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RESEARCH ARTICLE

Aboveground biomass and carbon sequestration potential of tree species in KRAEFI-Sumile Botanical and Zoological Garden

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ABSTRACT

Forest ecosystems are crucial to mitigating the effects of global warming because they function as carbon sinks and sources of carbon, regulating the flow of carbon dioxide (CO_2) in the atmosphere. This study estimated the aboveground biomass and potential of carbon sequestration of tree species within the Knights of Rizal Agricultural Endeavor Foundation, Incorporated (KRAEFI) Sumile Botanical and Zoological Garden in Butuan City, Philippines. A stratified random sampling design was employed to represent the tree population accurately. The assessment involved tree identification, diameter measurement at breast height (DBH), and the total tree height. Using an allometric equation, data from 18 plots revealed 115 individual trees representing 12 families. Among them, *Swietenia macrophylla, Gmelina arborea,* and *Acacia mangium* recorded the highest Importance Value at 180.76, 47.26, and 14.84, respectively, while *Eucalyptus deglupta* had the lowest at 1.77. The total aboveground biomass in the study site was 53,219.6 kg. Based on this biomass, the estimated total carbon sequestered was 86.46 Mg/ha. The study emphasized the critical influence of tree size and age on carbon sequestration potential, with older, larger trees storing more carbon. These findings are essential for guiding botanical garden management, restoration planning, and the selection of tree species with high carbon storage capacity to support climate change mitigation efforts.

1. INTRODUCTION

Climate change, primarily driven by greenhouse gases such as carbon dioxide (CO_2), methane, and nitrous oxide, has led to global warming (Ahmed et al., 2020). Forests play a dual role in this issue, both as a source of carbon when degraded and as a sink through carbon sequestration (Origenes & Lapitan, 2021). The Philippines covers woodlands and forests of about 8.4 million hectares, with around 11.60 million tons of aboveground biomass (FAO, 2015).

Trees play a crucial role in absorbing carbon from the air and mitigating the effects of climate change (Sharma et al., 2020). While carbon is released through respiration, carbon sequestration occurs when CO2 is absorbed during photosynthesis and retained in plant biomass and soils (Pechanec et al., 2022). However, continued emissions from burning fossil fuels and cutting down tropical forests are still increasing the amount of CO2 in the air (IPCC, 2014), which could significantly release stored carbon from forest areas (Avtar et al., 2020).

Aboveground biomass is a visible and measurable indicator of carbon storage. It is highlighted that biomass assessment can provide a direct estimate of CO2 that can be removed from the atmosphere, making it a key metric for mitigating climate change (Dahy et al., 2020). Conducting assessments specific to each location is crucial for making carbon data more accurate, especially in areas like the Philippines, which are at risk (Origenes & Lapitan, 2021).

Beyond their traditional roles in plant taxonomy and conservation education, botanical gardens are increasingly recognized as valuable research sites for investigating plant ecology, biodiversity patterns, and the impacts of climate change (Chen & Sun, 2018). Still, very little research has been conducted examining the specific ecological impacts of botanical gardens, particularly in terms of ecosystem services such as carbon storage. Most studies focus on natural forests or large-scale plantations while ignoring smaller managed green spaces like botanical gardens, which can help alleviate climate change.

Data on carbon storage potential in botanical gardens is virtually non-existent in the Philippine context, especially in those that feature both native and exotic species under conservation management. The KRAEFI-Sumile Botanical and Zoological Garden in Butuan City is famous for its diverse flora and fauna. It enables the study of aboveground biomass and the estimation of carbon absorption and storage by various tree species, although it remains understudied. This research aims to fill this gap by developing a scientific estimate of aboveground biomass and carbon stock in the garden, which can serve as a standard for planning and guiding future conservation, urban forestry, and climate action policies, as well as updating existing planning frameworks and policies.

2. 2. MATERIALS AND METHODS

2.1. Study area

The area of the study was conducted within the Knights of Rizal Agricultural Endeavor Foundation, Incorporated (KRAEFI) Botanical and Zoological Garden, located in Brgy. Sumile, Butuan City, Philippines (see Figure 1). The site is situated at a latitude of 8.851825 and has a longitude of 125.632205. Its elevation is about 116.3 meters or 381.6 feet above sea level. It has a tropical type II climate, categorized with no distinct wet or dry season.

