FOREST STRUCTURE AND TREE STEM CARBON STOCK OF GAMBARI NATURAL FOREST RESERVE, OYO STATE, NIGERIA

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ABSTRACT
Tree stems are major above-ground carbon pools in the tropical forest structure. Forest structure creates micro-climatic conditions for various ecosystem services. Natural and man-made disturbances cause changes in forest structure. However, the effect of forest structure dynamics on stem carbon sequestration is yet to be clarified in Gambari Natural Forest Reserve, Oyo State, Nigeria. Understanding influence forest structure dynamics on stem carbon could improve prediction of carbon sequestration potential of Gambari Natural Forest Reserve. Therefore, the aim of this study was to quantify forest structure and stem carbon stocks in Gambari Natural Forest Reserve. Ten sample (30m×30m^2) plots were randomly demarcated in Gambari Natural Forest using stratified random sampling method comprising 5 sample plots in each identified canopy structures; closed and open. Tree stems ≥10cm diameter-at-breast-height (dbh) were identified, enumerated and species diversity indices computed. Total height (TH) and diameter were also measured for volume and carbon estimation. Data collected were analyzed using descriptive statistics and ANOVA $\alpha_{0.05}$. A total of 50 tree species representing 25 families were identified in Gambari Natural Forest Reserve and closed canopy had higher diversity indices than open canopy structure. The lower and middle canopy class had the highest stems/ha in both structures. Diameter distribution of closed and open structure expressed extended reverse J-shaped and rotated sigmoid curves, respectively. Tree stem carbon stock were 0.66Mg/ha and 0.436Mg/ha in closed and open canopy structure, respectively. Microphyla pterigota (12.11%) and Triplochiton scleroxylon (25.84%) contributed highest carbon stock in closed and open canopy structures, respectively. The study concludes that the closed canopy structure of Gambari Natural Forest Reserve offers good option for carbon sequestration strategies as its structure and tree composition influences its stem carbon stock. However, only few tree species contributed to the high stem carbon stock in the study area. Therefore, these tree species can be considered in the establishment of carbon credit for carbon sequestration in Nigeria.

Keywords: Carbon sequestration, carbon stock, soil aggregate carbon, climate change.

INTRODUCTION
Forest trees are considered in the amelioration of climate change because of their large capacity of biomass. However, carbon stock varies among indigenous tropical trees (Bhatta *et al.*, 2018) and large proportion of soil organic carbon is derived from biomass of tree litters (Penne *et al.*, 2010). Thus, soil organic carbon is dependent on biomass productivity of tree stems. Understanding the role of tropical forest in climate change amelioration requires knowledge of carbon sequestration capacity of tree stems and species composition in a forest. The influence of forest structure on stem carbon density distribution has not been adequately described. Therefore, estimation of stem carbon among tree species composition is required for effective management of forest formation for optimum carbon sequestration. It is believed that stem density influence the distribution of carbon at the surface soil (Penne *et al.*, 2010). Conversely, there are little evidences on the effects of forest structure on the distribution of stem carbon density. Dynamics and spatial heterogeneity of forest structure make stem carbon estimation more difficult (Hu *et al.*, 2015). Hence, estimation of the carbon sequestration potential of Gambari Natural Forest requires understanding of forest structure dynamics.
The structure of the forests is described by vertical and spatial distribution of its component plant stems, plant diversity and their abundance (Akpata and Okali, 1986; Miren *et al.*, 2004). Natural and anthropogenic disturbances cause changes in forest structure. Hence, canopy and stem structures are rarely stable but in dynamic state (Clark, 1986). Therefore, forest structure can be closed or open canopy. Bottcher and Springob (2001) and Schulp *et al.* (2008) reported variation in carbon stock of forest floor over short distances in almost closed canopy structure and Penne *et al.* (2010) reported significant variation in carbon stock only for closed canopy structure. Both concluded that canopy structure may influence the spatial variation of organic inputs. Therefore, variation in structure could be used to predict the potential of a forest to retain or enhance stem carbon. Quantifying the spatial variability between

closed and open forest structure is necessary for effective management of forest formation for optimum carbon accumulation. Canopy and stem structures of forest create numerous micro-climatic conditions for various ecosystem functions and services (Chandler, 2016). However, the influence of forest structure on stem carbon sequestration is yet to be clarified. The detail understanding of distribution of carbon among species composition is required for planning mitigation strategy in Gambari Natural Forest Reserve. Therefore, this study is designed to quantify the forest structure and stem carbon stock of Gambari Natural Forest Reserve a view to estimating its contribution to climate change mitigation.

