

A Decade of Plant Conservation and Diversity: Eco-Taxonomic Insights from the University of Benin Botanical Garden

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Abstract

In Nigeria, deliberate efforts have been made to conserve plants through the establishment of protected areas, including parks, forests, and botanical gardens. Most tertiary institutions have also established botanical gardens to promote the conservation of plant biodiversity. This study focused on the University of Benin Botanical Garden, analyzing its ecological and economic value after ten years of development. Both quantitative and qualitative assessments of plant species were conducted, including species diversity indices, tree morphometrics, and the influence of tree shade on herbaceous growth, with comparisons drawn between shaded and open areas. A total of 34 tree species across 14 grids were identified and classified into distinct habits and life cycles. Notably, *Gliricidia sepium* (Fabaceae) was the most dominant tree species, while *Asystasia gangetica* (Acanthaceae) was the most prevalent herb, particularly under shade. Ecological indices such as Shannon diversity, Simpson index, and Fisher's alpha were calculated, revealing higher species evenness in shaded grids, with Grid 14 exhibiting the highest evenness index (0.8563). Tree morphometrics showed that *Bombax buonopozense* recorded the highest trunk volume (149.66 m³). Furthermore, plant species were categorized based on their economic importance, including medicinal, food, cultural, oil-producing, and ornamental values. *Elaeis guineensis* and *Psidium guajava* exhibited multipurpose uses across multiple value domains. The findings highlight that botanical gardens serve as vital repositories for conserving plant diversity and cultural heritage, especially in regions threatened by urbanization and environmental degradation. This Botanical Garden demonstrates significant ecological richness and economic relevance, supporting its role as a model for conservation in developing countries.

Keywords: Botanical Garden, Eco-Taxonomy, Plant Biodiversity, Species Diversity Indices, Economic Plant Classification, Ex Situ Conservation.

Introduction

Imagine a world without plants; perhaps it never existed! Plants are one of the most important classes of living organisms for the biosphere's function (Campbell et al., 2008). They occur in an extraordinary range of forms, from simple organisms like green algae and mosses to more complex species such as ferns, vines, grasses, shrubs, herbs, flowering plants, and towering trees (Raven et al., 2005, pp. 622–626). While some plants are parasitic, the majority use photosynthesis to make their sustenance (Taiz et al., 2015). Plants have been essential to humans since ancient times. Early humans relied on wild plants for food, and as they began forming settlements, they learned to cultivate crops.

Today, plants continue to provide essential resources such as food, fiber, shelter, medicine, and fuel. Green plants also release oxygen through photosynthesis, which is vital for sustaining life on Earth (IFAS Communications, 2019).

Plants contribute significantly to national economies by supplying raw materials for industries such as pharmaceuticals, textiles, timber, and beverages. According to the Food and Agriculture Organization (FAO, 2024), global trade in major plant-based commodities was valued at nearly USD 250 billion in 1998. Around 2.5 billion people still depend on subsistence farming, while countless others rely on extensive agricultural production and distribution systems. Beyond their economic value, plants also hold deep cultural significance. They are used in religious rituals, traditional medicine, and festivals, and often serve as national symbols, for example, the Lotus in India, the Rose in Slovakia, and *Costus spectabilis* in Nigeria (Wikipedia, 2024).

Plants are indispensable not only for ecological balance and economic sustenance but also for human health and well-being. Since prehistoric times, indigenous communities across all continents have harnessed the medicinal properties of plants to treat wounds, infections, and internal ailments. Today, these traditional remedies still form the backbone of primary healthcare for nearly 80% of the world's population, particularly in low-resource regions (Fabricant & Farnsworth, 2001). Furthermore, many modern pharmaceutical drugs trace their origins to natural plant compounds; examples include aspirin from willow bark, quinine from Cinchona, and morphine from the opium poppy (Newman & Cragg, 2012). This enduring relevance highlights the ecological and therapeutic importance of conserving plant diversity, especially as global demand for natural medicine and bioprospecting continues to grow.

Plant Conservative Strategies

Plant diversity supports all ecosystems and provides essential services that life depends on. Conservation efforts aim to prevent plant extinction through in situ (on-site) and ex-situ (off-site) methods (CBD, 2016). These include the preservation of wild populations, management of plant collections, environmental education, invasive species control, and restoration programs (Heywood, 2010; Federal Ministry of Environment, 2015).

Nigeria has approximately 7,895 documented plant species, including 128 endemics (Osawaru et al., 2022). Despite this richness, the country faces biodiversity threats due to over-collection, unsustainable practices, pollution, and urbanization (GSPC, 2020).

In Nigeria, documented conservation efforts include the establishment of protected areas such as Gashaka-Gumti National Park in Taraba State, the Okomu National Park in Edo State, and the Lekki Conservation Centre managed by the Nigerian Conservation Foundation. Each of these sites plays a unique role in preserving Nigeria's diverse ecosystems, though their focus is primarily on fauna and large-scale forest conservation. Meanwhile, institutional gardens like those at the University of Ibadan and Obafemi Awolowo University have made contributions toward ex situ conservation, focusing on

ethnobotanical research and student training. However, coordination between national, regional, and institutional conservation frameworks remains limited (Osawaru et al., 2022). To address this, various institutions, governmental, educational, and non-governmental, have initiated strategies such as establishing protected areas like botanical gardens, parks, and reserves (BGCI, 2018). These serve both conservation and educational purposes.

In situ conservation protects species within their natural habitats. Ex situ conservation, on the other hand, involves artificial environments such as botanical gardens, seed banks, and aquariums. Both are complementary in safeguarding biodiversity (Hamilton, 2013).

Role of Botanical Gardens in Biodiversity Conservation and Research

Plants are essential to human well-being and form a core component of global biodiversity. Thousands of species are economically and culturally valuable, providing resources such as food, medicine, fuel, clothing, and shelter. However, human activities, including over-collection, unsustainable agriculture, deforestation, urbanization, pollution, and climate change, pose serious threats to plant diversity, potentially endangering up to 100,000 species globally. Plant biodiversity is foundational to ecosystem services like watershed protection, erosion control, climate moderation, and habitat provision (Chapin III et al., 2000). It also supports food and nutrition security, pharmaceutical development, and livelihoods. Studies have demonstrated the link between high biodiversity and increased ecosystem resilience and multifunctionality, particularly in changing climates (Zavaleta et al., 2010; Gamfeldt et al., 2008).

Botanical gardens are educational and scientific institutions that maintain documented collections of living plants for research, conservation, display, and public education. According to Botanical Gardens Conservation International (BGCI) (BGCI, 2018), such institutions must demonstrate scientific foundations, labeling, documentation, seed exchange, and active research (Westwood et al., 2020). Globally, over 2,500 botanical gardens maintain around 80,000 plant taxa, about a quarter of the world's vascular species (Smith & Pence, 2017). Their main roles include preserving endangered plants, promoting biodiversity, conducting research, and offering public awareness and education programs. These gardens provide a bridge between ex situ conservation and community-based conservation initiatives.

Botanical gardens serve as outdoor laboratories for ecological and taxonomic research, conservation centers for rare, endemic, and endangered species, repositories for living plant materials and seed banking, training hubs for horticulture, forestry, and urban greening, and public education and environmental awareness venues (Chen & Sun, 2018). They are poised to support plant adaptation under climate change by introducing resilient plant germplasm. Historically, they played a central role in distributing economically valuable crops such as tea, rubber, and oil palm (Heywood, 2010). Today, a renewed focus on plant introduction supports sustainable agriculture, forestry, and urban landscaping.

Within Nigeria, university-based botanical gardens such as the University of Ibadan Botanical Garden, the ABU Zaria Garden, and the Obafemi Awolowo University Botanical Garden have historically contributed to taxonomic education and the conservation of

medicinal plants. For example, the University of Ibadan's Garden has hosted ethnobotanical research projects in partnership with pharmacognosy departments, while ABU Zaria's Garden supports dryland plant species typical of northern Nigeria. Regionally, Ghana's Aburi Botanical Gardens and Cameroon's Limbe Botanical Garden serve both educational and conservation roles, demonstrating similar functions across West Africa (Cable & Cheek, 1998; Pullaiah & Galbraith, 2023). Yet, many of these gardens lack regular biodiversity assessments, highlighting a broader gap in documentation and research, especially at the institutional level.

However, not all introductions are beneficial. Some introduced species have become invasive, particularly those selected for hardiness and adaptability. Around 80% of Europe's invasive alien species were initially introduced for ornamental or agricultural purposes (Dehnen-Schmutz et al., 2007). Therefore, modern botanical gardens must implement strategic collection policies and monitor ecological impacts to balance conservation and introduction goals.

Since their inception as medicinal gardens in 16th-century Europe, botanical gardens have evolved into centers of global plant conservation. In the 21st century, they are tackling pressing issues like biodiversity loss, climate change, food insecurity, and sustainability through education, research, and public engagement (Westwood et al., 2020). With increasing emphasis on environmental and social responsibility, modern botanical gardens function as interdisciplinary institutions, integrating taxonomy, horticulture, biotechnology, and restoration ecology.

Botanical gardens play a vital role in both ex situ and in situ conservation. They manage over 105,000 plant species, including about 41% of all classified threatened species, through living collections, seed banks, and propagation programs that support ecosystem restoration and genetic safeguarding (Thomas et al., 2022). Their research infrastructure supports species recovery strategies and advances scientific knowledge in taxonomy, systematics, and plant physiology. Furthermore, botanical gardens attract more than 300 million visitors each year, serving as effective platforms for environmental education (Wassenberg et al., 2015). Interpretive programs, exhibitions, and school partnerships have been shown to positively influence environmental attitudes and enhance public awareness of biodiversity issues. Thus, botanical gardens serve as crucial institutions at the intersection of science, conservation, and education.

Prominent botanical gardens around the world illustrate the diversity and scale of these institutions: Kew Royal Botanical Garden, UK, Largest plant collection, advanced glasshouses, extensive herbarium; New York Botanical Garden, USA, Historic greenhouses, conifer collection, and large library; Royal botanical Garden Sydney, Australia, Coastal location, diverse plant zones, oldest scientific institution in Australia; Singapore Botanical Gardens, Home to over 3,000 orchid species and a rare urban rainforest; Kirstenbosch National Botanical Garden, South Africa, Dedicated to indigenous flora; Orto Botanico di Padova, Italy, World's oldest Botanical garden still in operation; University of Ibadan Botanical Garden, Nigeria., Academic and recreational roles, diverse plant sections. These

gardens reflect the global commitment to conserving plant biodiversity and using science and education to achieve sustainable ecological goals.

History of the University Benin Botanical Garden

The Department of Plant Biology and Biotechnology Botanical Garden, located at the Ugbowo Campus of the University of Benin, was established in 2011 under the leadership of Prof. G.O. Anoliefo. The initiative followed a recommendation by then-Vice Chancellor, Late Professor Osayuki Godwin Oshodin, to create a research-oriented botanical garden. A seed grant of one million naira facilitated the collection of native and exotic plant species from across Nigeria.

