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Assessing trees and vascular epiphyte species diversity in Calabar, Nigeria

Martin Oghenerhiruona Ononyume*, Esther Aja Bassey Edu

Department of Plant and Ecological Studies, University of Calabar, Calabar, Nigeria

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Abstract

This study aimed to explore the species composition, distribution, and diversity of vascular epiphytes on tree species across five locations in Calabar. A total of 250 trees were sampled for vascular epiphytes along five 100-metre transects at each location. The coordinates of each sampled tree, the presence of vascular epiphytes, and their abundance, DBH, and tree height measurements were collected. Trees were categorized into seven DBH classes and three height classes. Twenty-four tree species, mostly exotic belonging to fifteen families, and seven vascular epiphyte species belonging to three families were encountered in all locations. The 40.1 cm to 60 cm DBH size class combined comprised 52%, and the 10.1 m to 20 m height class, comprised 58% of all sampled trees in the study. The highest tree diversity was at Murtala Mohammed Highway (H' = 2.19) and the Cross River University of Technology campus had the highest vascular epiphyte diversity (H' = 1.32). *Platycerium superbum* (family – Polypodiaceae) was the most prevalent vascular epiphyte species occurring in 55.43 % of the sampled locations. Our study's tree and vascular epiphyte species exhibited moderate to low diversity, likely due to the effects of urbanization on species diversity in the area. Our results provide vital exploratory information on the composition, diversity, and distribution of urban vascular epiphyte species in Calabar. These insights will aid in urban planning and biodiversity conservation efforts, while also establishing a baseline for long-term monitoring.

***Corresponding Author:** Martin Oghenerhiruona Ononyume ✉ martinononyume@unical.edu.ng

Introduction

Urban areas are increasingly recognized for their potential to support biodiversity, serving as important habitats for a variety of species, including vascular epiphytes (Lepczyk *et al.*, 2017).

Vascular epiphytes are non-parasitic plant species that require the structural aid of other plants, especially trees for support (Laube and Zotz, 2006). Of the nearly 343,000 species of vascular plants described globally, vascular epiphytes comprise 9% (Zotz, 2013; Govaerts *et al.*, 2021).

Vascular and non-vascular epiphytes and other plants contribute to the vegetation cover of forests and previously forested areas impacted by urbanization (Quiel and Zotz, 2021), providing distinct habitat forms and performing unique ecological functions (Zhang *et al.*, 2023). Vascular epiphytes play significant ecological roles in urban areas by enhancing species richness, supporting biodiversity, regulating microclimates, enhancing habitat complexity, retaining water, and serving as indicators of environmental health (Stuntz *et al.*, 2002; Jovan and Mccune, 2006; Bartels and Chen, 2012; Bhatt *et al.*, 2015). Despite their importance, the diversity and distribution of vascular epiphytes remain poorly studied in a fast-expanding urban region like Calabar. With green spaces becoming more fragmented due to urbanization, the ecological role and survival of vascular epiphytes are threatened among other factors by the absence of suitable host trees, climatic variability, and pollution (De Oliveira Alves *et al.*, 2014; Mondragón and Mora-Flores, 2024). Assuming these species survive such challenges, they face reduced species richness, and accelerated ecological homogenization (Alvim *et al.*, 2021). This study thus, aimed to explore the species composition, diversity, and distribution of vascular epiphytes on tree species across five areas in Calabar. The outcome is essential to understand how these plants adapt to urban environments and to establish a baseline for ongoing monitoring efforts. Further, the insights are critical for guiding conservation efforts, urban planning, and management strategies in Calabar.

Materials and methods

Study area

This study was done from May – June 2024 in five locations in Calabar. The University of Calabar Campus (UNICAL), the Cross River University of Technology Campus (CRUTECH), Atimbo, Murtala Mohammed Highway (M. M. Highway), and Ikot Effanga (Fig. 1). These areas represented roughly the major areas with high population of trees within Calabar metropolis. Calabar is located at 04° 58'N and 08° 21'E in the coastal zone of Nigeria. It has a tropical climate, with an average annual rainfall of over 3000 mm/year in the wet season (Adefolalu, 1984; Uchenna *et al.*, 2023).