MATERIALS AND METHODS

This study was conducted in Gambari Forest Reserve. The reserve is one of the first reserves established in Nigeria (Akinyemi, 1998). It is located between Latitude 7º 25´ and 7º 55´N and Longitude 3º 53´ and 3º 9´E within the lowland rainforest vegetation of Nigeria and covers a total land area of 17,984ha while the natural reserve is estimated as 10ha (Akinyemi, 1998). It is situated at the southern part of Ibadan, bounded on the west by River Ona and on the east by the main road of Ibadan to Ijebu-Ode (Akinyemi, 1998). The reserve is bounded by Abanla and Odo-Ona settlements in Oluyole local government area of Oyo State in the north and south by Mamu and Abatan settlements in Ijebu-Ode local government area of Ogun State. Rainy and dry seasons are experienced in the reserve. Rainy season lasts for 9 months (March to November). The average annual rainfall is about 1140mm and average annual temperature is about 26.4^{0}C (Akinyemi, 1998).

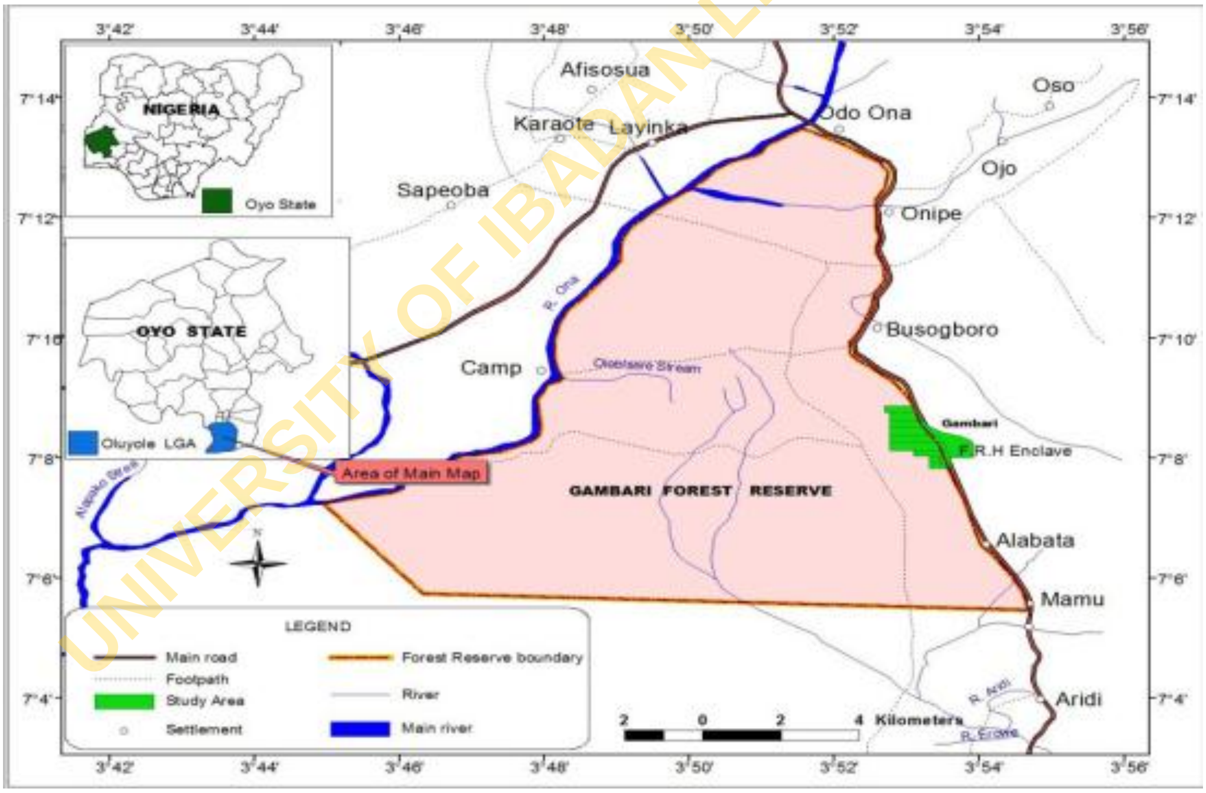

Figure 1: Map of the study area (Ige *et al*., 2013)

Methods of data collection

A reconnaissance survey was carried out to observe general physiognomy and structure of the forest reserve and to determine the sampling techniques to be used. It was observed that the forest was heterogonous in structure; some places were closely covered with canopy formation while others had open canopy formation, hence stratified random sampling method was used for plot selection and data collection. Canopy cover (%) of each plot was estimated from the center of the plots at noon of the day by measuring the proportion of plot area which is opened to sun ray (Clark, 1986). Plots with rays of sunlight greater than 10% of the plot area were regarded as open canopy while plots with less than 10% ray of sunlight were considered as closed canopy. In each structure, five 30m×30m sample plots were demarcated for data collection.

