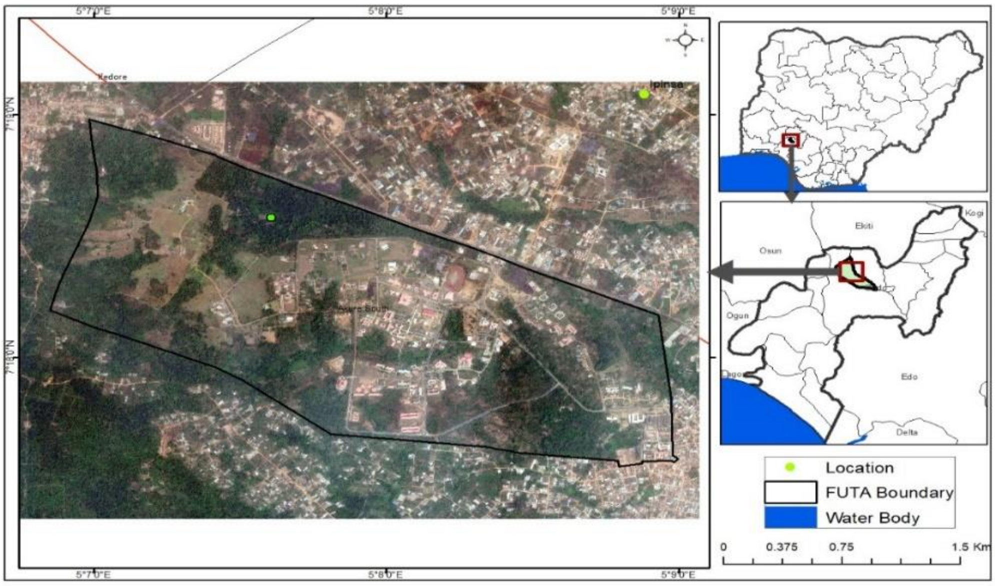

Fig. 1. Map of the study area

3. METHOD OF DATA COLLECTION

3.1 Tree Enumeration

All trees with Dbh above 10 cm were tagged for enumeration. Tree growth variables such as the Diameter at the base (Db), Diameter at breast height (Dbh), Diameter at the middle (Dm), Diameter at the top (Dt) and height were measured for basal area and volume estimation. Global Positioning System (GPS) was used to obtain coordinates of the forest boundaries to generate the digitized map (Fig. 1).

3.2 Tree Diversity Assessment

Frequency of occurrence of each of the tree species encountered was obtained. The scientific names of all trees tagged and enumerated were recorded. Where a tree's botanical name was not known, such tree was identified by its commercial or local name and later translated to botanical name using Gbile (1984) and Keay (1989).

4. METHOD OF DATA ANALYSIS

4.1 Basal Area Estimation

Tree basal area was estimated using equation 1.

$$BA = \frac{\pi D2}{4} \qquad (1)$$

Where BA = Basal Area (m2), D = Dbh (m) and π=3.142

4.2 Tree Volume Estimation

The volume of all trees was calculated using the Newton formula in eqn 2 [9].

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

Where, V= Volume of tree (m^3); Db= Diameter at the base (m); Dm= Diameter at the middle (m); Dt= Diameter at the top (m); H= height (m).

4.3 Tree Species Diversity Indices

(1) Relative density (%) of each species was computed using eqn 3.

$$RD = \frac{n_i}{N} \times 100 \qquad (3)$$

Where RD is the relative density of the species; ni is the number of individuals of species i, and N is the total number of all individual trees.

(2) Species Relative Dominance (%) of each species was estimated using eqn 4

$$RD_O = \frac{\sum Ba_i \times 100}{\sum Ba_n} \qquad (4)$$

Where: Bai = basal area of individual tree belonging to species I and Ban = stand basal area.

(3) The Species evenness (E): Species evenness in each plot was determined using Shannon's equitability (EH), which was obtained using eqn 5

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{S} P_i \ln(P_i)}{\ln(S)} \quad (5)$$

(4) Species Important Value Index (IVI%) was computed using eqn 6

$$IVI = \frac{(\mathrm{RD} + \mathrm{RDo})}{2} \quad (6)$$

Where RD is the Relative Density of the species; RDo is the Relative Dominance of the species.

