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Differential Biomass Apportionments and Carbon Stocks in Vegetation of Natural and Artificial Ecosystems in Akwa Ibom State, Nigeria

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ABSTRACT

Differential biomass and carbon stocks were investigated in vegetation of natural and artificial ecosystems in Akwa Ibom State. Three vegetation plots were used for each site. In each plot, three belt transects were laid and in each transect, vegetation were sampled systematically in ten 10 m × 10 m quadrat. Vegetation variables such as DBH, height of species were measured while their ages were estimated. The biomass and carbon stocks of species were estimated standardized allometric functions. The result revealed a total of 15, 30, 19 and 19 species in the mangrove, forest, arboretum and orchard, respectively. The biomass allocation in the various woody species components followed this decreasing order; stem > branches > leaves. The standing biomass in the ecosystems followed this decreasing order; forest (179.14 tons) > arboretum (53.94 tons) mangrove (33.03 tons) > orchard (17.14 tons). The carbon stock in the vegetation also followed this decreasing order: forest (89.65 tons) > arboretum (28.51 tons) > mangrove (16.52 tons) > orchard (8.57). Species such as *Elaeis guineensis* (in mangrove), *Coula edulis* (in forest), *Temarindus indica* (in arboretum) and *Anacardium occidentalis* (in orchard) had the highest values for biomass and sequestered carbon while species such as *Alchornea cordifolia* (in mangrove), *Maesoboytra dusenii* (in forest), *Rauwolfia vomitoria* (in arboretum) and *Anthocleista vogelli* (in orchard) had the least standing biomass and sequestered carbon. Conclusively, these results have practical implications in environmental monitoring and management, afforestation, forest protection and conservation, climate change and global warming.

***Keywords*:** Biomass apportionment, Carbon stocks, Mangrove, Forest, Arboretum, Orchard, Global warming, Climate change, Afforestation

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1. INTRODUCTION

The continuous release of CO_2 into the atmosphere emanating from fossil fuels and wood combustions especially in urban settings is a potential threat to humans and animals in the environment. These unwholesome activities leading to uncontrolled emission of CO_2 into the atmosphere in large amounts tend to endanger the security of humans and animals. Away from fossil fuel combustions, ceaseless logging and forest decimation have also been linked to increased emissions of CO_2, increase in greenhouse gases, changes in climate and global warming [1]. This is indeed problematic with regards to productivity of crops, security of humans and animals worldwide. As a result, concerns regarding the impact of CO_2 emissions arising from forest decimation and degradation globally have led to increased emphasis being placed on carbon stocks estimations and its changes in forest ecosystems worldwide.

Robust carbon stocks estimates in forests are important in order to constrain uncertainties in regional and global carbon budgets and predictions of climate change made using earth systems models [2]. These carbon estimates are also pivotal requirements for international forest-based climate change mitigation strategies like REDD+ (Reducing Emissions from Deforestation and Forest Degradation). REDD+ aims at achieving reductions in CO_2 emissions, forest protection, conservation and sustainable development by placing an economic value on forest carbon storage and facilitating the transfer of funds from developed to developing nations through international trade in carbon credits.

According to [3], carbon removal from the atmosphere and its storage in a reservoir or pool (terrestrial ecosystems) remains one of the successful approaches to reducing CO_2 concentrations in the atmosphere and mitigating climate change. This natural carbon sequestration approach has been implicated to be cost effective with many benefits added [4]. [5] estimated carbon in terrestrial ecosystems at 2000 ±500 Pg which represents about 25% of carbon stocks globally. Thus, [6] added that sequestration of carbon in vegetation and soils has been widely recognized and accepted towards mitigation of atmospheric CO_2 and global warming. This underscores the vegetation and soils as important pools in sequestrating carbon and climate change mitigation and further highlights the need to understand the diverse roles played by these terrestrial components in carbon sequestration.

Carbon stock quantification differs greatly in natural and artificial ecosystems. Natural ecosystems in this context refers to ecosystems that grow and operate under natural conditions without any major interference or disturbance from anthropogenic activities. Examples include forest, grassland, desert, spring, streams, river, lakes, ponds, pools, ditches, swamps and estuaries. Artificial ecosystems on the other hand imply ecosystems that are man-made and maintained artificially by man where the natural balance is disrupted regularly. Examples include such as orchards, rice-fields, wheat, sugarcane, maize, croplands, gardens, dams and aquarium. In this study, a mangrove ecosystem and forest ecosystem represent the natural ecosystems while an orchard and an arboretum represent an artificial ecosystems. The basis for their selection is that these ecosystems support diverse tree species as the amount of carbon stored in an ecosystem is highly dependent on the presence of trees, both standing and fallen, live and dead. Also, the age and size of the tree, density and characteristics of each species affect the carbon stock in an ecosystem.

Large scale deforestation and degradation of ecosystems such as mangroves and forests are increasing in a geometric rate especially in this anthropocentric regime. One-third of the world's mangrove forests have been lost in the past 50 years while one-third of salt marshes has disappeared [7] [8] due to anthropogenic upheavals of varying intensities. The presence of vegetation helps in the removal and regulation of atmospheric CO_2 especially during photosynthesis. Trees most especially sequester and store large amounts of carbon in them. But due to the insatiable quest of humans for timbers, wood and urbanization so many forest ecosystems inhabiting tree species are undergoing largescale deforestation and degradation. The rate of deforestation in terrestrial ecosystems especially forests is alarming and this unwholesome acts tend to release the already sequestered carbon back into the atmosphere. The constant emissions and accumulation of this gas (CO_2) being a major constituent of greenhouse gases contributes to global warming and climate change which is a topical issue in this present century. These have led to emphasis being placed on estimating current carbon stocks in forest ecosystems globally. In Nigeria, specifically in Akwa Ibom State, researches on quantification of carbon in diverse ecosystems are proceeding slowly. Thus, data on carbon pools are deficient for majority of common agro-ecosystems. It is important to note that data collected from tropical environments are used in estimating total world carbon sequestration potential because differences in soil climatic conditions and soil management practices influence the storage of carbon in the soil. To this end, robust assessments of carbon stocks as well as their changes in vegetation are therefore crucial in order to understand their importance in mitigating global warming and climate change.

