Phytosociological Analysis of Woody Plant Species as Determinant of above Ground Carbon Stock in the Guinea Savanna Ecological Zone of Nigeria

[a*]Jibrin, A., [b]Jaiyeoba, I. A., [c]Oladipo, E. O. and [d]Kim, I.
[a]Department of Geography, Ahmadu Bello University, Zaria, Nigeria
[b]Department of Geography, Federal University, Lokoja, Nigeria
[c]Department of Geography, University of Lagos, Lagos, Nigeria
[d]Department of Geography, Gombe State University, Gombe.
[*]Correspondence email: abdullahi717@hotmail.com

Abstract

Estimation of the magnitude of forests as carbon sinks or sources require accurate and reliable estimate of biomass density of the forests. However, poor knowledge of the quantity of biomass per species in a given ecosystem is one most uncertain factor involved in estimating carbon stock in developing countries. The aim of this study is to examine the relative phytosociological importance of woody species in determining above ground biomass/carbon stock in the Guinea savanna ecological zone of Nigeria. The research methodology employed field survey inventory, biometric measurements and laboratory analysis. Measurement was carried out in 45 quadrat sampling plots of 500 m^2. Destructive biomass sampling was used for biomass estimation. The phytosociological analysis carried out in this study revealed that ecologically dominant tree species in the study area in decreasing order were Vitellaria paradoxa,(32.73) Irvingia gabonensis, (28.38) Parkia biglobosa, (23.20) Anogeissus leiocarpus, (21.64) and Pterocarpus erinaceous (15.73). Others include Detarium microcarpum (13.85) Prosopis Africana (13.69) Danellia oliveri (11.91) Afzelia Africana (10.80); together accounting for about 65.2 % of total species dominance. By contrast, tree species that contribute most to the above ground biomass stock in the study area were Anogeissus leiocarpus, (705.82 kg) Parkia biglobosa, (631.47 kg) Pterocarpus erinaceous, (522.23 kg) Irvingia gabonensis (469.72 kg) and Vitellaria paradoxa (381.80 kg). Finding in this study implies that Anogeissus leiocarpus is the tree species with highest potential to store carbon in the study area. The study recommends that the identified ecologically dominant tree species be well protected in order to exploit their carbon sequestration potential for mitigating climate change.

Keywords: Phytomass, Carbon, Climate Change, Mitigation, Sequestration

INTRODUCTION

Savanna plant communities play very important role in sequestering large amount of atmospheric carbon through photosynthesis and act as sinks and sources of carbon. Savanna plant communities are typically characterized by regional variation in community composition, diversity, and spatial structure (Jibrin and Jaiyeoba, 2013; Jibrin, 2017). This variability ought to be considered in determining carbon storage of Savanna plant communities. This has become important because countries such as Nigeria, are required to provide robust estimates of carbon stocks in forests for effective implementation of climate change mitigation policies under Reduced Emission from Deforestation and Degradation Plus – (REDD+) programmes.

Phytosociology studies the structure, floristic composition, development and interrelationships between the species within plant communities. The above ground carbon stock is a function of plant community structure and composition (Grace, 2006). Vegetation structure refers to physiognomic variables like girth, height, diameter, crown cover, and basal area (Husch *et al*., 1982). Composition is the assemblage of plant species that characterize the vegetation (Martin, 1996). Plant species tend to be grouped in different combinations forming more or less definite communities due to the effect of ecological amplitude or environmental tolerance (Daubenmire, 1968; Fritts, 1976). It is from the knowledge of stand structure, species composition and its difference within and between stand that we can explain observable spatial variation in carbon stock density.

