

INSTITUTIONAL CONTRIBUTION TO URBAN BIODIVERSITY CONSERVATION, PRODUCTIVITY, AND CARBON SEQUESTRATION: A CASE STUDY OF THE FORESTRY RESEARCH INSTITUTE OF NIGERIA

Joshua OGUNADE¹, Quadri ONILUDE^{1*}, Jonathan ONYEKWELU²,
Olusola OGUNWANDE¹ and Zacharia YADUMA¹

¹Forestry Research Institute of Nigeria [FRIN], Jericho Hill, 200116, Ibadan, Nigeria;
email: ogunadeoluseun@gmail.com; solaogunwande@gmail.com; zachariaby@gmail.com

²Federal University of Technology Akure [FUTA], P.M.B. 704, Akure, Nigeria; email: jconyekwelu@futa.edu.ng

*Correspondence: omoonilu@gmail.com

Received: Jul. 18, 2025. Revised: Nov. 06, 2025. Accepted: Nov. 12, 2025. Published online: Jan. 12, 2026

ABSTRACT. Urban trees within developed areas provide essential ecosystem services that include carbon sequestration. But growing urban populations put pressure on vegetated urban ecosystem services and biodiversity. This study examined tree diversity, biomass, and carbon storage within the developed areas of the Forestry Research Institute of Nigeria (FRIN). A complete enumeration of 326 trees distributed among 57 tree species and 29 families was conducted. Biodiversity indices were computed using standard procedures, while biomass and carbon storage were estimated using a non-destructive method. Most species (61.4%) were indigenous, while 38.6% were exotic. *Pinus caribaea*, *Khaya senegalensis*, *Entandophragma angolense*, and *Gmelina*

arborea were among the dominant tree species. About 65.6% of the trees were very stable given their low slenderness coefficient. The high biodiversity index values (species richness = 57; Shannon-Wiener diversity index = 3.84; Margalef index = 9.68) suggest that the developed areas of FRIN have good biodiversity conservation status. Total basal area and volume productions were 49.54 m² ha⁻¹ and 660.32 m³ ha⁻¹, respectively, corresponding to 447.90 tons ha⁻¹ of biomass and 223.95 tons ha⁻¹ of carbon. Despite their small land size, the developed areas of FRIN are a significant carbon sink compared to similar institutional landscapes in Nigeria. This study highlights the need for institutional green-space management strategies to be integrated into national climate change



Cite: Ogunade, J.; Onilude, Q.; Onyekwelu, J.; Ogunwande, O.; Yaduma, Z.
Institutional contribution to urban biodiversity conservation, productivity, and carbon
sequestration: a case study of the Forestry Research Institute of Nigeria.
Journal of Applied Life Sciences and Environment **2025**, 58 (4), 577-599.
<https://doi.org/10.46909/alse-583194>

adaptation and biodiversity conservation policies for enhanced ecological resilience and sustainability.

Keywords: biodiversity conservation; carbon sink; developed area; FRIN; urban vegetation.

INTRODUCTION

Globally, biodiversity is decreasing at unprecedented rates due to continued unsustainable human activities (Camilo *et al.*, 2022; UNEP, 2024). This decline is projected to continue due to a lack of abatement and ongoing biologically destructive anthropogenic practices. Interventions such as afforestation and reforestation programmes have proved insufficient to reverse the trends (FDA, 2024). The 2024 Forest Declaration Assessment (FDA) report revealed that the rate of global forest loss in 2023 was 45% higher than the target required to end deforestation by 2030. This high rate of forest loss, has resulted in worldwide decline in flora and fauna species population and ecosystem integrity (FAO and UNEP, 2020; Şeren and Çelekli, 2024).

In Nigeria, urban and rural populations are growing at annual average rates of 4.5% and 1.4%, respectively (Akpan and Ebong, 2021; Olalude *et al.*, 2024; Onyekwelu, 2013). The rapid population growth in cities across Nigeria and other developing countries is partially attributed to high rural-urban migration rates (Agbelade *et al.*, 2016; Onyekwelu, 2013). According to the United Nations, Department of Economic and Social Affairs (UN DESA, 2013), about 60% of urban areas that will exist in 2050 have not yet been built, which is an indication that urban populations will be much higher in the

near future. The world has become an urban society, with over 50% of humanity currently living within urban areas and more than 70% expected to reside in urban areas by the year 2050 (Liu *et al.*, 2020; UN DESA, 2018).

Tree planting and conservation are essential tools for addressing climate change challenges as well as other environmental concerns. Conservation activities have multiple benefits, including biodiversity conservation, ecosystem protection, human well-being improvement, among others benefits (Goncalves-Souza *et al.*, 2021; FAO, 2025; Mi *et al.*, 2023; Naidoo *et al.*, 2019; UNCCD, 2025; Wang *et al.*, 2025). Information on the synergy between biodiversity and carbon storage has shown that urban trees, being an integral part of terrestrial ecosystem, reduce vegetation loss, buffers local climate variability and enhances ecosystem productivity, ultimately enlarging long-term carbon storage (Duncanson *et al.*, 2023; UNEP, 2021; Wang *et al.*, 2025; Weiskopf *et al.*, 2024).

Urban forestry is the art, science, and technology of managing trees and forest resources in and around some urban community ecosystems for the psychological, sociological, aesthetic, economic, and environmental advantages trees bring to the society (FAO, 2020; UNEP, 2021). It plays a critical role in achieving the UN Sustainable Development Goals (SDGs 11, 13, and 15) (UN DESA, 2022). Urban forestry plays an important role in addressing various environmental, ecological and socio-economic challenges associated with urbanization. Urban trees are integral components of urban landscape, which could provide important

ecosystem services like food, fruits/seeds, vegetables, carbon sequestration, environmental and micro-climate regulation (Agbelade *et al.*, 2017; Fuwape and Onyekwelu, 2011). Managing urban trees helps conserve carbon stocks, mitigate air pollution, urban heat island effect and enhance their sequestration, making it a cost-effective and eco-friendly strategy for mitigating climate change (Livesley *et al.*, 2016; Wang *et al.*, 2025).

In recent times, institutions in urban areas have become involved in tree planting, biodiversity conservation, natural resources management, among others, thereby contributing to the success of urban forestry. For instance, Oyerinde *et al.* (2018) reported avenue trees in selected tertiary institutions in Nigeria. Ajayi *et al.* (2020) and Abdulmuhyi *et al.* (2022) reported abundance and diversity of trees in academic institutions.

Globally, academic institutions contribute immensely to carbon sequestration through their forested landscapes by focusing on three broad but interconnected areas: capacity for carbon storage; biodiversity provision, and a wide range of ecosystem goods and services; and their function as dynamic living laboratories for research, education, and community engagement (Filho *et al.*, 2024; UNESCO, 2025). Forests established by institutions can be publicly and privately owned and may include avenue trees, trees in parks, school premises, research institutes, religious institutions, residential yards, among others location (Enisan *et al.*, 2020).