(5) Shannon-Wiener Diversity Index: Species diversity index was calculated using eqn 7

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \quad (7)$$

Where H1 = Shannon diversity index, S = the total number of species in the community, Pi = proportion S (species in the family) made up of the ith species and ln = natural logarithm.

4.4 Tree Density, Biomass and Carbon Stock

Density of each tree species was obtained from literature. The density was multiplied by the volume to obtain biomass (eqn 8). The biomass estimated was used to determine the amount of carbon stock in each of the tree since it is known that 50% of biomass estimate contains the Carbon (eqn 9) (Samaka et al., 2007). The total tree biomass and Carbon for the entire forest were obtained by adding the biomass and Carbon of all the trees.

Biomass = Density x Volume (kg) (8)

Carbon estimation = $\frac{\text{Biomass}}{2}$ (9)

5. RESULTS

The results of tree species composition in the study area are presented in Table 1. A total of 56 trees distributed among 21 tree species were encountered in this study. *Funtumia elastica* was the dominant tree species represented by 11 stems. This was followed by *Musanga cecropiodes* with 10 stems. Tree species represented by a single stem were *Acacia ataxacantha*, *Blighia sapida*, *Celtis zenkeri, Cola milenii, Newbouldia laevis, Pterygota spp*, *Symphonia globulifera, Trichilia monadelpha and Triplochiton scleroxylon*. *Funtumia elastica* had the highest Shannon Weiner index value of 0.32 while *Acacia ataxacantha*, *Blighia sapida*, *Celtis zenkerii, Cola milenii, Newbouldia laevis, Pterygota macrocarpa, Symphonia globulifera, Trichilia monadelpha and Triplochiton scleroxylon* all had Shannon Wiener index value of 0.07. Species evenness of 0.86 was recorded for the study area.

Table 2 is on the summary of tree growth variables. Total tree Dbh ranged from 15.5-333.6cm. It was found to be highest for *Funtumia elastica* with a Dbh of 333.6cm and *Lecaniodiscus cupanioides* had the lowest value of 11.60cm. *Lecaniodiscus cupanioides* had the lowest basal area of 0.01m^2 and the highest was recorded for *Ceiba pentandra* with 1.02m^2. The total volume of all the tree species ranged from 0.06-17.84m^3. It was found to be lowest for *Lecaniodiscus cupanioides* with 0.06m^3 and highest for *Ceiba pentandra* with a value of 17.84m$^{3.}$ Some of the tree species with low volume were *Acacia ataxacantha* (0.34m^3), *Cola milenii* (0.78m^3), *Newbouldia laevis* (0.16m^3) etc. Generally, the forest had a total Dbh of 2032cm, total basal area of 8.12m^2 and total tree volume of 113.13m^3.

As shown in Table 3, *Acacia ataxacantha*, *Blighia sapida, Celtis zenkeri, Cola milenii, Khaya ivorensis, Khaya senegalensis, Lecaniodiscus cupanioides, Newbouldia laevis, Pterygota macrocarpa* etc all had Relative Density of 1.79%. Some of the tree species with Species Relative Dominance(RD$_{O)}$ lower than 5% were *Blighia sapida, Alstonia bonnie, Blighia sapida, Lecaniodiscus cupanioides, Myrianthus arboreus, Newbouldia laevis,* among others. *Funtumia elastica* was the most important tree species in the study area with IVI of 15.96%, and *Lecaniodiscus cupanioides* had the lowest of 0.96%. IVI of 1.15%, 3.22%, 11.25%, 2.89%, 2.55%, 5.00%, 8.98%, 5.17% and 1.14% were obtained for *Acacia ataxacantha, Ficus exasperata, Albizia lebek, Alstonia bonnie, Blighia sapida, Ceiba pentandra, Celtis zenkeri and Cola milenii* respectively.