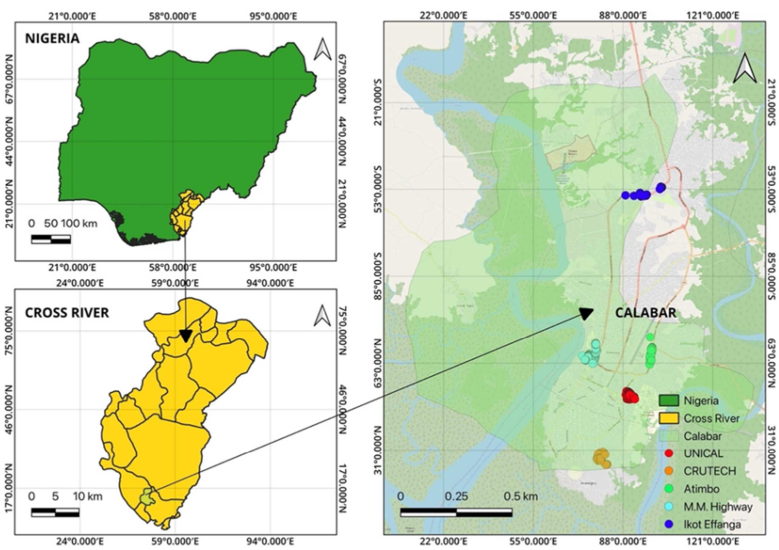

Fig. 1. Study area map

Sampling

A total of 250 trees (50 per location) with a diameter at breast height (DBH) greater than 5 cm were sampled across five selected areas in Calabar. Five 100-meter transects were laid out contiguously up to 500 meters. Starting points for laid transects were preselected using the OpenStreetMap layer in QGIS Version 3.2.23 Lima. All trees intersected by the transect lines were recorded until our limit was reached. The decision to sample fifty trees only per location is because this study was designed as an exploratory analysis aimed at gaining insight into preliminary patterns in tree and vascular epiphyte diversity in Calabar. Each tree species was identified, and the presence or absence of vascular epiphytes was noted. If epiphytes were present, they were identified, counted, and photographed. For epiphytes with a clumping or climbing nature, each distinct clump or climber was treated as a single individual if it occupied a continuous section of the tree. If the epiphyte extended from the base to the canopy, it was counted as multiple individuals based on distinct growing points or clusters. All field identifications were later validated at the Department of Plant and Ecological Studies Herbarium, University of Calabar, Nigeria, to ensure accuracy in species identification. The GPS coordinates of each sampled tree were recorded using a handheld Garmin GPSMAP 78s (United States). Each tree's DBH was measured 1.3 meters above the ground using a fiberglass diameter tape (Germany). Tree height was measured using the Nikon Forestry Pro-Rangefinder (Japan).

Data analysis

The species richness of the trees and vascular epiphytes was determined by counting the number of different trees and vascular epiphyte species observed in each sampled area. Abundance was calculated by the number of each tree/vascular epiphyte species in the sample. Relative abundance was calculated from the total abundance of the trees and vascular epiphytes in each sampled area expressed in Equation 1 (Alex *et al.*, 2021).

$$RA = \frac{a}{A} \times 100 \quad -------------- (1)$$

Where RA = Relative abundance

a = abundance of trees/vascular epiphytes

A = Total abundance

Alpha diversity of the trees and vascular epiphytes was measured using the Shannon-Wiener index expressed in equation 2 (Kumar *et al.*, 2022)

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

Where;

H' = Shannon Weiner Index

Pi = the proportion of individuals that belong to species i in each sample area.

s = the total number of species of trees/vascular epiphytes enumerated

In = Natural log

Trees were categorized into seven DBH classes as ≤ 20 cm, 20.1 cm - 30 cm, 30.1 cm - 40 cm, 40.1 cm - 50 cm, 50.1 cm - 60 cm, 60.1 cm - 70 cm, and > 70 cm and three height classes as ≤ 10 m, 10.1 m - 20 m, and > 20 m modified from Dangulla *et al.* (2019). The obtained coordinates were used to create maps of the sample points using Quantum Geographic Information System (QGIS) Version 3.2.23 Lima.