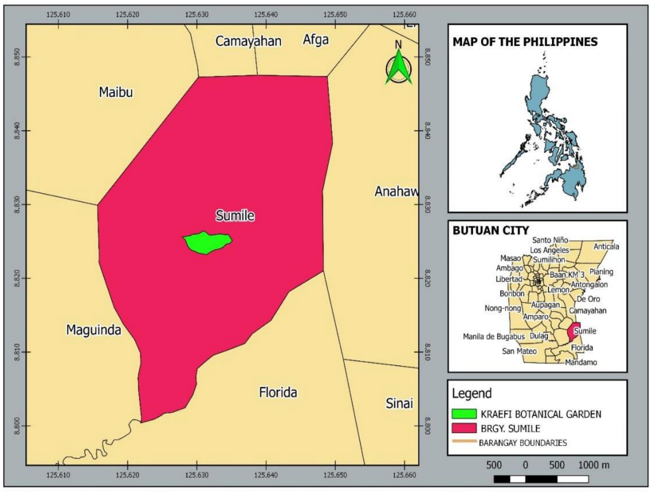

Figure 1: Location of the study

2.2 Sampling technique

A stratified random sampling design was utilized following Kauffman and Donato's (2012) framework to account for differences in vegetation within the study area. This approach ensured unbiased estimation of aboveground biomass, which depended on the diversity and distribution of tree species at the site. Three 150-meter-long transect lines were established perpendicular to the edge of the plantation and oriented in a straight line. Each transect had six circular plots (P1 to P6) placed every 25 meters, cumulating 18 plots for the entire study site. For tree measurements, two nested subplots were used: (a) For Diameter at breast height (DBH) > 5 cm trees, a 7-meter radius circle was used, (b) For DBH < 5 cm trees, a 2-meter radius circle was used. For every tree sampled species, DBH and total height were recorded. This design ensured that changes in plant structure throughout the botanical and zoological garden were accurately captured to measure biomass and evaluate carbon storage.

2.3 Data gathering procedure

2.3.1 Diameter at breast height (DBH)

Tree diameter measurements were collected using diameter tape, tree calipers, or other appropriate forestry instruments to ensure accuracy. Measurements were taken to the nearest centimeter, and the diameters were recorded as either Diameter at Breast Height (DBH) or Diameter Above Buttress (DAB), depending on how the tree appeared. DBH was measured 1.3 meters above the ground, on the side of the tree facing uphill, in accordance with the standard method used in forestry. DAB was measured at 0.30 meters above the highest buttress or flange and was used in cases where buttressing or swelling interfered with standard DBH measurements.

All trees, regardless of condition, including those with normal, swollen, leaning, forked, or otherwise abnormal stems, were measured according to DENR-FMB Technical Bulletin No. 03. This ensured consistent and accurate measurements of tree diameters, even when the trees had different shapes at the study site.

2.3.2 Tree identification

Tree species were initially identified based on their local or vernacular names, provided by knowledgeable community members familiar with the area. To ensure everything was accurate, the local names were compared with scientific names using an online database named World Flora Online (Home, 2023). Plant specimens, primarily leaves, were collected and referred to Forestry instructors and experts from Caraga State University (CSU) for proper taxonomic verification of species that were difficult to identify at the study site. In addition, unidentified and unfamiliar species were compared with photographs and descriptions from botanical sources and field guides to confirm their scientific classification. This careful process ensured that species identification was accurate and reliable, a crucial factor for estimating biomass and conducting ecological studies.

2.3.3 Vegetation analysis

To evaluate the structure and composition of tree species in the study area, vegetation analysis was conducted using the Mueller-Dombois and Ellenberg (1974) method. The analysis involved calculating key ecological parameters like density, frequency, dominance, relative density, and the Importance Value Index (IVI) (Mercado & Aribal, 2020). The Importance Value Index shows a species' ecological role in a plant community by combining its abundance, distribution, and biomass dominance. Sarmiento (2020) noted that the Species Importance Value (SIV) provides a more comprehensive assessment of a species' ecological function in its habitat than density alone. The SIV considers not only the number of individuals of a species but also their degree of widespreadness and structural dominance within the community.

These metrics helped determine the relative contribution of each tree species to the overall forest composition and carbon storage potential. These supports further interpretation of species dominance and ecological significance regarding carbon sequestration. The Species Importance Value (SIV) was calculated using the following equations: (Where RD; Relative Density, RF; Relative Frequency, RDom; Relative Dominance).

$$Dominance = \frac{basal\ area\ of\ a\ species}{area\ sampled}$$

$$Frequency = \frac{no\ of\ plots\ \ species\ occur}{total\ number\ of\ plots}$$

$$RDom = \frac{basal\ area\ of\ each\ species}{basal\ area\ of\ all\ species} \times 100$$

$$RF = \frac{no\ of\ trees\ species}{total\ no\ of\ trees} \times 100$$

$$RD = \frac{density\ of\ each\ species}{density\ of\ all\ species} \times 100$$

$$Importance\ value = \ RD + RF + DDom$$

2.3.4 Aboveground biomass

The collected field data was entered into a spreadsheet and organized into tables. An equation from the global models published by Brown (1997) was used to estimate the biomass. These models are widely accepted for assessing aboveground biomass (AGB) in tropical forests. They work well when we only have diameter and height measurements. The chosen allometric equations for this study were based on available tree parameters, such as Diameter at breast height (DBH) and, when relevant, total tree height. The equations estimate dry biomass in kilograms and apply to both natural and plantation forests in tropical areas.