Table 1. Tree species composition of the study area

S/n	Species	Family	Frequency	H^1	E
1	*Acacia ataxacantha (DC.) Kyal & Boatwr.*	*Fabaceae*	1	-0.07	-0.02
2	*Albizia lebbeck (L.) Benth*	*Fabaceae*	6	-0.24	-0.08
3	*Alstonia bonnie De Wild*	*Apocynaceae*	2	-0.12	-0.04
4	*Blighia sapida K.D. Koenig*	*Sapindaceae*	1	-0.07	-0.02
5	*Brachystegia eurycoma Harms*	*Fabaceae*	2	-0.12	-0.04
6	*Ceiba pentandra (L.) Gaertn*	*Malvaceae*	3	-0.16	-0.05
7	*Celtis zenkeri Engl.*	*Cannabaceae*	1	-0.07	-0.02
8	*Cola millenii K.Schum.*	*Malvaceae*	1	-0.07	-0.02
9	*Ficus exasperata Vahl*	*Moraceae*	3	-0.16	-0.05
10	*Funtumia elastica Stapf*	*Apocynaceae*	11	-0.32	-0.11
11	*Khaya ivorensis A. Chev.*	*Meliaceae*	1	-0.07	-0.02
12	*Khaya sengalensis (Desr.) A. Juss*	*Meliaceae*	1	-0.07	-0.02
13	*Lecaniodiscus cupanioides Planch. ex Benth*	*Sapindaceae*	1	-0.07	-0.02
14	*Musanga cecropioides R.Br. & Tedile*	*Urticaceae*	10	-0.31	-0.10
15	*Myrianthus arboreus P. Beauv. 1804*	*Urticaceae*	5	-0.22	-0.07
16	*Newbouldia laevis (P.Beauv.) Seem. ex Bureau*	*Bignoniaceae*	1	-0.07	-0.02
17	*Pterygota macrocarpa Schott & Endl.*	*Malvaceae*	1	-0.07	-0.02
18	*Ricinodendron heudelotii (Baill). Heckel*	*Euphorbiaceae*	2	-0.12	-0.04
19	*Symphonia globulifera L.f.*	*Clusiaceae*	1	-0.07	-0.02
20	*Trichilia monadelpha (Thonn.) JJ de Wilde*	*Meliaceae*	1	-0.07	-0.02
21	*Triplochiton scleroxylon K. Schum*	*Malvaceae*	1	-0.07	-0.02
	Total		**56**	**2.62**	**-0.86**

H^1= Shannon Wiener index, E= Species Evenness

Table 2. Total Dbh, Basal Area and Volume of each of the trees species encountered at the study site

S/n	Tree Spp	Frequency	Total Dbh (cm)	Total BA (m^2)	Total volume (m^3)
1	*Acacia ataxacantha (DC.) Kyal & Boatwr*	1	23.00	0.04	0.34
2	*Ficus exasperata Vahl*	3	54.20	0.09	1.04
3	*Albizia lebbeck (L.) Benth*	6	250.70	0.96	8.54
4	*Alstonia bonnie De Wild*	2	64.00	0.18	3.03
5	*Blighia sapida K.D. Koenig*	1	58.50	0.27	2.2
6	*Brachystegia eurycoma Harms*	2	101.50	0.52	8.9
7	*Ceiba pentandra (L.) Gaertn*	3	179.90	1.02	17.84
8	*Celtis zenkeri Engl*	1	94.00	0.69	15.12
9	*Cola millenii K. Schum*	1	22.70	0.04	0.78
10	*Funtumia elastica Stapf*	11	333.60	0.98	10.12
11	*Khaya ivorensis (Desr.) A. Juss*	1	33.00	0.09	3.71
12	*Khaya sengalensis (Desr.) A. Juss*	1	100.50	0.79	16.19
13	*Lecaniodiscus cupanioides Planch. ex Benth*	1	11.60	0.01	0.06
14	*Musanga cecropioides R.Br. & Tedile*	10	301.10	0.75	4.83
15	*Myrianthus arboreus P. Beauv. 1804*	5	79.30	0.11	2.43
16	*Newbouldia laevis (P.Beauv.) Seem. ex Bureau*	1	18.40	0.03	0.16
17	*Pterygota macrocarpa Schott & Endl.*	1	85.30	0.57	6.41
18	*Ricinodendron heudelotii (Baill). Heckel*	2	104.50	0.44	3.18
19	*Symphonia globulifera L.f*	1	15.50	0.02	0.2
20	*Trichilia monadelpha (Thonn.) JJ de Wilde*	1	24.00	0.05	2.29
21	*Triplochiton scleroxylon K. Schum*	1	77.00	0.47	5.77
	Total	**56**	**2032.30**	**8.12**	**113.13**

Table 3. Species Importance Value Index (IVI)