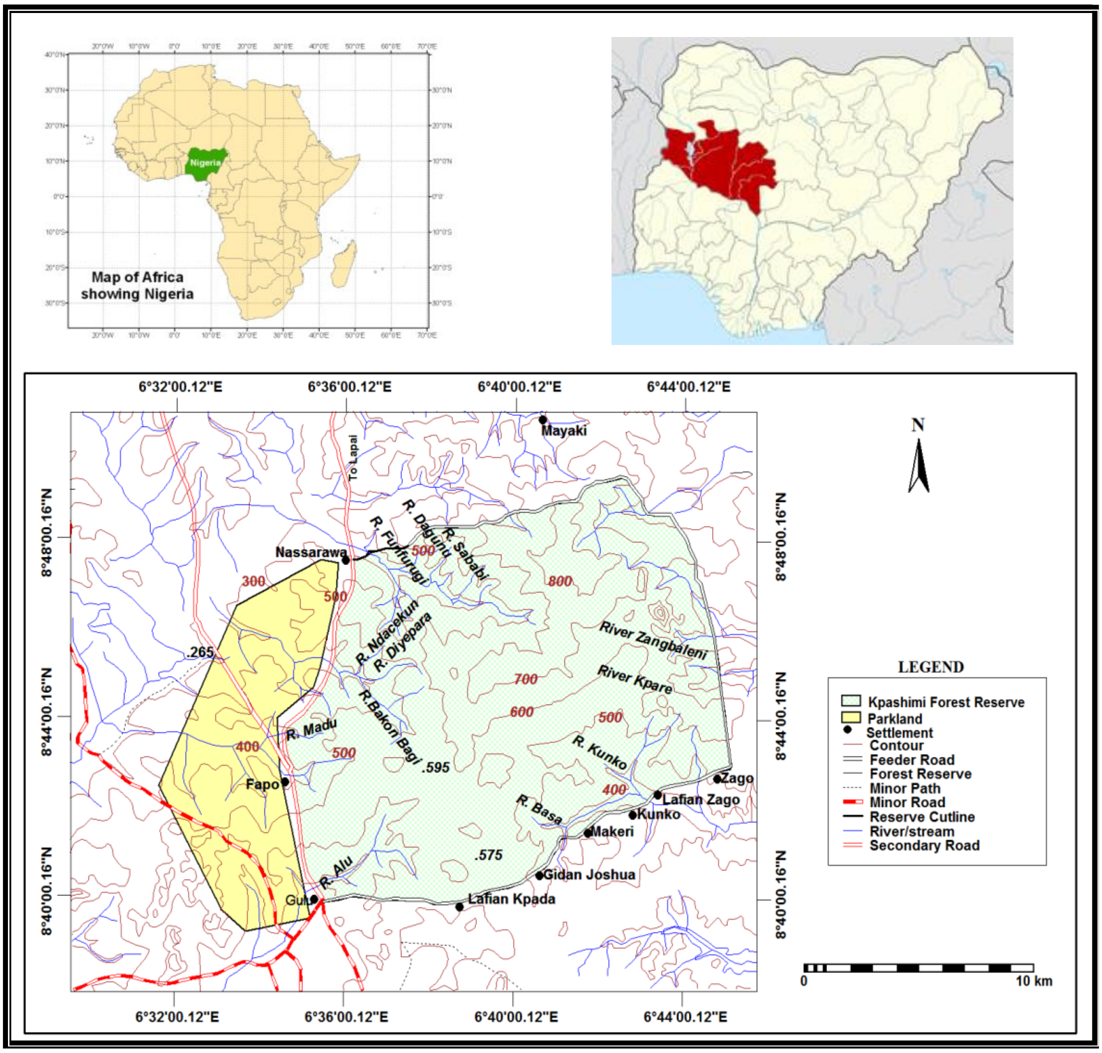


Figure 1: Geographical location of study area. Top left is Map of Nigeria (green), top right (Map of Nigeria showing Niger State) and bottom is study area as described in methodology.

Plants convert carbon from atmosphere into vegetal tissues by trapping CO_2 into their biomass through photosynthesis. Biomass is defined as the oven dry weight of all organic matter per unit area at particular time expressed in g/m^2 or kg/ha (FAO, 2008). The amount of carbon sequestered or emitted by a forest can be estimated from the biomass accumulation since approximately half of forest dry biomass weight constitutes carbon (Brown, 1997). Plant community structure and composition are closely linked to above ground carbon stock by virtue of their influence on the aggregate plant biomass or phytomass. Therefore, an accurate measurement of forest carbon is difficult to obtain without precise measurements of biomass (Malhi *et al*., 1999; Inter-governmental Panel On Climate Change- IPCC, 2007).