The biomass equations employed are as follows:

$$ABG = \exp(-2.134 + 2.53\ \times \ln(d))$$

Eq. 1; from Brown (1997), Where:

AGB = Aboveground biomass (kg)

DBH = Diameter breast height (cm)

2.3.5 Carbon stock computation

To determine the carbon stocks associated with the aboveground tree biomass, the study employed the carbon stock assessment procedure outlined by MacDicken (1997). This method is widely used in forestry carbon assessments, particularly in tropical forest settings, and provides a standardized approach for converting biomass estimates into carbon stock values.

The following equation was used:

$$Tree\ buinass\ density = \frac{Tree\ biomass}{Sample\ area\ (ha)}$$

C stored = Tree biomass density x C content, which is 45% the recommended default value for Philippine forests (Lumbres et al., 2023).

3. RESULT AND DISCUSSION

3.1 Species composition

Table 1 represents the diversity of tree species identified within the 18 sampling plots in the botanical garden, including indigenous and exotic species. A total of 115 individual trees, representing 16 species across 12 families, were accurately identified and recorded. Among the most frequently occurring species were *Swietenia macrophylla* (Meliaceae), with 54 individuals, *Gmelina arborea* (Verbenaceae), with 23 individuals, and *Acacia mangium* (Fabaceae), with seven individuals. Notably, all three species belonged to the exotic category, which is more frequent in the area compared to indigenous species. This indicates that they are widely planted.

Swietenia macrophylla, commonly known as big-leaf mahogany, was the most frequently encountered species. The Department of Environment and Natural Resources (DENR) has introduced this type of tree because it grows well in areas with poor or damaged soil, especially where the soil has been washed away or covered with muddy sediment. This makes it

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very useful, with research proving its remarkable adaptability (Coracero et al., 2023).

Likewise, *Gmelina arborea*, locally known as Yemane or white teak, also displayed high dominance. This tree is widely used in the area due to its ability to grow rapidly, and its adaptability makes it specifically valuable for reforestation, with studies recognizing substantial possible areas for cultivation (Jaramillo et al., 2019). It is valued as a multipurpose tree that can be utilized for short rotations (15-20 years), especially for fuelwood and timber production (Rojas-Sandoval et al., 2020).

Acacia manguim, also known as Manguim, is an Australian tree species that was recorded as the third most common tree in the area. Even though only a few individuals were recorded within the sampling plot, several were observed just outside the sampled area. The DENR also introduced the tree species due to its ability to serve as an indicator of disturbance, as it is often found in disturbed woodlands (Jambul et al., 2020).

3.2 Species importance value

The Importance Value (IV) was computed to reveal which tree species predominate the study site. According to Malabrigo et al. (2021), importance value is a standard ecological measurement that establishes the rank connection of species based on their relative dominance in basal area, frequency, and density within a given site. The factors, such as basal area, frequency of occurrence, and abundance of individuals, show the species' role in the ecosystem and distribution.

Table 2 summarizes the Importance Value (IV) results for the 16 tree species observed in the KRAEFI-Sumile Botanical and Zoological Garden, including both indigenous and exotic species such as *Acacia manguim, Artocarpus blancoi, Canaga odorata, Colona serratifolia, Diospyrus spp., Eucalyptus deglupta, Ficus septica, Fluegga flexuosa, Gmelina arborea, Pterocarpus indicus, Sandoricum koetjape, Shorea contorta, Shorea polysperma, Swietenia macrophylla, and Syzygium spp.*

Among all the mentioned species, these three species —S. *macrophylla,* G. *arborea,* and A. *manguim* — showed the greatest values of relative dominance at 85.19%, 8.32%, and 2.45%, respectively, which suggests that they occupy a substantial proportion of the basal area within the site. These species also had a greater relative frequency of 47.79%, 19.47%, and 6.19%, respectively, and a relative density confirming their abundant distribution and dominance in numbers across the sampling plots.