S/n	Species	Freq	RD(%)	RDo (%)	IVI(%)
1	*Acacia ataxacantha*	1	1.79	0.51	1.15
2	*Ficus exasperata*	3	5.36	1.09	3.22
3	*Albizia lebek*	6	10.71	11.79	11.25
4	*Alstonia bonnie*	2	3.57	2.22	2.89
5	*Blighia sapida*	1	1.79	3.31	2.55
6	*Brachystegia eurycoma*	2	3.57	6.42	5.00
7	*Ceiba pentandra*	3	5.36	12.60	8.98
8	*Celtis zenkeri*	1	1.79	8.55	5.17
9	*Cola millenii*	1	1.79	0.50	1.14
10	*Funtumia elastica*	11	19.64	12.28	15.96
11	*Khaya ivorensis*	1	1.79	1.05	1.42
12	*Khaya senegalensis*	1	1.79	9.77	5.78
13	*Lecaniodiscus cupanioides*	1	1.79	0.13	0.96
14	*Musanga cecropioides*	10	17.86	9.27	13.56
15	*Myrianthus arboreus*	5	8.93	1.29	5.11
16	*Newbouldia laevis*	1	1.79	0.33	1.06
17	*Pterygota macrrocarpa*	1	1.79	7.04	4.41
18	*Ricinodendron heudelotii*	2	3.57	5.35	4.46
19	*Symphonia globulifera*	1	1.79	0.23	1.01
20	*Trichilia monadelpha*	1	1.79	0.56	1.17
21	*Triplochiton scleroxylon*	1	1.79	5.74	3.76
	Total	**56**	**100**	**100**	**100**

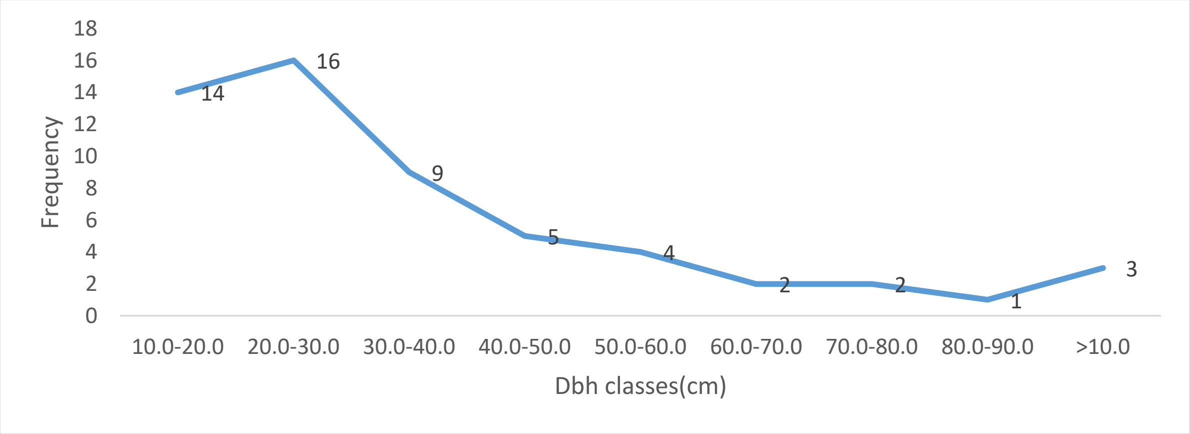

Fig. 2. Tree species distribution curve according to Dbh classes

Fig. 2 shows the distribution of tree species according to Dbh classes. It was observed that most of the trees (16 stems) fell in the Dbh class of 20-30cm. Also, 14 stems fell in the Dbh class of 10-20cm, and 9 stems fell in the Dbh class of 30-40cm. Only a few trees fell in the Dbh class of 40-50cm (5stems), 50-60cm (4 stems), 60-70cm (2 stems) and 70-80cm (2 stems). In addition, three trees were in the Dbh class greater than 100cm and only one tree was found in the Dbh class of 80-90cm.

Fig. 3 is on tree species distribution according to height classes. It was observed that most of the trees (19 stems) fell in the height class of 15-20m, and about 17 trees were in the height class of 10-15m. Only one tree fell in the height class below 5m.

As shown in Table 4, all the tree species encountered were distributed among 11 families. *Urticaceae family* had the highest relative density of 26.79%. This was followed by the family of apocynaceae with RD of 23.21%, and the lowest of 1.79% was recorded for the families of cannabaceae, bignoniaceae and clusiaceae. Family Relative Dominance ranged from 0.23-25.88%. It was lowest for clusiaceae and highest for malvaceae. It was also observed that the family of malvaceae had the highest FIV of

18.55% and Clusiaceae had the lowest of 2.26%. Family Important Value (FIV) of 16.36%, 3.74%, 15.75%, 5.47%, 5.03%, 10.34%, 15.62%, 2.29% and 4.56% were obtained for the families of fabaceae, moraceae, apocynaceae, sapindaceae, cannabaceae, meliaceae, urticaceae, bignoniaceae and euphorbiaceae respectively.