Professor M.E. Osawaru and other departmental staff played a vital role in sourcing plants, including field trips to regions like Ibadan, Eastern, and Northern Nigeria. The infrastructure, including fencing, was supported by Dr. E. Oshomo, then Chief Technologist.

Although the project faced setbacks, such as the submersible pump falling into the well, it laid the foundation for what is now a mini-forest with diverse plant species. The garden continues to serve educational, medicinal, cultural, and ecological purposes (Department of Plant Biology and Biotechnology, University of Benin, 2022).

Compared to more established institutions like the University of Ibadan Botanical Garden, which has been used for medicinal plant research and student training since the 1970s, the University of Benin Botanical Garden is relatively young, having been established in 2011. While international botanical gardens such as Kew Gardens in the UK or Singapore Botanic Gardens boast tens of thousands of species and serve as major global research centers, the University of Benin's garden functions primarily as a regional conservation and educational facility. Despite its smaller size, it holds significant value in preserving native and introduced species, supporting academic study, and promoting biodiversity awareness in southern Nigeria.

Research Gap

Despite the acknowledged importance of botanical gardens in plant conservation and education, there remains a noticeable lack of detailed studies examining their biodiversity profiles, ecological roles, and structural characteristics within institution-based botanical gardens, particularly in developing regions. Most of the existing research tends to focus on national parks, forest reserves, and large-scale conservation sites or globally renowned botanical gardens, often overlooking smaller academic or community-managed sites like the University of Benin Botanical Garden. This study addresses that gap by offering a systematic assessment of species composition, diversity indices, and morphometric data within this under-documented academic garden. In doing so, it provides essential baseline data that can inform local and regional conservation strategies, enrich environmental education, and serve as a reference for future ecological research and climate-resilience planning.

Research Justification

In Nigeria, institutions like Okomu National Park and Falcorp Mangrove Forest have promoted plant conservation. Many universities, including the University of Benin, have established botanical gardens to serve as conservation and research hubs.

Botanical gardens preserve both common and rare species, serving aesthetic, cultural, and scientific roles. This study focused on the botanical garden of the Department of Plant Biology and Biotechnology, Faculty of Life Sciences, University of Benin, Edo State.

This research aims to analyze, preserve, and showcase the value of this departmental garden. The study provides data that will aid future research on plant diversity and its ecological and economic roles.

Objectives

The specific objectives of the study were to:

- Obtain the geo-location and dimensions of the Plant Biology and Biotechnology departmental botanical garden.
- Identify plant species within the garden.
- Classify the trees by grade.
- Characterize plants based on their habit, whether they are trees, herbs, or shrubs, and their life cycle.
- Categorize plant species according to their economic significance, including ornamental, medicinal, timber, food, and religious uses.
- Determine the ecological diversity indices of the species present.
- Assess tree morphometrics such as volume, area covered, branch count, bole size, density, and forest profile.
- Examine the influence of tree shade on the growth and distribution of herbs within the garden.

Materials and Methods

Study Area

This research was carried out in the Department of Plant Biology and Biotechnology Botanical Garden at the University of Benin (Ugbowo campus), Benin City, Edo State.

Materials Used

Material used includes: Measuring tape, rope, cutlass, pegs, razor blade, mosquito repellent, safety coat, quadrant.

Research Methodology

Brief Tour around the Botanical Garden

The project began with a brief and fun-filled tour of the University's botanical garden. The botanical garden, which was about ten (10) years old, has diversified into a mini forest with

huge, tall trees, diverse herb and shrub species. The garden was explored and different sections of it were noted and highlighted: the tree-grown region, the herb region, and an area occupied by *Bambusa vulgaris*.

It was worth noting that the study was done during the early harmattan. The forest air was cool and damp. A major part of the forest was clothed in green. Some of the tree species dominated the air spaces with broad leaf branches around the canopy region and a height of more than 30 metres. The serenity and feel of nature in the garden were at their peak. It was amazing to see diverse plant species in such a location.

On-site Identification of Species in the Botanical Garden

On-site identification of plant species in the botanical garden was carried out. This was initially very difficult, especially looking at a great diverse population of plant species grown in the botanical garden, especially the diverse herb species, but a rough identification was still carried out. A part of the garden, located near the entrance, housed an outgrowth of the bamboo population. The various plant habits in the botanical garden were identified and properly documented.

Geo-location of the Botanical Garden

Geo-location of the botanical garden was done using Google Earth software to obtain GPS coordinates and assess the spatial layout of the study area. Historical satellite imagery was also retrieved to evaluate changes in topography since the garden's inception. A specialist from the Department of Optometry assisted in obtaining high-resolution satellite data through the use of advanced geospatial tools.

The coordinates of the botanical garden were obtained using Google Earth, with the primary coordinate recorded as 6.3974 (rounded to four significant figures). The spatial dimensions were measured digitally, and the geographic midpoint was calculated as (6.3972, 5.6160).

Construction of Grids in the Botanical Garden

The Botanical Garden was divided into grids using GPS. Sixteen (16) grids were constructed based on dimensions obtained using Google Earth. Each grid measured approximately 14.9 m × 15.75 m.

The midpoint of the Botanical Garden was determined physically. With the aid of ropes and pegs, the garden was divided into sixteen (16) grids, and the midpoint was located at 28.89 m. Major and minor grids were established: the major grids were laid out using ropes and pegs, while minor grids were created using quadrats, following multiples of the major grid size. Uniform sticks were used to delineate the grid boundaries.

Identification and Classification of Plant Species into Habits

The plants in the botanical gardens were classified into different habitats: trees, herbs, and shrubs. Some of the plant species were tree seedlings, still at the early stage of growth example was the Neem tree, *Azadirachta indica*. They were properly documented.

The tree-grown region was clearly distinct, with a uniform forest profile observed from some distance. Most of the trees were perennial with huge trunks and more than 30cm in height. Some of the trees found include *Terminalia catappa*, *Alstonia boonei*, *Annona muricata*, *Artocarpus altilis*, *Bauhinia purpurea*, *Bombax buonopozense*, *Boswellia dalzielii*, *Carica papaya*, *Chrysophyllum albidum*, *Citrus limon*, *Citrus simetris*, *Cocos nucifera*, *Delonix regia*, *Ficus sur* and others. Tree species identification was done with reference to major grids in the Botanical Garden. The trees found on each of the grids were identified and properly documented. The primary branching of each tree was counted two metres from the base of the trees and documented.

Some parts of the garden were not accessible because of a structure that acted as a barrier. Recall that the botanical garden featured a water system that was not completed. Grids in those areas were not accessible, and since it was difficult to get the names of plant species in those grids, assumptions and estimations were made.

Identification of herb species was done in the smaller grids constructed in the botanical garden. All herbs in the garden were identified, counted, and properly documented. For the identification of herb species, the quadrants were thrown on each grid, and the different herb species were counted. Plant species in the botanical garden were accurately counted and divided into their distinct habits and life cycles.

Categorization of Plant Species into their Economic Importance

The plant species were grouped according to their various economic importance. Plant species found in the garden were grouped into food plants, medicinal, sacred, wood production, and oil plants. The various categories of plants found in the botanical garden include those eaten for food, medicinal and traditional plants for treatment of all kinds of ailments, ornamental plants grown to maintain the aesthetic values of the garden, timber and wood production, and oil plants. Most of the plants in the botanical garden found use in traditional medicine and food. Most of the trees such as *Terminalia catappa*, *Alstonia boonei* were good sources of timber. The herbs and a few shrubs were a source of ornamental plants. The university botanical garden of study is a home to diverse plant varieties, serving both educational and economic benefits.

Identification of Herb Species under the Influence of Tree Shade in the Garden

Herbs associated with the predominant tree species on each grid were identified. This was done to get the species relationship between predominant trees and herbs and also to determine the influence of these tree shades on the growth of herbs in the garden. The herb species were taken at about a two-metre (2m) radius from the tree basal region under shade. Herb species found were properly identified and documented. This was done for the predominant trees at the different grids in the garden. Though other tree species were considered, this was done mostly for the tree species *Gliricidia sepium*. Herb species and density were also compared with the dominant tree of the grid where the quadrant was thrown. This was done similar to the two-meter radius from the dominant tree.

Determination of the Ecological Diversity indices of Plant Species

The ecological diversity indices for plant species (herbs and tree seedlings) under the influence of tree shade at the botanical garden were calculated and documented.

The Species taxa, Individuality, Dominance, Species Evenness_{e^H/S}, Menhinick and Margalef indexes were all calculated using a statistical software package, PAST® version 2.17c, according to Hammer *et al.* (2001) where necessary.

Plant species (herbs and tree seedlings) in the open and not under the influence of tree shade were also studied. This study was done at Hall 7 and Agric in the University of Benin, as there was little to no shade influence on the stated locations.

Diversity indices for plant species under the influence of tree shade in the garden, compared to those sampled away from the influence of tree shade and away from the garden, were also calculated. The various diversity indices were constructed using the PAST® version 2.17c according to Hammer *et al.* (2001), where necessary.

Determination of Tree Morphometrics

Various parameters for each tree according to grids in the Botanical Garden were determined. The tree volume, covered Area, primary branching, relative density, and tree density were all determined.

Data Analyses

Results were presented as the mean of 3 replicates. A complete randomized experimental design was adopted for the study having assumed homogeneity of the entire experimental plot when soils were pooled before use. A single-factor analysis of variances (ANOVA) was used. Statistical analyses were performed using SPSS® version 23 as well as PAST® version 2.17c was used according to Hammer *et al.* (2001) where necessary.

Results

The list of trees in the botanical garden is presented in Table 1 and it is divided into 14 grids. A total of 34 distinct tree species were identified. These were divided into 8 families. Amongst these, Moraceae was the most dominant family while *Gliricidia sepium* (Fabaceae) was the most dominant among the plant species. Generally, there was only one *Astonia bonei* tree in the botanical garden as well as one *Anona muricata*, *Artocarpus altilis* and *Bauhinia purpurea*. Four individual species of *carica papaya* and 7 standing tree species of *Gliricidia sepium* were recorded in the botanical garden.

As shown in Table 2, plant species whose habits were either herbs or tree seedlings were also identified within the 4 selected grids in the botanical garden. Nineteen different plant species were represented in all. Among these, only 3 were annuals, whereas the others were reportedly perennials. The most dominant among the plant species was *Asystasia gongylophylla* (family Acanthaceae), whereas the least dominant species, also a herb, was *Sida cordata* (Malvaceae). Other herbaceous or shrubby plant species were *Bauhinia purpurea* (Fabaceae), *Cestrum nocturnum* (Solanaceae), *Chrysophyllum albidum* (Sapotaceae), *Clerodendrum paniculata* (Lamiaceae) to name a few.