Results

Trees species abundance and diversity

Table 1 shows the tree species abundance in the sample areas. Twelve tree species belonging to nine families were sampled for vascular epiphytes at UNICAL campus. *Terminalia mantaly* had the highest abundance among the trees sampled (23 individuals) followed by *Pinus wangii* (7 individuals). Four tree species had the least abundance of 1 individual each - *Annona muricata*, *Areca catechu*, *Azadirachta indica*, and *Irvingia gabonensis*. At CRUTECH campus, eleven tree species belonging to nine families were sampled for vascular epiphytes. *Delonix regia* had the highest abundance among the trees sampled (28 individuals) followed by *Terminalia mantaly* (7 individuals). Seven tree species had the least abundance of 1 individual each – *Adenanthera microsperma*, *Azadirachta indica*, *Casuarina equisetifolia*, *Dacryodes edulis*, *Hura crepitans*, *Persia americana*, and *Pterocarpus indicus*. Four tree species belonging to four families were sampled for vascular epiphytes at Atimbo.

Table 1. Abundance of tree species sampled for vascular epiphytes

Location	Tree species	Family	Origin	Abundance
UNICAL	*Albizia kalkora* (Roxb.) Prain	Fabaceae	Exotic	4
	Albizia lebbeck (L.) Benth.	Fabaceae	Exotic	3
	Annona muricata L.	Annonaceae	Exotic	1
	Areca catechu L.	Arecaceae	Exotic	1
	Azadirachta indica A. Juss.	Meliaceae	Exotic	1
	Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	Exotic	2
	Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill.	Irvingiaceae	Native	1
	Juglans hindsii (Jeps.) R.E.Sm.	Juglandaceae	Exotic	2
	Mangifera indica L.	Anacardiaceae	Exotic	3
	Pinus durangensis Martínez	Pinaceae	Exotic	2
	Pinus wangii Hu & W.C. Cheng	Pinaceae	Exotic	7
	Terminalia mantaly H. Perrier	Combretaceae	Exotic	23
CRUTECH	*Adenanthera microsperma* Teijsm. & Binn.	Fabaceae	Exotic	1
	Azadirachta indica A. Juss.	Meliaceae	Exotic	1
	Casuarina equisetifolia L.	Casuarinaceae	Exotic	1
	Dacryodes edulis (G.Don) H.J.Lam	Burseraceae	Native	1
	Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	Exotic	28
	Hura crepitans L.	Euphorbiaceae	Exotic	1
	Mangifera indica L.	Anacardiaceae	Exotic	3
	Persea americana Mill.	Lauraceae	Exotic	1
	Pinus wangii Hu & W.C.Cheng	Pinaceae	Exotic	5
	Pterocarpus indicus Willd.	Fabaceae	Exotic	1
	Terminalia mantaly H.Perrier	Combretaceae	Exotic	7
Atimbo	*Azadirachta indica* A. Juss.	Meliaceae	Exotic	25
	Cassia fistula L.	Fabaceae	Exotic	3
	Casuarina equisetifolia L.	Casuarinaceae	Exotic	10
	Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	Exotic	1
	Mangifera indica L.	Anacardiaceae	Exotic	11
M. M. Highway	*Areca catechu* L.	Arecaceae	Exotic	1
	Azadirachta indica A. Juss.	Meliaceae	Exotic	8
	Calophyllum inophyllum L.	Calophyllaceae	Exotic	1
	Casuarina equisetifolia L.	Casuarinaceae	Exotic	10
	Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	Exotic	7
	Hura crepitans L.	Euphorbiaceae	Exotic	1
	Khaya senegalensis (Desr.) A. Juss.	Meliaceae	Native	4
	Mangifera indica L.	Anacardiaceae	Exotic	2
	Pinus wangii Hu & W.C. Cheng	Pinaceae	Exotic	5
	Pinus taeda L.	Pinaceae	Exotic	8
	Tabebuia rosea (Bertol.) DC.	Bignoniaceae	Exotic	1
	Terminalia catappa L.	Combretaceae	Exotic	2
Ikot Effanga	*Azadirachta indica* A. Juss.	Meliaceae	Exotic	1
	Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	Exotic	4
	Hura crepitans L.	Euphorbiaceae	Exotic	1
	Terminalia mantaly H.Perrier	Combretaceae	Exotic	44

Table 2. Diameter at breast height (DBH) size class of sampled trees

DBH class	UNICAL	CRUTECH	Atimbo	M.M. Highway	Ikot Effanga	Total
≤ 20 cm	2	-	-	2	-	4
20.1 cm - 30 cm	1	1	3	3	2	10
30.1 cm - 40 cm	7	5	10	5	5	32
40.1 cm - 50 cm	10	16	18	7	19	70
50.1 cm - 60 cm	11	10	10	12	17	60
60.1 cm - 70 cm	7	6	7	14	5	39
> 70 cm	12	12	2	7	2	35
						250