The results of density, volume, biomass and carbon of each of the tree species in the study area are presented in Table 5. The highest density of 0.75g/cm^3 was obtained for *Acacia ataxacantha,* and the lowest of 0.23g/cm^3 was recorded for both *Ceiba pentandra* and *Musanga cecropioides*. The tree volume ranged from 0.06-16.19m^3, and the biomass also ranged from 0.02g/m^2- 9.71g/m^2. Similarly, carbon obtained for the tree species ranged from 0.01-4.86 tonnes. *Khaya senegalensis (Desr.) A. Juss* had the highest biomass (9.71 $\mathrm{g/m^2}$) and carbon storage potential of 4.86 tonnes at this site, and *Ficus exasperata Vahl* had the lowest biomass and carbon storage potential of 0.02m^2 and 0.01 tonnes.

Table 6 shows the summary of tree growth variables, biomass, carbon and tree diversity indices obtained in the study area. A total of 56 trees were encountered in the study area with a Shannon wiener index of 2.62 and spp. evenness of 0.86. Mean basal area and total basal area of 0.15 and 8.12 were recorded. Mean volume and total volume were 2.02m^3 and 113.13m^3 respectively. Similarly, mean biomass and total biomass were 0.96 $\mathrm{g/m^2}$ and 53.64 $\mathrm{g/m^2}$ respectively. The mean and total carbon were recorded as 0.48 and 26.82tonnes.

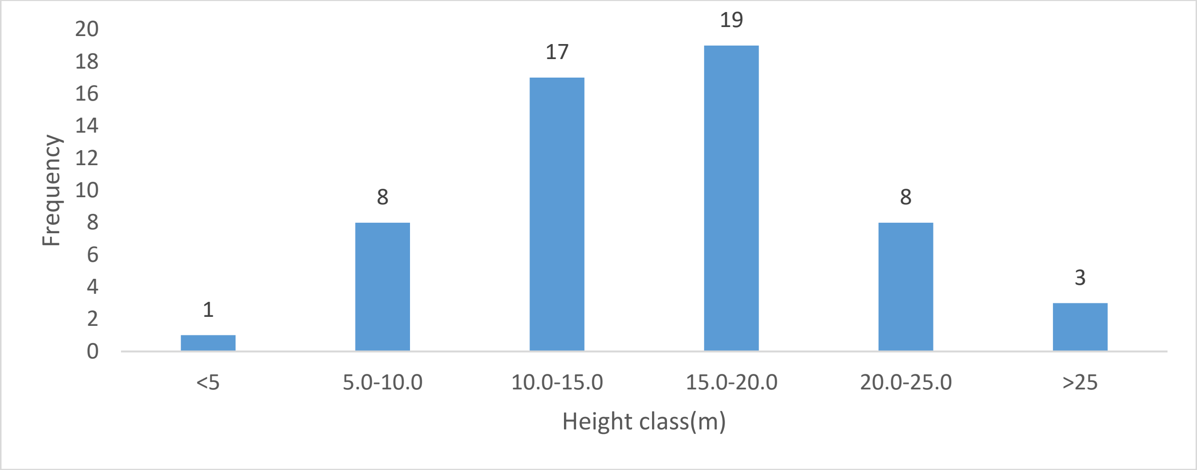

Fig. 3. Tree species distribution according to height classes

Table 4. Family Important Value (FIV) of tree species in the study area

S/N	Family	RD%	RF%	RDo%	FIV%
1	Fabaceae	16.07	14.29	18.72	16.36
2	Moraceae	5.36	4.76	1.09	3.74
3	Apocynaceae	23.21	9.52	14.5	15.75
4	Sapindaceae	3.57	9.52	3.31	5.47
5	Malvaceae	10.71	19.05	25.88	18.55
6	Cannabaceae	1.79	4.76	8.55	5.03
7	Meliaceae	5.36	14.29	11.38	10.34
8	Urticaceae	26.79	9.52	10.56	15.62
9	Bignoniaceae	1.79	4.76	0.33	2.29
10	Euphorbiaceae	3.57	4.76	5.35	4.56
11	Clusiaceae	1.79	4.76	0.23	2.26
	Total	**100**	**100**	**100**	**100**