Table 1: Trees at the Botanical Garden by Grids

Table 1: Trees at the Botanical Garden by Grids

species	family	(n)										Total No.
		grid 1	grid 2	grid 3	grid 4	grid 5	grid 6	grid 11	grid 12	grid 13	grid 14	
<i>Alstonia boonei</i>	Apocynaceae	0	0	0	0	0	0	0	1	0	0	1
<i>Annona muricata</i>	Annonaceae	0	0	0	0	1	0	0	0	0	0	1
<i>Artocarpus altilis</i>	Moraceae	0	0	0	0	1	0	0	0	0	0	1
<i>Azadirachta indica</i>	Meliaceae	0	0	0	0	0	0	0	1	1	0	2
<i>Bauhinia purpurea</i>	Fabaceae	0	0	0	0	0	1	0	0	0	0	1
<i>Bombax buonopozense</i>	Malvaceae	0	0	0	0	1	0	0	0	0	0	1
<i>Boswellia dalzielii</i>	Burseraceae	0	0	0	0	0	0	1	0	0	0	1
<i>Carica papaya</i>	Caricaceae	1	0	1	0	0	0	1	0	1	0	4
<i>Chrysophyllum albidum</i>	Sapotaceae	0	0	0	0	0	0	0	1	0	0	1
<i>Citrus limon</i>	Rutaceae	0	1	0	0	0	0	0	1	1	0	3
<i>Citrus simetris</i>	Rutaceae	0	0	0	0	0	0	0	1	0	0	1
<i>Cocos nucifera</i>	Arecaceae	1	0	0	1	0	0	0	0	0	0	2
<i>Delonix regia</i>	Fabaceae	0	0	0	0	0	1	0	0	0	1	2
<i>Ficus sur</i>	Moraceae	0	0	0	1	0	0	0	0	0	0	1
<i>Gliricidia sepium</i>	Fabaceae	1	0	1	0	1	1	1	1	0	1	7
<i>Hevea brasiliensis</i>	Euphorbiaceae	0	0	0	1	0	0	0	0	0	0	1
<i>Hura crepilis</i>	Euphorbiaceae	0	0	0	0	0	0	1	0	0	0	1
<i>Jatropha curcas</i>	Euphorbiaceae	0	1	0	0	0	0	0	0	0	0	1
<i>Lagerstroemia speciosa</i>	Lythraceae	0	0	0	0	0	0	0	1	0	0	1
<i>Macaranga spinosa</i>	Euphorbiaceae	0	0	0	0	0	0	1	0	0	0	1
<i>Milicia excelsa</i>	Moraceae	0	0	0	0	1	0	0	0	0	0	1
<i>Oxytenanthera abyssinica</i>	Poaceae	0	0	1	0	0	0	0	0	0	0	1
<i>Pechira galbra</i>	Malvaceae	0	0	0	0	1	0	0	0	0	0	1
<i>Peltophorum pterocarpum</i>	Fabaceae	0	0	0	0	0	0	0	0	1	0	1
<i>Pinus taeda</i>	Pinaceae	0	0	0	0	0	0	0	0	1	0	1
<i>Polyalthia longifolia</i>	Poaceae	0	0	0	1	0	1	0	1	0	0	3
<i>Psidium guajava</i>	Myrtaceae	0	0	1	0	0	1	1	0	0	0	3
<i>Rauvolfia vomitoria</i>	Apocynaceae	0	0	0	0	0	1	0	0	0	0	1
<i>Synsepalum dulcificum</i>	Sapotaceae	0	0	0	0	0	0	0	0	1	0	1
<i>Syzygium malaccense</i>	Myrtaceae	0	0	0	0	0	1	0	0	0	0	1
<i>Tecoma stans</i>	Bignoniaceae	0	0	1	0	0	0	0	0	0	0	1
<i>Terminalia catappa</i>	Combretaceae	0	0	0	0	1	1	0	1	0	0	3
<i>Terminalia ivorensis</i>	Combretaceae	0	0	0	0	0	0	0	0	1	0	1
Unknown	NA	0	0	0	0	0	1	0	0	0	0	1

Table 2: Plant Species (Herbs and Tree Seedlings) Under the Influence of Tree Shade in the Botanical Garden

Species	Family	Life Cycle	Habit	(n)										Total	Citation index	Rank
				Grid-1	Grid-2	Grid-3	Grid-4	Grid-5	Grid-6	Grid-11	Grid-12	Grid-13	Grid-14			
<i>Asystasia gangetica</i>	Acanthaceae	Perennial	Herb	8	10	15	17	9	60	32	30	17	25	223	1.0	1
<i>Azadirchata indica</i>	Meliaceae	Perennial	Tree seedlings	0	1	1	1	3	0	2	11	6	5	30	0.8	8
<i>Bauhonia purpurea</i>	Fabaceae	Perennial	Shrub	5	0	6	0	0	0	4	0	1	0	16	0.4	13
<i>Cestrum nocturnum</i>	Solanaceae	Perennial	Shrub	2	3	0	0	1	0	0	1	0	0	7	0.4	17
<i>Chrysophyllum albidum</i>	Sapotaceae	Perennial	Tree	0	1	0	1	0	1	1	0	0	0	4	0.4	20
<i>Clerodendrum paniculata</i>	Lamiaceae	Perennial	Shrub	0	2	0	2	3	3	3	0	1	0	14	0.6	14
<i>Coccinea grandis</i>	Cucurbitaceae	Perennial	Herb	6	0	7	0	0	0	0	0	0	0	13	0.2	15
<i>Delonix regia</i>	Fabaceae	Perennial	Tree	0	2	0	2	1	2	2	1	1	5	16	0.8	11
<i>Ficus sur</i>	Moraceae	Perennial	Tree	1	6	2	5	0	0	0	0	2	0	16	0.5	12
<i>Gliricidia sepium</i>	Fabaceae	Perennial	Shrub	2	2	1	0	0	0	0	0	1	0	6	0.4	18
<i>Polyalthia longifolia</i>	Annonaceae	Perennial	Tree	9	3	30	8	32	10	10	40	3	0	145	0.9	6
<i>Microstegium vimineum</i>	Poaceae	Annual	Herb	5	6	3	2	0	0	0	0	10	15	41	0.6	7
<i>Oplismenus undulatifolius</i>	Poaceae	Perennial	Herb	3	0	0	0	0	0	0	0	12	15	30	0.3	9
<i>Peperonia pelusida</i>	Piperaceae	Annual	Herb	0	2	0	0	10	0	0	0	4	5	21	0.4	16
<i>Phyllanthus epiphyllanthus</i>	Phyllanthaceae	Perennial	Shrub	3	0	0	0	3	0	0	4	0	0	10	0.3	2
<i>Sida acuta</i>	Malvaceae	Annual	Shrub	1	1	0	1	0	1	1	0	0	0	5	0.5	19
<i>Sida cordata</i>	Malvaceae	Perennial	Herb	0	0	0	0	1	0	0	1	0	0	2	0.2	21
<i>Talium triangulare</i>	Talinaceae	Perennial	Shrub	1	15	0	10	1	30	25	0	9	15	106	0.8	3
<i>Tradescantia fluminensis</i>	Commelinaceae	Perennial	Herb	10	19	30	2	2	0	0	0	10	12	85	0.7	4
Unidentified Plant 01	-	-	-	0	4	0	4	1	5	5	1	0	0	20	0.6	10
Unidentified Plant 02	-	-	-	0	1	0	10	6	1	0	15	18	6	57	0.7	5

Diversity indices for plant species (herbs and tree seedlings) under the influence of tree shade at the botanical garden, as represented in Table 3. Grids 1, 3, and 14 all had evenness indices of 0.7807, 0.5916, and 0.8563, respectively. The highest evenness index was recorded in grid 14.

Alpha diversity, which is a term that is used to describe within-species diversity, is a measure of how diverse a single plant species is, especially when taking into account the number of different plant species that were originally observed per grid at the botanical garden. It's important to state that alpha diversity metrics are also weighted by the abundance at which the individual plant species was specifically observed. Fisher alpha in the current study was highest at grid 2 (6.097), followed by grid 1 (5.316), but lowest at grid 12. (2.364).

In an attempt to show the relationship between individual plant species and the respective marked grid, the corresponding biplot was presented in Figure 1. Here results showed that *Polyalthia longifolia* was very closely associated with grid 5 and grid 10 compared to other grids. Similarly, *Bauhinia purpurea* was more associated with grid 1 than other grids. Grids 5

and 10 were most associated with each other compared to grid 1 and grid 3. There were areas in the botanical garden that were not affected by tree shade, despite the fact that the majority of the plants studied were shaded by trees due to the quantity of trees in the garden.

Plant species within those regions were also counted and recorded in Table 4. Here, the result showed that *Paspalum dilatatum* (Poaceae), which was not affected by tree shade but was present in the botanical garden, was found to be the most prevalent plant species there. In contrast, *Dioscorea communis* and *Setaria palmifolia* were found to be the least common. It should be noted that plant species in the open were not sampled within the botanical garden but were sampled in a controlled area located in the University of Benin Hall 7 and around an open fallow region at the Faculty of Agriculture, University of Benin.

Table 3 presents the ecological diversity indices for herbs and tree seedlings observed under tree shade across ten different grids in the botanical garden. Key metrics such as species richness (Taxa S), dominance (D), Simpson's diversity index, Shannon–Wiener index (H), Evenness ($e^{H/S}$), and Fisher's alpha were computed to assess species diversity and distribution. Notably, Grid 2 recorded the highest species richness (16 taxa), while Grid 12 had the lowest Fisher alpha (2.364), indicating lower diversity. Evenness values, which reflect the uniformity of species distribution, were highest in Grid 14 (0.8563), suggesting a more balanced representation of species there.