Furthermore, a great lacuna exist with regards to quantification of carbon stocks and sequestration rates in vegetation of natural and artificial ecosystems in Akwa Ibom State. In this epoch where natural ecosystems are facing extinction at an alarming rate, it is clearly necessary today to outline the carbon sequestration potential of various ecosystems (natural or created) so that, their compensatory roles in the mitigation process of climate change be made known. Such information when made available will accentuate the importance of vegetation in alleviating global warming and will form the basis for proper management of vegetation as well as implementing future climate change mitigation strategies through carbon stock enhancement programs. This dearth in information further obliged this study.

2. MATERIALS AND METHODS

2. 1. Study Areas

This study was carried out in natural and artificial ecosystems in Akwa Ibom State, Nigeria. A mangrove ecosystem in Iwuochang Village in Ibeno Local Government Area and a forest ecosystem in Ikot Efre Itak in Ikono Local Government Area represented the natural ecosystems while the Arboretum of the Department of Forestry and Natural Environmental Management in University of Uyo as well as a Cashew orchard along Uyo village road in Uyo L. G. A. represented the artificial ecosystems (Figure 1).

Iwuochang is one of the village which is found along Qua Iboe River estuary. Qua Iboe River estuary lies within latitude 4º 30 to 4º 45 N and longitude 7º 30 to 8º 00 E on the south eastern Nigerian coastline. It is located within the Niger Delta region. Qua Iboe River estuary is a mesotidal estuary having a tidal amplitude of 1 m and 3 m at neap and spring phases, respectively. The region is characterized by a humid tropical climate with an annual rainfall of 4021 mm, average relative humidity of 80 percent and mean minimum and maximum temperatures of 22 ºC and 30 ºC, respectively [9]. Like other estuaries in the Niger Delta, the Qua Iboe River estuary experiences great fluctuations in salinity, between the wet and the dry seasons, as well as the normal gradient extending upstream from the mouth of the river. Ecological habitats, therefore, vary from purely marine to those of brackish and freshwater. Tidal currents which are strong at the mouth of the estuary but weak along its upper reaches and creeks.

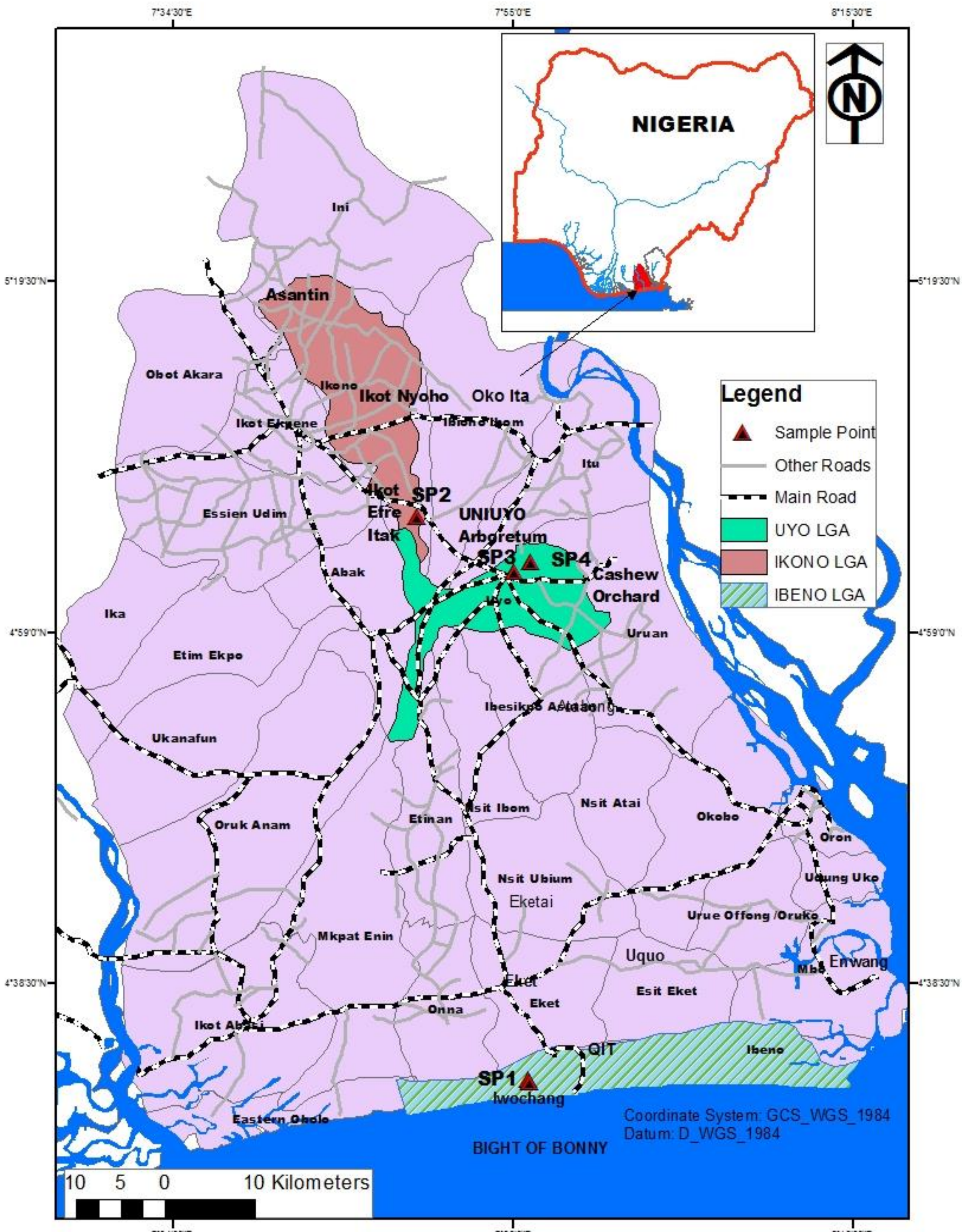

Figure 1. Map of the study areas.