Estimation of the forest structure

Tree stems with ≥ 10cm diameter-at-breast height (dbh) were identified to species level and enumerated. Stem total height and diameter-at-breast height were measured and categorized to height and stem classes, respectively. Also, diameter-at (-base, middle and top) were measured using girth tape and Spiegel relaskop (Dr. W. Bitterlich model). The enumerated tree species were identified taxonomically to species level following Keay (1989) field guide and the help of assistant. The sample specimens of unidentified plants were collected and compared with collections of reference available in the Herbarium of the Forestry Research Institute of Nigeria (FRINH).

Diversity Indices

Shannon-Weiner and **Simpson** diversity indices were used to computed species diversity values for close and open canopy structures.

(a) Shannon-Weiner index

$$H = -\sum P_i \; lnP_i \qquad \ldots\ldots(1)$$

$$P_i = \frac{N}{n} \qquad \ldots\ldots(2)$$

Where:

N = total number of individuals of species i

n = total number of individuals of all species.

ln= natural logarithm

(b) **Simpson diversity index**

$$D = 1 - \sum \frac{n(n-1)}{N(N-1)} \qquad \ldots\ldots (3)$$

Where:

n= **the total number of individual of a particular species**

N= **the total number of individual of all species**

Forest strata/layers

Most matured rainforests are multi-layered with five distinct strata (Adapted from Longman and Jenik, 1974 and Whitmore, 1993) and therefore the height of tree stems were categorized into height classes as expressed below:

i. Emergence tree stems (> 36m and above)
ii. Upper Canopy tree stems (26-35m)
iii. Middle Canopy tree stems (16-25m)
iv. Lower Canopy tree stems (6-15m)
v. Ground Level tree stems (0-5m).

Quantification of tree stems biomass and carbon stock of each species

Stem biomass of tree species was estimated to quantify the tree stem carbon stock in the study area. The stem volume of individual tree species was estimated per plot in both closed and open canopy structures. Stem volume of individual species were computed using Newton wood volume equation (Adekunle *et al.*, 2013; Fonwebau, 1997). Newton's formula is expressed as:

$$\text{Stem volume} = \frac{(Db+4Dm+Dt)}{6} xh \qquad \ldots\ldots (4)$$

Where,

Db= Tree diameter at the base

Dm= Tree diameter at the middle

Dt = Tree diameter at the top

h= Tree height

The volume of individual tree species obtained was multiplied with individual species wood density and converted to stem biomass per hectare. Accordint to Malhi *et al.* (2004), stem carbon is about 50% of tree biomass. Using information gotten from the Wood Density Database (Zanne *et al.,* 2009) for wood densities of species, stem carbon stock of species were calculated using the equation;

Stem carbon stock/species (Mg/ha) = SV×WD× constant (0.50)……………………… (4)

Where:

SV= Stem wood volume

WD = Wood density

RESULTS

The values of Shannon-Weiner diversity index ranged from 3.06 (open canopy structure) to 3.44 (closed canopy structure) with a mean of 3.25±0.05. Also, the values of Simpson diversity index ranged from 0.95±0.00 (open canopy structure) to 0.96±00 (closed canopy structure) with a mean of 0.91. (Table 1). Tree stem density ranged from 133.33±3.76 stems/ha (open canopy structure) to 228.89±4.52 stems/ha (closed canopy structure) with a mean of 362.22±4.14 stems/ha. The most common tree species in the closed canopy structure were *Microphylla pterigota* (25 stems/ha), *Triplochiton scleroxylon* (25 stems/ha), *Entandrophragma cylindricum* (14 stems/ha), while those in the open canopy structure included *Triplochiton scleroxylon* (22 stems/ha), *Antiaris africana* (11 stems/ha) and *Afzelia africana* (11 stems/ha).

Table 1: Forest structural attributes of Close and Open canopy structures of Gambari Natural Forest.

Forest structural attributes	Close canopy forest	Open canopy forest
Tree species richness	44.0	28.0
Shannon-Weiner diversity index	3.44±0.04	3.06±0.05
Simpson diversity index	0.96±0.00	0.95±0.00
Tree density (stems/ha)	228.89±4.52	133.33±3.76
Basal Area (m^2/ha)	14.47±10.64	12.45±10.57
Tree height (m)	20.47±9.21	20.61±10.58
Stand volume (m^3/ha)	73.66±08.84	73.17±03.35
Tree stem carbon (Mg/ha)	0.016±0.00	0.015±0.00
Dominant tree species	*Microphylla pterigota, Triplochiton scleroxylon and Entandrophragma cylindricum*	*Triplochiton scleroxylon, Antiaris africana and Afzelia africana*