Azadirachta indica had the highest abundance among the trees sampled (25 individuals) followed by *Mangifera indica* (11 individuals). *Delonix regia* had the least abundance of 1 individual. Twelve tree species belonging to ten families were sampled at Murtala Mohammed Highway. *Casuarina equisetifolia* had the highest abundance among the trees sampled with 10 individuals. This was followed by *Azadirachta indica* and *Pinus taeda* with 8 individuals each. Four tree species had the least abundance of 1 individual each – *Areca catechu*, *Calophyllum inophyllum*, *Hura crepitans*, and *Tabebuia rosea*. Four tree species belonging to four families were sampled for vascular epiphytes at Ikot Effanga. *Terminalia mantaly* had the highest abundance among the trees sampled (44 individuals) followed by *Delonix regia* (4 individuals). Two tree species had the least abundance of 1 individual each - *Azadirachta indica*, and *Hura crepitans*. UNICAL had the highest distribution of trees in the > 70 cm DBH class and 10.1 – 20 m height range. CRUTECH, Atimbo, and Ikot Effanga had their highest distribution in the 40.1 – 50 cm DBH size class. Tree height class for CRUTECH and Atimbo had the highest distribution of trees at ≤ 10 m range. Murtala Mohammed Highway had the highest distribution at 60.1 – 70 cm DBH size class and had a similar height class range with UNICAL, and Ikot Effanga at 10.1 – 20 m (Table 2; Table 3). Tree species diversity followed this trend – Murtala Mohammed Highway > UNICAL > CRUTECH > Atimbo > Ikot Effanga (Table 4).

Table 3. Height class of sampled trees

Height class	UNICAL	CRUTECH	Atimbo	M. M. Highway	Ikot Effanga	Total
≤ 10 cm	22	33	26	11	9	101
10.1 cm - 20 cm	27	17	24	36	41	145
> 20 cm	1	-	-	3	-	4
						250

Table 4. Tree species diversity indices

Variable	UNICAL	CRUTECH	Atimbo	M. M. Highway	Ikot Effanga
Richness	12	11	5	12	4
Evenness	0.75	0.64	0.77	0.88	0.34
Individuals	50	50	50	50	50
Shannon diversity index	1.87	1.55	1.25	2.19	0.47

Table 5. Abundance and relative abundance of vascular epiphytes

Species	Family	Abundance (Relative abundance %)				
		UNICAL	CRUTECH	Atimbo	M. M. Highway	Ikot Effanga
Pyrrosia eleagnifolia (Bory) Hovenkamp	Polypodiaceae	87 (8.26)	157 (20.63)	134 (27.23)	76 (20.76)	159 (32.98)
Microsorum pustulatum (G. Forst.) Copel	Polypodiaceae	7 (0.66)	269 (35.34)	37 (7.52)	82 (22.40)	37 (7.67)
Platycerium superbum de Jonch & Hennipman	Polypodiaceae	764 (72.62)	251 (32.98)	294 (59.75)	196 (53.55)	243 (50.41)
Pleopeltis polypodioides (L.) E.G. Andrews & Windham	Polypodiaceae	189 (17.96)	81 (10.64)	27 (5.48)	-	41 (8.50)
Calyptrochilum emarginatum (Afzel. Ex Sw.) Schltr.	Orchidaceae	3 (0.28)	2 (0.26)	-	9 (2.45)	-
Oncidium graminifolium (Lindl.) Lindl.	Orchidaceae	2 (0.19)	1 (0.13)	-	3 (0.81)	-
Philodendron rugosum Bogner & G.S. Bunting	Araceae	-	-	-	-	2 (0.41)
Total abundance		1052	761	492	366	482