Phytosociological analysis of woody species are required in order to understand the potential role of tree species in capturing carbon and with a view to exploiting their ecological importance for climate change mitigation. Knowledge of the quantity of biomass per species in Guinea savanna ecological zone of Nigeria is scarce owing to the dearth of research on biomass/carbon stock estimation. The aim of this study is to examine the relative phytosociological importance of woody species in determining above ground biomass/carbon stock in the guinea savanna ecological zone of Nigeria. The objectives were: to analyze phytosociological characteristics of woody species in the study area; and to determine the most ecologically important trees for carbon capture and storage in the study area.

METHODOLOGY

Study Site

The study area is located between latitude 8^{o} 40$'$ to 8^{o} 52$'$ and longitude 6^{o} 39$'$ to 6^{o} 49$'$, covering approximately 213.101km^2 (Figure 1). It is characterized by alternating wet and dry season climate coded as 'Aw' by Koppen's classification. The mean annual rainfall is about 1,400 mm and mean annual temperature is 28^{o}C (Ojo, 1977). The geology of the study area is made up of cretaceous sedimentary rocks underlain by the Precambrian basement complex rocks (Forest Management Evaluation and Coordinating Unit - FORMECU, 1994). Phytogeographically, the study area lies within the Southern Guinea savannah zone classified as woodland savannah vegetation with the understory dominated by annual grasses (Keay, 1953).

The research employed field survey sampling, morphometric measurements and laboratory analysis. Reconnaissance survey was conducted at the preparatory stage and was followed by a pilot survey; for the determination of sampling frame. Fieldwork for the research took place between September and October, 2015. Based on the preliminary inventory data collected; during pilot survey, the mean and standard deviation of plot tree basal areas was calculated, precision sampling error (E) of 10% at 95% confidence level and the number of sampling units (n) was determined using the formula (equation 1). A total of 45 sampling units (n) was determined for the study. Inventory and basal area measurement was carried out in 45 quadrat sampling plots of about 500 m^2 (22.4m × 22.4m)

$$n = \frac{CV^2\, t^2}{E^2} \quad \text{(Philip, 1994)} \qquad (1)$$

Where:

CV = is the coefficient of variation of tree basal area at breast height

t = is the t value for the 95% confidence interval.

E = is the allowable sample error of estimation.

Phytosociological analysis was determined based on the plant Species Importance Value (S.I.V.) developed by Cottam and Curtis (1956). S.I.V. is defined as the sum of its relative density, relative dominance, and relative frequency according to the formula:

SIV = relative density + relative dominance + relative frequency

Where:

$$\text{Relative density} = \frac{Number\ of\ individuals\ of\ a\ species}{Total\ number\ of\ individuals}\ x\ 100$$

$$\text{Relative dominance} = \frac{Total\ basal\ area\ \ of\ a\ species}{Total\ basal\ area\ of\ all\ species}\ \ x\ 100$$

$$\text{Relative frequency} = \frac{Frequency\ of\ a\ species}{Sum\ frequency\ of\ all\ species} \quad x\ 100$$

Where:

Density is the number of individuals (n/N).
Dominance is the basal area (m^2/ha).
Frequency is the number of plots in which a species is represented.

The basal area was obtained by the formula: equation 2.

$$G = \pi * \frac{Di^2}{4} \tag{2}$$

Where: G is basal area, π= 3.14, Di is the diameter of tree at 1.3m above the ground level

Reitsma (1988) considered those having S.I.V. > 10 as ecological dominant species. The values of S.I.V. allow identifying the leading dominant entities, i.e. those species and families having the highest ecological value.

With regards to biomass sampling, Walker *et al.* (2012) formulated destructive/harvesting method of biomass sampling was used. Five most ecological dominant tree species were selected for destructive biomass sampling. A total of 30 samples (six sample trees per species) was used based on six DBH classes as presented in Table 1.