Table 5. Density, volume, biomass and carbon of trees in the study area

S/n	Species name	Volume (m^3)	Density $(\mathrm{g/cm}^3)$	Biomass $(\mathrm{g/m}^2)$	Carbon (tonnes)
1	*Ceiba pentandra (L.) Gaertn*	2.90	0.23	0.67	0.33
2	*Albizia lebbeck (L.) Benth*	1.01	0.55	0.56	0.28
3	*Funtumia elastica Stapf*	0.58	0.51	0.30	0.15
4	*Brachystegia eurycoma Harms*	8.23	0.52	4.28	2.14
5	*Triplochiton scleroxylon K. Schum.*	5.77	0.32	1.84	0.92
6	*Trichilia monadelpha (Thonn.) JJ de Wilde*	2.29	0.50	1.15	0.57
7	*Acacia ataxacantha (DC.) Kyal & Boatwr.*	0.34	0.75	0.26	0.13
8	*Albizia lebbeck (L.) Benth*	2.02	0.55	1.11	0.55
9	*Albizia lebbeck (L.) Benth*	3.44	0.55	1.89	0.95
10	*Albizia lebbeck (L.) Benth*	1.35	0.55	0.74	0.37
11	*Ceiba pentandra (L.) Gaertn*	1.31	0.23	0.30	0.15
12	*Brachystegia eurycoma Harms*	0.67	0.52	0.35	0.17
13	*Myrianthus arboreus P. Beauv 1804*	0.51	0.54	0.27	0.14
14	*Myrianthus arboreus P. Beauv 1804*	0.57	0.54	0.31	0.15
15	*Myrianthus arboreus P. Beauv 1804*	0.22	0.54	0.12	0.06
16	*Myrianthus arboreus P. Beauv 1804*	0.57	0.54	0.31	0.15
17	*Myrianthus arboreus P. Beauv 1804*	0.56	0.54	0.30	0.15
18	*Albizia lebbeck (L.) Benth*	0.26	0.55	0.14	0.07
19	*Albizia lebbeck (L.) Benth*	0.46	0.55	0.25	0.13
20	*Lecaniodiscus cupanioides Planch. ex Benth*	0.06	0.57	0.03	0.02
21	*Newbouldia laevis (P.Beauv.) Seem. ex Bureau*	0.16	0.31	0.05	0.03
22	*Ficus exasperata Vahl*	0.89	0.40	0.36	0.18
23	*Symphonia globulifera L.f.*	0.20	0.58	0.11	0.06
24	*Ficus exasperata Vahl*	0.11	0.40	0.04	0.02
25	*Ricinodendron heudelotii (Baill). Heckel*	1.82	0.36	0.65	0.33
26	*Funtumia elastica Stapf*	0.29	0.51	0.15	0.08
27	*Ficus exasperata Vahl*	0.04	0.40	0.02	0.01
28	*Celtis zenkerii L.*	15.12	0.59	8.92	4.46
29	*Alstonia bonnie De Wild*	2.00	0.70	1.40	0.70
30	*Alstonia bonnie De Wild*	1.03	0.40	0.41	0.21
31	*Cola millenii K.Schum.*	0.78	0.40	0.31	0.16
32	*Funtumia elastica Stapf*	1.34	0.51	0.68	0.34
33	*Musanga cecropioides R.Br. & Tedile*	0.31	0.23	0.07	0.04
34	*Musanga cecropioides R.Br. & Tedile*	0.65	0.23	0.15	0.07
35	*Musanga cecropioides R.Br. & Tedile*	0.41	0.23	0.09	0.05
36	*Musanga cecropioides R.Br. & Tedile*	0.51	0.23	0.12	0.06
37	*Musanga cecropioides R.Br. & Tedile*	0.65	0.23	0.15	0.08
38	*Musanga cecropioides R.Br. & Tedile*	0.30	0.23	0.07	0.03
39	*Musanga cecropioides R.Br. & Tedile*	0.23	0.23	0.05	0.03
40	*Funtumia elastica Stapf*	0.24	0.51	0.12	0.06
41	*Funtumia elastica Stapf*	0.28	0.51	0.14	0.07
42	*Funtumia elastica Stapf*	0.55	0.51	0.28	0.14
43	*Funtumia elastica Stapf*	1.19	0.51	0.61	0.30
44	*Musanga cecropioides R.Br. & Tedile*	0.54	0.23	0.13	0.06
45	*Musanga cecropioides R.Br. & Tedile*	0.61	0.23	0.14	0.07
46	*Musanga cecropioides R.Br. & Tedile*	0.62	0.23	0.14	0.07
47	*Blighia sapida K.D. Koenig*	2.20	0.72	1.59	0.79
48	*Funtumia elastica Stapf*	0.24	0.51	0.12	0.06
49	*Ricinodendron heudelotii (Baill). Heckel*	1.36	0.36	0.49	0.25
50	*Ceiba pentandra (L.) Gaertn*	13.63	0.23	3.14	1.57