Epiphyte abundance and diversity

Table 5 shows the results on the abundance and relative abundance of vascular epiphytes sampled in five locations in Calabar. Six vascular epiphytes belonging to 2 families were recorded on the tree species sampled at UNICAL and CRUTECH each. Four species belonged to the Polypodiaceae family, and two belonged to the Orchidaceae family for both locations respectively. A total of 1052 individuals distributed among the six epiphyte species were recorded at UNICAL. *Platycerium superbum* ranked the highest with a total abundance of 764 individuals and a relative abundance of 72.55%. This was followed by *Pleopeltis polypodioides* with a total abundance of 189 individuals and a relative abundance of 17.95%. *Oncidium graminifolium* had the least total abundance and relative abundance of 2 and 0.19% respectively. At CRUTECH, 761 individuals were recorded altogether for the six epiphyte species. *Microsorum pustulatum* ranked the highest with a total abundance of 269 individuals and a relative abundance of 35.34%. This was followed by *Platycerium superbum* with a total abundance of 251 individuals and a relative abundance of 32.98%. *Oncidium graminifolium* had the lowest total abundance and relative abundance of 1 and 0.13% respectively. Four species of vascular epiphytes were recorded at Atimbo. All four species belonged to the Polypodiaceae family. A total of 492 individuals were distributed among the four epiphyte species recorded. *Platycerium superbum* ranked the highest with a total abundance of 294 individuals and a relative abundance of 59.75%. This was followed by *Pyrrosia eleagnifolia* with a total abundance of 134 individuals and a relative abundance of 27.23%. *Pleopeltis polypodioides* ranked least with a total abundance of 27 individuals and a relative abundance of 5.48%. Five species of vascular epiphytes were recorded at Murtala Mohammed Highway. Three species belonged to the Polypodiaceae family, and two species belonged to the Orchidaceae family. A total of 366 individuals distributed among the five epiphyte species were recorded. *Platycerium superbum* ranked the highest with a total abundance of 196 individuals and a relative abundance of 53.55%. This was followed by *Microsorum pustulatum* with a total abundance of 82 individuals and a relative abundance of 22.40%. *Oncidium graminifolium* ranked the lowest with a total abundance and relative abundance of 3 and 0.81% respectively. Six species of vascular epiphytes were recorded on the tree species sampled at Ikot Effanga. Four species belonged to the Polypodiaceae family, one belonged to the Araceae family. A total of 482 individuals distributed among the six epiphyte species were counted. *Platycerium superbum* ranked the highest with a total abundance of 243 individuals and a relative abundance of 50.41%. This was followed by *Pyrrosia eleagnifolia* with a total abundance of 159 individuals and a relative abundance of 32.98%. *Philodendron rugosum* had the lowest total abundance and relative abundance of 2 and 0.41 % respectively. The epiphyte species diversity followed this trend - CRUTECH > Ikot Effanga > Murtala Mohammed Highway > Atimbo > UNICAL (Table 6).

Table 6. Vascular epiphytes diversity indices

Variable	UNICAL	CRUTECH	Atimbo	M. M. Highway	Ikot Effanga
Richness	6	6	4	5	5
Evenness	0.45	0.74	0.73	0.70	0.71
Individuals	1052	761	492	366	482
Shannon diversity index	0.809	1.32	1.02	1.13	1.14