Structure of close and open canopy of Gambari Natural Forest

The vertical stratification of closed and open canopy structures was assessed in terms of the height distribution (Figure 1). Both structures had trees in lower layer (6m-15m), middle layer (16m-37m), upper layer (26-35) and emergent layer (above 36.0m). The height distribution of tree stems of Gambari natural forest indicated that most of the stems were within the range of lower (5m-15m) and middle (15m-37m) layers. The closed canopy structure had 36.4% and 51.3% of its stem density in the lower and middle layers respectively, while 39.0% and 37.2% of the stem density in lower and middle layers respectively in the open canopy structure. The emergent layer had the least stem density in closed canopy structure (12.3%). However, the lower (64 stems/ha) and middle layers (61 stems/ha) had almost the same proportion of stem density in Open canopy structure and there were more emergent (31 stems/ha) than the upper canopy layers (8 stem/ha) in the open canopy structure. The maximum tree stems of 161 and 80 stems/ha occurred at the middle layer (15m-37m) height class in closed and open canopy structures respectively, while the minimum of tree stems 28 and 17 stems/ha occurred at the emergent layer in closed and open canopy structures, respectively, in Gambari Natural Forest.

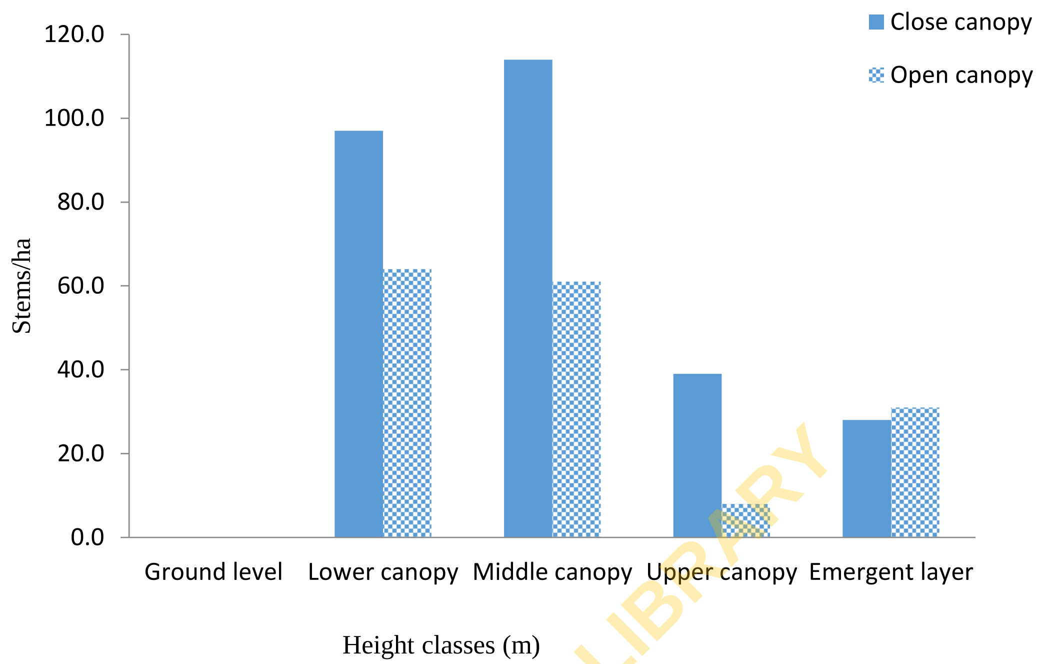

Figure 1. Stem height distribution of tress in Close and Open canopy structures in Gambari Forest Reserve

Diameter Classes

Close canopy structure had the highest stem density value of 164 stems/ha (57%) in diameter class 10-20 cm dbh followed by a steep decline to 42 stems/ha (14%) at 20-30cm dbh (Figure 2). The least stem density occurred at 90-100cm dbh (3 stems/ha) and 110-120cm dbh (3 stems/ha). The close canopy diameter distribution curve was truncated at 110-120cm dbh. There was no stem representation at 100-110cm dbh in Close canopy structure

Open canopy structure had the highest stem density value of 92 stems/ha (58%) in diameter class 10-20 cm dbh followed by a steep decline in tree density to 22 stems/ha (14%) at 20-30cm dbh (Figure 2). The least stem density occurred at 80-90 (3 stems/ha), 130-140 (3 stems/ha) and 190-200 cm dbh classes (3 stems/ha). There was no stem representation at 60-70, 70-80, 100-110, 110-120 and 120-130cm dbh classes in open canopy structure. The open canopy diameter distribution curve was truncated at 190-200cm dbh and therefore the distribution extended to 190-200cm dbh class.