Ikot Efre Itak forest is located between latitudes 4° 30’ and 5° 30’ N and longitudes 7° 31’ and 8° 20’ E. It covers an area of approximately 29.57 km^2 hectare [10]. The mean annual rainfall of the state is between 2400 mm and 3000mm. The average minimum and maximum temperature are 26 ºC and 30.5 ºC, respectively, while the mean relative humidity of the area is about 83%. The forest fragment is an evergreen forest fragment with an area of 3.2 ha managed by the Ikot Efre Itak community as a sacred grove. The forest is only accessed through the consent of the village council who gives such permission. The forest is rich with a good number of plant species. However, several anthropogenic disturbances such as incessant logging, unregulated species exploitation and infrastructural encroachments are common features evidenced in and around the forest.

The Arboretum lies between latitudes 4°35’ and 5º35’N and longitudes 7º35’ and 8°25’E. It was allocated to the then Department of Forestry and Wildlife by the Faculty of Agriculture of University of Uyo farm committee in 1994 for arboretum and departmental nursery. It covers an area of 1.08 ha. The area was organized into compartment and assigned to cover different forestry operations: *Gmelina* woodlot, bush fallow, *Cassia* species woodlot, Agroforestry. In 1995 planting season, *Gmelina* and *Cassia* species woodlots were established along with all the trees marking the nursery boundary. Indigenous tree species planted in the Arboretum include: *Lovoa weineana*, *Mammea africana*, *Pterocarpus* species, *Mimusops djave*, *Tectona grandis*, *Entandrophragma* species and *Nauclea diderrichii*. The area marked out for bush fallow was planted up in 1996 with *Anthonatha macrophylla and Dactyladenia baterii* and was allowed to grow undisturbed into forest. About hundred metres from the Department of Forestry and Natural Environmental Management of the University of Uyo to the entrance of the Aboretum is planted with two rows of Teak (*Tectona grandis*) along the walkway, with none of the trees being below 20 metres in height. This creates a natural canopy which shades the non-vegetated walkway. The annual rainfall of the area is about 2,450mm, mean annual temperature varies between 28.48 °C and 30.18 °C and mean relative humidity is 74.8%. The soil characteristics are silt loam.

The cashew orchard along Uyo Village Road is located at latitude 5º 3’ 4” N and longitude 7º 56’ 06”E. This orchard shares proximity with the main road. Human settlements are sparsely found around this region due to the siting of a dumpsite along the road. The topography is somewhat undulating.

2. 2. Vegetation Sampling and Soil Collection

Three vegetation plots were used for each study site. In each plot, three belt transects were laid and in each transect, vegetation and soil were sampled systematically [11] in 10 m × 10 m quadrats spaced at regular intervals of 20 m. In each quadrat, vegetation components measured were height and DBH (Diameter at Breast Height) while the age of the plants were estimated. Plant species were identified to species level.

2. 3. Estimation of Standing Biomass and Sequestered Carbon

The standing biomass of each tree species was estimated using the allometric functions of [12] developed for tropical rainforest and dry evergreen forest trees.

The functions are expressed in Equations 1, 2 and 3.

$$Ws = 0.0509\times(D^2H)^{0.919} \quad \text{Equation 1}$$

$$Wb = 0.00893\times(D^2H)^{0.977} \quad \text{Equation 2}$$

$$Wl = 0.0140\times(D^2H)^{0.669}$$ Equation 3

where

Ws = Stem biomass (tons/individual tree)

Wb = Branch biomass (tons/individual tree)

Wl = Leaf biomass (tons/individual tree),

D = Diameter at breast height (cm) and H = Height (m).

The stem, branch and leaf biomass together constituted the standing biomass of individual tree. The sequestered carbon in the standing biomass of individual tree was estimated by multiplying 0.5 conversion factor with the estimated standing biomass, which implies that 50% of the standing biomass is carbon [13], [14].

2. 4. Statistical Data Analysis

Means and standard errors of triplicates were obtained using Graph Pad Prism 6.0.

3. RESULTS

3. 1. Floristic Catalogue of the Ecosystems

The floristic catalogue of the mangrove ecosystem is presented in Table 1. In all, fifteen (15) species belonging to 14 families were encountered. The tallest species was *Elaeis guineensis* with height of 14.00 ±0.71 m while *Aframomum danielli* was the shortest species (3.13 ±0.19m). *Elaeis guineensis* also had the largest Diameter at Breast Height (DBH) (6.20 ±0.05 cm) while the least value was seen in *Alchornea cordifolia* (0.57 ±0.07 cm). Nonetheless, some of the species were ephemerals with negligible sizes and girths. The oldest plant in the mangrove was *Elaeis guineensis* (30 years) while the youngest species were *Anchomanes difformis* (1 year), *Aframomum danielli* (1 Year) and *Costus afer* (1 year).

The floristic composition of the forest ecosystem is presented in Table 2. A total of thirty (30) plant species belonging to twenty (20) families were encountered. In terms of height, the tallest and shortest species were *Berlinia confusa* (19.03 ±3.05 m) and *Ancomanes difformis* (2.05 ±0.03 m). For the DBH, *Khaya ivorensis* recorded the highest value of 8.84 ±1.45 cm while *Maesoboytra dusenii* recorded the least value of 0.35 ± 0.05 cm. The oldest plant species was *Berlinia confusa* (15 years) while *Podococcus barteri* (1 year), *Cnestis ferruginea* (1 year) and *Smilax anceps* (1 year) were the youngest plant species.

The floristic inventory of the arboretum is presented in Table 3. A total of nineteen (19) woody species belonging to thirteen (13) families were encountered. *Temarindus indica* had the largest diameter at breast height (DBH) (4.00 ±0.98 cm) while *Rauwolvia vomitoria* had the least DBH value (0.001 ±0.000 cm). In terms of height, *Nauclea diderichii* was the tallest species (41.00 ±0.50 m) while the shortest were *Rauwolfia vomitoria* (3.00 ±0.02 m), *Lonchocarpus griffeonus* (3.00 ±0.03 m) and *Cnestis ferruginea* (3.00 ±0.05 m). Regarding the age of the trees, the oldest plants in the arboretum were *Gmelina arborea* (22 years), *Senna siamea* (22 years) and *Ceiba pentandra* (22 years). The floristic catalogue of the orchard is presented in Table 4.