S/n	Species name	Volume (m^3)	Density $(\mathrm{g/cm}^3)$	Biomass $(\mathrm{g/m}^2)$	Carbon $(\mathbf{tonnes})$
51	*Funtumia elastica Stapf*	2.13	0.51	1.08	0.54
52	*Funtumia elastica Stapf*	0.60	0.51	0.31	0.15
53	*Khaya senegalensis (Desr.) A. Juss*	16.19	0.60	9.71	4.86
54	*Khaya ivorensis A. Chev.*	3.71	0.44	1.63	0.82
55	*Funtumia elastica Stapf*	2.68	0.51	1.37	0.68
56	*Pterogota spp. Schott & Endl.*	6.41	0.57	3.65	1.83
	Total	**113.13**	**25.01**	**53.64**	**26.82**

Table 6. Summary of tree growth variables, biomass, carbon and diversity indices

Diversity indices & tree growth variables	Values
No of trees	56
No of family	11
Shannon Wiener index	2.62
Species Evenness	0.86
Mean Basal Area (m^2)	0.15
Total Basal Area (m^2)	8.12
Mean Volume (m^3)	2.02
Total Volume (m^3)	113.13
Mean Biomass $(\mathrm{g/m}^2)$	0.96
Total Biomass $(\mathrm{g/m}^2)$	53.64
Mean Carbon (tonnes)	0.48
Total Carbon (tonnes)	26.82

Table 7. Correlation matrix all tree growth variables

	Dbh(cm)	Ht (m)	BA (m^2)	Vol. (m^3)	Ln Vol. (m^3)	Ln BA (m^2)	Ln Ht
Dbh(cm)	1						
Ht (m)	0.66	1					
BA (m^2)	0.97	0.60	1				
Volume (m^3)	0.85	0.60	0.93	1			
Ln Volume (m^3)	0.88	0.76	0.83	0.79	1		
Ln BA (m^2)	0.95	0.69	0.86	0.71	0.89	1	
Ln Ht (m)	0.61	0.97	0.54	0.50	0.71	0.69	1

Dbh- Diameter at breast height, Ht-height, BA- Basal Area, Vol.-volume, Ln- Natural log

The relationship between tree growth variables is shown in Table 7. There was a strong positive correlation value of 0.66 between Dbh and height. Also, a correlation coefficient of 0.85 occurred between Dbh and volume, 0.97 between Dbh and basal area, 0.88 between Dbh and Ln volume, 0.95 between Dbh and Ln BA, 0.61 between Dbh and Ln Height. Other relationship such as the height and basal area (0.60), volume and basal area (0.93) also showed a high level of relationship.

6. DISCUSSION

6.1 Tree Species Diversity of the Forest

Tree species diversity and abundance is vital to rainforest biodiversity [4,10]. Forest ecosystem plays vital roles in water cycles, climate change mitigation and carbon sequestration. According to Akindele & LeMay [11], the tropical ecosystem has been adjudged to be the richest single ecosystem in the world due to its species richness and diversity. The results of the study showed that all the encountered plants in the forest were mostly indigenous tropical hardwood species. A total of 56 trees distributed among 21 tree species were found in the study area. *Funtumia elastica* had the highest number of occurrence (11 stems) and a relative density of 19.64 %. Therefore, it could be considered as the most abundant species in the forest. The low number of trees, species and families in this forest could be attributed to logging activities that have occurred in the forest in the past years and have reduced the number of trees by hectare. This affirms what was reported by Akinbowale et al. [12] that rainforests are disappearing at an alarming rate as a result of over-exploitation. High number of valuable species are being threatened while some are becoming extinct. These threats have resulted majorly from land use and climate change. As one of the important components of the tropical forest, tree species diversity is fundamental to rainforest biodiversity [4]. Tree species of high economic and aesthetic value such *Melicia excelsa, Mansonia altissima, Terminalia superba, Nuclea diderrichi, Khaya spp.* etc. have been over-exploited in this study area and were only represented by few or no stems. Hence, timber contractors and loggers now resulted in harvesting low quality softwood species that have been abandoned over the years.