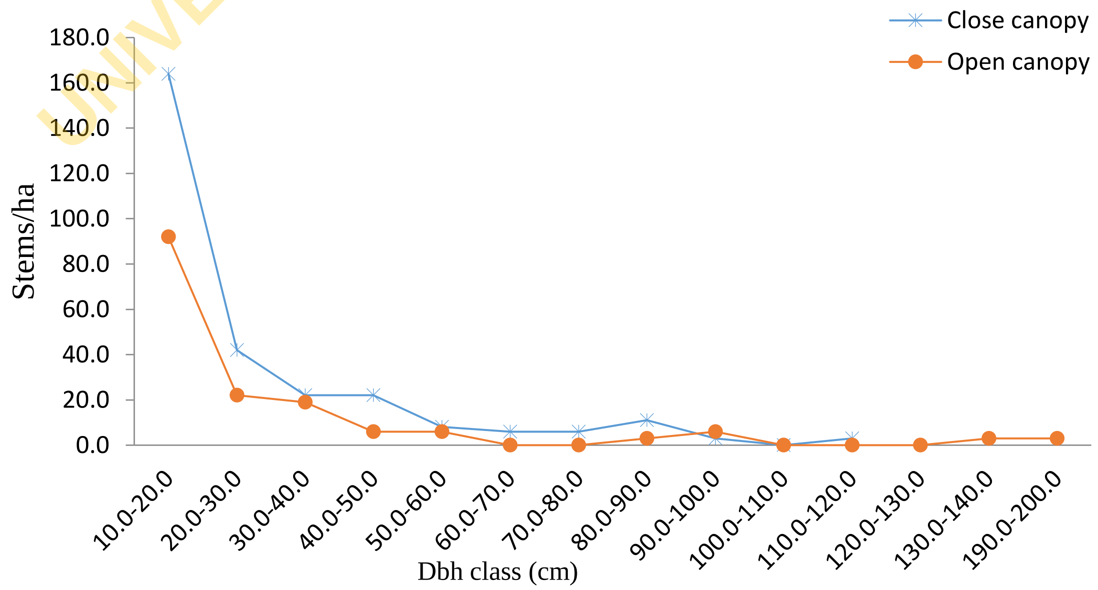

Figure 2. stem size distribution of tress in Close and Open canopy structure of Gambari Forest Reserve

Above-ground biomass and carbon stock of tree species in close and open canopy structures of Gambari Natural Forest

The smallest diameter class 10.0-20.0 cm dbh contained the largest amount of stem carbon (0.195 and 0.115 kg/ha) in closed and open canopy structures, respectively. This class contributed 23.3% and 21.1% of the total carbon in closed and open canopy structure, respectively. This is followed by 20.0 - 30.0 and 190.0 - 200.0 cm dbh with 0.125 and 0.084 kg/ha of stem carbon in closed and open canopy structures, respectively. The diameter class of 10.0-50.0 cm dbh contributed 59.6% and 49.82% of the total stem carbon in closed and open canopy structures respectively. Conversely, diameter class of 190.0-200.0 cm dbh (with 3stems/ha of *Vitex doniana*) contributed 15.38% to the total stem carbon of open canopy structure. The diameter class of 80.0-90.0 and 130.0-140.0 dbh (with 3stems/ha of *Triplochiton scleroxylon*) contributed 5.86%, 8.42% and 15.38%, respectively, to the total stem carbon of open canopy structure in Gambari natural forest. Also, diameter class 90.0-100.0 and 110-120.0cm dbh (with 3stems/ha of *Triplochiton scleroxylon*) contributed 5.38% and 5.50%, respectively, to the total stem carbon of open canopy structure.