Table 1: List of Plant Species in KRAEFI Botanical Garden

Species No.	No. of individuals	Family Name	Scientific Name	Common/Local Name	Endemicity
1	1	Alogres (LN)	Alogres (LN)	Alogres (LN)	Indigenous
2	4	Annonaceae	*Cananga odorata*	Ylang-Ylang	Indigenous
3	3	Dipterocarpaceae	*Shorea polysperma*	Tanguile	Indigenous
4	2	Dipterocarpaceae	*Shorea contorta*	White Lauan	Indigenous
5	3	Ebenaceae	*Diospyrus spp.*	Itoman	Indigenous
6	7	Fabaceae	*Acacia manguim*	Manguim	Exotic
7	3	Legumes	*Pterocarpus indicus*	Narra	Indigenous
8	1	Malvaceae	*Colona seratifolia*	Anilao	Indigenous
9	54	Meliaceae	*Swietenia macrophylla*	Mahogany	Exotic
10	2	Moraceae	*Artocarpus blancoi*	Antipolo	Indigenous
11	1	Moraceae	*Ficus septica*	Hauili	Indigenous
12	4	Myrtaceae	*Syzygium spp.*	Tambis-tambis	Indigenous
13	1	Myrtaceae	*Eucalyptus deglupta*	Bagras	Exotic
14	1	Phyllantaceae	*Fluegga flexuosa*	Anislag	Indigenous
15	5	Sapotaceae	*Sandoricum koetjape*	Santol	Indigenous
16	23	Verbenaceae	*Gmelina arborea*	Gmelina/Yemane	Exotic

The computed IVs underscore their ecological importance: S. *macrophylla* had the highest IV at 180.76%, while G. *arborea* and A. *manguim* had IVs of 47.26% and 14.84%, respectively. These results indicate that exotic species prevail in the vegetation framework of the botanical garden. This confirms and shows that exotic species tend to be invasive, outcompeting the indigenous vegetation and drastically diminishing the diversity of indigenous species (Philips, 2025).

In comparison, species such as *Flueggea flexuosa, Eucalyptus deglupta,* and *Ficus septica* showed lower ecological dominance. Each exhibited very low values for relative dominance, at 0.01%, 0.00%, and 0.00%, respectively. The frequency was 0.88% for all. The density was also 0.88% for all. Their corresponding IVs, at 1.78%, 1.77%, and 1.77%, respectively, indicate limited distribution and ecological influence in the area.

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In short, the study of plants shows that only a few non-native tree types are very common, especially S. *macrophylla,* G. *arborea,* and A. *manguim.* These species contribute importantly to the area's current vegetation structure and dynamics. Each species has its abundance, dominance, and contribution to the overall composition of the vegetation. Their distribution and dominance are essential for conducting biodiversity conservation and management of species strategies within the botanical garden, particularly in addressing the ecological impact of introduced species.

Table 2: Species Importance Value of Tree Species in KRAEFI Botanical Garden

Species	RDom	RFreq	RDen	IV
Acacia maguim	2.45	6.19	6.19	14.84
Alogres (LN)	0.09	0.88	0.88	1.86
Artocarpus blancoi	0.07	1.77	1.77	3.61
Colona seratifolia	0.02	0.88	0.88	1.79
Cananga odorata	0.16	3.54	3.54	7.24
Diospyrus sp	0.04	2.65	2.65	5.35
Eucalyptus deglupta	0.00	0.88	0.88	1.77
Ficus septica	0.00	0.88	0.88	1.77
Flueggea flexuosa	0.01	0.88	0.88	1.78
Gmelina arborea	8.32	19.47	19.47	47.26
Pterocarpus indicus	1.01	1.77	1.77	4.55
Sandoricum koetjape	2.45	4.42	4.42	11.30
Shorea contorta	0.05	1.77	1.77	3.59
Shorea polysperma	0.04	2.65	2.65	5.35
Swietenia macrophylla	85.19	47.79	47.79	180.76
Syzgium sp	0.11	3.54	.3.54	7.19

3.3 Aboveground biomass

Accurate estimation of carbon dynamics and ecosystem carbon sequestration capabilities requires estimating aboveground biomass (AGB) (Dossa & Miassi, 2024). This study estimated AGB by assessing different species and transects to determine biomass distribution within the botanical garden.

As shown in Figure 2, Transect 1 had the highest aboveground biomass accumulation with a total of 34,521.69 kg (see Table 3). This suggests that the sampling plots along this transect featured a greater proportion of trees with diameters at breast height (DBH) ranging from 30 cm to more than 70 cm. The presence of trees with large diameters, taller heights, higher stem volumes, and larger basal areas — characteristics associated with mature, biomass-rich individuals — explains the importance of AGB in this transect.

