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Tree species diversity, volume yield, biomass and carbon sequestration in urban forests in two Nigerian cities

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Abstract
Urban forests contribute greatly to the conservation of biodiversity and are able to store carbon in the same way as other forest ecosystems. This research investigated the diversity, volume yield, biomass and carbon sequestration of tree species in urban forests in two Nigerian cities (Port Harcourt and Ilorin) selected using simple random sampling. In Nigeria there is no record of quantitative assessment of carbon sequestration in urban forests. Biodiversity and growth data were obtained from about 20% of the built-up areas of the two cities. Non-destructive approach was used for above ground biomass estimation. Biomass data was used to quantify carbon stock to estimate the amount of carbon sequestrated by the urban forests in the two cities. The results revealed a total of 746 individual trees distributed among 37 species and 19 families in Port Harcourt, while 556 individual trees distributed among 46 species and 18 families in Ilorin urban forest. Shannon-Wiener diversity index for Port Harcourt was 3.39 while that of Ilorin was 3.61. The total carbon stored by the urban forest of Port Harcourt was estimated at 67,979.08 tons and Ilorin urban forest carbon stored was estimated at 91,512.49 tons. The average carbon density of the urban forest of Port Harcourt was estimated at 136.15 tons/ha and 7.82 tons/ha was estimated for Ilorin urban forest. Tree species diversity has greater impact on biomass accumulation which determines carbon sequestration and mitigation of harsh climatic conditions. Selection and planting the right species as avenue trees, building parks and gardens, urban landscaping can improve urban forest carbon sequestration and producing other urban forest ecosystem functions.

Keywords Biomass · Carbon storage · Ecosystem functions · Species diversity · Urban forests

Introduction

The impact of urbanization on the environment, species diversity and conservation can be positive or negative on the global climate (Golubiewski 2006). Urban forest is an integral component of the forest ecosystem which could generate significant ecosystem services such as offsetting carbon emission, removing air pollutants, regulating the micro environment and mitigating climate change (Fuwape and Onyekwelu 2011; Konijnendijk et al. 2006). Urban forest represents a valuable component of the vegetation cover of urban environment. Ecosystem services are the benefits people obtain from ecosystems within their immediate environment. These include provision of food; water; regulating environmental temperature and climate change; reduction of flood and disease control; recreational and amusement parks; and nutrient cycling, which contribute to maintaining the conditions of life on earth (Adekunle et al. 2013; Banda et al. 2006; McHale et al. 2009). These ecosystem services contribute significantly to improving environmental quality and quality of life, beautification and sustainable urban development.

Sustainable conservation and management of urban forest requires a basic understanding of the spatial and temporal ranges of the vegetation cover with the understanding of the principal factors that govern species distribution and survival (Banda et al. 2006; Onyekwelu et al. 2008). Forest degradation, as a result of indiscriminate exploitation, massive conversion of forested land to other land uses (especially infrastructural development), has negative impacts on biological diversity conservation, soil properties, forest yield and the environment (Miles et al. 2006; Salunkhei et al. 2016). Researches indicated that cities in developing countries

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contribute greatly to global greenhouse gas emissions (Gibbs et al. 2007; Pan et al. 2011; Saatchi et al. 2011). As a result of inadequate planning of urban green infrastructures, many urban centres are confronted with the challenges of environmental degradation.

Research workers have indicated that urban forests have the ability to store carbon like other forest ecosystems (McPherson 1998; Pataki et al. 2006). There are difficulties in sampling and measuring urban tree parameters used in volume and biomass estimations (Mcpherson and Simpson 2001; Pataki et al. 2006).

The quantity of carbon stored in trees is determined by the quantity of biomass accumulated by the tree (Brown 1997; Zhou and Hemstrom 2009; Chandra et al. 2011; Azyleah et al. 2014). Carbon sequestration is the net removal of CO_2 from the atmosphere, which includes the uptake of carbon from atmosphere by all chlorophyllous plants through photosynthesis. Forested lands are richer in carbon per unit area than any other land-use type (Hossain et al. 2013). Tree diameter at breast height (dbh) is the commonly used parameter for estimation of carbon stocks through the calculation of Above Ground Biomass (AGB) (Brown 1997; Chave et al. 2005; Komiyama et al. 2008; Ketterings et al. 2001). The present study was carried out to investigate tree species diversity status, estimate volume yield and biomass accumulation of urban forests in two vegetation zones of Nigeria. Therefore, this research addresses these two research questions: 1. What are the contributions of urban forest in supporting tree species diversity in the two Nigerian cities? 2. What is the carbon storage potential of the urban forest in the two Nigerian cities?

Materials and methods

Study area

This study for biomass estimation, volume yield and tree species diversity was limited to urban forests in two major cities located within two vegetation zones of Nigeria. Simple random sampling design was used to select the two cities (Port Harcourt and Ilorin) for this study. Port Harcourt is situated between coordinates 04°46′82"N - 04°54′17"N and 06°58′23″E - 07°02′31″E, with mean annual rainfall of 2708 mm, average annual temperature of 26.4 °C (Fig. 1). Port Harcourt is located within the rainforest ecological zone of Nigeria. The vegetation cover of this city is very rich and diverse due to the favourable climatic conditions, altitude and ecological habitats existing within tropical forest ecosystems of the country. Port Harcourt is the capital and largest city in River State as well as the 5th largest city by population in Nigeria. It lies along Bonny River, located in the Niger Delta and South-South region of Nigeria. It has an estimated population of 1,148,665. Floristic structure, diversity and biomass estimation data were conducted in the 20% urban forests sites of Port Harcourt metropolis covering about 2496.4 ha. The selected sections of the city are the cores of the city centres. The Government of Rivers State's aim of forest conservation activities in these areas is to plant exotic tree species and to preserve indigenous tree species for beautification purposes.

Ilorin is situated within the 08°26′237"N - 08°31′267"N and 04°30′02″E - 04°33′77″E co-ordinates, with a mean annual rainfall of 1217 mm, average annual temperature of 27.2 °C. The city is located within the ecological region of Nigeria's Guinea savanna. Ilorin is the capital of the state of Kwara in Nigeria's north-central region and the 11th largest population city in Nigeria. Ilorin has a population projection of 814,192. The data for this analysis were obtained from the central district of Ilorin covering approximately 11,704.5 ha and comprising approximately 20% of urban forests. This portion of the city's core area, with activities of forest management ranges from home gardens and government reserves that enhanced city greening.