Forestry Research Institute of Nigeria (FRIN), an ideal model of

institutional urban forestry with managed vegetation that together represent a significant urban forest ecosystem. FRIN contributes not only to research and education but also to biodiversity conservation, carbon sequestration, and ecosystem services provision within urban landscapes. Traditional institutions like sacred forests located around human settlements promote ecosystem sustainability through biodiversity conservation, carbon sequestration and provision of numerous ecosystem services (Davi *et al.*, 2021; Onyekwelu *et al.*, 2024). Despite the increasing involvement of institutions in tree planting and management, information on their contributions to biodiversity conservation and ecosystem services as components of urban forestry is lacking. Past studies (Agbelade *et al.*, 2022; Ogunkunle and Jimoh, 2019) mainly assessed tree species richness, density, and composition in urban green spaces.

However, these studies failed to integrate biodiversity conservation with tree productivity metrics. This limits the capacity to holistically evaluate the ecological importance and benefits of institutional green vegetation. Also, most trees in institutions were originally planted to conserve natural landscapes, with little known about their effectiveness for carbon storage.

Given the predicted dramatic reduction in biodiversity over the coming decades (CBD, 2019; UNEP, 2024), collaborative global and institutional actions are essential to reverse this trend and promote conservation. Few studies in Nigeria have integrated biodiversity indices with carbon stock estimation, and most of them focused separately on

species composition or biomass productivity, thereby limiting understanding of how institutional green spaces contribute simultaneously to biodiversity conservation and carbon sequestration (Akomolafe *et al.*, 2025; Ubaekwe, 2020).

To this end, this study was designed to assess the contributions of the Forestry Research Institute of Nigeria (FRIN, 2025) to urban biodiversity conservation, productivity, and carbon sequestration. It is hoped that the empirical evidence will guide policy and challenge other institutions (governmental and private) to actively engage in integrated urban forestry strategies to support national and global climate adaptation goals.

MATERIALS AND METHODS

The study area

This study was conducted within the premises of FRIN located in an urban area at Government Reserved Area (GRA), Jericho Hill, Ibadan North in Oyo State, Nigeria (can be accessed at <https://frin.gov.ng/contact-us/>). It lies between 7° 25' and 7° 55' N and 3° 9' and 3° 53' E. The study area experiences two distinct seasons. The rainy season runs April–October, while the dry season spans November–March. The climate is usually warm, with mean daily temperature ranging 18.7–34.4 °C. Mean annual rainfall ranges 1,400–1,500 mm. Relative humidity ranges from about 60% between December and February to 82% between June and September (Lawal *et al.*, 2020). The soil texture ranges from loamy sand in surface horizons to sandy loam and sandy clay loam in subsurface horizons (Ishola *et al.*, 2021; Onemayin *et al.*, 2020). These soils correspond

mainly to Acrisols or Alfisols, which are typical of humid tropical regions (Food and Agriculture Organization-United Nations Educational, Scientific and Cultural Organization, 2015; United States Department of Agriculture, 2014). FRIN covers a total land area of 104.89 ha comprised of developed areas (offices and staff quarters), forest plantation, natural forest, and fallow land. The developed areas cover about 19.73 ha of the entire land and consists of hard surfaces (e.g., paved) and landscape with beautiful ornamental flowers, shrubs, grasses, and trees (indigenous and exotic species). The institution is well guarded with boundaries (brick fence), buildings are linked by a good road network, lawns, and pedestrian walkways. The integration of trees and vegetation within the developed areas of FRIN enhances air quality, supplies non-timber products, and functions as windbreaks that protect infrastructures from damage while also creating a peaceful, beautiful, and serene environment.

Brief history of FRIN

The institute was established as the Federal Department of Forestry Research in 1954, but in 1977 its status was changed to Research Institute, a status it maintains to date. The mandate of FRIN is to conduct research into all aspects of forestry, forest product utilisation, watershed management, wildlife, agroforestry and to train technical personnel in forestry and related fields. The focus of FRIN is to apply scientific knowledge to the management and conservation of forest resources in Nigeria in a way that meets the needs of present and future generations (Onyekwelu, 2024).

In addition to research at its headquarters at Ibadan, FRIN research activities are carried out at 17 hubs and research stations spread across all ecological zones of Nigeria. One of the means through which FRIN strives to meet its mandate is the establishment of demonstration forest plantations within its headquarters and stations. Forest plantation establishment at FRIN headquarters commenced about 25 years ago. Since then, indigenous and exotic tree species have been established, with *Nauclea diderrichii*, *Terminalia superba*, *Terminalia ivorensis*, *Gmelina arborea*, and *Khaya senegalensis* being the prominent tree species.

Data collection, processing, and analysis

Data collection was limited to the developed areas of FRIN. All trees with a diameter at breast height (DBH) ≥ 10 cm were counted. Tree identification (by scientific and common names) was undertaken by an experienced taxonomist. Species identifications were later confirmed at the Forest Herbarium Ibadan located at FRIN headquarters. Keay (1989) was used as a guide for tree nomenclature as well as family placement. The following measurements were made on all trees: diameter at 1.3 m above the ground surface using a diameter tape; diameters at the base, middle, and top of the tree; tree height (measured from the base of the tree to the top of the tree using a spiegel relaskop); marketable height (usable length of a tree's bole measured from the ground to a specified upper diameter limit); crown height (the vertical distance from the ground to the lowest live branch that forms part of the tree's crown); and

crown diameter (the average width of the spread of a tree crown).

Biodiversity indices

Eight biodiversity indices were computed using the methods suggested and/or adopted by Onyekwelu *et al.* (2008, 2021) and others.

• Species relative density (RD, %)

is an index for assessing species relative distribution within an ecosystem (Equation 1).

$$RD = \left(\frac{n_i}{N} \right) \times 100 \quad (1)$$

where n_i is the number of individuals of species i , and N is the total number of all individuals of all species in the study area.

• Species relative dominance (Rdo, %)

is useful for assessing the relative space occupancy of a species (Equation 2).

$$RDo = \frac{(\sum Ba_i \times 100)}{\sum Ba_n} \quad (2)$$

where Ba_i is the basal area of all trees of species i , and Ba_n is the total basal area of all species.

• **Menhinick's index (D)** measures species richness in the ecosystem (Equation 3).

$$D = \frac{S}{\sqrt{N}} \quad (3)$$

where S is the number of species, and N is the number of individuals.

• **Shannon-Wiener diversity index (H')** accounts for species richness and evenness (Equation 4)

$$H = - \sum_{i=1}^s p_i \ln(p_i) \quad (4)$$

where S is the number of species in the study area, p_i is the proportion of S consisting of the i^{th} species, and $\ln$ is the natural logarithm.