Table 3: Diversity Indices for Plant Species (Herbs and Tree Seedlings) Under Tree Shade Influence in the Botanical Garden

	Grid-1	Grid-2	Grid-3	Grid-4	Grid-5	Grid-6	Grid-11	Grid-12	Grid-13	Grid-14
Taxa_S	13	16	9	13	13	9	10	9	14	9
Individuals	56	78	95	65	73	113	85	104	95	103
Dominance_D	0.1148	0.1335	0.2355	0.1451	0.2396	0.3635	0.2504	0.265	0.1227	0.1466
Simpson_1-D	0.8852	0.8665	0.7645	0.8549	0.7604	0.6365	0.7496	0.735	0.8773	0.8534
Shannon_H	2.317	2.321	1.672	2.175	1.883	1.334	1.689	1.547	2.272	2.042
Evenness_e ^{H/S}	0.7807	0.6367	0.5916	0.6768	0.5057	0.4218	0.5414	0.5219	0.6925	0.8563
Brillouin	2.013	2.05	1.537	1.912	1.66	1.228	1.529	1.43	2.06	1.893
Menhinick	1.737	1.812	0.9234	1.612	1.522	0.8466	1.085	0.8825	1.436	0.8868
Margalef	2.981	3.443	1.757	2.875	2.797	1.692	2.026	1.723	2.855	1.726
Equitability_J	0.9035	0.8372	0.7611	0.8478	0.7342	0.6071	0.7335	0.704	0.8608	0.9294
Fisher_alpha	5.316	6.097	2.441	4.886	4.601	2.299	2.944	2.364	4.532	2.372
Berger-Parker	0.1786	0.2436	0.3158	0.2615	0.4384	0.531	0.3765	0.3846	0.1895	0.2427
Chao-1	14	17.2	9.5	13.6	18	10.5	10.33	15	17	9

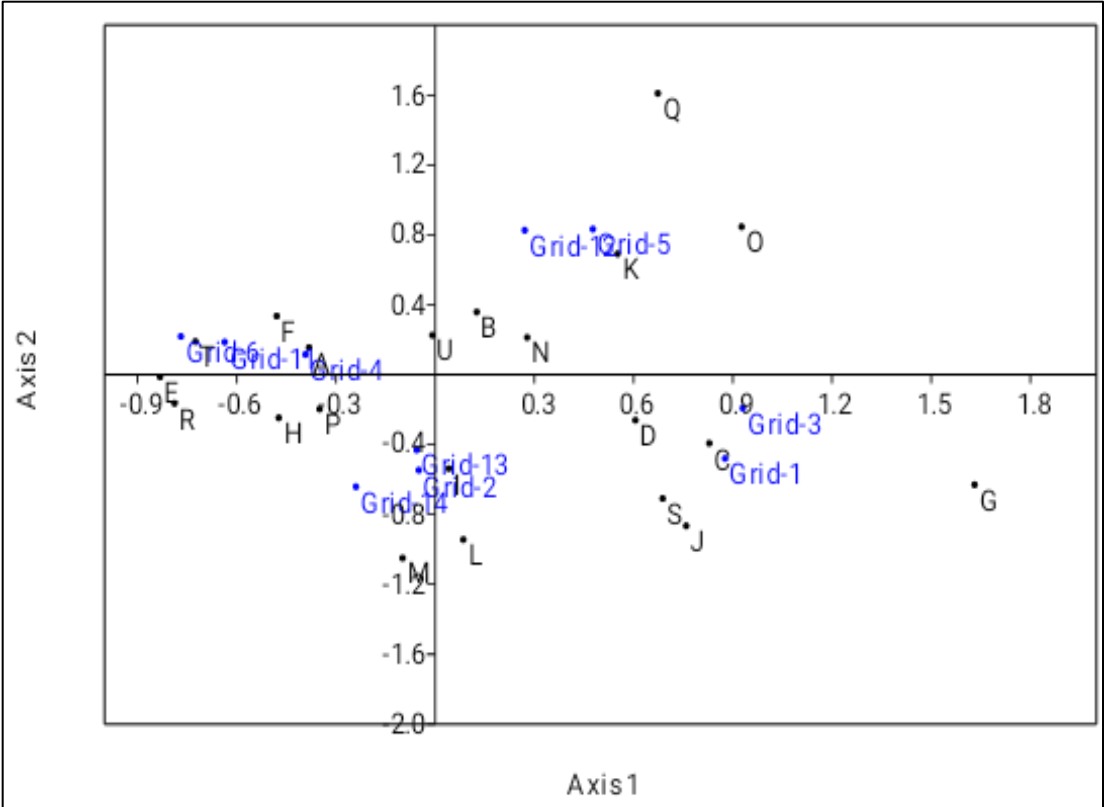


Fig. 1: Correspondence Biplot Showing the Relation Among Sampled Plant Species and the Respective Grids Under the Influence of Tree Shade at the Botanical Garden.

	KEY		<i>Polyalthia longifolia</i>	K
<i>Asystasia gangetica</i>	A		<i>Microstegium vimineum</i>	L
<i>Azadirchata indica</i>	B		<i>Oplismenus undulatifolis</i>	M
<i>Bauhonia purpurea</i>	C		<i>Peperonia pelusida</i>	N
<i>Cestrum nocturnum</i>	D		<i>Phyllanthus epiphyllanthus</i>	O
<i>Chrysophyllum albidium</i>	E		<i>Sida acuta</i>	P
<i>Clerodendrum paniculata</i>	F		<i>Sida cordata</i>	Q
<i>Coccinea grandis</i>	G		<i>Talium triangulare</i>	R
<i>Delonix regia</i>	H		<i>Tradescantia fluminensis</i>	S
<i>Ficus sur</i>	I		Unidentified Plant o1	T
<i>Glirichidia indica</i>	J		Unidentified Plant o2	U

Table 4: Plant Species (Herbs and Tree Seedlings) in Open Areas Not Influenced by Tree Shade

species	family	Life Cycle	Habit	(n)				Total	Average	Citatio n index	Ran k
				Hall 7 A	Hall 7 B	Agric A	Agric B				
<i>Alternanthera brasiliana</i>	Amaranthaceae	Perennial	Herb	0	0	0	20	20	5	0.25	9
<i>Amaranthus spinosus</i>	Amaranthaceae	Annual	Herb	0	3	0	8	11	2.75	0.5	12
<i>Arthraxon hispidus</i>	Poaceae	Annual	Herb	3	0	2	4	9	2.25	0.75	13
<i>Asystasia gangetica</i>	Acanthaceae	Perennial	Herb	6	5	10	0	21	5.25	0.75	8
<i>Cestrum nocturnum</i>	Solanaceae	Perennial	Shrub	0	2	0	0	2	0.5	0.5	22
<i>Commelina erecta</i>	Commelinaceae	Perennial	Herb	0	5	0	0	5	1.25	0.25	18
<i>Cyperus esculentus</i>	Cyperaceae	Perennial	Herb	15	0	0	0	15	3.75	0.25	11
<i>Delonix regia</i>	Fabaceae	Perennial	Tree	0	0	8	0	8	2	0.25	15
<i>Dioscorea communis</i>	Dioscoreaceae	Perennial	Herb	0	1	0	0	1	0.25	0.25	25
<i>Galinsoga quadriradiata</i>	Asteraceae	Annual	Herb	70	0	0	0	70	17.5	0.25	4
<i>Gliricidia sepium</i>	Fabaceae	Perennial	Shrub	0	1	0	2	3	0.75	0.5	20
<i>Monoon longifolium</i>	Annonaceae	Perennial	Tree	0	0	6	0	6	1.5	0.25	16
<i>Paspalum dilatatum</i>	Poaceae	Perennial	Shrub	100	0	0	70	170	42.5	0.5	1
<i>Peperomia pellucida</i>	Piperaceae	Annual	Herb	0	0	30	100	130	32.5	0.5	3
<i>Petiveria alliacea</i>	Phytolaccaceae	Perennial	Herb	0	0	0	2	2	0.5	0.25	22
<i>Physalis philadelphica</i>	Solanaceae	Annual	Herb	0	50	0	0	50	12.5	0.25	5
<i>Schinus areira</i>	Anacardiaceae	Perennial	Tree	0	0	4	0	4	1	0.5	19
<i>Setaria barbata</i>	Poaceae	Annual	Herb	0	2	2	4	8	2	0.75	15
<i>Setaria palmifolia</i>	Poaceae	Perennial	Herb	0	0	1	0	1	0.25	0.25	25
<i>Sida rhombifolia</i>	Malvaceae	Perennial	Shrub	0	0	0	15	15	3.75	0.25	11
<i>Synedrella nodiflora</i>	Asteraceae	Annual	Herb	0	0	0	150	150	37.5	0.25	2
<i>Syngonium podophyllum</i>	Araceae	Perennial	Shrub	0	30	0	0	30	7.5	0.25	7
<i>Thunbergia species</i>	Acanthaceae	Perennial	Shrub	0	0	40	0	40	10	0.25	6
<i>Tradescantia fluminensis</i>	Commelinaceae	Perennial	Herb	0	5	0	0	5	1.25	0.25	18
<i>Vepris trichocarpa</i>	Rutaceae	Perennial	Shrub	0	0	1	0	1	0.25	0.25	25

Table 5 comparatively presents the abundance of plant species in the botanical garden that are not under the influence of tree shade when compared with those plant species outside but within similar dimensions. For *Alternanthera brasiliana*, no plant species was reported under tree shade but 20 were reported in an open environment, the same was true of *Amaranthus spinosus* and *Arthraxon hispidus*. For *Asystasia gangetica*, there were 223 distinct species under tree shade compared to just 21 collected in the open environment. Generally, the plant species during the study that were not reported under tree shades included *Alternanthera brasiliana*, *Amaranthus spinosus*, *Arthraxon hispidus*, *Commelina erecta*, *Cyperus esculentus*, *Galinsoga quadriradiata*, *Paspalum dilatatum* and *Petiveria alliacea*, to mention but a few. Whereas *Azadirachta indica*, *Bauhinia purpurea*, *Chrysophyllum albidum*, *Clerodendrum paniculata* and others, were basically not found in the open environment of the present study.

Table 5: Comparative Abundance of Plant Species (Herbs and Tree Seedlings) in the Botanical Garden Under Tree Shade Influence Versus Open-Site Species of Similar Grid Dimensions

Species	Under tree shade	Open environment
<i>Alternanthera brasiliana</i>	0	20
<i>Amaranthus spinosus</i>	0	11
<i>Arthraxon hispidus</i>	0	9
<i>Asystasia gangetica</i>	223	21
<i>Azadirachta indica</i>	30	0
<i>Bauhinia purpurea</i>	16	0
<i>Cestrum nocturnum</i>	7	2
<i>Chrysophyllum albidum</i>	4	0
<i>Clerodendrum paniculata</i>	14	0
<i>Coccinea grandis</i>	13	0
<i>Commelina erecta</i>	0	5
<i>Cyperus esculentus</i>	0	15
<i>Delonix regia</i>	16	8
<i>Dioscorea communis</i>	0	1
<i>Ficus sur</i>	16	0
<i>Galinsoga quadriradiata</i>	0	70
<i>Gliricidia sepium</i>	7	3
<i>Polyalthia longifolia</i>	145	6
<i>Microstegium vimineum</i>	41	0
<i>Oplismenus undulatifolia</i>	30	0
<i>Paspalum dilatatum</i>	0	170
<i>Peperomia pellucid</i>	21	130
<i>Petiveria alliacea</i>	0	2
<i>Phyllanthus epiphyllanthus</i>	10	0
<i>Physalis philadelphica</i>	0	50
<i>Schinus areira</i>	0	4
<i>Setaria barbata</i>	0	8
<i>Setaria palmifolia</i>	0	1
<i>Sida acuta</i>	5	0
<i>Sida cordata</i>	2	0
<i>Sida rhombifolia</i>	0	15
<i>Synedrella nodiflora</i>	0	150
<i>Syngonium podophyllum</i>	0	30
<i>Talium triangulare</i>	106	0
<i>Thunbergia species</i>	0	40
<i>Tradescantia fluminensis</i>	85	5
Unidentified Plant 01	20	11
Unidentified Plant 02	57	9
<i>Vepris trichocarpa</i>	0	1
Total	868	797

Table 6 presents the diversity indices for plant species under the influence of tree shade at the botanical garden compared to those sampled away from the influence of tree shade and away from the garden. The total number of taxa identified was 21 in areas with tree shade as opposed to 27 in areas without tree shade. There were 868 and 797 distinct plant species in total, respectively. Plant species under tree shades appear to show more dominance compared to those in the open environment, whereas for the Fisher alpha index, the values of the Fisher alpha index were higher in the open environment (5.398) than for plant species under tree shade (3.878). Figure 2 shows the principal component analysis biplot showing a relationship between shade conditions and plant species. Results showed that the growth of *Peperomia pellucida* was most likely supported in an open environment rather than a shaded environment. *Polyalthia longifolia* was most associated with the shaded environment. Generally, more plants were associated with a shaded environment than with an open environment.