Data collection Tree inventory was conducted between February and October 2017 to collect the data for this analysis. The main streets in Port Harcourt were chosen for inventory data collection in various sections of the city (Mgbuoba, Rumuadaolu, Rumuogba, Rumuomasi, Rumuokoro, Rumuodara, Ogbunabali, Government House, and Rumuola). The data for Ilorin were collected from Ilorin central district (Taiwo road, Offa road, Ahmadu Bello Avenue, Fade, Tonke, Muritala Mohammed road, Kwara Polytechnic campus and University of Ilorin campus). All woody plants along the streets in the selected city section with diameter at breast height (dbh) of 10 cm and above as suggested by Hall et al. (2003) were measured and identified. The following tree data were collected; diameter at breast height using girth tape, diameters over bark at the base, middle, merchantable height and total height using a Spiegel Relaskop (Cottam and Curtis 1956; Kaye et al. 2005; Onyekwelu and Olusola 2014). Forked trees were assessed as separate trees beneath the breast-height level. All species of tree have been classified with their botanical names and distributed to their respective families.

Data computation and analysis The volume of each tree was computed using Newton's formula (Husch et al. 2003), eq. 1. Total volume for each species was obtained by adding the volume of individual trees of the species in the sampled areas of each city.

$$\mathrm{V} = \frac{h}{6}(Db + 4Dm + Dt) \qquad (1)$$

where: V = Tree volume (m^3), D_b, D_m and D_t = tree cross-sectional area (m^2) at the base, middle and top of merchantable

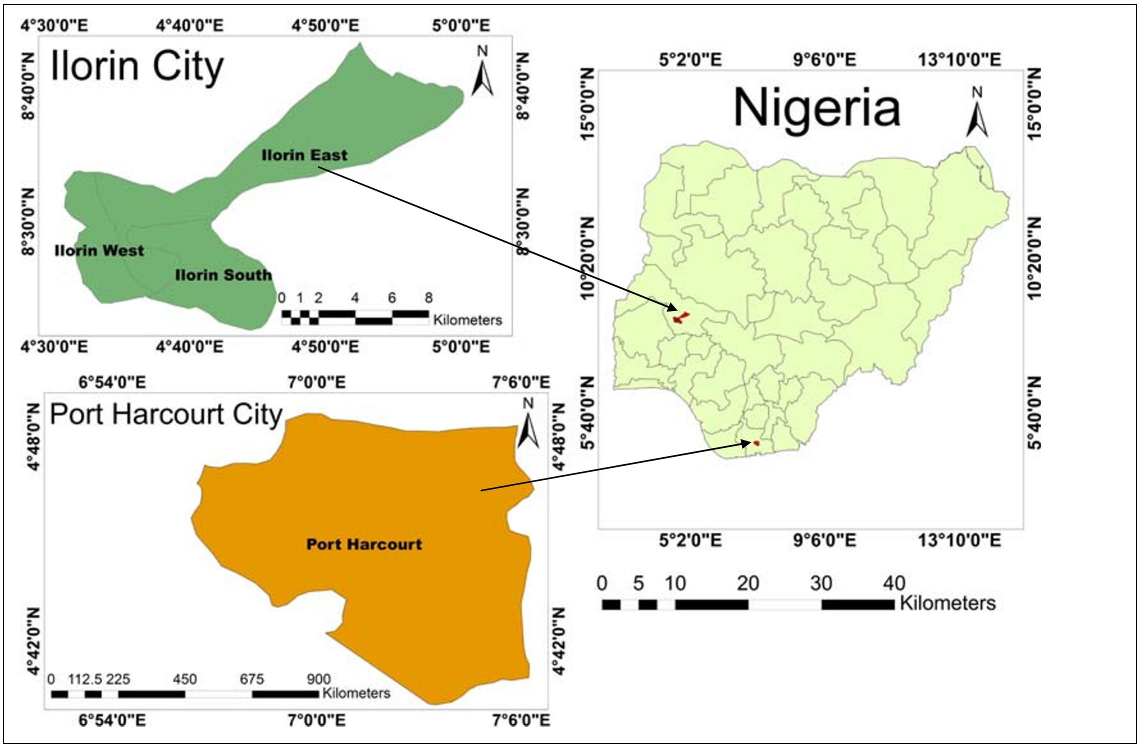

Fig. 1 Map of the study areas

height, respectively, and h = total height (in meters).

Data for urban forest tree species were analyzed for relative frequency, relative dominance and relative density while the sum of values for these parameters represented importance value index (IVI) for various species (Kershaw 1973). Species diversity was calculated using Shannon and Wiener formula (Motz et al. 2010; Chandrashekara and Sankar 1998) eq. 2.

$$H' = -\sum_{i=1}^{s} Pi\ In(Pi) \quad (2)$$

Where H' is the Shannon-Wiener diversity index, S in the total number of species in the community; Pi is the proportion of S made up of the ith species and in natural logarithm.

Above-Ground Biomass (AGB) was estimated using equation (eq. 3) developed by Brown (1997) for biomass estimation in tropical forests, the equation has been used by some research workers in the determination of carbon storage for some developing countries (Baccini et al. 2008; NIACS 2008; McHale et al. 2009; Kridiborworn et al. 2012; Salunkhei et al. 2016; Adekunle et al. 2014; Woldegerima et al. 2017).

$$AGB = 34.4703 - 8.067(D) + 0.6589\left(D^2\right) \quad (3)$$

where: AGB = Biomass per tree (kg) and D = dbh (cm).

Woldegerima et al. (2017) stated that it was possible to determine below ground biomass (BGB) by multiplying the above ground biomass by a factor of 0.2 based on the relationship between tree root and tree stem (Cairns et al. 1997; Brown 2002), as applied in this research. The amount of carbon stock in urban forest for each city was calculated by using the Pearson et al. (2005); Tang et al. (2016) formula (Carbon Stock = aboveground biomass + belowground biomass).

Results

Species abundance and structure of the urban forests

Tables 1 and 2 present analyzes of the diversity of tree species and the structural characteristics of urban forests. A total of 746 and 556 individual trees (dbh ≥ 10 cm) were recorded within the sampled areas in Port Harcourt and Ilorin, respectively. These were distributed among 37 species in Port Harcourt and 19 families, 46 species in Ilorin and 18 families. The highest relative abundance of species in Port Harcourt was recorded for *Terminalia mantaly* (15.01%) followed by *Delonix regia* (7.51%), with *Bombax buonopozense* reporting the lowest relative abundance of species (Fig. 2). In the Ilorin urban forest *Azadirachta indica* (7.91%) and *Polyalthia longifolia* had the highest number (7.91%), while *Albizia lebbeck* reported the lowest relative abundance (0.36%) (Fig. 3). The highest volume of species reported at Port Harcourt was *Gmelina arborea* and *Avicennia nitida* (127.84 m^3 and

76.77 m^3) while *Antiaris Africana* (0.06) was the lowest volume yield.

The highest volume of *Gmelina arborea* and *Polyalthia longifolia* (105,68 m^3 and 74,53 m^3 respectively) was obtained from *Dalbergia latifolia* (0,12 m3) in urban forests of Ilorin. The Family Importance Value (FIV) for the urban forests analysis is provided in Tables 3 and 4. In Port Harcourt, the Moraceae family had the highest FIV (17.35%) followed by the Euphorbiaceae family (11.22%) while the Cupressaceae family gave the lowest FIV (1.45%). The Fabaceae family also had the highest FIV (30.74%), followed by the Myrtaceae family (8.37%), while the lowest FIV was reported for Sapotaceae.