• **Shannon's equitability index (E_H)**

measures species evenness (Equation 5).

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

• **Importance value index (IVI, %),**

or coverage index is used to determine the overall importance of each species in the community (Equation 6).

$$IVI = \left(\frac{RD + RD_0}{2} \right) \quad (6)$$

This index shows how abundant, widespread and dominant each species is.

• **Simpson's Diversity Index (D)**

measures species diversity by considering both richness (number of species) and evenness (relative abundance) (Onilude *et al.*, 2020). It is calculated using Equation 7.

$$D = \sum \left(\frac{n_i}{N} \right)^2 \quad (7)$$

where n_i is the number of individuals belonging to species i , and N is the total number of individuals observed across all species.

The value of $1 - D$ (Simpson's index) was then used to represent diversity, where values closer to 1 indicate higher diversity and values near 0 indicate lower diversity.

• **Margalef's Index (d)** was used to calculate the species richness. The Margalef's index (d) is independent of sample size. It is based on the relationship between total number of species (S) and total number of individuals (N) (ADIO *et al.*, 2019) (Equation 8).

$$d = \frac{S - 1}{\ln(N)} \quad (8)$$

where S is the total number of species, N is the total number of individuals, and $\ln$ is the natural logarithm.

Growth and yield

Three statistics were calculated to assess tree size and shape.

• **Basal area (BA)** of each tree was estimated using the equation from Husch *et al.* (2003) (Equation 9)

$$BA = \frac{\pi DBH^2}{4} \quad (9)$$

where π is 3.142 (constant). The total basal area for the developed areas was computed as the sum of the basal areas of all trees. Basal area per ha was obtained by dividing the total basal area by the number of hectares covered by the developed areas of FRIN.

• **Volume (Vol)** of each tree was estimated using Newton formula (Husch *et al.*, 2003) (Equation 10):

$$Vol = \pi H \left[\frac{D_b^2 + 4D_m^2 + D_t^2}{24} \right] \quad (10)$$

where H is the tree height (m), D_b is the diameter at the base (cm), D_m is the diameter at the middle (cm), D_t is the diameter at the top (cm). The total volume of trees in the developed areas was calculated by adding the volumes of all trees. The volume per ha was obtained by dividing the total volume by the number of hectares covered by the developed areas of FRIN. It is important to note that, for monodic tree species, volume estimation was based on the main trunk of the tree, while in sympodic species, the most vigorous and robust stem was selected for measurement.

• **Tree slenderness coefficient (SLC)** was estimated by dividing the height of a tree by its DBH (Equation 11).

$$SLC = \frac{H}{DBH} \quad (11)$$

The tree slenderness coefficient often serves as an index of tree stability

(Onilude and Adesoye, 2007). The SLC of each trees was categorised in one of three coefficient classes:

- a) High slenderness coefficient:
Slenderness coefficient Class 1: $SLC > 99$,
- b) Moderate slenderness coefficient:
Slenderness coefficient Class 2: $70 < SLC < 99$,
- c) Low slenderness coefficient:
Slenderness coefficient Class 3: $SLC < 70$ (Onilude and Adesoye, 2007).

Estimation of aboveground biomass and carbon stock

The aboveground biomass (AGB) of standing trees per ha estimated using a non-destructive method was obtained by summing the biomass of all trees in the developed areas of FRIN and dividing the sum by the number of hectares covered by the developed areas (Equation 12).

$$AGB = VOB \times WD \times BEF \quad (12)$$

where *BEF* is the Biomass Expansion Factor; *VOB* is the volume over bark (m^3), and *WD* is the wood density (g/cm^3). Since species-specific biomass equations were not used, the *BEF* of 1.3 was used, based on Intergovernmental Panel on Climate Change (2019) guidelines for tropical moist forests. Each tree species' wood density was obtained from the Global Wood Density Database (Zanne et al., 2009).

The carbon stock (Cs) of any forest tree is usually estimated as 50% of its biomass (Sharma et al., 2020; Onyekwelu et al., 2024). Therefore, the amount of carbon sequestered by each tree was calculated by multiplying the AGB by 0.5

Paleontological Statistics (PAST) software package version 3.12 (Hammer et al., 2001) was used to assess the biodiversity indices. Microsoft Excel

software was used to process the growth and yield, biomass, and carbon stock data.

RESULTS

Our results suggest that the developed areas of FRIN contribute greatly to biodiversity conservation due to presence of 57 tree species distributed among 29 families. A total of 326 trees were measured within the developed areas of the institute, which are predominantly Fabaceae (19.3%), Meliaceae (10.5%), Sterculiaceae (5.3%), Leguminosae (5.3%), Combretaceae (5.3%), Moraceae (5.3%), and Sapindaceae (5.3%) (Table 1).

A high percentage of the tree species are indigenous (61.4%), while 38.6% of the species are exotic. Tree species with a high frequency of occurrence are *E. angolense* (n = 51), *P. caribaea* (n = 44), *Terminalia mantaly* (n = 26), *K. senegalensis* (n = 23), and *Albizia lebeck* (n = 22) (Table 1).

Other tree species with appreciable representation were *Azadirachta indica* (n = 12), *Ptericarpus osun* (n = 10), *Morinda lucida* (n = 8), *T. superba* (n = 7), and *Triplochiton scleroxylon* (n = 6). Several tree species, *Acacia holosericea*, *Cedrela odorata*, *Chrysophyllum albidum*, *Cola gigantea*, *Hildergadia barteri*, *Newbouldia leavis*, and others, are represented by only one individual. Many of the tree species are economically important tropical rainforest species in Nigeria. However, there are a few savanna or transition zone tree species, such as *Parkia biglobosa* and *Vitex doniana*, and agricultural species, such as *Mangifera indica* and *Anacardium occidentale*.

Tree species with a high RDo were *P. caribaea* (17.75%), *K. senegalensis* (11.62%), *E. angolense* (5.99%), *G. arborea* (4.32%), and *A. indica* (4.21%) (Table 1). Most of these tree species also emerged as being very important in the floristic composition of the study area, based on the IVI. Tree species with a high IVI included *P. caribaea* (15.62%), *E. angolense* (10.82%), *K. senegalensis* (9.34%), *T. mantaly* (5.48%), and *A. lebbeck* (4.51%) (Table 1).

The SLC of individual trees varied greatly, ranging 8.33–318.52, which indicated that there were very stable trees as well as very unstable trees within the study area. While most of the trees are stable, a small percentage of the trees were very unstable (Figure 2).