Table 1. Floristic Inventory of the Mangrove Ecosystem.

Plant species	Family	Habit	Age (years)	Height (m)	DBH (cm)
Acrostichum aureum L.	Pteridaceae	Fern	10	4.07 ±0.52	-
Aframomum danielli (Hook.f.) K. Schum	Zingiberaceae	Herb	1	3.13 ±0.19	-
Alchornea cordifolia (Schum, & Thonn.) Mull. Arg	Euphorbiaceae	Shrub	4	5.75 ±0.25	0.57 ±0.07
Anchomanes difformis (Bl.) Engl.	Araceae	Shrub	1	3.50 ±0.50	-
Avicennia africana P. Beau	Avicenniaceae	Tree	7	5.83 ±0.73	0.82 ±0.01
Barteria nigritiana Hook.f	Passifloraceae	Tree	9	6.00 ±1.00	0.70 ±0.06
Costus afer Ker Gawl.	Costaceae	Herb	1	-	-
Cyperus polystachyos Rottb	Cyperaceae	Grass	3	-	-
Elaeis guineensis Jacq.	Arecaceae	Tree	30	14.00 ±0.71	6.20 ±0.05
Laguncularia racemosa (L.) C.F. Gaertn	Combretatceae	Tree	6	5.00 ±0.58	1.20 ±0.001
Lannea acida A.Rich	Anacardiaceae	Tree	5	4.75 ±0.25	3.02 ±0.21
Lophira alata Banks ex Gaertn.	Ochnaceae	Tree	15	8.00 ±0.58	3.02 ±0.03
Nephrolepis cordifolia (L.) K. Presl	Nephrolepidaceae	Fern	2	-	-
Nypa fruticans Wurmb.	Arecaceae	Prostrate palm	20	3.80 ±0.61	4.60 ±0.02
Palisota hirsuta (Thunb.) K. Schum	Commelinaceae	Herb	2	4.50 ±0.50	-

Table 2. Floristic Inventory of the Forest Ecosystem.

Plant species	Family	Habit	Age (years)	Height (m)	DBH (cm)
Aframomum daniella Sm.	Fabaceae	Herb	2	-	-
Afzelia africana Sm. ex Pers.	Fabaceae	Tree	5	5.62 ±0.63	3.65 ±0.06
Alchornea cordifolia Mull.Arg.	Euphorbiaceae	Shrub	3	3.62 ±0.05	0.71 ±0.01
Alstonia boonei De Wild	Apocynaceae	Tree	5	4.57 ±0.05	1.42 ±0.08
Anchomanes difformis Blume.	Araceae	Shrub	2	2.05 ±0.03	-

Anthonatha macrophylla P. Beauv.	Fabaceae	Tree	3	2.61 ±0.30	0.50 ±0.03
Bambusa vulgaris Schrad. Ex Wend	Poaceae	Tree	4	5.59 ±0.29	1.59 ±0.10
Barteria nigritiana Hook.f	Passifloraceae	Tree	7	6.97 ±0.29	2.10 ±0.06
Berlinia confusa Hoyle	Leguminosae	Tree	15	19.03 ±3.05	6.34 ±0.98
Calamus deeratus Mann and Wendl	Arecaceae	Tree	3	6.31 ±0.63	-
Cannarium schweinfurthii Engl.	Burseraceae	Tree	3	4.30 ±2.00	2.27 ±0.52
Cnestis ferruginea Vahl ex DC.	Connaraceae	Herb	1	-	-
Coelocaryon preusii Warb.	Myristicaceae	Tree	12	14.36 ±3.83	2.01 ±0.63
Cola argentea Mast.	Sterculiaceae	Tree	4	5.87 ±0.28	6.34 ±0.87
Coula edulis Baill.	Olacaceae	Tree	12	15.50 ±5.12	7.15 ±0.67
Elaeis guineensis Jacq.	Arecaceae	Tree	8	7.20 ±0.39	5.25 ±0.41
Erythrophleum ivorense A. Chev.	Fabaceae	Tree	5	6.23 ±2.10	2.97 ±0.03
Guarea cedrata (A. Chev.) Pellegrin	Meliaceae	Tree	4	5.21 ±1.00	5.48 ±0.14
Khaya ivorensis A. Chev.	Meliaceae	Tree	6	8.50 ±2.50	8.84 ±1.45
Khaya senegalensis (Desr.) A.Juss.	Meliaceae	Tree	3	4.15 ±0.73	7.44 ±0.45
Maesoboytra dusenii (Pax) Hutch.	Euphorbiaceae	Tree	4	3.14 ±0.08	0.35 ±0.05
Mansonia altissima (A.Chev.) A.Chev.	Malvaceae	Tree	7	10.57 ±1.80	2.99 ±0.07
Musanga cecropioides R. Br	Papilionaceae	Tree	9	11.69 ±5.54	2.63 ±0.03
Palisuta hirsuta (Thunb.) K. SChum	Commelinaceae	Herb	2	3.00 ±0.25	-
Pentaclethra macrophylla Benth	Fabaceae	Tree	6	9.88 ±3.50	6.79 ±0.62
Piptadeniastrum africanum Hook.f	Leguminosae	Tree	10	14.20 ±3.21	2.10 ±0.01
Podococcus barteri G.Mann & H. Wendl.	Podococceae	Herb	1	-	-
Pycnathus angolensis (Welw.) Warb.	Myristicaceae	Tree	6	8.58 ±0.05	5.03 ±0.54
Smilax anceps Willd.	Smilacaceae	Herb	1	-	-
Synsepalum dulcificum (Schum and Thonn.) Daniell	Sapotaceae	Tree	9	12.68 ±4.01	2.53 ±0.07

Table 3. Floristic catalogue of the Arboretum.