Table 1 Tree species diversity and structural characteristics of urban forest in Port Harcourt Metropolis

Family	Tree species	Individual tree	Mean Ht (m)	Mean dbh (cm)	B.A. (m^2)	Volume (m^3)	RD (%)	RDo (%)	IVI (%)	piLnpi H'
Apocynaceae	*Alstonia congensis* De Wild.	2	12.54	47.00	0.35	1.85	0.27	2.12	1.19	0.05
Anacardiaceae	*Anacardium occidentale* L.	2	8.67	95.00	1.42	5.22	0.27	8.65	4.46	0.14
	Mangifera indica L.	86	14.40	15.87	0.04	10.40	11.53	0.24	5.88	0.17
Annonaceae	*Annona muricata* L.	4	10.45	31.00	0.15	1.34	0.54	0.92	0.73	0.04
	Polyalthia longifolia (Sonn.) Thwaites	46	11.98	12.99	0.03	3.10	6.17	0.16	3.16	0.11
Apocynaceae	*Nerium oleander* L.	2	14.56	72.00	0.81	5.03	0.27	4.97	2.62	0.10
	Plumeria alba L.	26	8.18	37.77	0.22	10.11	3.49	1.37	2.43	0.09
	Plumeria rubra L.	20	8.65	19.33	0.06	2.15	2.68	0.36	1.52	0.06
Arecaceae	*Roystonea regia* (H.B.K) F.cook	44	10.19	27.33	0.12	11.16	5.90	0.72	3.31	0.11
Avicenniaceae	*Avicennia nitida* Jacq.	44	11.32	68.00	0.73	76.77	5.90	4.43	5.17	0.15
	Jacaranda mimosacfolia L.	4	14.56	75.60	0.90	11.10	0.54	5.48	3.01	0.11
Bombacaceae	*Bombax buonopozense* P. Beauv.	2	18.56	83.60	1.10	8.65	0.27	6.70	3.48	0.12
Burseraceae	*Dacryodes edulis* (G. Don) H.J. Lam	2	11.26	62.00	0.60	2.89	0.27	3.68	1.98	0.08
Casuarinaceae	*Casuarina equistetifolia* Linn.	32	10.67	16.70	0.04	3.17	4.29	0.27	2.28	0.09
Cecropiaceae	*Musanga cecropioides* R. Br.	2	10.20	47.00	0.35	1.50	0.27	2.12	1.19	0.05
Combretaceae	*Terminalia catappa* L.	48	11.80	11.63	0.02	2.55	6.43	0.13	3.28	0.11
	Terminalia mantaly H. Perrier	112	12.40	12.42	0.02	7.14	15.01	0.15	7.58	0.20
	Terminalia superba Engl. & Diels	12	13.80	18.37	0.05	1.86	1.61	0.32	0.97	0.04
Cupressaceae	*Thuja occidentalis* L.	6	6.30	14.10	0.03	0.25	0.80	0.19	0.50	0.03
Euphorbiaceae	*Croton zambesicus* Müell. Arg.	4	6.10	22.70	0.08	0.42	0.54	0.49	0.52	0.03
	Hevea brasiliensis Müell. Arg.	2	11.19	98.00	1.51	7.16	0.27	9.21	4.74	0.14
	Hura crepitans L.	24	9.40	69.40	0.76	36.22	3.22	4.62	3.92	0.13
Fabaceae	*Caesalpinia pulcherrima* (L.) Sw.	2	6.73	26.00	0.11	0.30	0.27	0.65	0.46	0.02
	Delonix regia (Hook) Raf.	56	11.20	14.99	0.04	4.70	7.51	0.22	3.86	0.13
	Senna siamea (Lam) Irwin & Barneby	6	8.40	31.60	0.16	1.68	0.80	0.96	0.88	0.04
	Dialium guineense Willd.	6	15.00	26.30	0.11	2.08	0.80	0.66	0.73	0.04
Meliaceae	*Azadirachta indica* A. Juss	36	12.18	28.87	0.13	12.18	4.83	0.80	2.81	0.10
Moraceae	*Antiaris africana* Engl.	2	4.68	14.00	0.03	0.06	0.27	0.19	0.23	0.01
	Ficus benjamina L.	4	7.90	29.50	0.14	0.92	0.54	0.83	0.69	0.03
	Ficus thonningii Blume	2	10.14	55.00	0.48	2.04	0.27	2.90	1.58	0.07
	Ficus tomentosa Roxb. Ex willd.	2	9.30	85.00	1.14	4.48	0.27	6.93	3.60	0.12
	Milicia excelsa (Welw.) C.C. Berg.	4	12.18	51.00	0.41	4.22	0.54	2.49	1.51	0.06
	Treculia africana var. nitida Engl.	2	8.00	73.30	0.84	2.87	0.27	5.15	2.71	0.10
Myrtaceae	*Eucalyptus camaldulensis* Dehn	36	15.60	11.55	0.02	2.50	4.83	0.13	2.48	0.09
	Eucalyptus globulus Labill	2	18.22	86.00	1.16	8.98	0.27	7.09	3.68	0.12
Pinaceae	*Pinus caribaea* Var. Barr. & Golf.	8	10.56	94.00	1.39	24.88	1.07	8.47	4.77	0.15
Verbenaceae	*Gmelina arborea* Roxb.	52	13.40	74.19	0.86	127.84	6.97	5.28	6.12	0.17
		746			16.4	409.8				3.39

Table 2 Tree species diversity and structural characteristics of urban forest in Ilorin Metropolis