Using the categories of Onilude and Adesoye (2007), 65.6% of the trees (n = 214) have a low SLC (very stable trees), 16.3% (n = 53) have a moderate SLC (moderately stable trees), and 18.1% (n = 59) have a high SLC (unstable trees).

The DBH of the trees ranged 10.8–169.5 cm. The DBH frequency distribution followed an inverted-J pattern (Figure 3) similar to the DBH

frequency distribution pattern of trees in natural tropical forest ecosystems (Adekunle, 2013; Onilude and Adesoye, 2007; Onyekwelu *et al.*, 2021, 2024). About 53% of the trees had a DBH less than 30 cm, 29.9% had a DBH of 30–60 cm, and only 1.2% had a DBH greater than 100 cm. About 56% of the trees had height less than 20 m, 46.8% were 20–40 m high, and 7.7% were less than 40 m high. Tree basal area varied from 0.009 m² to 2.26 m², while tree volume ranged 0.042–27.09 m³, indicating the presence of small trees as well as very big trees, which is supported by the wide range of tree crown diameter from 2.31 m to 25.47 m. Mean tree DBH and height were 37.2 cm and 20.7 m, respectively (Table 2). Mean crown height and crown diameter were 8.48 m and 9.81 m, respectively. Total basal area and volume of all trees in the developed areas of FRIN were 49.54 m² ha⁻¹ and 660.32 m³ ha⁻¹, respectively (Table 2). The relationship between DBH and biomass followed a negative trend (Figure 4). The moderately high R² indicates that DBH accounted for about 65% of the variation in biomass.

Table 1 – Diversity indices of tree species found within the built-up areas at FRIN headquarters

Family	Species	Freq	Ba (m ²)	RD (%)	RDo (%)	IVI	IUCN	Habitat status
Fabaceae	<i>Acacia holosericea</i>	1	0.64	0.31	1.28	0.80	LC	Exotic
Leguminosae	<i>Azizelia africana</i>	4	0.81	1.23	1.64	1.43	VU	Native
Leguminosae	<i>Albizia lebbeck</i>	22	1.12	6.75	2.26	4.51	LC	Exotic
Anacardiaceae	<i>Anacardium occidentale</i>	2	0.40	0.61	0.82	0.72	LC	Exotic
Combretaceae	<i>Anogeissus leiocarpa</i>	3	1.52	0.92	3.08	2.00	LC	Native
Moraceae	<i>Antiaris africana</i>	4	0.27	1.23	0.54	0.88	LC	Native
Araucariaceae	<i>Araucaria araucana</i>	2	0.62	0.61	1.26	0.94	EN	Exotic
Meliaceae	<i>Azadirachta indica</i>	12	2.09	3.68	4.21	3.95	LC	Exotic
Balanitaceae	<i>Balanite egyptia</i>	1	0.10	0.31	0.20	0.25	LC	Native
Sapindaceae	<i>Blighia sapida</i>	2	0.23	0.61	0.46	0.54	LC	Native _e
Malvaceae	<i>Bombax bouonopozense</i>	2	0.10	0.61	0.21	0.41	LC	Native
Fabaceae	<i>Cassia fistula</i>	2	0.23	0.61	0.46	0.54	LC	Exotic

Meliaceae	<i>Cedrela odorata</i>	1	0.02	0.31	0.04	0.18	VU	Exotic
Bombacaceae	<i>Ceiba pentandra</i>	2	0.05	0.61	0.10	0.36	LC	Native
Ulmaceae	<i>Celtis zenkeri</i>	2	0.12	0.61	0.23	0.42	LC	Native
Sapotaceae	<i>Chrysophyllum albidum</i>	1	0.03	0.31	0.06	0.19	LC	Native _e
Sterculiaceae	<i>Cola gigentia</i>	1	0.45	0.31	0.91	0.61	LC	Native
Boraginaceae	<i>Cordia alliodora</i>	8	0.77	2.45	1.55	2.00	LC	Exotic
Burseraceae	<i>Dacryodes edulis</i>	3	0.62	0.92	1.25	1.08	LC	Native _e
Fabaceae	<i>Delonix regia</i>	5	0.74	1.53	1.50	1.52	LC	Exotic
Meliaceae	<i>Ekebergia senegalensis</i>	3	1.33	0.92	2.68	1.80	LC	Native
Meliaceae	<i>Entadophragma angolense</i>	51	2.97	15.64	5.99	10.82	NT	Native
Meliaceae	<i>Entadophragma cylindricum</i>	2	0.68	0.61	1.38	0.99	VU	Native
Myrtaceae	<i>Eucalyptus camaldulensis</i>	3	0.27	0.92	0.55	0.74	NT	Exotic
Myrtaceae	<i>Eucalyptus torrelliana</i>	3	0.58	0.92	1.16	1.04	LC	Exotic
Fabaceae	<i>Gliricidia sepium</i>	2	0.06	0.61	0.12	0.36	LC	Exotic
Verbenaceae	<i>Gmelina arborea</i>	7	2.14	2.15	4.32	3.24	LC	Exotic
Sterculiaceae	<i>Hildegardia barteri</i>	1	0.01	0.31	0.03	0.17	NE	Native
Irvingiaceae	<i>Irvingia gabonensis</i>	2	0.09	0.61	0.19	0.40	VU	Native _e
Meliaceae	<i>khaya senegalensis</i>	23	5.76	7.06	11.62	9.34	VU	Native
Sapindaceae	<i>Lecaniodiscus cupanioides</i>	1	0.01	0.31	0.03	0.17	LC	Native _e
Fabaceae	<i>Leuceana leucocephala</i>	1	0.04	0.31	0.07	0.19	LC	Exotic
Anacardiaceae	<i>Mangifera indica</i>	2	0.36	0.61	0.72	0.67	LC	Exotic
Moraceae	<i>Milicia excelsa</i>	3	0.74	0.92	1.50	1.21	NT	Native
Annonaceae	<i>Monodora myristica</i>	1	0.26	0.31	0.52	0.41	LC	Native _e
Rubiaceae	<i>Morinda lucida</i>	8	0.71	2.45	1.43	1.94	LC	Native
Moringaceae	<i>Moringa oleifera</i>	3	0.10	0.92	0.21	0.57	LC	Exotic
Rubiaceae	<i>Nauclea diderrichii</i>	2	0.55	0.61	1.10	0.86	NT	Native _e
Bignoniaceae	<i>Newbouldia leavis</i>	1	0.03	0.31	0.06	0.19	LC	Native _e
Fabaceae	<i>Parkia biglobosa</i>	2	0.33	0.61	0.66	0.64	LC	Native
Fabaceae	<i>Peltophorum pyetocarpum</i>	1	0.43	0.31	0.87	0.59	LC	Native
Fabaceae	<i>Pericopsis elata</i>	4	1.41	1.23	2.84	2.03	EN	Native
Pinaceae	<i>Pinus caribaea</i>	44	8.80	13.50	17.75	15.63	LC	Exotic
Leguminosae	<i>Pterocarpus osun</i>	10	0.92	3.07	1.86	2.46	LC	Native _e
Fabaceae	<i>Senna siamea</i>	6	0.64	1.84	1.30	1.57	LC	Exotic
Dipterocarpaceae	<i>Shorea roxburghii</i>	3	0.61	0.92	1.22	1.07	EN	Exotic
Solanaceae	<i>Solandra maxima</i>	2	0.15	0.61	0.30	0.46	NE	Exotic
Combretaceae	<i>Terminalia mantaly</i>	26	1.48	7.98	2.99	5.48	LC	Exotic _e
Combretaceae	<i>Terminalia superba</i>	7	1.91	2.15	3.85	3.00	LC	Native
Fabaceae	<i>Tetrapleura tetraptera</i>	3	0.22	0.92	0.45	0.69	LC	Native _e
Moraceae	<i>Treculia africana</i>	5	0.96	1.53	1.94	1.73	LC	Native _e
Sterculiaceae	<i>Triplochiton scleroxylon</i>	6	2.05	1.84	4.14	2.99	LC	Native
Lamiaceae	<i>Vitex doniana</i>	1	0.06	0.31	0.12	0.21	LC	Native
Apocynaceae	<i>Voacanga africana</i>	1	0.03	0.31	0.06	0.18	LC	Native
Fabaceae	<i>Xylocarpus xylocarpa</i>	4	1.20	1.23	2.43	1.83	LC	Exotic
Sapindaceae	<i>Zanha gongensis</i>	1	0.72	0.31	1.46	0.88	LC	Native
Rutaceae	<i>Zanthoxylum zanthoxyloides</i>	1	0.03	0.31	0.06	0.18	NE	Native