Plant species	Family	Habit	Age (years)	Height (m)	DBH (cm)
Anthocleista djalonensis A.Chev.	Loganiaceae	Tree	19	40.00 ±0.81	1.20 ±0.01
Anthonatha macrophylla P. Beauv.	Fabaceae	Tree	7	3.20 ±0.05	0.02 ±0.00
Baphia nitida Lodd.	Fabaceae	Tree	19	3.10 ±0.20	0.07 ±0.002
Barteria nigritiana Hook.f.	Passifloraceae	Tree	5	8.00 ±0.01	0.40 ±0.05
Brachystegia eurycoma Harms	Fabaceae	Tree	19	38.00 ±0.53	2.80 ±0.12
Carpolobia lutea G. Don	Polygalaceae	Tree	3	4.00 ±0.12	0.02 ±0.001
Ceiba pentandra (L.) Gaertn.	Malvaceae	Tree	22	40.00 ±0.36	1.20 ±0.03
Chrsophyllum albidum G.Don	Sapotaceae	Tree	7	5.00 ±0.07	0.30 ±0.06
Cnestis ferruginea Vahl ex DC.	Connaraceae	Tree	4	3.00 ±0.05	0.07 ±0.002
Entandrophragma utile Dawe & Sprague	Meliaceae	Tree	19	17.00 ±0.10	1.35 ±0.08
Gmelina arborea Roxb.	Lamiaceae	Tree	22	18.00 ±0.15	1.60 ±0.04
Hura crepitans L.	Euphorbiaceae	Tree	5	5.00 ±0.04	0.20 ±0.05
Lonchocarpus griffeonus	Fabaceae	Tree	4	3.00 ±0.03	0.01 ±0.006
Nauclea diderichii (De Wild. & T. Durand) Merrill	Rubiaceae	Tree	19	41.00 ±0.50	1.80 ±0.25
Rauwolfia vomitoria Afzel.	Apocynaceae	Tree	1.5	3.00 ±0.02	0.001 ±0.000
Senna siamea (Lam.) Irwin et Barneby	Fabaceae	Tree	22	32.00 ±0.51	1.15 ±0.02
Tectona grandis L.f.	Lamiaceae	Tree	18	15.00 ±0.14	1.30 ±0.05
Temarindus indica L.	Fabaceae	Tree	17	40.00 ±0.84	4.00 ±0.98
Treculia africana Decne.	Moraceae	Tree	7	8.00 ±0.10	1.20 ±0.02

Table 4. Floristic catalogue of the Orchard Ecosystem.

Plant Species	Family	Habit	Age (years)	Height (m)	DBH (cm)
Acacia auriculiformis A.Cunn. ex Benth.	Fabaceae	Tree	15	7.50 ±0.15	0.50 ±0.001
Alchornea cordifolia Mull. Arg.	Euphorbiaceae	Shrub	10	5.12 ±0.32	0.50 ±0.002

Anacardium occidentalis L.	Anacardiaceae	Tree	17	7.00 ±0.13	6.01 ±0.25
Anthocleista vogelli Afzel. Ex R.Br.	Gentianaceae	Tree	3	1.20 ±0.03	0.01 ±0.002
Anthonatha macrophylla P Beauv.	Fabaceae	Tree	3	3.00 ±0.23	0.02 ±0.005
Barteria nigritiana Hook.f.	Passifloraceae	Tree	8	3.60 ±0.02	0.01 ±0.005
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	Herb	1	-	-
Cnestis ferruginea Vahl ex DC	Connaraceae	Shrub	5	2.01 ±0.03	0.01 ±0.003
Costus afer Ker-Gawl.	Costaceae	Herb	2	2.00 ±0.04	-
Cyperus polystachyos	Cyperaceae	Grass		-	-
Diodia sarmentosa Sw.	Rubiaceae	Herb	1	-	-
Dracaena arborea (Willd.) Link	Dracaenaceae	Tree	12	4.00 ±0.00	0.10 ±0.01
Elaeis guineensis Jacq.	Arecaceae	Tree	4	3.10 ±0.12	4.30 ±0.35
Entandrophragma utile Dawe & Sprague	Meliaceae	Tree	5	5.00 ±0.41	0.20 ±0.06
Harungana madagascariensis Lam. Ex Poir.	Hypericaceae	Tree	4	3.00 ±0.20	4.10 ±0.54
Melastomastrum capitatum (Vahl) A & R Fernandes	Melastomataceae	Herb	1	-	-
Pentaclethra macrophylla Benth.	Fabaceae	Tree	17	9.00 ±2.36	1.30 ±0.04
Rauvolfia vomitoria Afzel.	Apocynaceae	Tree	10	4.50 ±1.20	0.25 ±0.002
Urena lobata L.	Malvaceae	Herb	1	-	-

3. 2. Carbon Stocks in Vegetation of the Study Ecosystems.

3. 2. 1. Carbon Sequestered by Woody in the Mangrove Ecosystem

From the result, a total of nineteen (19) species were encountered belonging to seventeen (17) families. The oldest plant in this ecosystem was *Anacardium occidentalis* (17 years old) while the youngest species were *Chromolaena odorata*, *Costus afer*, *Diodia sarmentosa*, *Melastomastrum capitatum* and *Urena lobata* with 1 year old, respectively. The tallest and shortest species were *Pentaclethra macrophylla* (9.00 ±2.36 m) and *Anthocleista vogelli* (1.20 ±0.03 m). The highest DBH was recorded in *Anacardium occidentalis* (6.01 ±0.25 cm) while the least value was recorded in *Anthocleista vogelli* (0.01 ±0.002 cm), *Barteria nigritiana* (0.01 ±0.005 cm) and *Cnestis ferruginea* (0.01 ±0.003 cm).

The amount of carbon sequestered by individual woody species in the mangrove ecosystem is presented in Table 5. From the result, the standing biomass of the mangrove varied between 0.14 tons and 21.55 tons. Specifically, *Elaeis guineensis* had the highest standing biomass (21.55 tons) while *Alchornea cordifolia* had the least standing biomass (0.14 tons).