Individual trees were felled, separated into component (Trunk, leaves, and branches). Each component was weighed, while a subsample was collected for oven drying. The volume of the discs (aliquots) were determined by the water-displacement method (Brown, 1997).

Table 1: Diameter at Breast Height Class Groups of Tree Biomass Sample

Class intervals	Frequency (n)	Percent	Girth (cm)	Mean dbh (cm)
1-10.4	211	11.6	22.6	7.2
10.5-20.4	490	27.0	52.8	16.8
20.5-30.4	544	30.0	78.2	24.9
30.5-40.4	461	25.4	110.5	35.2
40.5-50.4	101	5.6	136.0	43.3
50.5-60.4	9	.5	175.2	55.8
Total	1816	100.0		

The discs were oven dried to constant weight at 70^O C for 48- 96 hours. Total dry weight (TDW) of each component of sample tree was calculated from the total fresh weight (TFW), the fresh weight of the organ sample (SFW) and the dry weight of sample (SDW) based on the equation 3.

$$TDW = \frac{SDW}{SFW}\ x\ TFW \tag{3}$$

RESULTS AND DISCUSSION

Species Importance Value Analysis

A total of 2,161 individual woody stands representing 58 species, 49 genera and 18 families were identified and enumerated in all plant communities found in the study area. Table 2 shows the woody species relative density (RD), relative dominance (RDo) and relative frequency (RF) that were computed to determine the woody species importance value (SIV) over the entire study area.

Based on the Species Importance Value index analysis presented in Table 2, the ecologically dominant tree species in the study area in decreasing order are *Vitellaria paradoxa*,(32.73) *Irvingia gabonensis*, (28.38) *Parkia biglobosa*, (23.20) *Anogeissus leiocarpus*, (21.64) and *Pterocarpus erinaceous* (15.73). Others include *Detarium microcarpum* (13.85) *Prosopis Africana* (13.69) *Danellia oliveri* (11.91) *Afzelia Africana* (10.80); which together account for about 65.2 % of total species dominance. This confirms findings by Keay (1989) that, Southern Guinea Savannah in Niger state is the major *Vitellaria paradoxa* zone in Nigeria. Similarly, Odebiyi *et al*. (2004) reported high population of *vitellaria paradoxa and parkia biglobosa* over moist and dry Guinea savanna in Nigeria; with *Vitellaria paradoxa* being more dominant. In contrast, Mama and Adeniyi (2005), found the dominant tree species in the savanna were *Anogeissus leiocarpus, Burkea Africana, Vitellaria paradoxa, Burkea africana and Pterocarpus erinaceus.* Hall *et al*. (1996) and Boffa (1999) also reported *Vitellaria paradoxa* as the most dominant in savanna where it is associated with other species such as *Parkia biglobosa, Acacia senegalis and Terminalia avicenniodes.*