Table 6: Diversity Indices for Plant Species Under Tree Shade in the Botanical Garden Compared to Those in Open Areas Outside the Shade and Garden.

Indices	Under tree shade	Open environment
Taxa_S	21	27
Individuals	868	797
Dominance_D	0.1303	0.1262
Simpson_1-D	0.8697	0.8738
Shannon_H	2.413	2.454
Evenness_e^H/S	0.5317	0.4307
Brillouin	2.359	2.387
Menhinick	0.7128	0.9564
Margalef	2.956	3.892
Equitability_J	0.7925	0.7444
Fisher_alpha	3.878	5.398
Berger-Parker	0.2569	0.2133
Chao-1	21	28

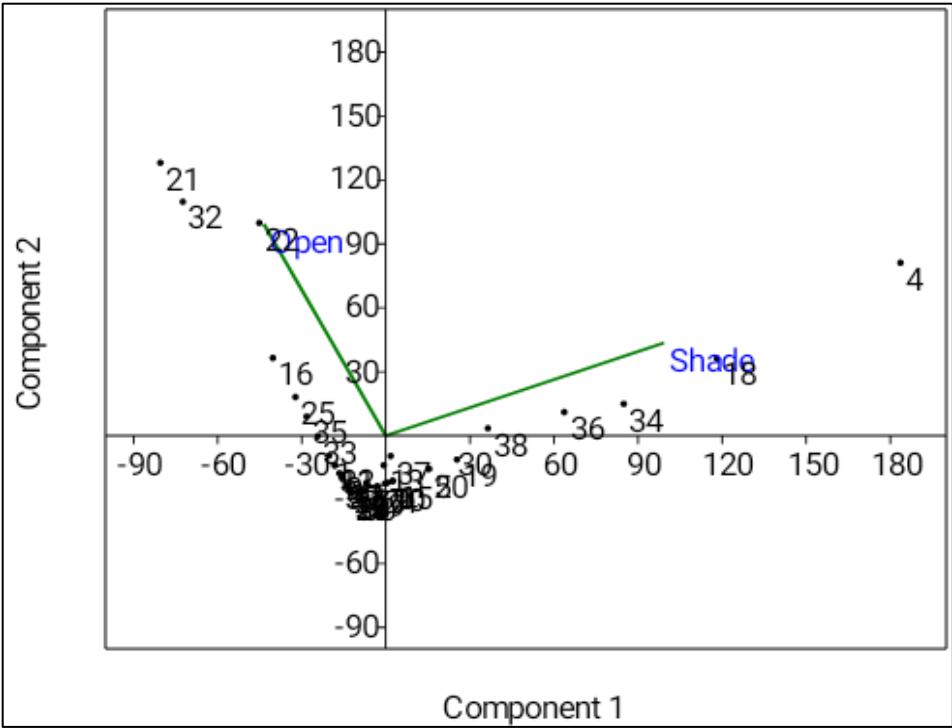


Fig. 2: Principal Component Analysis (PCA) Biplot Showing the Relationship Between Shade Conditions and Plant Species

KEY:

<i>Alternanthera brasiliana</i>	1	<i>Paspalum dilatatum</i>	21
<i>Amaranthus spinosus</i>	2	<i>Peperomia pellucid</i>	22
<i>Arthraxon hispidus</i>	3	<i>Petiveria alliacea</i>	23
<i>Asystasia gangetica</i>	4	<i>Phyllanthus epiphyllanthus</i>	24
<i>Azadirchata indica</i>	5	<i>Physalis philadelphica</i>	25
<i>Bauhinia purpurea</i>	6	<i>Schinus areira</i>	26
<i>Cestrum nocturnum</i>	7	<i>Setaria barbata</i>	27
<i>Chrysophyllum albidium</i>	8	<i>Setaria palmifolia</i>	28
<i>Clerodendrum paniculata</i>	9	<i>Sida acuta</i>	29
<i>Coccinea grandis</i>	10	<i>Sida cordata</i>	30
<i>Commelina erecta</i>	11	<i>Sida rhombifolia</i>	31
<i>Cyperus esculentus</i>	12	<i>Synedrella nodiflora</i>	32
<i>Delonix regia</i>	13	<i>Syngonium podophyllum</i>	33
<i>Dioscorea communis</i>	14	<i>Talium trangulare</i>	34
<i>Ficus sur</i>	15	<i>Thunbergia species</i>	35
<i>Galinsoga quadriradiata</i>	16	<i>Tradescantia fluminensis</i>	36
<i>Gliricidia sepium</i>	17	Unidentified Plant o1	37
<i>Polyalthia longifolia</i>	18	Unidentified Plant o2	38
<i>Microstegium vimineum</i>	19	<i>Vepris trichocarpa</i>	39
<i>Oplismenus undulatifolia</i>	20		

The categorization of plant species based on their economic values is presented in Table 7. Economic uses are divided into five categories: medicinal, food, ornamental, oil production, and cultural use. *Carica papaya* and *Chrysophyllum albidum* had a used citation index of 0.4, implying that, of the five economic uses of the plant, at least two were implicated. With a used citation index of 0.6, the results showed that *Psidium guajava* (Myrtaceae) were used for food, medicine, as well as oil production. It was also observed that *Elaeis guineensis* (Arecaceae), which was present in the botanical garden, had a utilization citation index of 0.8, indicating that it was suitable for cultural use, oil extraction, and as an ornamental plant.

The classification of plant species into their various habits and life cycles, as well as their economic values, is also presented in Table 8. Results showed that *Alternanthera brasiliana* (Amaranthaceae), with a used citation index of 0.5, has medicinal and ornamental uses, whereas *Bauhinia purpurea* (Fabaceae) is utilized in medicine, food, and ornamentals. Additionally, *Syzygium cumini* (Myrtaceae) is used in food, medicine, ornamentals, and culture.

Table 7: Categorization of Plant Species Based on Economic Importance

Plant species	Family	Medicinal	Food	Ornamental	Oil	Culture	Use citation index
<i>Alstonia boonei</i>	Apocynaceae	+	-	-	-	-	0.2
<i>Annona muricata</i>	Annonaceae	+	+	-	-	-	0.4
<i>Artocarpus altilis</i>	Moraceae	-	+	-	-	-	0.2
<i>Bauhinia purpurea</i>	Fabaceae	-	-	+	-	-	0.2
<i>Bombax buonopozense</i>	Malvaceae	+	-	+	-	-	0.4
<i>Boswellia dalzielii</i>	Burseraceae	+	-	-	-	-	0.2
<i>Carica papaya</i>	Caricaceae	+	+	-	-	-	0.4
<i>Chrysophyllum albidum</i>	Sapotaceae	+	+	-	-	-	0.4
<i>Citrus limon</i>	Rutaceae	+	+	-	-	-	0.4
<i>Citrus simetris</i>	Rutaceae	+	+	-	+	-	0.6
<i>Cocos nucifera</i>	Arecaceae	+	+	-	+	-	0.6
<i>Delonix regia</i>	Fabaceae	+	-	-	-	-	0.2
<i>Ficus sur</i>	Moraceae	+	-	-	-	-	0.2
<i>Gliricidia sepium</i>	Fabaceae	-	+	-	-	-	0.2
<i>Hevea brasiliensis</i>	Euphorbiaceae	-	-	-	+	-	0.2
<i>Hura crepilans</i>	Euphorbiaceae	+	-	+	-	-	0.4
<i>Jatropha curcas</i>	Euphorbiaceae	+	-	-	+	-	0.4
<i>Lagerstroemia speciosa</i>	Lythraceae	+	-	+	-	-	0.4
<i>Macaranga spinosa</i>	Euphorbiaceae	+	-	-	-	-	0.2
<i>Pechira galbra</i>	Malvaceae	-	+	+	-	-	0.4
<i>Peltophorum pterocarpum</i>	Fabaceae	+	-	+	-	-	0.4
<i>Pinus taeda</i>	Pinaceae	-	-	+	-	-	0.2
<i>Polyalthia longifolia</i>	Poaceae	-	-	+	-	-	0.2
<i>Psidium guajava</i>	Myrtaceae	+	+	-	+	-	0.6
<i>Rauvolfia vomitoria</i>	Apocynaceae	+	-	-	-	-	0.2
<i>Synsepalum dulcificum</i>	Sapotaceae	+	-	-	-	-	0.2

<i>Syzygium malaccense</i>	Myrtaceae	+	-	-	-	-	0.2
<i>Tecoma stans</i>	Bignoniaceae	+	-	-	-	-	0.2
<i>Terminalia catappa</i>	Combretaceae	+	+	+	+	-	0.6
<i>Terminalia ivorensis</i>	Combretaceae	+	+	+	+	-	0.6
<i>Milicia excels</i>	Moraceae	+	-	-	-	+	0.4
<i>Azadirachta indica</i>	Meliaceae	+	-	-	-	-	0.2
<i>Chrysophyllum albidum</i>	Sapotaceae	+	+	-	-	-	0.4
<i>Delonix regia</i>	Fabaceae	+	+	+	-	-	0.6
<i>Elaeis guineensis</i>	Arecaceae	+	-	+	+	+	0.8
<i>Ficus sur</i>	Moraceae	+	-	+	-	+	0.6
<i>Gliricidia sepium</i>	Fabaceae	+	-	+	-	-	0.4

Table 8: Classification of Plant Species into their Various Habits and Life Cycles