Note: Freq = Frequency, BA = Basal area, RD = Relative density, RDo = Relative dominance, IVI = Importance value index, LC – Least concern; NT – Near threatened; EN – Endangered; NE – Not evaluated; VU – Vulnerable. Habitat status – Native: naturally occurring species within the region; Exotic: species introduced from outside the region. Subscript “e” denotes endemism (e.g., Native_e = endemic to the local bioregion; Exotic_e = endemic to its natural region of origin).

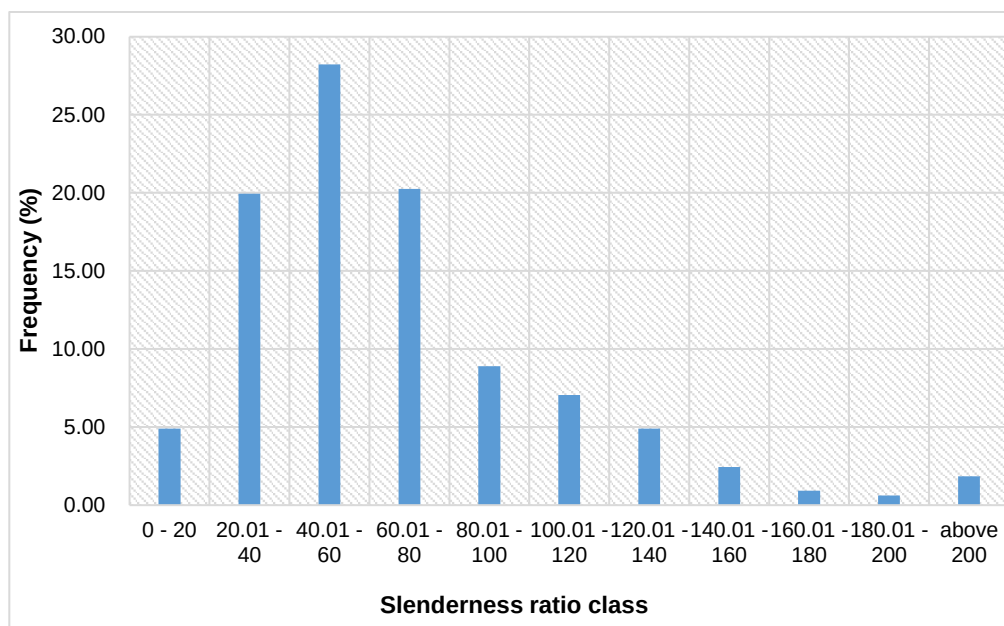


Figure 2 – Frequency distribution of the slenderness coefficients (stability ratio) of trees within the developed areas of the Forestry Research Institute of Nigeria

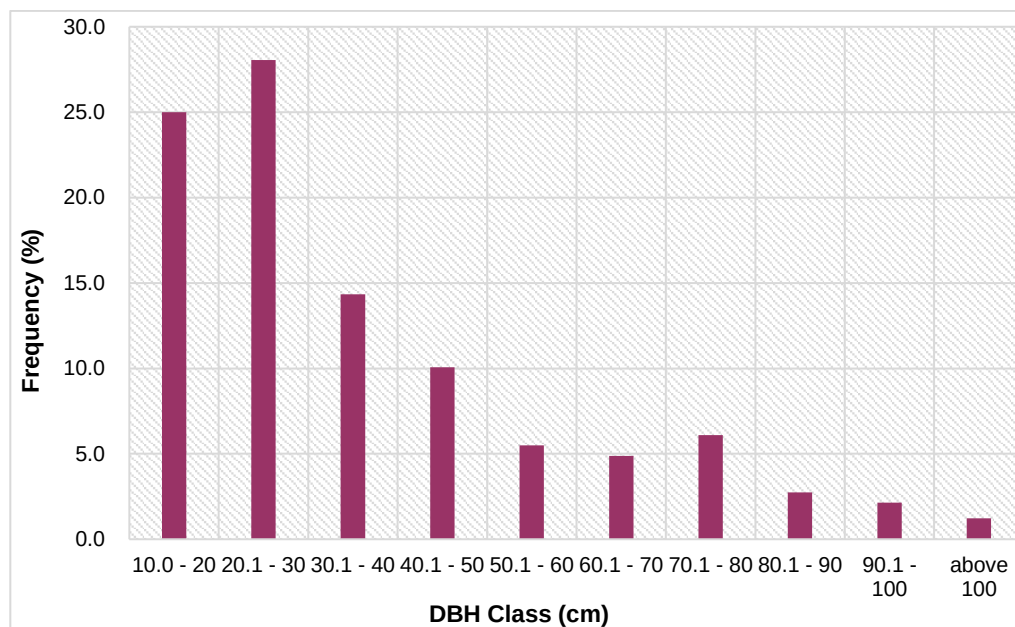


Figure 3 – Frequency distribution of the diameter at breast height (DBH) of trees in the developed areas of the Forestry Research Institute of Nigeria