Table 2: Specie Importance Value Index over the study area

S/N	Woody Species	Total No	RD	RDo	RF	SIV
1	*Vitalleria paradoxa*	299	13.82	13.08	5.84	32.73
2	*Irvingia gabonensis*	199	9.20	15.94	3.24	28.38
3	*Parkia biglobosa*	174	8.04	9.84	5.32	23.20
4	*Anogeissus leiocarpus*	165	7.65	9.32	4.67	21.64
5	*Pterocarpus erinaceous*	161	7.43	4.02	4.28	15.73
6	*Detarium microcarpum*	123	5.67	4.41	3.76	13.85
7	*Prosopis africana*	124	5.73	4.46	3.50	13.69
8	*Danellia oliveri*	92	4.24	3.90	3.76	11.91
9	*Afzelia africana*	76	3.52	3.90	3.37	10.80
10	*Khaya senegalensis*	74	3.41	3.68	2.33	9.43
11	*Burkea africana*	48	2.20	2.00	2.33	6.53
12	*Combretum molle*	48	2.20	2.11	1.95	6.26
13	*Terminalia avicennoides*	33	1.54	1.39	2.33	5.27
14	*Adansonia digitata*	23	1.05	1.04	3.11	5.20
15	*Tamarindus indica*	20	0.94	0.91	3.11	4.96
16	*Isoberlina doka*	30	1.38	1.15	1.82	4.35
17	*Acacia albida*	21	0.99	0.79	2.46	4.25
18	*Vitex doniana*	20	0.94	1.09	1.95	3.98
19	*Mangifera indica*	13	0.61	0.45	2.72	3.78
20	*Lophira lanceolata*	20	0.94	0.77	1.82	3.52
21	*Terminalia glaucescens*	20	0.94	0.72	1.69	3.34
22	*Ceiba pentandra*	20	0.94	1.03	1.30	3.26
23	*Elaeis guineensis*	18	0.83	0.71	1.69	3.22
24	*Annona senegalensis*	17	0.77	0.54	1.56	2.87
25	*Acacia tortilis*	15	0.72	0.97	1.17	2.86
26	*Hyphaenia thebeica*	13	0.61	0.50	1.69	2.79
27	*Azadirachta indica*	7	0.33	0.39	1.95	2.66
28	*Acacia raddiana*	12	0.55	0.42	1.69	2.66
29	*Acacia nilotica*	11	0.50	0.50	1.30	2.29

30	*Borassus eathiopium*	13	0.61	0.32	1.30	2.22
31	*Bombax costatum*	10	0.44	0.38	1.30	2.12
32	*Acacia senegal*	4	0.17	0.14	1.43	1.73
33	*Ximenia americana*	10	0.44	0.35	0.91	1.70
34	*Balanites aegyptiaca*	10	0.44	0.44	0.78	1.65
35	*Anacardium occidentale*	1	0.06	0.02	1.56	1.63
36	*Afromosia laxiflora*	10	0.44	0.25	0.91	1.60
37	*Psidium guajava*	13	0.61	0.30	0.65	1.55
38	*Gmalina arborea*	4	0.17	0.06	1.04	1.26
39	*Cola gigantea*	7	0.33	0.26	0.65	1.24
40	*Ficus polita*	2	0.11	0.06	1.04	1.20
41	*Nauclea latifolia*	5	0.22	0.32	0.52	1.06
42	*Antiaris africana*	5	0.22	0.18	0.52	0.92
43	*Parinary polyandra*	4	0.17	0.16	0.52	0.84
44	*Tectona grandis*	4	0.17	0.20	0.39	0.75
45	*Ficus sycomorus*	1	0.06	0.04	0.65	0.75
46	*Strychnos innocua*	4	0.17	0.19	0.39	0.74
47	*Citrus sinensis*	1	0.06	0.02	0.65	0.72
48	*Carica papaya*	2	0.11	0.07	0.52	0.70
49	*Sterculia tragacantha*	5	0.22	0.08	0.39	0.69
50	*Ficus capensis*	1	0.06	0.00	0.52	0.58
51	*Gardenia terifolia*	4	0.17	0.07	0.26	0.50
52	*Cocos nucifera*	1	0.06	0.09	0.13	0.28
53	*Cola nitida*	1	0.06	0.05	0.13	0.24
54	*Prosopis julifera*	1	0.06	0.05	0.13	0.23
55	*Diosyros mespiliformis*	1	0.06	0.04	0.13	0.22
56	*Upaka togoensis*	1	0.06	0.03	0.13	0.21
57	*Ziziphus americana*	1	0.06	0.02	0.13	0.21
58	*Albizia zysia*	1	0.06	0.02	0.13	0.20
59	Others	142	6.55	5.76	4.54	16.85
	Total	2161	100.00	100.00	100.00	300.00

The foregoing analysis reveals that the study area is characterized by typical Guinea Savanna tree species. Moreover, plant species tend to be grouped in different combinations forming more or less definite communities due to the effect of ecological amplitude or environmental tolerance (Daubenmire, 1968; Fritts, 1976). The observed dominance of specific species and species families over the study area can be attributed to the effect of species ecological amplitude (environmental tolerance) whereby plant communities are basically a consequence of rigorous habitat selection that denies opportunity to all but a relatively few of the great variety of species (Daubenmire, 1968, 1972; Tivy, 1971; Fritts, 1976). The implication of most dominant tree species in the study site is that they are the ones which contribute most of the above ground carbon stock.