Family	Tree species	Individual tree	Mean Ht (m)	Mean dbh (cm)	B.A. (m^2)	Volume (m^3)	RD (%)	RDo (%)	IVI (%)	piLnpi H’
Asclepiadaceae	*Calotropis procera* (Aiton) Ait.f.	2	22.00	76.75	0.93	8.64	0.36	4.17	2.26	0.09
Anacardiaceae	*Lannea acida* A. Rich	4	22.50	88.10	1.22	23.28	0.72	5.49	3.10	0.11
	Mangifera indica L.	42	7.80	35.50	0.20	13.76	7.55	0.89	4.22	0.13
	Anacardium occidentale L.	22	6.50	27.50	0.12	3.60	3.96	0.53	2.25	0.09
	Lannea barteri (Oliv) England	2	5.20	25.00	0.10	0.22	0.36	0.44	0.40	0.02
Annonaceae	*Polyalthia longifolia* (Sonn.) Thwaites	44	14.50	59.20	0.55	74.53	7.91	2.48	5.20	0.15
Apocynaceae	*Plumeria alba* L.	26	14.50	18.90	0.06	4.49	4.68	0.25	2.46	0.09
	Plumeria rubra L.	18	16.30	13.10	0.03	1.68	3.24	0.12	1.68	0.07
Araucariaceae	*Araucaria cunninghamii* (Aiton)	2	13.60	59.50	0.56	3.21	0.36	2.50	1.43	0.06
Arecaceae	*Cocos nucifera* L.	12	12.60	53.10	0.44	14.21	2.16	1.99	2.08	0.08
	Roystonea regia (H.B.K) F.cook	26	16.20	22.00	0.08	6.80	4.68	0.34	2.51	0.09
Asteraceae	*Vernonia amygdalina* Del.	2	7.80	32.52	0.17	0.55	0.36	0.75	0.55	0.03
Bignoniaceae	*Crescentia cujete* L.	8	8.60	23.10	0.08	1.22	1.44	0.38	0.91	0.04
	Newbouldia laevis (P. Beauv)	8	6.00	42.00	0.28	2.82	1.44	1.25	1.34	0.06
Bisnoniaceae	*Spathodea campanulata* P. Beauv.	2	11.40	41.70	0.27	1.32	0.36	1.23	0.79	0.04
Casuarihaceae	*Casuarina equisetifolia* L.	12	22.10	56.70	0.51	28.42	2.16	2.27	2.22	0.08
Combretaceae	*Combretum molle* R.Br. ex G.Don	2	13.00	58.00	0.53	2.92	0.36	2.38	1.37	0.06
	Terminalia catappa L.	42	11.00	41.00	0.26	25.89	7.55	1.19	4.37	0.14
	Terminalia mantaly H. Perrier	26	13.50	52.00	0.42	31.64	4.68	1.91	3.29	0.11
Euphorbiaceae	*Hura crepitans* L.	16	12.70	96.40	1.46	62.94	2.88	6.57	4.73	0.14
Fabaceae	*Daniella oliveri* (Rolf) Hutch & Dalz	2	14.90	45.90	0.33	2.09	0.36	1.49	0.92	0.04
	Erythrina senegalensis Dc.	2	12.00	52.00	0.42	2.16	0.36	1.91	1.14	0.05
	Acacia polycantha willd.	4	8.60	21.70	0.07	0.54	0.72	0.33	0.53	0.03
	Afezelia africana SM.	2	12.40	37.90	0.23	1.19	0.36	1.02	0.69	0.03
Fabaceae	*Albizia lebbeck* (Lam) Benth.	2	12.00	96.00	1.45	7.37	0.36	6.52	3.44	0.12
	Delonix regia (Hook) Raf.	4	15.60	67.80	0.72	9.56	0.72	3.25	1.99	0.08
	Pterocarpus erinaceus Poir.	2	12.00	94.00	1.39	7.07	0.36	6.25	3.30	0.11
	Cassia fistula Linn.	8	10.00	95.00	1.42	24.07	1.44	6.38	3.91	0.13
	Parkia biglobosa (Jacq) R.Br ex G. Don	24	16.50	27.60	0.12	10.06	4.32	0.54	2.43	0.09
	Senna siamea (Lam) Irwin & Barneby	4	10.70	17.30	0.05	0.43	0.72	0.21	0.47	0.02
	Albizia coriaria Welwex Oliv.	2	11.60	37.50	0.22	1.09	0.36	0.99	0.68	0.03
	Dalbergia latifolia Roxb.	2	13.87	11.50	0.02	0.12	0.36	0.09	0.23	0.01
	Prosopsis africana (Guill & Perr) Taub.	2	11.16	29.00	0.13	0.63	0.36	0.59	0.48	0.03
	Erythrina sigmoidea Hua.	2	12.29	45.00	0.32	1.66	0.36	1.43	0.90	0.04
Meliaceae	*Azadirachta indica* A. Juss	44	11.96	34.40	0.19	20.76	7.91	0.84	4.38	0.14
	Khaya senegalensis (Desr) A. Juss	12	11.95	28.50	0.13	3.88	2.16	0.57	1.37	0.06
	Khaya grandifoliola C. DC.	8	15.19	45.00	0.32	8.20	1.44	1.43	1.44	0.06
Moraceae	*Ficus sur* Forssk.	8	11.31	45.00	0.32	6.11	1.44	1.43	1.44	0.06
	Ficus mucoso Welw ex Ficalho	12	12.83	96.00	1.45	47.30	2.16	6.52	4.34	0.14
Myrtaceae	*Eucalyptus citrodora* Hook.	12	22.70	84.50	1.12	64.83	2.16	5.05	3.60	0.12
	Eucalyptus toreliana F. Muell	12	19.60	62.80	0.62	30.92	2.16	2.79	2.47	0.09
	Eucalyptus camadalensis Dehn.	16	21.50	58.10	0.53	38.71	2.88	2.39	2.63	0.10
Sapotaceae	*Vitellaria paradoxa* Gaertn.f	2	12.40	28.00	0.12	0.65	0.36	0.55	0.46	0.02
Verbenaceae	*Gmelina arborea* Roxb	24	18.50	84.50	1.12	105.68	4.32	5.05	4.68	0.14
	Vitex doniana (Sweet)	2	11.90	62.80	0.62	3.13	0.36	2.79	1.57	0.07
	Tectona grandis Linn. F.	24	13.00	58.10	0.53	35.11	4.32	2.39	3.35	0.11
		556			22.2	745.4				3.61