Biodiversity assessment is important for the tropical forest because it enables us to understand the interrelationship between the forest and its components. Tree diversity indices were used to put the tree species composition of the forest on a scale of comparison. The higher the value of an ecological index, the higher the species richness [13]. The floristic composition and diversity (H^1=2.62) of this study site is still within the range of value that can be recorded for tropical rainforest, and it compares favorably with some selected forest reserves in southwest Nigeria [14,15]. The high species evenness recorded showed a forest with an evenly distributed number of tree species and stems.

The distribution of tree species according to their diameter classes indicates how well the forest is regenerating [15]. The diameter distribution of trees is used to represent the population structure of forests ranging from small to large diameter [16]. Our results revealed that as tree diameter increases, the number of trees decreases. The level of relationship found in the tree growth variables were positively strong. Tree basal area was found to increase as the Dbh increases. Similarly, increase in height brought about increase in the volume. The floristic composition of the forest was dominated by a suite of understory trees because the natural forest is dominated by trees with small diameters. Similar results have been reported by previous workers in other tropical rainforest ecosystems of Nigeria [14]. The reason for few numbers of trees having Dbh greater than 50cm in this forest could be as a result of degradation which might have removed large trees, as well as the fact that some trees with large diameters would have been removed through selective logging for use and sales. This implies that the natural forest had experienced exogenous or endogenous disturbances.

Tonolli et al. [17] reported that tree stem volume is vital in forest management and sustainability. However, it requires data collection from the field. Many researchers have adopted different formulas to calculate tree volume, and these have resulted in obtaining different results because some formulas overestimate while some underestimate. However, the analytical formula, popularly known as “Newton's formula” [9], was used to calculate trees volume in this study. To use this formula, tree growth variables were measured for all trees during forest inventory. The total volume obtained for this study was below what was obtained by other researchers who have worked in the similar tropical forest ecosystems. The reason for this might be attributed to the volume estimation method and that trees with large diameter have been removed from this site in time past.

6.2 Biomass and Carbon Storage of Tree Species Encountered in the Forest

The above ground wood biomass (AWB) of tropical forests plays important role in the global carbon cycle, and local AWB estimates provide essential data that enable the extrapolation of biomass stocks of an ecosystem [18]. Ramachandran *et al.* [19] reported that the absorbing of carbon dioxide from the atmosphere and moving it into the physiological system and biomass of the plants, and finally into the soil, is the only practical way of removing large volumes of this major greenhouse gas from the atmosphere into the biological system. To understand the roles of trees in climate change mitigation, it is therefore important to assess biomass because it provides information on the structure and functional attributes of the forest to mitigate climate change and sequestrate Carbon from the atmosphere [20]. The total Above Ground Biomass of 53.64 g/m^2, which is equivalent to 26.82tonnes of Carbon was stored in all trees encountered at this study site. This low value of AGB and Carbon stored by this forest could be that valuable economic tree species with high carbon storage potential have been harvested from this forest. Generally, the big trees, which are always the target of tree fellers in Nigeria, contributed immensely to the carbon sink. The AGB of this forest is less than the worldwide tropical average of 278 Mg/ha [21] and 206–382 Mg/ha of flood plain forests in the Peruvian Amazon [22]. The variation in these values could be attributed to factors like the methods of biomass estimation, sampling intensity, inter-location variations, soil properties and the different climatic conditions. And the degree of forest degradation that has occurred in the study area.

7. CONCLUSION

The results from this study showed that there is high level of degradation in the study area. Important tree species of high economic values have being over-exploited and are on the brink of extinction. Forest plays vital roles in carbon sequestration. Though, the forest could only store small quantity of carbon as a result of the high level of degradation but it has been able to reduce the amount of carbon that could have escaped into the atmosphere. Conservative measures should be set up to protect the forest from further degradation and more protected forest should be established. This will go a long way to mitigate climate change by acting as carbon sinks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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