Biomass of ecologically dominant species

Summary of data on sampled phytomass of tree components parts is presented in Table 3. At species level, plants vary in their biomass and carbon content and the relative contribution of these species can be assessed by determining the species that contribute most to the aggregate carbon stock in the study site.

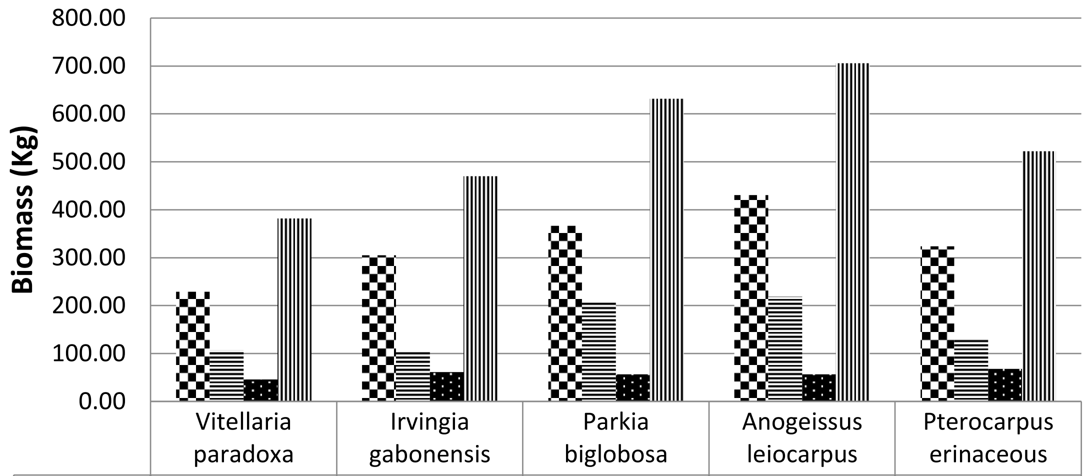
Analysis of the result in Table 3 reveals that the total phytomass of five most dominant tree species in decreasing order were *Anogeissus leiocarpus*, (705.82 kg) *Parkia biglobosa*, (631.47 kg) *Pterocarpus erinaceous*, (522.23 kg) *Irvingia gabonensis* (469.72 kg) and *Vitellaria paradoxa* (381.80 kg) (see Figure 2).

Table 3: Phytomass of Sampled Tree Components

S/N	Species name	Trunk (kg)	Branches (kg)	Leaves (kg)	Total biomass (kg)
1	*Vitellaria paradoxa*	34.7	16.2	6.9	57.8
2	*Vitellaria paradoxa*	92.4	43.1	18.5	154
3	*Vitellaria paradoxa*	161.7	75.5	32.3	269.5
4	*Vitellaria paradoxa*	231	107.8	46.2	385
5	*Vitellaria paradoxa*	369.6	172.5	73.9	616
6	*Vitellaria paradoxa*	485.1	226.4	97	808.5
7	*Irvingia gabonensis*	43.3	14.7	8.7	66.6
8	*Irvingia gabonensis*	129.8	43.9	26	199.7
9	*Irvingia gabonensis*	216.4	73.2	43.3	332.9
10	*Irvingia gabonensis*	317.3	107.4	63.5	488.2
11	*Irvingia gabonensis*	476	161.1	95.2	732.3
12	*Irvingia gabonensis*	649.1	219.7	129.8	998.6
13	*Parkia biglobosa*	52.7	30	8.2	90.9
14	*Parkia biglobosa*	158.2	90	24.6	272.8
15	*Parkia biglobosa*	281.3	160.1	43.7	485
16	*Parkia biglobosa*	404.3	230	62.7	697.1
17	*Parkia biglobosa*	509.8	290.1	79.1	879
18	*Parkia biglobosa*	791.1	450.1	122.8	1364
19	*Anogeissus leiocarpus*	62	31.5	8.1	101.6
20	*Anogeissus leiocarpus*	186	94.5	24.4	304.9
21	*Anogeissus leiocarpus*	310	157.5	40.7	508.2
22	*Anogeissus leiocarpus*	454.7	231.1	59.6	745.4
23	*Anogeissus leiocarpus*	682	346.6	89.4	1118
24	*Anogeissus leiocarpus*	888.6	451.6	116.5	1456.8
25	*Pterocarpus erinaceous*	47	19	9.9	75.8
26	*Pterocarpus erinaceous*	141	56.9	29.6	227.4
27	*Pterocarpus erinaceous*	235	94.8	49.3	379.1
28	*Pterocarpus erinaceous*	344.7	139	72.3	555.9
29	*Pterocarpus erinaceous*	517	208.5	108.4	833.9
30	*Pterocarpus erinaceous*	658	265.3	138	1061.3