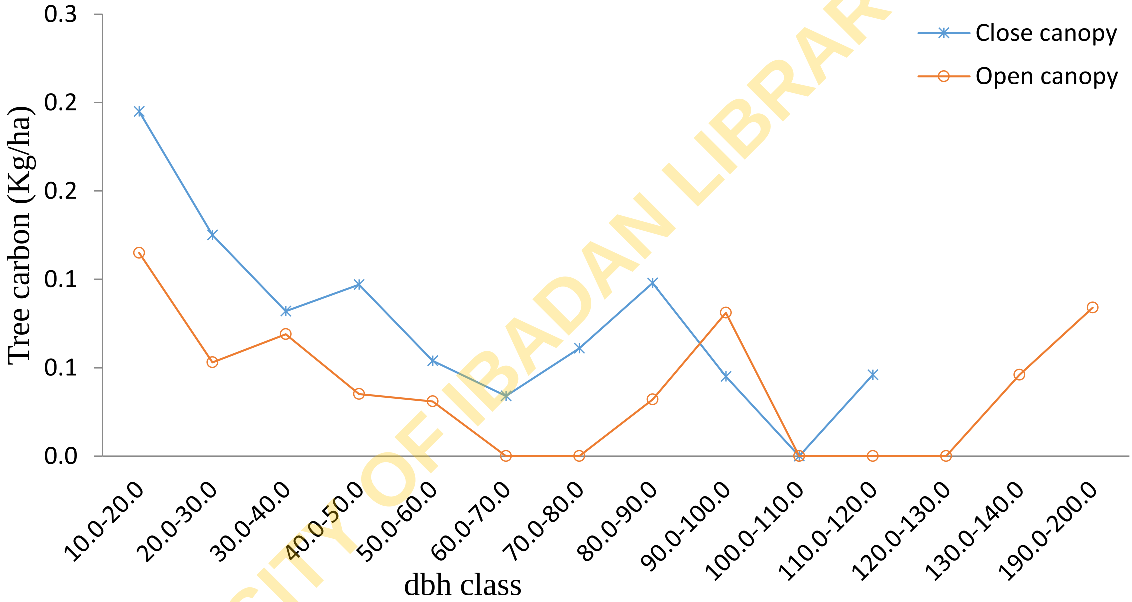

Figure 3. Stem biomass carbon of close and open canopy structures in Gambari Natural Forest Reserve

The above-ground biomass and carbon stock of top ten tree species in close and open canopy structures of Gambari Natural Forest is presented in Table 3 and 4. The summary of the above ground biomass and stems carbon stock of the top ten tree species in the close and open canopy structures of Gambari Natural Forest were presented in Table 3 and 4.

It was discovered that the amount of carbon accumulated varies among the species because the stem carbon depends on stem size and wood density.

Total amount of stem carbon stock in close canopy structure was 0.6639Mg/ha. The stem of *Microphylla pterigota* contributed highest proportion of carbon stock (12.11%), followed by *Triplochiton scleroxylon* (10.37%), *Entandrphragma cylindricum* (5.65%), *Chrysophyllum albidum* (5.46%), *Terminalia ivorensis* (4.18%), *Milicia excelsa* (4.18%), *Afzelia africana* (4.18%) and *Nauclea latifolia* (3.75%).The total amount of stem carbon stock in open canopy structure was 0.4360Mg/ha. The stem of *Triplochiton scleroxylon* contributed highest proportion of carbon stock (25.84%), followed by *Antiaris africana* (18.17%), *Afzelia africana* (10.29%), *Milicia exelsa* (8.56%), *Cola gigantea* (5.97%), *Microphyla pterigota* (5.91%), *Bombax boonoposense* (4.84%), *Morus mesozygia* (4.10%). In summary, total amount of tree stem biomass and carbon per hectare in the study area was 2457.69kg/ha and 1.0999Mg/ha, respectively.

Table 2: Carbon stock and biomass of tree species in close canopy structure of Gambari Natural Forest.

Tree Species	Stems/ha	Stem biomass (kg/ha)	Stem carbon (Mg/ha)	%Carbon/ha
Microphyla pterigota	7.0	180.33	0.0811	12.11
Triplochiton scleroxylon K. Schum	20.0	154.44	0.0694	10.37
Entandrophragma cylindricum	4.0	84.24	0.0379	5.65
Chrysophyllum albidum (G. Don)	2.0	81.36	0.0360	5.46
Terminalia ivorensis A. Chev.	4.0	62.33	0.0280	4.18
Milicia excelsa C.C. Berg	7.0	62.02	0.0279	4.18
Afzelia africana Sm	11.0	72.02	0.0263	4.18
Nauclea latifolia	4.0	55.91	0.0251	3.75
Cedrela mexicana	9.0	55.31	0.0248	3.71
Antiaris africana A. Chev.	9.0	54.64	0.0240	3.67
Cedrela odorata	4.0	53.8	0.0242	3.61
Canthium mannii Lam.Linn.	2.0	52.64	0.0236	3.53
Cola gigatea A. Chev.	9.0	43.96	0.0197	2.95
Alstonia boonei De Wild.	4.0	43.44	0.0195	2.91
Ceiba petandra (L.) Gaerth	2.0	39.98	0.0179	2.68
Diospyrus dendo Welw. ex. Hiern	11.0	37.87	0.0170	2.54
Cola millenii K. Schum	20.0	37.80	0.0170	2.53
Albizia zygia (DC) J.f. Macbr	2.0	37.31	0.0168	2.50
Canthium mannii Lam	2.0	32.82	0.0147	2.20
Funtumia elastica (Preuss) Stapf	2.0	23.09	0.0100	1.55
Lecaniodiscus cupanioides Planch. Ex Benth	4.0	20.89	0.0094	1.40
Celtis reticulum Engl	4.0	19.98	0.0089	1.34
Khaya grandifoliola C. DC	2.0	19.24	0.0086	1.29
Ficus elastica (Preuss) Stapf	4.0	18.38	0.0082	1.23
Pterygota macrocarpa K. Schum	9.0	17.24	0.0077	1.15
Bombax buonopozense P. Beauv.	4.0	16.27	0.0073	1.09
Khaya ivorensis A. Chev.	4.0	15.42	0.0069	1.03
Rhizophora racemosa G.F.W. Meyer	2.0	14.00	0.0063	0.94
Ricinodendron heudelotti (Baill) Heckel	4.0	14.00	0.0063	0.94
Pycnanthus angolensis (Welw.) Warb	2.0	12.69	0.0057	0.85
Kigeli African (Lam.) Benth	4.0	11.60	0.0052	0.77
Cordia millenii Lam.	11.0	11.47	0.0051	0.77
Anogeissus leiocarpa (DC.) Guill	2.0	10.98	0.0049	0.73
Holarrhena floribunda Dur. & Schinz	7.0	5.16	0.0023	0.34
Motandra guineensis	2.0	4.69	0.0021	0.31
Newbouldia levis Seemann ex. B	4.0	2.58	0.0021	0.17
Celtis Africana Engl.	2.0	2.49	0.0011	0.16
Rothmannia hispida	2.0	1.89	0.0008	0.12
Ficus exasprata Vahl	2.0	1.84	0.0008	0.12
Pericopsis laxiflora (Benth ex. Bak.) van	2.0	1.80	0.0008	0.12
Treculia africana Decne	2.0	0.84	0.0003	0.05
Total		1488.78	0.6639	