The total carbon sequestered in the mangrove ranged from 0.07 tons to 10.78 tons. Similarly, *Elaeis guineensis* sequestered the highest carbon in the mangrove (10.78 tons) this was followed by *Nypa fruticans* (1.89 tons), *Lophira alata* (1.73 tons) and *Lannea acida* (1.07 tons). *Alchornea cordifolia* on the other hand sequestered the least amount of carbon (0.07 tons). The total standing biomass of the mangrove ecosystem was 33.03 tons. Generally, the total amount of carbon sequestered by the vegetation was 15.97 tons.

Table 5. Amount of carbon sequestered by woody species in the mangrove ecosystem.

Species	Stem biomass	Branch biomass	Leaf biomass	Standing Biomass (tons)	Amount of carbon sequestered (tons)
Alchornea cordifolia	0.10	0.02	0.02	0.14	0.07
Avicennia africana	1.01	0.21	0.12	1.34	0.67
Barteria nigritiana	0.14	0.03	0.03	0.20	0.10
Elaeis guineensis	16.45	4.16	0.94	21.55	10.78
Laguncularia racemosa	0.31	0.06	0.05	0.42	0.21
Lannea acida	1.62	0.35	0.17	2.14	1.07
Lophira alata	2.62	0.59	0.25	3.46	1.73
Nypa fruticans	2.87	0.65	0.26	3.78	1.89
Total				33.03	16.52

3. 2. 2. Carbon Sequestered by Woody Species in the Forest Ecosystem

Table 6. Amount of carbon sequestered by woody species in the forest ecosystem.

Species	Stem biomass	Branch biomass	Leaf biomass	Standing Biomass (tons)	Amount of carbon sequestered (tons)
Afzelia africana	2.69	0.61	0.25	3.55	1.78
Alchornea cordifolia	0.09	0.02	0.02	0.13	0.07
Alstonia boonei	0.39	0.08	0.06	0.53	0.27
Anthonatha macrophylla	0.03	0.01	0.01	0.05	0.03
Bambusa vulgaris	0.58	0.12	0.08	0.78	0.39

Barteria nigritiana	1.19	0.25	0.14	1.58	0.79
Berlinia confusa	22.74	5.86	1.19	29.79	14.90
Calamus deeratus	0.51	0.10	0.08	0.69	0.35
Cannarium schweinfurthii	0.88	0.18	0.11	1.17	0.59
Coelocaryon preusii	2.13	0.47	0.21	2.81	1.41
Cola argentea	7.72	1.86	0.54	10.12	5.06
Coula edulis	23.49	6.07	1.22	30.78	15.39
Elaeis guineensis	6.58	1.57	0.48	8.63	4.32
Erythrophleum ivorense	2.02	0.45	0.20	2.67	1.34
Guarea cedrata	5.29	1.24	0.41	6.94	3.47
Khaya ivorensis	19.97	5.11	1.08	26.16	13.08
Khaya senegalensis	7.53	1.81	0.53	9.87	4.94
Maesoboytra dusenii	0.02	0.004	0.007	0.031	0.016
Mansonia altissima	3.33	0.76	0.29	4.38	2.19
Musanga cecropioides	2.88	0.65	0.26	3.79	1.90
Pentaclethra macrophylla	14.12	3.53	0.84	18.49	9.25
Piptadeniastrum africanum	2.28	0.51	0.22	3.01	1.51
Pycnathus angolensis	7.15	1.71	0.51	9.37	4.69
Synsepalum dulcificum	2.89	0.66	0.27	3.82	1.91
Total				179.14	89.65

The amount of carbon sequestered by individual woody species in the forest ecosystem is presented in Table 6. The standing biomass of the ecosystem ranged from 0.031 tons to 30.78 tons. *Coula edulis* and *Maesoboytra dusenii* had the highest (30.78 tons) and least (0.031 tons) standing biomass, respectively. For the total carbon sequestered in this ecosystem, its value ranged from 0.016 tons to 15.39 tons. In a similar vein, *Coula edulis* sequestered the highest carbon (15.39 tons) and this was followed by *Berlinia confusa* (14.90 tons), *Khaya ivorensis* (13.08 tons) and *Pentaclethra macrophylla* (9.25 tons) while *Maesoboytra dusenii* sequestered the least amount of carbon (0.016 tons). The total standing biomass of the forest ecosystem was 179.14 tons. In all, the total sequestered carbon in the fallow ecosystem by the woody species was 89.65 tons.

3. 2. 3. Carbon Sequestered by Woody Species in the Arboretum

In Table 7, the amount of carbon sequestered by individual woody species in the arboretum is presented. The result revealed that the standing biomass of the species in the arboretum varied between 0.000003 tons and 25.29 tons. *Temarindus indica* had the highest standing biomass (25.29 tons) while *Rauwolfia vomitoria* had the least value of 0.000003 tons. The total carbon sequestered in the arboretum varied between from 0.000002 tons and 12.65 tons. The species with the highest sequestered carbon in the arboretum was *Temarindus indica* (12.65 tons) while *Rauwolfia vomitoria* on the other hand, sequestered the least amount of carbon (0.000002 tons). The total standing biomass in the arboretum was 53.94 tons. The total amount of carbon sequestered by woody species in the arboretum was 28.51 tons.

Table 7. Amount of carbon sequestered by woody species in the arboretum.