Table 2 – Biodiversity indices, stand growth, and yield characteristics of trees within the developed areas of the Forestry Research Institute of Nigeria

Biodiversity indices and growth variables	Values
No. of species	57
No. of trees	326
No. of families	29
Shannon-Weiner Index (H')	3.84
Simpson diversity index	0.93
Menhinick's index	3.16
Margalef index	9.68
Shannon equitability index	0.81
Dominance index	0.07
Mean diameter at breast height (cm)	37.2
Mean total height (m)	20.7
Mean crown height (m)	8.48
Mean crown diameter (m)	9.81
Total basal area (m ² ha ⁻¹)	49.54
Total volume (m ³ ha ⁻¹)	660.32
Mean tree slenderness ratio	68.62%
Total aboveground biomass (tons ha ⁻¹)	373.25
Total biomass (tons ha ⁻¹)	447.90
Total carbon stock (tons ha ⁻¹)	223.95
Native to Nigeria	35
Exotic to Nigeria	22

The developed areas of FRIN have high tree species diversity as indicated by the high H' of 3.84 and Simpson index of 0.93 (Table 2). Menhinick's index value was 3.16. The low D index of 0.06619 is an indication that no single species dominated the study area. Instead, the tree species were relatively and evenly distributed, as indicated by the results of the Margalef index and Shannon Equitability index values of 9.68 and 0.81, respectively.

FRIN's developed areas contain species with variable International Union for Conservation of Nature (IUCN) conservation status. According to IUCN classification, 5.3% of the tree species are endangered, 73.7% are in the least concern category, 7% are near threatened, and 8.8% are vulnerable; 5.3% are not categorised.

A wide range of tree biomass values were recorded in the study area, due mainly to the variable tree sizes. While biomass per tree was as low as 0.0133 tons for some trees, it was as high as between 10–20 tons for others. Tree species with very high biomass were *K. senegalensis* (19.51 tons), *Milicia excelsa* (12.95 tons), *Shorea roxburghii* (8.83 tons), *Anoigessus leocarpus* (8.57 tons), *Entandrophragma cylindricum* (8.34 tons), indicating their high carbon sequestration potential.

On the other hand, some trees species had substantially lower; these included *Ceiba pentandra* (0.0133 tons), *M. lucida* (0.0280 tons), *Antiaris africana* (0.0292 tons), *Delonix regia* (0.0331 tons), and *P. caribaea*, among many others.

The trees within the developed areas of FRIN had a total biomass and carbon stock of 447.90 tons ha⁻¹ and 223.95 tons ha⁻¹ respectively.

The developed areas of FRIN had good growth characteristics with higher total height and greater DBH and basal area compared to the statistics from other sites (*Table 3*).

However, the developed areas of FRIN had lower biomass and carbon storage compared to most of the other sites. This discrepancy may be attributed to the lower tree density in FRIN's developed areas compared to most of the study areas in *Table 3*.

DISCUSSION

Urban tree composition and species richness

Due to the current rising populations in urban areas and the pressure exerted on

limited resources, the well-being of the increased human populace is secured by the presence of urban vegetation to provide essential ecosystem goods and services. The families and tree species in in the developed areas of FRIN are characteristic of the Nigerian tropical forest region. There is agreement in the published literature (Adekunle, 2006; Agbelade and Onyekwelu, 2020; Onyekwelu *et al.*, 2008, 2024) that the Nigerian tropical forest region is largely dominated by the same tree families found to dominate the floristic composition in the study area. The number of families in the study area is higher or within the range reported for various tropical forest ecosystems, especially in Nigeria (Adekunle *et al.*, 2013; Agbelade *et al.*, 2017; Dangulla *et al.*, 2021; Nero *et al.*, 2024; Onyekwelu *et al.*, 2024).

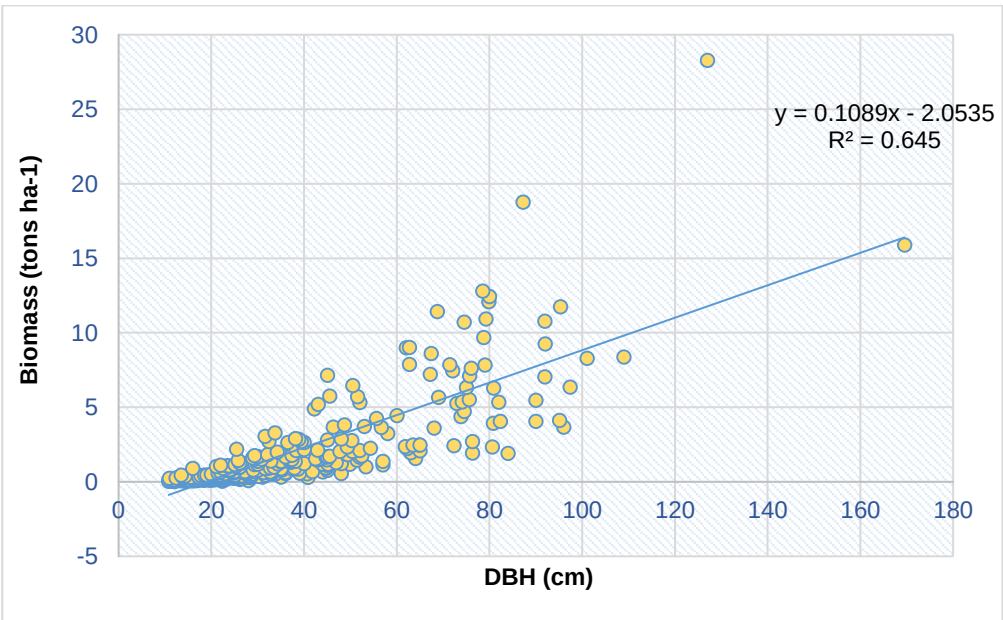


Figure 4 – Relationship between diameter at breast height (DBH) and biomass of the trees within the developed areas of the Forestry Research Institute of Nigeria

Table 3 – Comparison of biodiversity indices and carbon storage of trees within the developed areas of the Forestry Research Institute of Nigeria (FRIN) with various published results