Table 3: Carbon stock and biomass of tree species in open canopy structure of Gambari Natural Forest.

Tree Species	Stems/ha	Stem biomass (kg/ha)	Stem carbon (Mg/ha)	%Carbon/ha
Triplochiton scleroxylon K. Schum	8.0	250.40	0.1126	25.84
Antiaris africana A. Chev.	4.0	176.11	0.0792	18.17
Afzelia africana Sm	4.0	99.69	0.0448	10.29
Milicia excelsa C. C. Berg	2.0	83.00	0.0373	8.56
Cola gigatea A. Chev.	4.0	57.98	0.0260	5.97
Microphylla pterigota	1.0	57.33	0.0258	5.91
Bombax buonoposense P. Beauv.	3.0	46.91	0.0211	4.84
Morus mesozygia	4.0	39.80	0.0179	4.10
Terminalia ivorensis A. Chev.	1.0	18.02	0.0081	1.86
Cola millenii	5.0	17.84	0.0080	1.84
Alstonia boonei De Wild	2.0	16.89	0.0076	1.74

Kigelia Africana (Lam.) Benth	2.0	16.24	0.0073	1.67
Pentacleithra macrophylla Benth.	1.0	15.62	0.0070	1.61
Lophira alata Banks ex. Gaerth.f.	1.0	14.24	0.0064	1.47
Celtis zenkeri Engl.	1.0	9.00	0.0040	0.92
Nauclea latifolia Sm.	1.0	8.33	0.0037	0.86
Rhizophora racemosa G.F.W. Meyer	1.0	8.20	0.0036	0.84
Newbouldia levis Seeman ex. B.	2.0	7.62	0.0034	0.78
Cedrela Mexicana	1.0	5.82	0.0026	0.60
Diospyrus dendo Welw. ex. Hiern	1.0	2.98	0.0013	0.30
Holarrhena floribunda Dur. & Schinz	2.0	2.96	0.0013	0.30
Ficus capensis hunb.	1.0	2.80	0.0012	0.29
Cedrela odorata Linn.	1.0	2.69	0.0012	0.28
Ficus exaspirata Vahl	2.0	2.36	0.0010	0.23
Ceiba petandra L. Gaerth	1.0	1.91	0.0008	0.19
Cordia millenii Bak.	1.0	1.87	0.0008	0.19
Vitex doniana Sweet	1.0	1.44	0.0006	0.14
Rauvolfia vomitoria Afzel.	1.0	0.84	0.0003	0.08
Total			0.4360	100.00