Species	Stem biomass	Branch biomass	Leaf biomass	Standing Biomass (tons)	Amount of carbon sequestered (tons)
Anthocleista djalonensis	2.11	0.46	0.21	2.78	1.39
Anthonatha macrophylla	0.00007	0.000013	0.00016	0.00024	0.0001
Baphia nitida	0.0011	0.00014	0.0009	0.0021	0.0011
Barteria nigritiana	0.06	0.011	0.02	0.09	0.05
Brachystegia eurycoma	9.56	2.33	0.12	12.01	6.01
Carpolobia lutea	0.0001	0.000016	0.0018	0.0019	0.00096
Ceiba pentandra	2.11	0.47	0.21	2.79	1.40
Chrsophyllum albidum	0.02	0.004	0.008	0.03	0.02
Cnestis ferruginea.	0.001	0.0001	0.0008	0.0019	0.00095
Entandrophragma utile	1.19	0.26	0.14	1.59	0.80
Gmelina arborea	1.72	0.38	0.18	2.28	1.14
Hura crepitans	0.01	0.0018	0.005	0.017	0.008
Lonchocarpus griffeonus	0.00003	0.000003	0.00006	0.00009	0.00005
Nauclea diderichii	4.55	1.06	0.37	5.98	2.99
Rauwolfia vomitoria	0.0000004	0.00000004	0.000003	0.000003	0.000002
Senna siamea	1.59	0.35	0.17	2.11	1.06
Tectona grandis	0.99	0.21	0.12	1.32	0.66

Temarindus indica	19.30	4.93	1.06	25.29	12.65
Treculia africana	0.48	0.10	0.07	0.65	0.33
Total				53.94	28.51

3. 2. 4. Carbon Sequestered by Woody Species in the Orchard Ecosystem

The carbon sequestered by woody species in the orchard ecosystem is presented in Table 8. The value for the standing biomass of the species ranged from 0.00005 tons to 10.78. The highest and least standing biomass were recorded by *Anacardium occidentalis* (10.78 tons) and *Anthocleista vogelli* (0.00005 tons). The amount of carbon sequestered by each woody species varied from 0.000025 tons in *Anthocleista vogelli* and 5.39 tons in *Anacardium occidentalis*. The total standing biomass in the orchard ecosystem was 17.14 tons. Altogether, the total carbon sequestered in the orchard ecosystem was 8.57 tons.

Table 8. Amount of carbon sequestered by woody species in the orchard ecosystem.

Species	Stem biomass	Branch biomass	Leaf biomass	Standing Biomass (tons)	Amount of carbon sequestered (tons)
Acacia auriculiformis	0.09	0.02	0.02	0.13	0.065
Alchornea cordifolia	0.06	0.01	0.02	0.09	0.045
Anacardium occidentalis	8.22	1.99	0.57	10.78	5.39
Anthocleista vogelli	0.000012	0.0000013	0.000033	0.00005	0.000025
Anthonatha macrophylla	0.00011	0.000013	0.00016	0.00028	0.00014
Barteria nigritiana	0.000035	0.0000039	0.000069	0.00011	0.000055
Cnestis ferruginea	0.000020	0.0000022	0.000047	0.000069	0.000035
Dracaena arborea	0.003	0.0004	0.002	0.0054	0.0027
Elaeis guineensis	2.10	0.47	0.21	2.78	1.39
Entandrophragma utile	0.01	0.002	0.005	0.017	0.0085
Harungana madagascariensis	1.87	0.41	0.19	2.47	1.235
Pentaclethra macrophylla	0.62	0.13	0.09	0.84	0.42
Rauwolfia vomitoria	0.02	0.003	0.006	0.029	0.0145
Total				17.14	8.57

4. DISCUSSION

The floristic compendium showed variabilities and heterogeneity across the study ecosystems with regards to composition and quantification of species. The quantification of species in the mangrove ecosystem is low when compared with the number of species documented by other scholars in similar ecosystem. For instance, [15] reported 20 plant species in mangrove swamps of southern Nigeria, while [16] reported 16 species in 14 genera and 12 families in Mahanadi Mangrove. In the same vein, the number of species in this study is at equilibrium with the number of species reported by [17] in mangrove swamp of Okorombokho community in Eastern Obolo Local Government Area of Akwa Ibom State, Nigeria. Be that as it may, the number of species in this study is considerably high when compared with the number of species reported by [18] and [19]. While the former reported 5 species in Tumpat Kelantan Delta, Malaysia, the latter reported 8 species in a Micro Tidal Estuary on the North-western Coast of Sri Lanka. These differences in species composition in the mangroves may justify the reports of [20] that the composition, structure and productivity of mangroves are highly variable. This also tangles with the reports of [21] and [22] that since mangrove plants grow in different soil types, their vegetation, species composition and structure may vary considerably at the global, regional and local scales.

The thirty (30) species recorded in the forest ecosystem is comparatively low with the floristic reports of [23] and [24]. The former reported a total of seventy two (72) species in Oban Forest, Cross River State, Nigeria, while the latter reported a total of one hundred and eight (108) species in Tinte Bepo Forest Reserve. This conspicuous margin in species composition with the present study may pin point the varying levels of conservation and protection policies attached to the forests. It may also underscore the varying intensities of anthropogenic perturbations and interventions policies in the forests.

For the arboretum, the 19 species encountered is relatively small compared to the number reported by other scholars. [25] reported 35 trees in Popham Arboretum, Sri Lanka. [26] reported 36 tree species in roadside plantations in southwestern Bangladesh, [27] from their survey documented a total of 26 tree species in Department of Forestry and Wildlife Arboretum, University of Benin, Benin City, Nigeria while [28] reported a total of 20 tree species in the Botanical Gardens of University of Ibadan, Nigeria. These variations in abundance of tree species may be allied to the purpose and objective for the establishment of the arboretum, differences in physiographic and geographic coverage and environmental gradients. In justifying this, [26] had stated that fast growing timber species were planted in roadside plantation with the objective of getting a quick return, while in home gardens, multipurpose tree species, including fruit, timber, and ornamental species were planted.

The low tree species in this study when compared with other studies may be allied to several factors such as inadequate space for more tree planting, poor silvicultural techniques, anthropogenic perturbations, whirling wind actions as well as pedological factors. For the orchard ecosystem, the 19 species recorded is fairly high in comparison with the 18 species reported by [29] and [30] in orchards of Eastern Wienerwald, Lower Austria and orchard of Federal University Dutse, Jigawa State, Nigeria. These variations in species composition may not be unconnected to the size of the orchard, species preference, soil conditions, anthropogenic disturbances and management techniques.

In comparing the species diversity on the whole, the forest ecosystem had the highest number of species (30) while the mangrove ecosystem had the least number of species (15).