Discussion

Urban tree species diversity is a critical factor influencing ecological services, biodiversity, and the health of urban environments. Urban trees contribute to the modification of microclimatic conditions, lowering of surface and air temperatures (Loughner *et al.*, 2012), storage and sequestration of carbon (Nowak *et al.*, 2013), and the essential provisioning services such as food, fuelwood, and animal fodder. They also offer shade and habitat for different classes of organisms, enhancing urban biodiversity (Agbelade *et al*., 2017). The diversity of urban trees is influenced by various factors, including land use types, soil characteristics, and urban heterogeneity. This study demonstrates that different urban land uses, such as institutional grounds, green spaces, and roadsides, exhibit varying levels of species diversity, that corroborate previous reports (Jim and Liu, 2001; Bourne and Conway, 2013). Our results reveal a higher prevalence of exotic species compared to native species. Only three native species—*Irvingia gabonensis*, *Dacryodes edulis*, and *Khaya senegalensis*—were recorded, and these were in low abundance and occurrence compared to exotic species like *Terminalia mantaly*, *Azadirachta indica*, and *Delonix regia*. This pattern may be attributed to the impacts of urbanization, which often favors the growth of exotic species, exacerbated by factors such as pollution, species introductions, and urban development (English *et al*., 2022). Similar reports of exotic species dominance in urban areas have been documented globally, including in Chile (Figueroa *et al*., 2018), Brazil (De Souza e Silva *et al*., 2020), and India (Divakara *et al*., 2022). The dominance of exotic species in urban environments could have negative ecological outcomes, including potential disruptions to native biodiversity and alterations in the normal functioning of the ecosystem (De Carvalho *et al*., 2022). Conversely, some studies have reported that native species can outperform exotic ones, suggesting that native species not only possess a high propensity to adapt but also offer fringe benefits for biodiversity, stabilizing the ecosystem, and human well-being (Berthon *et al*., 2021; Jimenez *et al*., 2022). The Shannon-Weiner diversity indices observed in our study are consistent with the ranges reported in some other urban settings, such as London (Roebuck *et al*., 2022) and Rivers State, Nigeria (Oladele *et al*., 2021). However, higher diversity values have been reported in Abuja, Nigeria (Agbelade *et al*., 2017), and this may be due to the varied abundance of individual tree species in the different locations. Typically, more species lead to higher diversity index values, indicating greater species richness and evenness (Mwavu and Witkowski, 2015; Kumar *et al*., 2022). However, the diversity value is often impacted by the dominance of a single species, for instance, the high abundance of *Terminalia mantaly*, contributed to the low tree species diversity and structural evenness observed in our study (Bouman, 2015). The 40.1 cm to 60 cm DBH size class combined comprised 52%, and the 10.1 m to 20 m height class, comprised 58% of all sampled trees in our study suggesting that more than half of the tree species are still maturing (Morgenroth *et al*., 2020). In forested ecosystems, agroecological, and urban landscapes, maturing trees serve as reserve resources that have the potential to provide future ecological benefits. Yang *et al*. (2022) reported a lower DBH class than what we observed in our study, but the height class was similar in China. In northern Nigeria, Dangulla *et al*. (2020) found a comparable but slightly higher height class, compared with our results. We attribute it possibly to similar species composition in both study areas and the species' ability to adapt to both local conditions (Asgarzadeh *et al*., 2014). However, variations in local climatic conditions and maintenance practices may explain the slight differences observed (Dervishi *et al*., 2022; Muscas *et al*., 2023). The vascular epiphytes recorded in this study belonged to three families. Four of the seven species belonged to Polypodiaceae (Ferns), two species Orchidaceae (Orchids), and one Araceae (Aroid). The abundance values in all sampled locations showed that *Platycerium superbum* (Polypodiaceae) was the most prevalent vascular epiphyte species occurring in 55.43 % of the sampled locations. Previous reports have shown that Polypodiaceae is one of the most diversified epiphytic fern groups, and has the highest species diversity in tropical and subtropical regions (Wei and Zhang, 2022). Several other species of vascular epiphytes have been reported to dominate urban landscapes other than the Polypodiaceae, for instance, Oloyede *et al*. (2014) reported dominance of species in the family Nephrolepidaceae in Ile-Ife, Bromeliaceae in Brazil (Furtado and Neto, 2015), and Moraceae in South Africa (Bhatt *et al*., 2015). The connection between tree species and vascular epiphyte species diversity in urban areas is influenced by several ecological and environmental factors. While vascular epiphytes are not limited to growing on trees, the presence of different tree species (exotic or native) in an area improves the variety of vascular epiphytes found there (Mondragón and Mora-Flores, 2024). The tree community characteristics like tree size, relative humidity, and soil factors influence the diversity of vascular epiphytes to varying degrees (Ding *et al*., 2016). Further, the microclimatic conditions created by tree canopies create favorable environments for the growth, reproduction, and survival of the vascular epiphytes.

Conclusion

This study examined the distribution and diversity of trees and vascular epiphytes in an urban environment. Our study's tree and vascular epiphyte species exhibited moderate to low diversity, comparable to findings in other urban landscapes reported in the literature. Exotic tree species dominated the sample, likely due to the effects of urbanization on species diversity in the area.

Vascular epiphytes in the Polypodiaceae family were the most represented in our study. Given the dearth of information on tree species and vascular epiphytes in our study area, our results provide a foundational understanding of the ecological relationship between trees and vascular epiphytes in Calabar. It is important to note that this study did not consider factors such as microclimatic conditions, historical land use, and other environmental variables, which influence plant diversity and distribution in urban landscapes. Despite these limitations, we employed rigorous sampling methods and appropriate data analyses, ensuring that our results are reliable and contribute meaningfully to existing knowledge. These findings offer valuable preliminary insights that can inform more extensive future studies. Our results provide vital exploratory information on the composition, diversity, and distribution of urban vascular epiphyte species in Calabar. These insights will aid in urban planning and biodiversity conservation efforts, while also establishing a baseline for long-term monitoring.

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