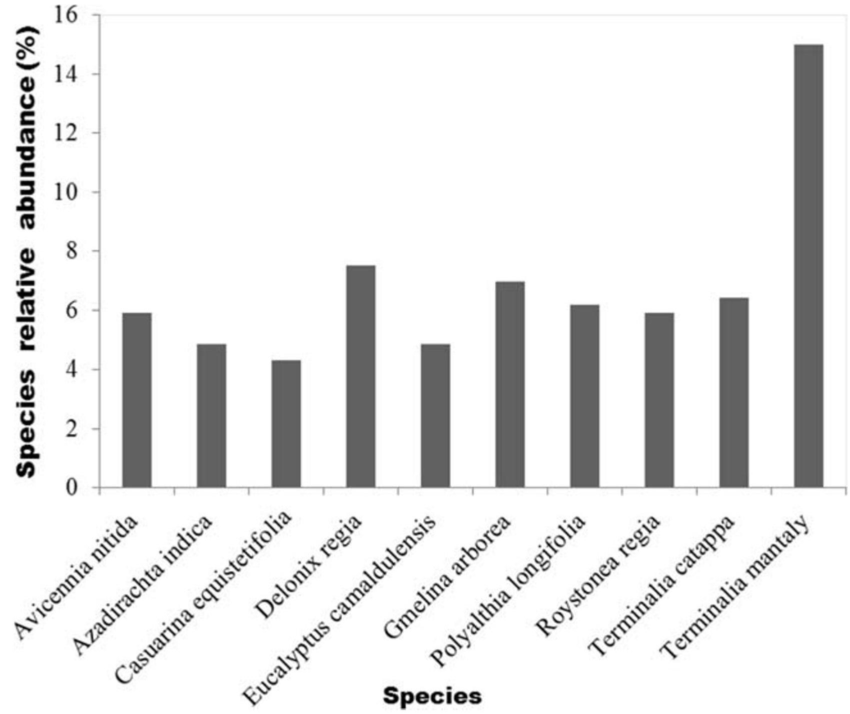

Fig. 2 Ten most abundant species in Port Harcourt

Biodiversity indices and tree growth variables

Biodiversity indices and tree growth variables for urban forests in the two cities were calculated and presented in Table 5. The Shannon-Wiener diversity index computed for Port Harcourt was 3.39 while that of Ilorin was 3.61. The result of Pielou's evenness index was 0.54 and 0.55 for Port Harcourt and Ilorin, respectively. The summary of tree growth variables showed that the total basal area for Port Harcourt was 16.39 m^2 while the total volume for trees for the selected city segment was 409.78 m^3. In the urban forest of Ilorin, 22,21 m^2 was calculated as the total basal area while in the selected city portion the total volume for trees was 745,44 m^3.

The tree diameter distribution in both cities showed the presence of the highest number of individual trees in the small diameter class (10–60 cm), while in Ilorin the lowest number of trees occurred in the 61–100 cm diameter class (Table 6). In Port Harcourt, the highest number of trees was found in the

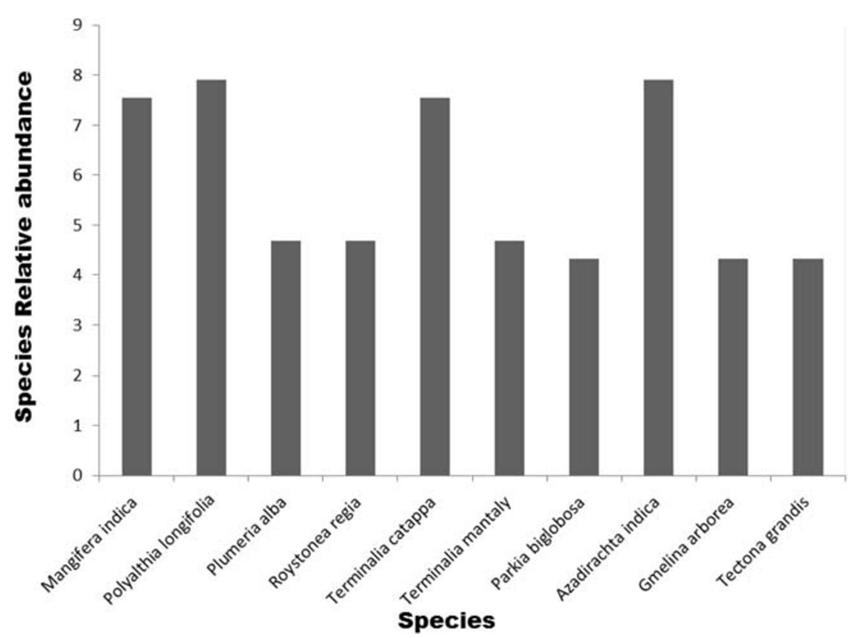

Fig. 3 Ten most abundant species in Ilorin

Table 3 Families Important Value for the selected urban forest in Port Harcourt City

S/N	Family	B.A. (m^2)	Volume (m^3)	RD (%)	RDo (%)	FIV (%)
1	Apocynaceae	0.35	1.85	2.70	2.12	2.41
2	Anacardiaceae	1.46	15.61	5.41	8.90	7.15
3	Annonaceae	0.18	4.44	5.41	1.10	3.25
4	Apocynaceae	1.10	17.30	8.11	6.71	7.41
5	Arecaceae	0.12	11.16	2.70	0.72	1.71
6	Avicenniaceae	1.62	87.87	5.41	9.88	7.64
7	Bombacaceae	1.10	8.65	2.70	6.69	4.70
8	Burseraceae	0.60	2.89	2.70	3.68	3.19
9	Casuarinaceae	0.04	3.17	2.70	0.27	1.48
10	Cecropiaceae	0.35	1.50	2.70	2.12	2.41
11	Combretaceae	0.10	11.56	8.11	0.61	4.36
12	Cupressaceae	0.03	0.25	2.70	0.19	1.45
13	Euphorbiaceae	2.35	43.80	8.11	14.33	11.22
14	Fabaceae	0.41	8.75	10.81	2.50	6.66
15	Meliaceae	0.13	12.18	2.70	0.80	1.75
16	Moraceae	3.03	14.59	16.22	18.48	17.35
17	Myrtaceae	1.18	11.48	5.41	7.20	6.30
18	Pinaceae	1.39	24.88	2.70	8.46	5.58
19	Verbenaceae	0.86	127.84	2.70	5.27	3.99

10–30 cm diameter class whereas the lowest number of trees was found in the 91–100 cm diameter range. In the diameter class of 91–100 cm, the highest basal area of 7.17 m^2 occurred while the highest volume of 230.91 m^3 occurred in the diameter class of 51–60 cm for trees in Ilorin metropolis. The same pattern was observed in Port Harcourt with the 91–100 cm diameter class having the highest basal area of 4.31 m^2 while the 61–70 cm diameter class had the lowest 146.84 m^3 volume.

Table 4 Families Important Value for the selected urban forest in Ilorin City

S/N	Family	B.A. (m^2)	Volume (m^3)	RD (%)	RDo (%)	FIV (%)
1	Asclepiadaceae	0.93	8.64	2.17	4.17	3.17
2	Anacardiaceae	1.63	40.87	8.70	7.34	8.02
3	Annonaceae	0.55	74.53	2.17	2.48	2.33
4	Apocynaceae	0.08	6.17	4.35	0.36	2.35
5	Araucariaceae	0.56	3.21	2.17	2.51	2.34
6	Arecaceae	0.52	21.01	4.35	2.34	3.35
7	Asteraceae	0.17	0.55	2.17	0.75	1.46
8	Bignoniaceae	0.36	4.05	4.35	1.62	2.98
9	Bisnoniaceae	0.27	1.32	2.17	1.23	1.70
10	Casuarihaceae	0.51	28.42	2.17	2.28	2.22
11	Combretaceae	1.22	60.44	6.52	5.50	6.01
12	Euphorbiaceae	1.46	62.94	2.17	6.58	4.38
13	Fabaceae	6.89	68.03	30.43	31.04	30.74
14	Meliaceae	0.63	32.84	6.52	2.84	4.68
15	Moraceae	1.77	53.40	4.35	7.97	6.16
16	Myrtaceae	2.27	134.46	6.52	10.23	8.37
17	Sapotaceae	0.12	0.65	2.17	0.55	1.36
18	Verbenaceae	2.27	143.91	6.52	10.23	8.37