These disparities in quantifications may underpin the adaptation abilities of plant species to changes in habitats, topography, pedological factors as well as anthropogenic perturbations. The high species composition in the forest may be an indication of the suitability of the pedological conditions which favoured the establishment and proliferations of diverse species. In addition, since the forest is a community forest where the activities of people are regulated a bit, the low anthropogenic activities like indiscriminate logging of timber species might have contributed to its species richness. The low species in the mangrove is consistent with the assertion that mangroves have very low diversity in contrast to other tropical forest ecosystems [31], [32], [33]. Additionally, the inabilities of species to adapt and tolerate turbulent environmental conditions like anoxia, tidal inundations, salinity regimes, anthropogenic pressures and perturbations in the mangrove might have accounted for its low species record. [34] and [35] had also affirmed this in their study studies.

Since the diameter of the stem occupies a greater percentage of the total biomass in plants [36], woody species encountered in the four ecosystems were employed in the determination of the biomass. In all, 8, 24, 19, and 13 woody species were used in the mangrove, forest, arboretum and orchard, respectively. With regards to the biomass, variations were observed in stems, branches and leaves of species. The biomass allocation in trees followed this decreasing order; stem > branches > leaves. This may be interpreted to mean that the apportionments of biomass differed in different components of the trees. This is in synchrony with the findings of [37]. The high biomass apportionments in the stem is akin to the findings of [38] that the stem wood contributes the maximum plant biomass followed by root, branch and foliages. Various scholars have reported similar findings in this regards. For instance, [39] found that stems of trees contribute up to 83% of total above ground biomass production. [36] stated that DBH is 95% of the total biomass. Hence, trees with a large diameter usually account for a comparatively greater proportion of the aboveground biomass [40], [41]. [42] in his study also maintained that the bulk of above-ground biomass of a tree is stored in the bole. He also stressed the relevance of tree heights in biomass apportionments in plant components.

Species with the highest and least standing biomass are indications that biomass composition differ greatly among species [43], [44]. [45] attributed the low value in standing biomass of trees to small stem diameter or light wood quality and high biomass to larger bole diameter and genetic constitution of the tree species. This is congruent with this study. The standing biomass in the ecosystems followed this decreasing order; forest (179.14 tons) > arboretum (53.94 tons) mangrove (33.03 tons) > orchard (17.14 tons). The low standing biomass in the orchard despite its third ranking in abundance of trees may be linked to woody species having small girth sizes or DBH. This is in unison with the findings of other scholars. [46] affirmed this in their study that the biomass value is influenced by the diameter size of the tree, because the larger the tree diameter, the higher the biomass value. This is also evidenced in this study.

Similarly, [47] explained that the biomass increased because the vegetation absorbs CO_2 in the atmosphere and transforms it to organic compound (carbohydrate) through photosynthetic process; which results in vertical or horizontal growth, indicated by increased diameter and height. It was also observed in this study that the amount of stored biomass increased with increasing age and vice versa. This may entail that aside from the larger diameter of trees contributing majorly to the standing biomass, the amount of stored biomass is significantly related to age. [42] and [48] had reported a significant positive relationship of biomass with the heights and ages of trees. In a recent finding, [48] reported that the total tree, aboveground, stem and root biomass of Mongolian pine increased with increasing stand age. In Korean pine, [49] reported that the total biomass of the tree increased swiftly from the 8th to the 35th year and increased slowly during the 35th to the 51st year. Also, the rapidity of growth of a tree species has been identified to have a positive linear correlation with biomass accumulation [50]. For the carbon stock, similar trend in biomass accumulation was observed. Species such as *Elaeis guineensis* (in mangrove), *Coula edulis* (in forest), *Temarindus indica* (in arboretum) and *Anacardium occidentalis* (in orchard) with the highest biomass also recorded the highest carbon storage while species such as *Alchornea cordifolia* (in mangrove), *Maesoboytra dusenii* (in forest), *Rauwolfia vomitoria* (in arboretum) and *Anthocleista vogelli* (in orchard) had the least standing biomass and least amount of carbon.

This increase in carbon with increasing biomass confirms a direct relationship between the two vegetation variables. This is consistent with the findings of [51] that every addition of biomass content will be followed by the addition of carbon stock. This further implies that anything which elevates or lowers the biomass will result in a corresponding increase or decrease in carbon stock. This view does not differ from the findings of other researchers. For instance, [52] asserted that carbon stock percentage increases in line with the increase in biomass. [53] in their study, also confirmed a positive relationship between mangrove biomass and carbon stock content. [54] attributed majority of the carbon stored in plants to the stem. According to these scholars, stem is part of wood and consists 50% of cellulose.

Cellulose is the main part of tough wall which covers vegetation cell and consists of linear sugar molecule in a long chain of carbon [55]. Hence, the higher the cellulose, the higher the carbon content value. The age of woody species in the ecosystem is believed to play a decisive role in the amount of carbon stored in the species as revealed by the correlations between floristic components and carbon stock variables. This is synonymous to the findings of [29] that the age of tree functions not only in light competition but also in carbon inputs. Hence, the low carbon storage in aforementioned species is attributed to their juvenile stage and small stem diameter. Generally the carbon sequestered by the ecosystems followed this decreasing pattern; forest > arboretum > mangrove > orchard. The high carbon storage in the forest is not unconnected to the abundance of older trees with large bole or girth sizes while the presence of trees with small girth sizes or stem diameter might have accounted for low carbon storage in the orchard.

5. CONCLUSIONS

Trees are important components of the terrestrial ecosystems in this era of climate change and global warming due to their intrinsic roles in CO_2 sequestration and subsequent storage in their tissues. This study revealed that biomass and carbon storage vary among diverse ecosystems due to differences in woody species, age of species and levels of disturbances. It also revealed that individual species differ in their CO_2 sequestration rates across the ecosystems. Conclusively, the results of this work show that the forest ecosystems with high woody species have a greater potentials in carbon storage than species with low woody species. Hence, afforestation is highly encouraged as while as conservation and protection of ecosystems with woody species against decimation. Furthermore, species with high carbon sequestration abilities as seen in this study should be planted especially in areas with high CO_2 emissions.

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