The result shows that tree species have different phytomass weight and would definitely store different amount of carbon. It is noteworthy that *Anogeissus leiocarpus* which is the 4th on the list of Species Importance Value, weighed highest, while *Vitellaria paradoxa* in the 1st position of Species importance value, weighed least among the five most dominant species in the study area. This study thus indicates that though there are five most important tree species in the study area, their contribution to total above ground carbon stock varies.

The findings in this study imply that *Anogeissus leiocarpus* is the species with highest potential to store carbon in the study area. The influence of plant community composition on carbon stock as found in this study reflects the importance of functional traits of dominant plant species (Bunker *et al*., 2005). This corroborates Treydte *et al.*, (2008) findings that the structure and composition of savannas are strongly determined by their woody component; particularly by large trees, which play a key role in ecosystem function. Such findings are in agreement with Grace (2006) that aboveground carbon stocks varied widely, depending on the extent of the tree cover and associated physiognomic characteristics. These findings are also in line with Struhsaker (1997) and Babaasa *et al*. (2004) assertions that variation in the structure and composition of plant communities and quantitative properties of their diversity constitute variables that determine variation in carbon stock over a landscape.



	Vitellaria paradoxa	Irvingia gabonensis	Parkia biglobosa	Anogeissus leiocarpus	Pterocarpus erinaceous
Trunk	229.08	305.32	366.23	430.55	323.78
Branches	106.92	103.33	208.38	218.80	130.58
Leaves	45.80	61.08	56.85	56.45	67.92
Total	381.80	469.72	631.47	705.82	522.23

Figure 2: Comparison of biomass of the five most dominant tree species

CONCLUSION

The phytosociological analysis carried out in this study revealed that the ecologically dominant tree species in the study area in descending order were *Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa, Anogeissus leiocarpus, Pterocarpus erinaceous, Detarium microcarpum, Prosopis africana, Danellia oliveri,* and *Afzelia Africana*; which together account for about 65.2 % of total species dominance. Moreover, the most dominant families were *Fabaceae, Malvaceae, Moraceae,* and *Combrataceae*. In contrast, the phytomass of five most dominant tree species in decreasing order are *Anogeissus leiocarpus, Parkia biglobosa, Pterocarpus erinaceous, Irvingia gabonensis* and *Vitellaria paradoxa*. The study showed that species composition followed the trend in the eco-region with dominance of typical Guinea savanna tree species while the implication of the most dominant tree species in the study site is that they contribute most to the above ground biomass/carbon stock.

This study recommends the preservation of tree species such as *Anogeissus leiocarpus, Parkia biglobosa, Pterocarpus erinaceous, Irvingia gabonensis and Vitellaria paradoxa* for carbon offset purposes; because they are indigenous, ecologically important and show high carbon sequestration potential by virtue of their biomass stocks. In view of the observed potentials of carbon sequestration capacity in the study area, this study recommends the need for defining a sustainable forest management programme such as carbon offset trading which will provide window of opportunities for accessing carbon credits through the Clean Development Mechanism (CDM) tool of the Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC).

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