Table 5 Biodiversity indices and tree growth variables in Nigerian urban centres

Biodiversity indices	Port Harcourt	Ilorin	Tree growth variables	Port Harcourt	Ilorin
Number of individuals	556	746	Mean dbh (cm)	44.84	49.74
Number of species	37	46	Dominant dbh (cm)	98.00	96.40
Number of families	19	18	Mean height (m)	11.10	13.35
Shannon Wiener index (H')	3.39	3.61	Dominant height (m)	18.56	22.70
Pielou's evenness index (EH)	0.54	0.55	Total basal area/ha (m^2)	16.39	22.21
Maximum diversity (Hman)	6.32	6.61	Total volume/ha (m^3)	409.78	745.44

The distribution of the height class suggested the physiognomy of the urban forests, shown by the vertical structure and distribution of tree heights (Table 7). The height range of 10.01–15.00 m in Port Harcourt metropolis had a total number of 606 individual trees, a cumulative basal area of 9.17 m^2 and a cumulative volume of 335.37 m^3. Similarly, the largest number of individual trees (298 stem), cumulative basal area (12.47 m^2), and cumulative volume (361.88 m^3) in Ilorin metropolis were in the height range of 10.01–15.00 m. It was observed that the highest concentration of different tree species (22) and family (16) occurred in the 10.01–15.00 m height class in Port Harcourt while the highest concentration of tree species (26) and family (12) occurred in the 10.01–15.00 m height class at Ilorin.

Biomass and carbon stock estimation

The total accumulation of biomass for trees in Port Harcourt was estimated at 67,979.08 tons while 91,512.49 tons were calculated for Ilorin (Tables 8 and 9). The overall biomass differed considerably between species of one tree and another. Figures 4 and 5 show the ten organisms selected for this analysis with the highest accumulation of biomass in the two cities. The species with the highest accumulation of biomass in Port Harcourt was *Hevea brasiliensis* (6686.38 tons) followed by *Anacardium occidentale* (6257.61 tons) while the *Eucalyptus camaldulensis* (35.03 tons) had the lowest accumulation of biomass in the city. At Ilorin *Hura crepitans* had the highest biomass (6455.93 tons), followed by *Albizia lebbeck* (6398.95 tons) and *Plumera rubra* had the lowest biomass (50.24 tons) (Table 9). The result showed that carbon

Table 6 Diameter distribution of tree species in Port Harcourt and Ilorin metropolis

Port Harcourt	Diameter class	Number of species	Number of families	Number of tree	Basal area (m^2)	Volume (m^3)
	10–20	11	9	456	0.39	37.89
	21–30	6	4	96	0.68	27.06
	31–40	3	3	36	0.53	13.13
	41–50	2	2	4	0.69	3.35
	51–60	2	1	6	0.88	6.27
	61–70	3	3	70	2.09	115.88
	71–80	4	4	60	3.42	146.84
	81–90	3	3	6	3.39	22.11
	91–100	3	3	12	4.31	37.26
Ilorin	Diameter class	Number of species	Number of families	Number of tree	Basal area (m^2)	Volume (m^3)
	10–20	4	2	50	0.16	6.67
	21–30	9	7	102	0.95	27.60
	31–40	5	4	92	1.01	37.35
	41–50	7	7	72	2.10	48.09
	51–60	9	8	140	4.43	230.91
	61–70	3	3	18	1.96	43.55
	71–80	1	1	2	0.93	8.64
	81–90	3	3	40	3.46	193.79
	91–100	5	3	40	7.17	148.75

Table 7 Height distribution Status of tree species in Port Harcourt and Ilorin

Port Harcourt	Height class	Number of species	Number of families	Number of tree	Basal area (m^2)	Volume (m^3)
	1.01–5.00	1	1	2	0.03	0.06
	5.01–10.00	11	6	98	4.95	64.62
	10.01–15.00	22	16	606	9.17	335.37
	15.01–20.00	3	2	40	2.28	20.13
Ilorin	Height class	Number of species	Number of families	Number of tree	Basal area (m^2)	Volume (m^3)
	5.01–10.00	8	4	96	2.43	46.79
	10.01–15.00	26	12	298	12.47	361.88
	15.01–20.00	7	6	116	3.00	172.89
	20.01–25.00	5	4	46	4.30	163.88

storage differed between the two cities. The total carbon stored in Port Harcourt by trees was estimated at 67,979.08 tons and the carbon stored in Ilorin urban forest was estimated at 91,512.49 tons. Port Harcourt's average carbon density of trees was estimated at 136.15 tons / ha while Ilorin was estimated at 7.82 tons / ha for trees.

Discussion

The results of the assessment of urban forest tree species showed that both indigenous and exotic hardwood species were present in the two Nigerian cities. Trees offer ecological services and enhance the harsh environmental conditions connected to urban centres. The findings of the assessment of urban forests on tree diversity, volume yield and carbon storage have shown that the two Nigerian cities have the capacity to provide ecosystem services as other tropical forest reserves provide ecosystem services to the population. Tree species that were found in the two cities belong to both indigenous and exotic tropical hard wood tree species.

Tree species diversity and Phytosociological characteristics

The number of tree species recorded from the two Nigerian cities (Port Harcourt and Ilorin) is much less than the number of species recorded in Nigeria for other natural forest reserves. Lawal and Adekunle (2013) finding showed that 406/ha species for Strict Nature reserve of Akure and Adekunle et al. (2014) research indicated that 500/ha species from Eda protected forest all in the rainforest vegetation zone of Nigeria. These two urban forests belong to different vegetation zones of Nigeria Port Harcourt in the Rainforest and Ilorin in the Guinea savanna zone. The tree species composition in these cities could be attributed to the nature of the vegetation zones and the climatic conditions of the cities. These urban forests act as biodiversity reserves and provide ecological services (such as enhancing harsh environmental conditions connected to urban centres). It has been reported that volume estimation is the determinant of the tree growth structure and is the most important parameter for forest management (Adekunle 2006; Tonolli et al. 2011; Adekunle et al. 2013). The estimated volume for this study was 409.8 m^3 for urban forests in Port Harcourt and 745.4 m^3 for urban forests in Ilorin, which was very small compared to similar studies in protected forests. Adekunle et al. (2013) estimated volume of 387 m^3/ha for Akure strict Nature Reserve, Adekunle et al. (2014) estimated volume of 287.49 m^3/ha for Eda protected forest, Wittmann et al. (2008) estimated volume of 259.45 m^3/ha for Southern Pantanal, Brazil. The sharp variation in the values recorded for this study could be attributed to tree species density. Banda et al. (2006) and Munishi et al. (2011) found that, management activites had significant influence on plant species abundance and the volume yield.