DISCUSSION

Species diversity of close and open canopy structures of Gambari Natural Forest

Gambari Natural Forest is relatively a mature forest because it comprise relatively few common tree species. The tree species richness and diversity of close canopy structure were higher than open canopy structure because close canopy had more trees of different species and created numerous micro-sites suitable for regeneration and growth of these tree species (Huang *et al.*, 2003). The mean values of Shannon-Weiner and Simpson diversity indices were 3.25±0.05 and 0.96±0.00 in Gambari Natural Forest, respectively. Shannon-Weiner index of diversity values ranged from 0.1 to 5.0. Hypothetically, the index ranges from 1.5 to 3.5 and it exceeds 4.5 very rarely. The value above 3.0 indicate that the structure of forest is stable and balanced. Also, high value of tree species diversity indicates high tree species richness and their abundance. Therefore, Gambari Natural Forest has stable and resilient structure. The increased stability and structure is a direct result of high tree species richness (Huang, 2003). The density of stems in close canopy structure was relatively higher when compare with open canopy. *Triplochiton scleroxylon* was the most common tree species in open and close canopy suggest that the tree species had comparatively large niche for regeneration and growth in open and close canopy structures. *Triplochiton scleroxylon* is a pioneer species and most times forest outliers (Keay, 1989).

Structure of closed and open canopy of Gambari Natural Forest

The height distribution of closed and open canopy structures indicated that there was no stem in the ground level probably because most stems in this stratum contained dbh that were < 10cm dbh. Also, it could be attributed to the fact that majority of the stems occupied the lower and middle strata, thus forming a closed canopy that probably suppressed the stems in the ground layer. Similar findings were reported in Tanzania tropical forest (Huang *et al.*, 2003) which is an indication of good tree regeneration behavior in the forest ecosystem (Saxena and Singh, 1984). Also, forest ecosystem that are associated with only adult trees with little or no incidence of lower strata, is believed to face local extinction of its species in the near future (Malik and Bhatt, 2016). Therefore, Gambari Natural Forest had a satisfactory regeneration behavior. The incidence of trees in the emergent stratum of any forest ecosystem is an indication of a good conservation success (Jimoh *et al.*, 2012).

The closed and open canopy structures expressed truncated and extended negative exponential distribution of stem density and diameter classes, respectively. This showed an inverse relationship between tree density and stem size, thus suggesting good reproduction but low recruitment. Westphal *et al*. (2006) confirmed that the forests that lack large tree stems are more likely to show a negative exponential diameter distribution. Piovesan *et al*. (2005) expressed it as rotated sigmoid distribution. This distribution is viewed as characteristic of a stable or steady-state forest (Coomes *et al*. 2003). The open canopy structure showed high stem density in the lower dbh class followed by a rapid decrease and a few representative stems in the middle class. This suggests good reproduction but discontinuous recruitment.

Lack of middle class in open canopy indicates few stems of reproductive size and this can retard the regeneration rate (Piovesan *et al*. 2005).

Carbon stock and biomass of tree stems in close and open canopy structures
Triplochiton scleroxylon and *Vitex doniana* with larger dbh contributed to the high proportion of stem carbon density in both closed and open canopy structures respectively. Therefore, growth potential of the two species could be enhanced for carbon sequestration capacity of Gambari natural forest. This confirmed the report of Hu *et al*. (2015) that small number of tree stems of large diameter class could contribute predominantly to biomass carbon accumulation. Most of the stem carbon (50% of stem carbon) occurred in trees with dbh ≤50cm. However, there was individual stems that contained large proportion of carbon and this confirmed the report of Vesterdal *et al.* (2008) that carbon accumulation varies among tree species. Stem carbon stock density was higher in close canopy structure than in open canopy structure of Gambari Natural Forest because of variations in the stem carbon stocks among the species. *Microphyla pterigota* and *Cedrela mexicana* contributed the highest proportion of stem carbon but were not the species with highest stem density in close canopy structure. Conversely, *Triplochiton scleroxylon* and *Antiaris africana* contributed the highest proportion of stem carbon stock density but only *Triplochiton scleroxylon* had high stem density in open canopy structure. Therefore, carbon content of tree stem is dependent on its density, wood density and the size of the tree. Stem carbon density is independent on high stem density. This is in accordance with Brown (2002) observation that the amount of carbon in a tree biomass depends on the tree size (diameter and height) as it is the most important predictor variables of above ground-carbon.

CONCLUSION
Closed canopy forest was more structurally developed than Open canopy structure in Gamabari natural forest reserve. Stem carbon density of Close canopy was higher than Open canopy structures and this indicates that stem carbon density reflect the pattern of forest structure. Therefore, maintenance of close canopy structure may be a good option for stem carbon sequestration in Gambari Natural Forest Reserve. Few tree species contributed the highest stem carbon stock, *Triplochiton scleroxylon* and *Vitex doniana* are among the few species that has high potential to increase carbon pool of Gambari natural forest reserve and therefore, these tree species can be considered in establishment of credit plantations for carbon sequestration in Nigeria. The stem carbon stock of the forest was relatively high and showed that Gambari Natural Forest has the potential for carbon sequestration and climate change mitigation. Therefore, its conservation and management is essential.

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