Plant species	Family	Life Cycle	Habit	Economic importance	Use citation index
<i>Alternanthera brasiliana</i>	Amaranthaceae	Perennial	Herb	M,D	0.5
<i>Amaranthus spinosus</i>	Amaranthaceae	Annual	Herb	M,F	0.5
<i>Arthraxon hispidus</i>	Poaceae	Annual	Herb	M	0.25
<i>Asystasia gangetica</i>	Acanthaceae	Perennial	Herb	M, D	0.5
<i>Bauhinia purpurea</i>	Fabaceae	Evergreen	Shrub	M, F,D	0.75
<i>Cestrum nocturnum</i>	Solanaceae	Prerennial	Shrub	M,D	0.5
<i>Clerodendrum paniculatum</i>	Lamiaceae	Perennial	Shrub	M, D	0.5
<i>Coccinia grandis</i>	Cucurbitaceae	Perennial	Herb	M,F	0.5
<i>Commelina erecta</i>	Commelinaceae	Perennial	Herb	M,D	0.5
<i>Cyperus esculentus</i>	Cyperaceae	Perennial	Herb	M,D	0.5
<i>Dioscorea communis</i>	Dioscoreaceae	Perennial	Herb	M,F	0.5
<i>Dioscorea hispida</i>	Dioscoreaceae	Perennial	Herb	M,F	0.5
<i>Galinsoga quadriradiata</i>	Asteraceae	Annual	Herb	M	0.25
<i>Microstegium vimineum</i>	Poaceae	Annual	Herb	D	0.25
<i>Monoon longifolium</i>	Annonaceae	Perennial	Shrub	M,D	0.5
<i>Oplismenus undulatifolia</i>	Poaceae	Perennial	Herb	M	0.25
<i>Paspalum dilatatum</i>	Poaceae	Prerennial	Shrub	F	0.25
<i>Peperomia pellucida</i>	Piperaceae	Annual	Herb	M	0.25
<i>Petiveria alliacea</i>	Phytolaccaceae	Perennial	Herb	M,D	0.5
<i>Phyllanthus epiphyllanthus</i>	Phyllanthaceae	Perennial	Shrub	M,D	0.5
<i>Physalis philadelphica</i>	Solanaceae	Annual	Herb	M	0.25
<i>Setaria barbata</i>	Poaceae	Annual	Herb	M	0.25
<i>Setaria palmifolia</i>	Poaceae	Perennial	Herb	M,D	0.5
<i>Sida acuta</i>	Malvaceae	Annual	Shrub	M,D	0.5
<i>Sida cordata</i>	Malvaceae	Perennial	Herb	M,D	0.5
<i>Sida rhombifolia</i>	Malvaceae	Perennial	Shrub	M,D	0.5
<i>Synedrella nodiflora</i>	Asteraceae	Annual	Herb	M	0.25
<i>Syngonium podophyllum</i>	Araceae	Perennial	Shrub	D	0.25
<i>Syzygium cumini</i>	Myrtaceae	Perennial	Shrub	M,F,D,C	1
<i>Talium triangulare</i>	Talinaceae	Perennial	Shrub	M,F,D	0.75
<i>Thunbergia alata</i>	Acanthaceae	Perennial	Shrub	M,D	0.5
<i>Clerodendrum paniculatum</i>	Lamiaceae	Perennial	Shrub	M,D	0.5
<i>Desmodium tortuosum</i>	Fabaceae	Perennial	Herb	M,D	0.5

<i>Ipomea purpurea</i>	Convolvulaceae	Annual	Herb	D	0.25
<i>Ipomoea setifera</i>	Convolvulaceae	Annual	Herb	M,D	0.5
<i>Merremia tuberosa</i>	Convolvulaceae	Perennial	Shrub	M,F,D	0.75
<i>Pueraria montana</i>	Fabaceae	Perennial	Shrub	M	0.5

M - medicine, F - food, D - ornamental, C - culture

General tree morphometrics within the botanical garden as represented in Table 9. The Result showed that the highest girth obtained was for *Bombax buonopozense* (1.77m). *Carica papaya* had a mean girth of 0.26m while *Gliricidia sepium* had a girth of 0.77m. At a height of 6.00m, *Terminalia ivorensis* was recorded as the biggest tree within the garden. Tree height was 16m in *Alstonia boonei*, 15m in *Artocarpus altilis*, and 13.50m in *Terminalia ivorensis*. The trunk surface area ranged from 0.1m² to 0.25m², with a volume of as low as 1.03m³ in *Annona muricata*. Tree volume was highest at 149.66m³ for *Bombax buonopozense*.

Table 9: Tree Morphometrics in the Botanic Garden

Species	PB	Girth (m)	Bole (m)	height (m)	trunk surface (m ²)	volume (m ³)	radius (m)	covered area (m ²)
<i>Alstonia boonei</i>		1.33	1.00	16.00	0.14	75.11	6.00	113.04
<i>Annona muricata</i>		0.29	1.00	5.00	0.01	1.03	1.50	7.07
<i>Artocarpus altilis</i>		1.04	1.50	15.00	0.09	43.06	5.00	78.50
<i>Azadirachta indica</i>	2	1.08	1.67	9.67	0.10	34.16	4.67	81.64
<i>Bauhinia purpurea</i>	3		0.90	4.00	0.00	0.00	2.50	19.63
<i>Bombax buonopozense</i>		1.77	4.00	18.00	0.25	149.66	4.00	50.24
<i>Boswellia dalzeilii</i>		0.58	2.00	9.00	0.03	8.04	4.00	50.24
<i>Carica papaya</i>		0.26	2.75	3.73	0.01	0.73	2.00	18.84
<i>Chrysophyllum albidum</i>		0.47	2.00	11.00	0.02	6.45	4.00	50.24
<i>Citrus aurantifolia</i> ?		0.51	0.30	4.00	0.02	2.76	3.50	38.47
<i>Citrus limoni</i>	4	0.96	0.40	6.50	0.04	9.78	3.50	38.47
<i>Citrus sinensis</i>	6	1.07	0.05	5.50	0.05	9.12	2.50	20.41
<i>Cocos nucifera</i>		0.99	4.50	8.85	0.08	23.18	4.60	68.45
<i>Delonix regia</i>	2	1.29	2.97	16.00	0.07	33.12	9.50	284.17
<i>Ficus sur</i>		0.50	4.00	12.00	0.02	7.96	1.00	3.14
<i>Gliricidia sepium</i>	2	0.77	0.91	7.88	0.05	13.60	3.50	42.54
<i>Greenwayodend suave</i>		0.58		13.00	0.03	11.61	2.00	12.56
<i>Hevea brasiliensis</i>		0.82	3.75	11.75	0.05	20.91	5.75	104.41
<i>Hura crepitans</i> ?		0.90	3.00	9.00	0.06	19.35	5.00	78.50
<i>Jatropha curcas</i>		0.41	0.30	3.00	0.01	1.34	1.00	3.14
<i>Lagerstroemia speciosa</i>		0.60	1.50	9.00	0.03	8.60	2.50	19.63
<i>Macaranga spinosa</i>	3	0.36	0.00	6.00	0.01	2.06	5.00	78.50
<i>Milicia excelsa</i>		0.46	4.00	10.00	0.02	5.63	2.75	23.94
<i>Oxytenanthera abyssinica</i>					0.00	0.00		0.00
<i>Pachira glabra</i>		0.48	2.25	7.25	0.02	4.64	2.75	28.65
<i>Peltophorum pterocarpum</i>		1.03	0.10	9.00	0.08	25.34	5.00	78.50

<i>Pinus teada?</i>		0.80	4.65	12.00	0.05	20.26	3.25	33.36
<i>Polyalthia longifolia</i>		0.71	2.00	10.67	0.04	14.88	2.17	17.01
<i>Psidium guajava</i>	3	0.82	0.66	7.67	0.02	4.16	3.17	33.76
<i>Rauvolfia vomitoria</i>		0.36		5.00	0.01	1.72	2.00	12.56
<i>Synsepalum dulcificum</i>		0.26	0.13	3.00	0.01	0.54	1.00	3.14
<i>Syzygium malaccense</i>		0.39	1.50	10.00	0.01	4.04	3.00	28.26
<i>Tecoma stans</i>	2	0.61	0.10	8.00	0.03	7.90	3.00	28.26
<i>Torminalia catappa</i>		0.34	2.00	6.50	0.01	2.30	2.70	24.65
<i>Terminalia ivorensis</i>		1.09	6.00	13.50	0.09	43.10	5.50	102.05
Unnamed tree 1		0.24	1.51	6.00	0.00	0.54	2.25	16.09
Unnamed tree 2		0.86	2.63	12.00	0.06	23.10	3.50	40.82



1



2

Plate 1: A picture of the Department Botanical Garden, Faculty of Life Science, University of Benin. (Front view)

Plate 2: Identification of herb species taken at about a two-metre (2m) radius around the tree basal region under shade.



3



4

Plate 3: Preparation for onsite identification of plant species in the botanical garden

Plate 4: Assessment of diverse plant species in the botanical garden



5



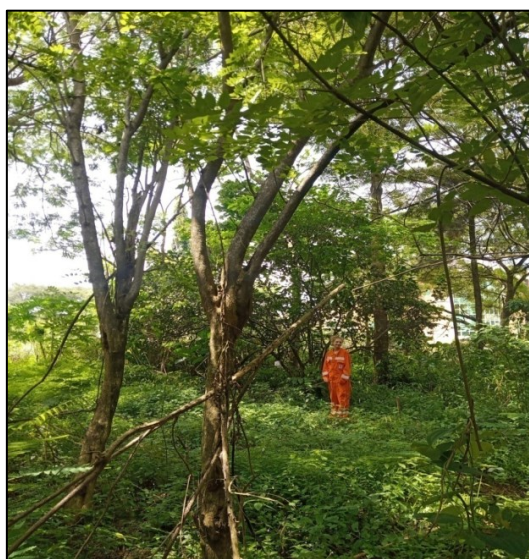
6

Plate 5: Identification of herb species associated with *Gliricidia sepium* at 2m radius within shade in the botanical garden

Plate 6: A rope used to construct one of the grids in the botanical garden



7



8

Plate 7: A small tree not under the influence of shade studied outside the botanical garden