Urban forest trees composition and diversity

The estimated diversity of Shannon-Wiener for this analysis was H′ = 3.39 for the urban forest of Port Harcourt and H′ = 3.39 for the urban forest of Ilorin, close to the estimated diversity for some protected forests in Nigeria. Adekunle et al. (2013) estimated 3.74 Shannon-diversity for Akure strict Nature Reserve, 2.12 for Eda protected forest, Agbelade et al. (2016) estimated 3.08 Shannon-diversity for Minna urban forest, and Agbelade et al. (2017) estimated 3.56 Shannon-diversity for Abuja urban forest. The higher diversity values measured for these two urban forests reflect the planning and management that the Ministry of Environment and Government has placed in place to boost the city's greeness cover. The higher species diversity is expected to promote ecosystem services and animal protection policies to boost the population in these cities. Forest habitats play an important role in the functioning of the biosphere, in

Table 8 Biomass and carbon stock of species in urban forest area of Port Harcourt

Family	*Tree species*	AGB	BGB	C Stock
Apocynaceae	*Alstonia congensis De Wild.*	1110.83	222.17	1333.00
Anacardiaceae	*Anacardium occidentale L.*	5214.68	1042.94	6257.61
	Mangifera indica L.	72.40	14.48	86.87
Annonaceae	*Annona muricata L.*	417.60	83.52	501.12
	Polyalthia longifolia (Sonn.) Thwaites	40.86	8.17	49.04
Apocynaceae	*Nerium oleander L.*	2869.38	573.88	3443.26
	Plumeria alba L.	669.75	133.95	803.70
	Plumeria rubra L.	124.73	24.95	149.68
Arecaceae	*Roystonea regia (H.B.K) F.cook*	306.15	61.23	367.38
Avicenniaceae	*Avicennia nitida Jacq.*	2532.67	506.53	3039.20
	Jacaranda mimosacfolia L.	3190.46	638.09	3828.55
Bombacaceae	*Bombax buonopozense P. Beauv.*	3965.09	793.02	4758.11
Burseraceae	*Dacryodes edulis (G. Don) H.J. Lam*	2067.13	413.43	2480.55
Casuarinaceae	*Casuarina equisetifolia Linn.*	83.51	16.70	100.21
Cecropiaceae	*Musanga cecropioides R. Br.*	1110.83	222.17	1333.00
Combretaceae	*Terminalia catappa L.*	29.77	5.95	35.73
	Terminalia mantaly H. Perrier	35.92	7.18	43.10
	Terminalia superba Engl. & Diels	108.63	21.73	130.36
Cupressaceae	*Thuja occidentalis L.*	51.72	10.34	62.07
Euphorbiaceae	*Croton zambesicus Müell. Arg.*	190.87	38.17	229.05
	Hevea brasiliensis Müell. Arg.	5571.98	1114.40	6686.38
	Hura crepitans L.	2648.12	529.62	3177.74
Fabaceae	*Caesalpinia pulcherrima (L.) Sw.*	270.14	54.03	324.17
	Delonix regia (Hook) Raf.	61.60	12.32	73.92
	Senna siamea (Lam) Irwin & Barneby	437.50	87.50	525.01
	Dialium guineense Willd.	278.06	55.61	333.68
Meliaceae	*Azadirachta indica A. Juss*	350.75	70.15	420.90
Moraceae	*Antiaris africana Engl.*	50.68	10.14	60.81
	Ficus benjamina L.	369.90	73.98	443.88
	Ficus thonningii Blume	1583.96	316.79	1900.75
	Ficus tomentosa Roxb. Ex willd.	4109.33	821.87	4931.19
	Milicia excelsa (Welw.) C.C. Berg.	1336.85	267.37	1604.22
	Treculia africana var. nitida Engl.	2983.36	596.67	3580.03
Myrtaceae	*Eucalyptus camaldulensis Dehn*	29.20	5.84	35.03
	Eucalyptus globulus Labill	4213.93	842.79	5056.72
Pinaceae	*Pinus caribaea Var. Barr. & Golf.*	5098.21	1019.64	6117.86
Verbenaceae	*Gmelina arborea Roxb.*	3062.67	612.53	3675.20
	Total	56,649.23	11,329.85	67,979.08

relation to the conservation of plant gene bank (EU 2008). Urban forests will make an enormous contribution to the protection of biodiversity and could function as bio-resources if effective management and planning was implemented. Species diversity and richness is an important attribute of a forest community that influences the functioning of an ecosystem which satisfy human needs (Magurran 2004; Salunkhei et al. 2016; Onyekwelu et al. 2008).

Carbon storage capacity of these urban forests

The carbon sequestration in the study areas varied with the vegetation zones and climatic conditions of these locations 136.15 tons/ha and 7.82 tons/ha in urban forests of Port Harcourt and Ilorin respectively. The carbon storage of the urban forest of Port Harcourt (rainforest) is comparable to similar study conducted in the same vegetation zone Nigeria 156.73

Table 9 Biomass and carbon stock of species in urban forest area of Ilorin

Family	Tree species	AGB	BGB	C Stock
Asclepiadaceae	Calotropis Procera (Aiton) Ait.f.	3296.62	659.32	3955.94
Anacardiaceae	Lannea acida A. Rich	4437.89	887.58	5325.47
	Mangifera indica L.	578.47	115.69	694.16
	Anacardium occidentale L.	310.92	62.18	373.11
	Lannea barteri (Oliv) England	244.61	48.92	293.53
Annonaceae	Polyalthia longifolia (Sonn.) Thwaites	1866.11	373.22	2239.33
Apocynaceae	Plumeria alba L.	117.37	23.47	140.84
	Plumeria rubra L.	41.87	8.37	50.24
Araucariaceae	Araucaria cunninghamii (Aiton)	1887.15	377.43	2264.59
Arecaceae	Cocos nucifera L.	1463.95	292.79	1756.74
	Roystonea regia (H.B.K) F.cook	175.90	35.18	211.08
Asteraceae	Vernonia amygdalina Del.	468.95	93.79	562.74
Bignoniaceae	Crescentia cujete L.	199.72	39.94	239.66
	Newbouldia laevis (P. Beauv)	857.96	171.59	1029.55
Bisnoniaceae	Spathodea campanulata P. Beauv.	843.83	168.77	1012.60
Casuarihaceae	Casuarina equisetifolia L.	1695.36	339.07	2034.43
Combretaceae	Combretum molle R.Br. ex G.Don	1783.12	356.62	2139.75
	Terminalia catappa L.	811.33	162.27	973.60
	Terminalia mantaly H. Perrier	1396.65	279.33	1675.98
Euphorbiaceae	Hura crepitans L.	5379.94	1075.99	6455.93
Fabaceae	Daniella oliveri (Rolf) Hutch & Dalz	1052.37	210.47	1262.85
	Erythrina senegalensis Dc.	1396.65	279.33	1675.98
	Acacia polycantha willd.	169.69	33.94	203.62
	Afezelia africana SM.	675.18	135.04	810.22
Fabaceae	Albizia lebbeck (Lam) Benth.	5332.46	1066.49	6398.95
	Delonix regia (Hook) Raf.	2516.39	503.28	3019.66
	Pterocarpus erinaceus Poir.	5098.21	1019.64	6117.86
	Cassia fistula Linn.	5214.68	1042.94	6257.61
	Parkia biglobosa (Jacq) R.Br ex G. Don	313.74	62.75	376.49
	Senna siamea (Lam) Irwin & Barneby	92.11	18.42	110.54
	Albizia coriaria Welwex Oliv.	658.54	131.71	790.24
	Dalbergia latifolia Roxb.	28.84	5.77	34.61
	Prosopsis africana (Guill & Perr) Taub.	354.66	70.93	425.59
	Erythrina sigmoidea Hua.	1005.73	201.15	1206.87
Meliaceae	Azadirachta indica A. Juss	536.68	107.34	644.02
	Khaya senegalensis (Desr) A. Juss	339.75	67.95	407.70
	Khaya grandifoliola C. DC.	1005.73	201.15	1206.87
Moraceae	Ficus sur Forssk.	1005.73	201.15	1206.87
	Ficus mucoso Welw ex Ficalho	5332.46	1066.49	6398.95
Myrtaceae	Eucalyptus citrodora Hook.	4057.52	811.50	4869.02
	Eucalyptus toreliana F. Muell	2126.46	425.29	2551.75
	Eucalyptus camadalensis Dehn.	1789.97	357.99	2147.96
Sapotaceae	Vitellaria paradoxa Gaertn.f	325.17	65.03	390.21
Verbenaceae	Gmelina arborea Roxb	4057.52	811.50	4869.02
	Vitex doniana (Sweet)	2126.46	425.29	2551.75
	Tectona grandis Linn. F.	1789.97	357.99	2147.96
	Total	76,260.41	15,252.08	91,512.49