Variable	FRIN	Port Harcourt	Ilorin	Kumasi Zoological Garden	Developed area in Zaria, Nigeria	Sacred groves in Nigeria	Urban green sites in India
No. of species	57	37	46	43	37	41–85	-
Tree density	326	746	556	185 ha ⁻¹	252	311–423	-
No. of family	29	19	18	15	21	22–32	-
Shannon-Weiner Index	3.84	3.39	3.61	2.42	3.1	2.63–3.55	-
Mean dbh (cm)	37.2	44.84	49.74	51	48.9	24.4–31.9	-
Mean total height (m)	20.7	11.1	13.35	20	19.1	9.8–13.7	-
Maximum dbh (cm)	169.5	98	96.4	122	-	105–185	-
Total basal area (m ² ha ⁻¹)	49.54	16.39	22.21	-	-	-	-
Total volume (m ³ ha ⁻¹)	660.32	409.78	745.44	-	-	245.0–343.1	-
Total biomass (tons ha ⁻¹)	447.9	67,979.1	91,512.5	-	407.2	78.8–231.9	545.4
Total Carbon (tons ha ⁻¹)	224	33,989.5	45,756.3	53.9 mg C ha ⁻¹	203.6	43.9–115.9	272.2
Reference	This study	Agbelade and Onyekwelu, 2020	Nero <i>et al.</i> , 2024	Dangulla <i>et al.</i> , 2021	Onyekwelu <i>et al.</i> , 2024	Pradhan <i>et al.</i> , 2022	

The species richness in FRIN's developed areas is within the range reported for forested sites in Nigeria (Adekunle, 2006; Lowe, 1997; Onyekwelu and Olusola, 2014; Onyekwelu *et al.*, 2024). A high number of trees have been reported for urban forests. Moshood *et al.* (2022a) enumerated 3,225 trees in Ilorin, Nigeria, and Agbelade and Onyekwelu (2020) reported 746 and 556 trees in Port Harcourt and Ilorin urban forests, respectively, which are higher than the 326 trees in the developed areas of FRIN. However, there could be size differences among study areas. The five recreation centres in Ibadan studied by Bolanle-Ojo *et al.* (2020) had higher number of trees than FRIN's developed areas. The low number of trees in FRIN's developed

areas can be attributed to its small size (19.73 ha). Given that the developed areas of FRIN are dispersed among administrative, residential, laboratory, library, workshops, recreation and sporting facilities, and other buildings with few vacant places, the presence of 326 trees should be appreciated and considered substantial.

Indigenous vs. exotic tree species in the study area

The higher proportion of indigenous tree species (61.4%) in the study area compared to exotic species (38.6%) is an indication of the role and contribution of FRIN to the conservation of tree species, especially the native species, which are important given their ecological importance. Some cities and developed

areas are known to have higher percentage of exotic than indigenous species, thus showing FRIN's efforts in conservation of indigenous tree species. The higher frequency of indigenous tree species in our study could be attributed to the commitment of FRIN to fulfilment of its mandate of promoting the conservation of native species. This also enhances ecological resilience, as native trees are better adapted to local climatic and edaphic conditions, supporting greater biodiversity and ecosystem stability (Chazdon *et al.*, 2016; Onyekwelu, 2024). Some of the indigenous tree species were intentionally planted at FRIN, with the intention of introducing them to visitors, thus the developed areas of FRIN can also be regarded as an arboretum of a sort. The presence of endemic species within FRIN enhances its conservation significance. Endemic species represent unique genetic resources that have evolved in response to the local environment. Their occurrence reflects the ecological integrity and biogeographical uniqueness of FRIN.

Exotic tree species accounted for 63.4% of all species in the developed areas of Zaria, Nigeria (Dangulla *et al.*, 2021), which is substantially more than the 35.1% reported in our study area. About 80% of the trees used in public spaces in Lima, Peru were non-native species (Moreno *et al.*, 2024). Similar to our results, Aremu *et al.* (2023) found a higher percentage of indigenous tree species (mean 67%) in urban green areas of Osogbo, Nigeria. Conversely, a high proportion of exotic species could increase vulnerability to pests, diseases, and environmental stressors, and in some cases, lead to invasive tendencies that can alter native community structures (Pysek

et al., 2020). Hence, the higher frequency of indigenous species in our study area highlights FRIN's contribution to sustainable urban forest management and ecological stability.

Stability and structural suitability of tree species in the study area

Despite our study area having moderate species richness, only a few tree species dominated the floristic composition. Five species (*P. caribaea* - 15.6%, *E. angolense* - 10.8%, *K. senegalensis* - 9.3%, *T. mantaly* - 5.5%, and *A. lebbbeck* - 4.5%) accounted for about half (45.8%) of the IVI and by implication the dominance of the study area. Among these species, only *T. mantaly* is widely used as avenue trees in urban and developed areas (Agbelade and Onyekwelu, 2020; Nero *et al.*, 2024). The other dominant tree species are typical native tropical timber species, thus their dominance in FRIN's developed areas can be ascribed to intentional native species conservation efforts by FRIN.

Several authors have demonstrated that trees with low SLC values are less susceptible to wind induced throw down or damage (Onilude and Adesoye, 2007; Ige, 2017; Moshood *et al.*, 2022b; Olajiire-Ajayi *et al.*, 2024). The high percentage of very stable trees (i.e., with low SLC values) in our study area is an indication of good management and proof of the suitability of the trees for developed environments since the likelihood of their throw down or damage by wind or rainstorm, and possible harm to human lives and property, is very low. Cautious measures must be taken concerning trees with a high SLC, which constitute about 18.1% of the trees within the developed areas of FRIN, since they

have been shown to be very unstable and highly susceptible to wind throw and damage (Ige, 2017; Olajiire-Ajayi *et al.*, 2024). High risk to wind-throw and damage pose a significant challenge for trees with high SLC in developed areas. During heavy wind or rainstorms, these unstable trees can cause harm to humans if they are thrown down or their branches are broken. Thus, efforts must be made by FRIN management to improve their stability and prevent or minimise the risks to humans and properties. In the worst case scenario, these unstable trees can be removed.

Biodiversity indices and conservation status

The high H' and other biodiversity indices (e.g., Simpson diversity index - 0.93, Margalef index - 9.68), and Shannon Equitability index - 0.81) of FRIN's developed areas are indications of the good biodiversity conservation status of the study area. A check of the published literature revealed that the H' in our study area is higher and comparable to those of some cities and developed areas. Abuja and Ibadan urban forests had an H' of 3.56 and 3.35, respectively (Agbelade *et al.*, 2016a, b) while Port Harcourt urban forests recorded an H' of 3.39 (Agbelade and Onyekwelu, 2020). Agbelade *et al.* (2022) reported H' values of 3.08–3.61 for three cities in north-central Nigeria. The developed area of Zaria had an H' of 3.1 (Dangulla *et al.*, 2021). Nero *et al.* (2024) found H' values of 1.68–2.77 for botanical gardens and parks in Ghana. The H' of the developed areas of FRIN was also comparable or higher than those of some tropical forest ecosystems in Nigeria (Adekunle *et al.*, 2013; Onyekwelu *et al.*, 2008).