Plate 8: Tree and herb species distribution as seen in the botanical garden

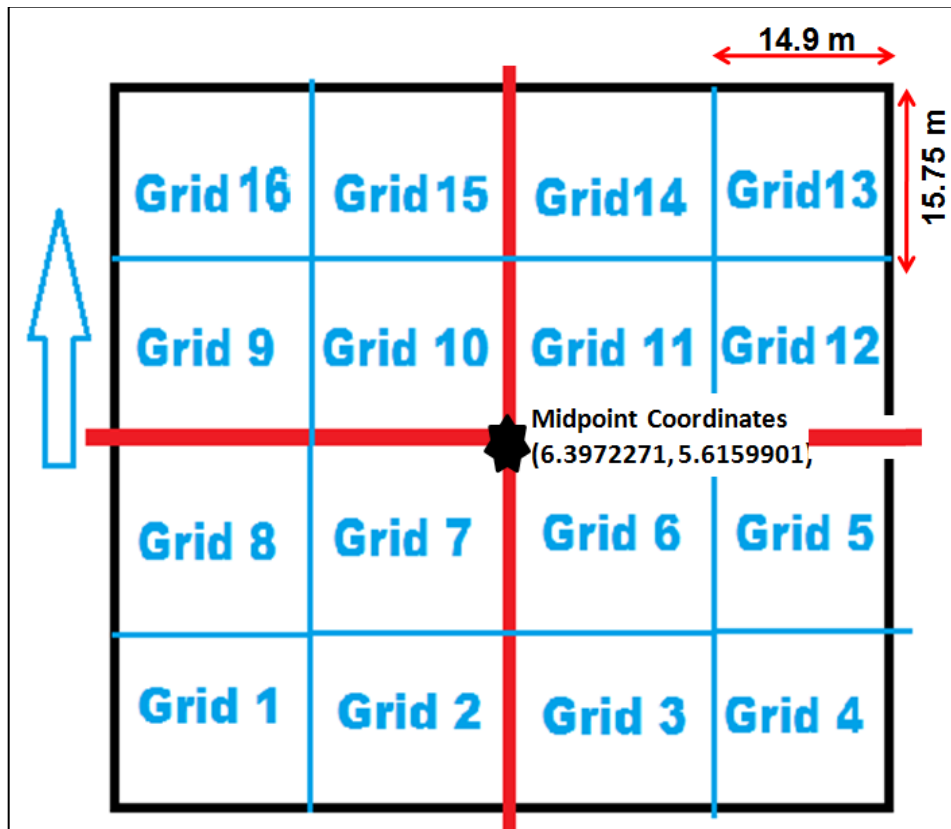


Plate 9: The Botanical Garden was divided into grids using GPS. Each of the various grids had dimensions of about 14.9m x 15.75m.

Discussion

The project was successfully carried out over a period of two months. The ten years old undisturbed botanical garden which housed diverse plant species across all habits and life cycles was characterized, studied, and compared to the open (Duco et al., 2024). Results were obtained and accurately documented.

The most prevalent among the plant species in the botanical garden was *Asystasia gengtica* (Acanthaceae) while *Gliricidia sepium* (Fabaceae) was well represented among the tree species (Elevitch, 2007; Manzitto-Tripp et al., 2021). *Asystasia gangetica* being a procumbent herb, growing up to 1 meter or more in height with ovate leaves, pointed tips and rounded or narrowed base was found on almost all grids studied in the botanical garden. *Asystasia gangetica* is one of the invasive species from the Acanthaceae family (Rosleine & Khalishah, 2024). It is an evergreen herb that smothers more desirable ground plants with mat-like structures, reducing the biodiversity and agricultural potential of specific habitats. This is due to its fast growth rate, adaptability to different environmental conditions, natural ability to withstand harsh environments, ability to reproduce by vegetative propagation, and form dense vegetation mats (Yap et al., 2021). *Asystasia gangetica* had been reported to be a highly shade-tolerant herb species, and studies show that it can even grow well under 90% shade (Asbur et al., 2018).

The botanical garden, which was mainly influenced by tree shades on underground herbs, supported the growth of this invasive herb species. *Gliricidia sepium*, on the other hand, dominated the tree-grown region of the botanical garden, extending its canopy and providing shade to the herbaceous life forms underneath. This tree species is a versatile, fast-growing tree, and studies showed that it can disperse seeds up to 40m from the parent tree from exploding pods, which may be one of the reasons for gaining dominance (Alamu et al., 2023). It is also regarded as a potential weed and as a moderately invasive species in many countries across Asia, Africa, and the West Indies, due to its successful colonization of disturbed and undisturbed areas, roadside ditches, abandoned farmland, and regions close to cultivation (Rojas-Sandoval, 2022).

In the current study, the Family Acanthaceae was the most prevalent herbaceous family, while the family Fabaceae was well represented, having more tree species in the garden.

Acanthaceae are among the most taxonomically diverse, geographically widespread, and morphologically and ecologically variable lineages of flowering plants (Manzitto-Tripp et al., 2021). This diversity is marked by exceptional morphological variation, particularly with respect to floral forms, growth forms, and pollen types.

Generally, plant distribution was affected by shade. Plant communities are subject to biotic and abiotic stressors, which influence how they respond to their surroundings (Valladares et al., 2016; Ma et al., 2019). In the understory vegetation of the botanical garden of study, the presence of tree shade was one of the most relevant environmental factors that influenced shrub and herb distribution and abundance. It is well accepted that shade tolerance is essential to many biological processes, ranging from populations to ecosystems (Avalos, 2019). Key factors in determining the structure and dynamics of forest stands are thought to be interspecific variations in the capacity to compete for light and also to tolerate shade (Zavala et al., 2007).

There were areas in the botanical garden that were not affected by tree shade, even though the majority of the plants studied were shaded due to the number of trees in the garden. *Paspalum dilatatum* (Poaceae), which was not affected by tree shade but was present in the botanical garden, was found to be the most prevalent plant species in one of the studied grids (Manzur et al., 2020). Plant species that were naturally shade lovers did well under tree shade, while others were prevalent in open spaces (Nieto-Lugilde et al., 2014). The botanical garden, being diverse in shade-producing tree species, saw the rapid growth of shade-loving herbs like *Asystasia gangetica*, *Azadirachta indica* (tree seedlings), *Bauhinia purpurea*, *Chrysophyllum albidum*, *Clerodendrum paniculata*, to mention but a few (Yap et al., 2021).

Shade trees have been reported to reduce weed growth, especially of perennial grasses and sedges. Shade trees add leaf litter to the soil, acting as a mulch and adding organic matter and minerals to the soil (Beer et al., 1997).

For *Alternanthera brasiliana*, *Amaranthus spinosus*, and *Arthraxon hispidus*, no plant species were reported under tree shade but in an open environment. As a result, plants that prefer shade will always do well in shady conditions. In general, plant species that were not

recorded growing beneath tree shading during the study included *Alternanthera brasiliana*, *Amaranthus spinosus*, *Arthraxon hispidus*, *Commelina erecta*, *Cyperus esculentus*, *Galinsoga quadriradiata*, *Paspalum dilatatum*, *Petiveria alliacea*, to mention but a few. Plant species under tree shades appear to show more dominance compared to those in the open environment.

When compared to life in the open, understory life (shade in its broadest sense) might be beneficial for plants (Valladares & Niinemets, 2008).

The botanical garden, which was divided into three grown regions and an open, non-shady region, had a total of 54 individual tree species, including *Elaeis guineensis*, *Carica papaya*, and *Cocos nucifera*. The botanical garden, which had been left abandoned for some time and had turned into a mini forest, exhibited good species diversity. Over 600 herbaceous individuals were counted in the botanical garden. Though dominated by tall, shady trees, herbs were diversely distributed throughout the garden.

A meta-analysis conducted in the Mediterranean basin aimed to determine the impact of land abandonment on species richness and abundance. The results showed a slight increase in plant and animal species richness and abundance overall; however, they were heterogeneous, exhibiting differences in effect size across taxa, spatial-temporal scales, land uses, landforms, and climate (Plieninger et al., 2014).

Plant species were almost evenly distributed in the botanical garden as compared to the open disturbed areas, where invasive plant species like *Paspalum dilatatum*, *Peperomia pellucida* grossly dominated the others.

The majority of plant species found in disturbed areas of studies were invasive annuals and perennial herbs that colonize these regions. These plants can be termed ruderals, which thrive well in disturbed environments. *Paspalum dilatatum* and *Synedrella nodiflora*, not influenced by tree shade, were predominant in the disturbed areas outside the garden. The botanical garden played a crucial role in housing diverse plant species. Most of the plants identified were located in the botanical gardens.

In the past, botanical gardens have focused primarily on aesthetic displays of horticultural collections, taxonomy, and botanical discovery (Chen & Sun, 2018; Dunn, 2017). Botanical gardens are more relevant socially and scientifically than ever (Maunder et al., 2001), thanks to their significant contributions to plant genetic conservation, informal science education, climate change research, invasive plant investigations, and other environmental challenges.

The University Botanical Garden played a key role in promoting a diverse plant population. Nineteen different plant species were identified within just four grids, whereas in the open areas, a single plant species often dominated large portions of land. For example, Grids 1, 3, and 14 recorded evenness indices of 0.7807, 0.5916, and 0.8563, respectively. The highest evenness index, observed in Grid 14, reflected a greater level of species diversity and balance. Overall, the study shows that the botanical garden enhanced plant diversity, as indicated by the diversity indices recorded across the grids.

Conclusion

This study has shown that the University of Benin Botanical Garden, though relatively young, serves as an important repository for plant biodiversity, combining ecological value with academic and economic relevance. With over 30 tree species and numerous herbaceous plants recorded, the garden demonstrates high species richness and functional diversity, particularly within shaded grids. The influence of tree canopy on herbaceous growth was significant, with shade-tolerant species such as *Asystasia gangetica* thriving under dominant trees like *Gliricidia sepium*.

The application of ecological indices provided insight into species evenness, dominance, and richness across different grids, affirming the ecological importance of maintaining both shaded and open areas within managed conservation sites. Tree morphometric data further contributed to understanding the structural complexity and biomass distribution within the garden.

Beyond biodiversity documentation, this study advances knowledge in the management of institutional botanical gardens by offering baseline data for long-term monitoring and practical insights into species selection, spatial planning, and ecological interaction. It also underscores the potential of university-based gardens to contribute to conservation education, ex situ species preservation, and the safeguarding of ethnobotanical knowledge. To enhance the conservation value of such gardens, regular biodiversity assessments, strategic control of invasive species, improved taxonomic labeling, and integration into national conservation policies are recommended. Future studies should explore ecological succession patterns, soil–plant interactions, and the impacts of anthropogenic disturbance on garden dynamics.

The University of Benin Botanical Garden stands as a model for regional conservation, demonstrating that with minimal disturbance and focused stewardship, academic botanical gardens can play a critical role in sustaining plant diversity in the face of growing environmental challenges.