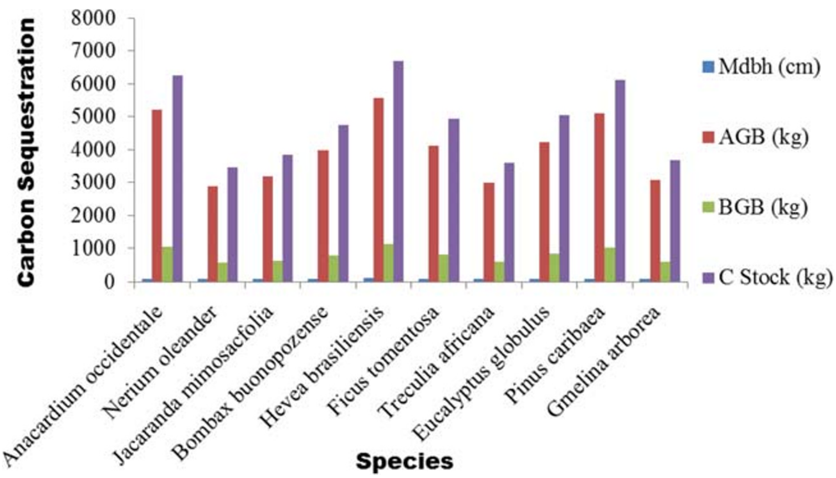

Fig. 4 Ten tree species with highest carbon storage in Port Harcourt

tons/ha for Eda protected forest Adekunle et al. (2014). The carbon storage of Ilorin urban forest in Nigeria is less than the studies conducted in protected forest in Nigeria 156.73 tons/ha for Eda protected forest Adekunle et al. (2014), urban forest of Shenyang, China (Liu and Li 2012) and 172 ton/ha for urban forest of Addis Ababa. The carbon content of trees in urban areas in this study is an indication that the conservation of biodiversity in urban areas could contribute significantly to greenhouse gas emission reduction. The carbon storage estimated for this study demonstrated the level of variability of carbon sequestration that could exist within different urban centres in different vegetation zones. The variation in these values may not only depend on species, climatic condition, anthropogenic disturbances but also could be attributed to model used in estimating biomass and sampling intensity. The amount of carbon stored by Port Harcourt is encouraging to further conserve and manage the present urban forest structure. The carbon stored by Ilorin urban forest is highly disturbing which could be due to deforestation of urban trees without replacement and climatic conditions of the location that can increase the carbon dioxide to the atmosphere. Therefore, selecting and planting the right species as avenue trees, building parks and gardens, inclusion of tree in urban landscaping can improve urban forest carbon sequestration and producing other urban forest ecosystem functions (Day et al. 2013; Ramachandran et al. 2007; Sitoe et al. 2014; Woldegerima et al. 2017).

Conclusion

This study has demonstrated that the urban forest of Port Harcourt and Ilorin needs urgent attention due to the rate of exposure of the urban forest to degradation, low conservation and management. Improvement of the management strategies of these urban forests would increase tree species diversity, volume yield and carbon storage potential thereby performing their ecosystems functions. The low estimated carbon storage values for this study could be as results of indiscriminate, unconcern attitude of both the Government and the citizen alike. Deforestation within the urban forests would reduce the level of ecosystems functions and services to the environment. In addition to the opportunity of carbon storage in urban

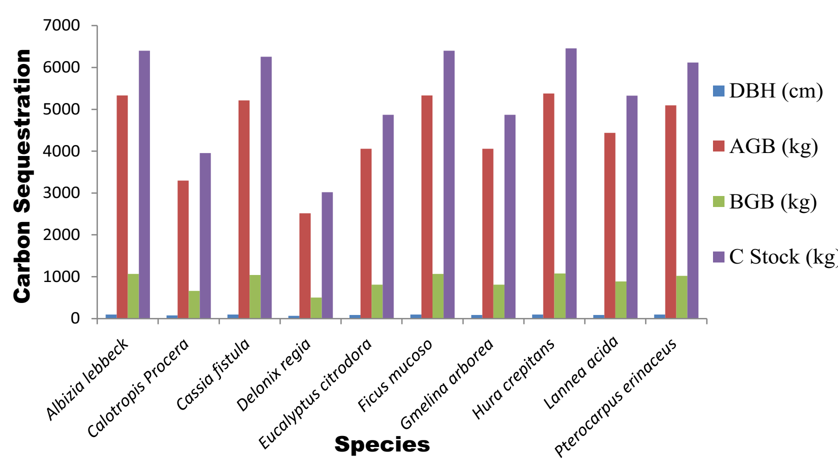

Fig. 5 Ten tree species with highest carbon storage in Ilorin

forests, there are arrays of other ecosystem services and ecological functions of urban forests that could be beneficial to urban populace. The results of this study showed the importance of forests in urban settlement and how the urban forests has been exposed to high level of degradation which had made the cities to be prone to different environmental hazards. However, there are different challenges in Nigerian cities in balancing forest conservation with infrastructural development with urban livelihood improvement. These challenges can be better solved by applying institutional frameworks that are geared toward increasing the awareness of the importance of urban forests. High amount of carbon dioxide is removed from environment by trees annually and are stored as carbon in plant biomass. These low values of tree volume and carbon storage should awaken urban forest managers and policy makers to strategize ways by which silvicultural activities could be on the increase in these Nigerian cities.

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