Species evenness (0.81) in our study area was higher than the ranges given by Bolanle-Ojo *et al.* (2020) and Agbelade *et al.* (2022) but within the ranges reported by Onyekwelu *et al.* (2024) and Nero *et al.* (2024). Although high species evenness was observed, an uneven distribution of trees within some species within the developed areas was noticed, indicating a skewed distribution. These patterns are common in tropical forests, where a few species are ecologically dominant while numerous others persist at low numbers per ha (Ojo, 2004; Onyekwelu *et al.*, 2008; Adekunle *et al.*, 2006). This was confirmed by the low D value of 0.0662.

The high values of biodiversity indices in our study area can be attributed to the continuous planting of various tree species within the FRIN premises. Although FRIN's developed areas have only experienced minimal expansion in size to date, tree planting has been going on since its inception. However, planting is only done when the need arises, and the rate of planting and replacement of dead trees is low. The latter can and should be improved upon. The distribution of tree species among the IUCN status categories revealed a predominance of species with stable populations (least concern). However, the presence of species in the endangered, near threatened, and vulnerable categories reveals the need for improved conservation efforts and strategies.

Biomass and carbón sequestration potentials of tree species in the study area

Biomass plays a very important and sensitive role as an indicator to determine or predict rate of carbon sequestration or

carbon storage. It can also be used as an indicator of forest health such as ecosystem productivity and resilience. Esperon-Rodriguez *et al.* (2022) showed that cities are planting trees for resilience through urban greening initiatives as governments understand the importance of urban forests in improving the quality of life and mitigating climate change. Climate regulation through carbon sequestration has become one of the crucial ecosystem services of forests. Many tree species in FRIN have the capacity to store large amounts of biomass and thus sequester large amounts of carbon. These species include *K. senegalensis* (19.56 tons), *M. excelsa* (12.95 tons), *S. roxburghii* (8.83 tons), *Anogeissus leiocarpus* (8.57 tons), *E. cylindricum* (8.34 tons), *Afzelia africana* (8.10 tons), *Pericopsis elata* (7.88 tons). These tree species have been noted to have the characteristics of attaining very large dimensions upon maturity (Keay, 1989), making them ideal candidates for carbon sequestration. *Anogeissus leiocarpus* is a very strong tree species with high calorific value that is often preferred for charcoal production because it burns slowly, which suggests heavy carbon storage within its tissue. Jumawan *et al.* (2024) reported that *Ficus benjamina*, *Eucalyptus deglupta*, *G. arborea*, and *Cocos nucifera* produced high aboveground biomass in Bood Promontory and Eco-Park in the Philippines. In Port Harcourt, *Hevea brasiliensis* and *A. occidentale* had high biomass accumulation, while *Hura crepitans* and *A. lebbek* accumulated high biomass in Ilorin (Agbelade and Onyekwelu, 2020). In Lima, Peru, *Ficus pertusa*, *Erythrina falcata*, and *Eucalyptus camaldulensis* had the highest

carbon trapping rates (Moreno *et al.*, 2024). These tree species have the capacity to store a large amount of biomass and thus contribute significantly to carbon storage and atmospheric carbon sequestration.

The total biomass and carbon storage in the developed areas of FRIN was 447.90 tons and 223.95 tons, respectively. Given the small size of these areas, this can be considered a substantial contribution to atmospheric carbon sequestration. Moreno *et al.* (2024) reported carbon storage of 2,859.0 tons in 43 ha of urban green spaces in Lima, Peru, which is much higher than the 223.95 tons in the 19.73 ha of FRIN's developed areas. The urban green spaces in Lima had a much higher number of trees (28,123) (Moreno *et al.*, 2024) compared to our study area (326), which can explain the higher carbon sink potential in Lima than in the developed areas of FRIN. The 203.60 tons of carbon stored in the developed area of Zaria (Dangulla *et al.*, 2021) compares favourably to the carbon stored in the developed areas of FRIN.

Thus, despite its small land size, the developed areas of FRIN can be considered an excellent source of carbon sequestration and climate change mitigation.

Comparison with other studies

A comparison of the results of our study with the results in published literature (Table 3) revealed that the developed areas of FRIN have good biodiversity conservation status, good productivity, and good carbon storage potential.

Although the developed areas of FRIN had a lower tree population

compared to most of the other studies, it had higher tree species richness than most of the other sites (*Table 3*). It had a comparable species richness with the sacred groves in Nigeria (Onyekwelu *et al.*, 2024). The H' of FRIN's developed areas was higher than that of Kumasi Zoological Garden, Ghana (Nero *et al.*, 2024), the developed area in Zaria (Dangulla *et al.*, 2021) and some sacred grove sites in Nigeria (Onyekwelu *et al.*, 2024).

CONCLUSIONS

The developed areas of FRIN have high biodiversity conservation status, good productivity, and good carbon sink potential. The number of tree species (57) and the high diversity indices of the areas are higher or comparable to those of some cites, indicating its significant contributions to urban biodiversity.

The high proportion of indigenous tree species (61.4%) shows the commitment and contribution of FRIN to native species conservation. Most of the trees (65.6%) are suitable for developed environments since the likelihood of their throw-down or damage by storms and causing harm to life and property is very low due to their low SLC. Many trees in FRIN stored large amount of carbon, making them ideal candidates for atmospheric carbon sequestration. Total basal area, volume, biomass, and carbon productions were 49.54 m², 660.32 m³, 447.90 tons ha⁻¹, and 223.95 tons ha⁻¹, respectively.

Despite the small land size, the developed areas of FRIN serve as significant carbon sinks with notable potential for climate change mitigation initiatives. Documentation of the endemic

taxa within FRIN affirms its role as a microrefuge for regional biodiversity and underlines the need for targeted conservation.

Expanding the green spaces within FRIN can help to improve urban sustainability and biodiversity. Findings from this study could inform Nigeria's National Biodiversity Action Plan and support evidence based urban greening and climate mitigation policies. Future research should incorporate remote sensing validation, full propagation analysis, long-term carbon monitoring, and spatial modeling to improve accuracy and scalability of institutional carbon biodiversity assessments.

There is a need for FRIN management to strengthen conservation practices, expand monitoring of biodiversity, and carbon stocks. This can be used to attract policy support, partnerships, and funding to be able to enhance FRIN's role in the urban environment's sustainability.

Acknowledgment: We are grateful to all the anonymous reviewers for their feedback on the paper and their thoughtful suggestions on all aspects of the paper.

Funding: There was no external funding for this study.

Author contributions: Conceptualisation: JO, JC; Methodology: JC, QA; Data collection: QA, JO, JC; Analysis: QA, JC; Data curation: QA, OA; Writing: QA, JO; Review: QA, ZB; Supervision: ZB. All authors declare that they have read and approved the publication of the manuscript in this present form.

Data availability statement: The data presented in this study are available on request from the corresponding author (omoonilu@gmail.com).

Conflicts of interest: There is no conflict of interest.

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Academic Editor: Dr. Iuliana MOTRESCU

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