References

- Alamu, E. O., Adesokan, M., Fawole, S., Maziya-Dixon, B., Mehreteab, T., & Chikoye, D. (2023). *Gliricidia sepium* (Jacq.) Walp applications for enhancing soil fertility and crop nutritional qualities: A review. *Forests*, 14(3), 635. <https://doi.org/10.3390/f14030635>
- Asbur, Y., Purwaningrum, Y., Ariyanti, M., Asbur, Y., Purwaningrum, Y., & Ariyanti, M. (2018). Growth and nutrient balance of *Asystasia gangetica* (L.) T. Anderson as cover crop for mature oil palm (*Elaeis guineensis* Jacq.) plantations. *Chilean Journal of Agricultural Research*, 78(4), 486–494. <https://doi.org/10.4067/S0718-58392018000400486>
- Avalos, G. (2019). Shade tolerance within the context of the successional process in tropical rain forests. *Revista de Biología Tropical*, 67(2SUPL), S53–S77. <https://doi.org/10.15517/rbt.v67i2supl.37206>
- Beer, J., Muschler, R., Kass, D., & Somarriba, E. (1997). Shade management in coffee and cacao plantations. *Agroforestry Systems*, 38(1/3), 139–164. <https://doi.org/10.1023/a:1005956528316>
- BGCI. (2018). *Botanic gardens and plant conservation*. Botanic Gardens Conservation International. <https://www.bgci.org/about/botanic-gardens-and-plant-conservation/>

- Cable, S., & Cheek, M. (1998). *The plants of mt cameroon : A conservation checklist*. Royal Botanic Gardens, Kew.
- Campbell, N. A., Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Jackson, R. B. (2008). *Biology*. Pearson Benjamin Cummings.
- CBD. (2016). *State of the world's plants*. Convention on Biological Diversity. <https://stateoftheworldsplants.org/2016/>
- Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., & Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405(6783), 234–242. <https://doi.org/10.1038/35012241>
- Chen, G., & Sun, W. (2018). The role of botanical gardens in scientific research, conservation, and citizen science. *Plant Diversity*, 40(4), 181–188. <https://doi.org/10.1016/j.pld.2018.07.006>
- Dehnen-Schmutz, K., Touza, J., Perrings, C., & Williamson, M. (2007). A century of the ornamental plant trade and its impact on invasion success. *Diversity and Distributions*, 13(5), 527–534. <https://doi.org/10.1111/j.1472-4642.2007.00359.x>
- Department of Plant Biology and Biotechnology, University of Benin. (2022). Historical overview of the departmental botanic garden. [Unpublished Internal Document].
- Duco, R. A., Bejar, S. Gabriel F., Bañez, J. G., Fidelino, J. S., Duya, M. V., Ong, P. S., & Duya, M. R. (2024). Forest fragments matter: A look into the species richness and diversity patterns of birds in a small, isolated, protected landscape in mindanao island, philippines. *Nature Conservation Research*, 9(2). <https://doi.org/10.24189/ncr.2024.012>
- Dunn, C. P. (2017). Biological and cultural diversity in the context of botanic garden conservation strategies. *Plant Diversity*, 39(6), 396–401. <https://doi.org/10.1016/j.pld.2017.10.003>
- Ekor, M. (2014). The growing use of herbal medicines: Issues relating to adverse reactions and challenges in monitoring safety. *Frontiers in Pharmacology*, 4(177). <https://doi.org/10.3389/fphar.2013.00177>
- Elevitch, C. R. (2007). Traditional trees of pacific islands: Their culture, environment, and use. *Native Plants Journal*, 8(2), 125–125. <https://doi.org/10.2979/npj.2007.8.2.125>
- Fabricant, D. S., & Farnsworth, N. R. (2001). The value of plants used in traditional medicine for drug discovery. *Environmental Health Perspectives*, 109(suppl 1), 69–75. <https://doi.org/10.1289/ehp.01109s169>
- FAO. (2024). *Plant production and protection division: State of the world's plant genetic resources*. Fao.org. <https://www.fao.org/agriculture/crops/thematic-sitemap/theme/seeds-pgr/sow/en/>
- Federal Ministry of Environment. (2015). *Nigeria fifth national biodiversity report*. <https://www.cbd.int/doc/world/ng/ng-nr-05-en.pdf>
- Gamfeldt, L., Hillebrand, H., & Jonsson, P. R. (2008). Multiple functions increase the importance of biodiversity for overall ecosystem functioning. *Ecology*, 89(5), 1223–1231. <https://doi.org/10.1890/06-2091.1>
- GSPC. (2020). *Global strategy for plant conservation*. Wwww.cbd.int. <https://www.cbd.int/gspc/>
- Hamilton, A. (2013). Plant conservation. In *Routledge eBooks*. Informa. <https://doi.org/10.4324/9781849772181>
- Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). Past: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4(4), 9–178. http://palaeo-electronica.org/2001_1/past/past.pdf
- Heywood, V. H. (2010). The role of botanic gardens as resource and introduction centres in the face of global change. *Biodiversity and Conservation*, 20(2), 221–239. <https://doi.org/10.1007/s10531-010-9781-5>
- IFAS Communications. (2019). *UF/IFAS - university of florida, institute of food and agricultural sciences*. Ufl.edu. <https://ifas.ufl.edu/>
- Ma, P., Han, X.-H., Lin, Y., Moore, J., Guo, Y.-X., & Yue, M. (2019). Exploring the relative importance of biotic and abiotic factors that alter the self-thinning rule: Insights from individual-based

- modelling and machine-learning. *Ecological Modelling*, 397, 16–24. <https://doi.org/10.1016/j.ecolmodel.2019.01.019>
- Manzitto-Tripp, E. A., Darbyshire, I., Daniel, T. F., Kiel, C. A., & McDade, L. A. (2021). Revised classification of Acanthaceae and worldwide dichotomous keys. *TAXON*, 71(1), 103–153. <https://doi.org/10.1002/tax.12600>
- Manzur, M. E., Grimoldi, A. A., & Striker, G. G. (2020). The forage grass *Paspalum dilatatum* tolerates partial but not complete submergence caused by either deep water or repeated defoliation. *Crop and Pasture Science*, 71(2), 190–190. <https://doi.org/10.1071/cp19303>
- Maunder, M., Lyte, B., Dransfield, J., & Baker, W. (2001). The conservation value of botanic garden palm collections. *Biological Conservation*, 98(3), 259–271. [https://doi.org/10.1016/s0006-3207\(00\)00160-9](https://doi.org/10.1016/s0006-3207(00)00160-9)
- Newman, D. J., & Cragg, G. M. (2012). Natural products as sources of new drugs over the 30 years from 1981 to 2010. *Journal of Natural Products*, 75(3), 311–335. <https://doi.org/10.1021/np200906s>
- Nieto-Lugilde, D., Lenoir, J., Abdulhak, S., Aeschmann, D., Dullinger, S., Gégout, J.-C., Guisan, A., Pauli, H., Renaud, J., Theurillat, J.-P., Thuiller, W., Van Es, J., Vittoz, P., Willner, W., Wohlgemuth, T., Zimmermann, N. E., & Svenning, J.-C. (2014). Tree cover at fine and coarse spatial grains interacts with shade tolerance to shape plant species distributions across the Alps. *Ecography*, 38(6), 578–589. <https://doi.org/10.1111/ecog.00954>
- Osawaru, M. E., Ogwu, M. C., & Ahana, C. M. (2022). Current status of plant diversity and conservation in Nigeria. *Nigerian Journal of Life Sciences (ISSN: 2276-7029)*, 3(1), 168–178. <https://doi.org/10.52417/njls.v3i1.120>
- Plieninger, T., Hui, C., Gaertner, M., & Huntsinger, L. (2014). The impact of land abandonment on species richness and abundance in the mediterranean basin: A meta-analysis. *PLoS ONE*, 9(5), e98355. <https://doi.org/10.1371/journal.pone.0098355>
- Pullaiah, T., & Galbraith, D. A. (2023). Botanical gardens and their role in plant conservation. In *CRC Press eBooks*. Informa. <https://doi.org/10.1201/9781003282150>
- Raven, P. H., Evert, R. F., & Eichhorn, S. E. (2005). *Biology of plants* (pp. 622–626). W.H. Freeman and Company.
- Rojas-Sandoval, J. (2022). *Gliricidia sepium* (Gliricidia). *CABI Compendium*, *CABI Compendium*. <https://doi.org/10.1079/cabicompendium.25380>
- Rosleine, D., & Khalishah, A. R. (2024). Population structure and risk assessment of invasive species *asystasia gangetica* in urban area of bandung, west java, indonesia. *Biodiversitas Journal of Biological Diversity*, 25(6). <https://doi.org/10.13057/biodiv/d250606>
- Smith, P., & Pence, V. (2017). The role of botanic gardens in ex situ conservation. *Cambridge University Press eBooks*, 102–133. <https://doi.org/10.1017/9781316556726.007>
- Taiz, L., Murphy, A. S., Møller, I. M., & Zeiger, E. (2015). *Plant physiology and development*. Sinauer Associates.
- Thomas, G., Sucher, R., Wyatt, A., & Jiménez, I. (2022). Ex situ species conservation: Predicting plant survival in botanic gardens based on climatic provenance. *Biological Conservation*, 265, 109410. <https://doi.org/10.1016/j.biocon.2021.109410>
- Valladares, F., Laanisto, L., Niinemets, Ü., & Zavala, M. A. (2016). Shedding light on shade: Ecological perspectives of understorey plant life. *Plant Ecology & Diversity*, 9(3), 237–251. <https://doi.org/10.1080/17550874.2016.1210262>
- Valladares, F., & Niinemets, Ü. (2008). Shade tolerance, a key plant feature of complex nature and consequences. *Annual Review of Ecology, Evolution, and Systematics*, 39(1), 237–257. <https://doi.org/10.1146/annurev.ecolsys.39.110707.173506>

- Wassenberg, C. L., Goldenberg, M. A., & Soule, K. E. (2015). Benefits of botanical garden visitation: A means-end study. *Urban Forestry & Urban Greening*, 14(1), 148–155. <https://doi.org/10.1016/j.ufug.2015.01.002>
- Westwood, M., Cavender, N., Meyer, A., & Smith, P. (2020). Botanic garden solutions to the plant extinction crisis. *Plants, People, Planet*, 3(1). <https://doi.org/10.1002/ppp3.10134>
- Wikipedia. (2024). *List of national flowers*. Wikipedia. https://en.wikipedia.org/wiki/List_of_national_flowers
- Yap, C. K., Chew, W., Al-Mutairi, K. A., Al-Shami, S. A., Nulit, R., Ibrahim, M. H., Wong, K. W., Bakhtiari, A. R., Sharifinia, M., Cheng, W. H., Okamura, H., Ismail, M. S., & Saleem, M. (2021). Invasive weed *asystasia gangetica* as a potential biomonitor and a phytoremediator of potentially toxic metals: A case study in peninsular malaysia. *International Journal of Environmental Research and Public Health*, 18(9), 4682. <https://doi.org/10.3390/ijerph18094682>
- Zavala, M. A., Angulo, Ó., Bravo de la Parra, R., & López-Marcos, J. C. (2007). An analytical model of stand dynamics as a function of tree growth, mortality and recruitment: The shade tolerance-stand structure hypothesis revisited. *Journal of Theoretical Biology*, 244(3), 440–450. <https://doi.org/10.1016/j.jtbi.2006.08.024>
- Zavaleta, E. S., Pasari, J. R., Hulvey, K. B., & Tilman, G. D. (2010). Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. *Proceedings of the National Academy of Sciences*, 107(4), 1443–1446. <https://doi.org/10.1073/pnas.0906829107>