On the other hand, Transects 2 and 3 had the lowest AGB values, totaling 9,292.70 kg and 9,405.21 kg, respectively (see Table 3). These transects were predominantly composed of smaller trees with DBH values less than 30 cm, resulting in lower stem volume, basal area, and biomass contribution.

A key finding of the study is the inverse relationship between tree density and biomass: although large-diameter trees (80-100 cm DBH) were fewer in number, they contributed disproportionately to the total aboveground biomass. Using Spearman's correlation yielded a coefficient of r_s = 0.06 with a p-value = 0.90, showing a weak and statistically insignificant relationship. These results suggest that the accumulated biomass is not primarily driven by tree density, but rather by the structural attributes of individual trees, such as height, Diameter at Breast Height (DBH), and wood density. Although smaller in size, classes comprise more individual trees; their contribution to the total biomass remains relatively low. In contrast, fewer large-diameter trees dominate the overall biomass due to their substantially greater stem volume and wood mass (Lee et al., 2022). This emphasizes the important function of large trees in carbon storage despite their low density within the stand. These results place emphasis on the importance of preserving older trees in forested and managed landscapes, since they act as important carbon sinks due to their high biomass content.

3.4 Carbon sequestered

As shown in Figure 3, it illustrates the potential for carbon sequestration in relation to DBH (Diameter at breast height) size classes, following the guidelines of the DENR-FMB Technical Bulletin No. 03. In Transect 1, tree species within the larger DBH classes, specifically 35-44 cm,45-54 cm, 55-64 cm, and 65-74cm demonstrated notable carbon sequestration potentials, estimated at 11.12, 9.85, 12.38, and 8.50 Mg/ha, respectively. These size classes represent mature trees with greater biomass accumulation, thus storing more carbon.

In contrast, the tree species in Transects 2 and 3 showed carbon sequestration potential primarily within the 35-44 cm DBH class, as no species above 45 cm DBH were recorded in these transects. This means that the trees in those areas are usually younger or smaller. They also have a lower ability to store carbon compared to those in Transect 1.

The findings show that tree species with DBH sizes between 30 and 80 cm are crucial in carbon sequestration across all transects. Transect 1 contains more trees in these size classes than Transects 2 and 3. This indicates that Transect 1 has higher biomass and greater carbon storage potential. While most species in Transects 2 and 3 fall within the 4.5 to 20 cm DBH class, this does not diminish their ecological value.

These smaller trees represent future carbon sinks. If left undisturbed and properly managed, these young stands can mature into higher biomass contributors over time, demonstrating higher productivity and larger carbon storage capacity than unmanaged forests (Dalmonech et al., 2022).

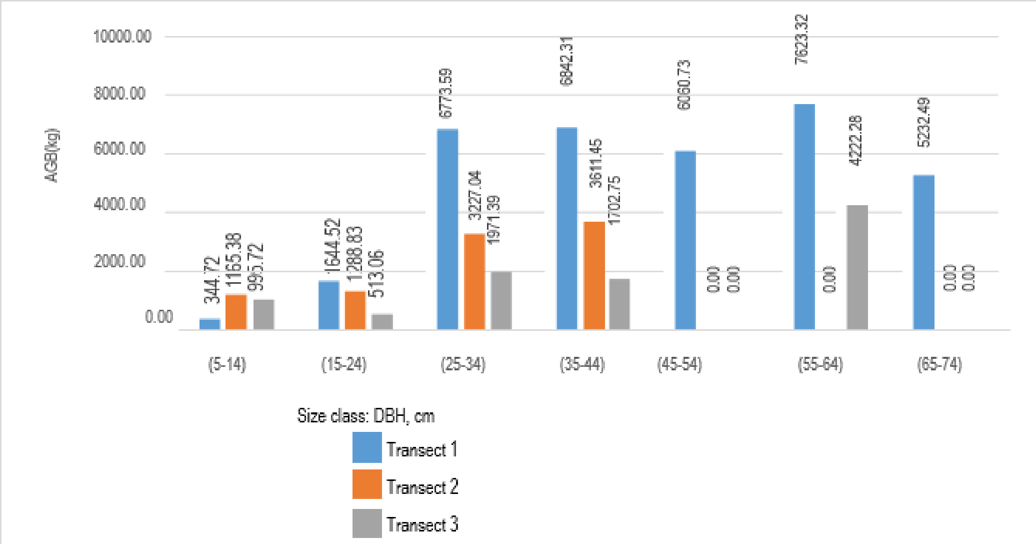
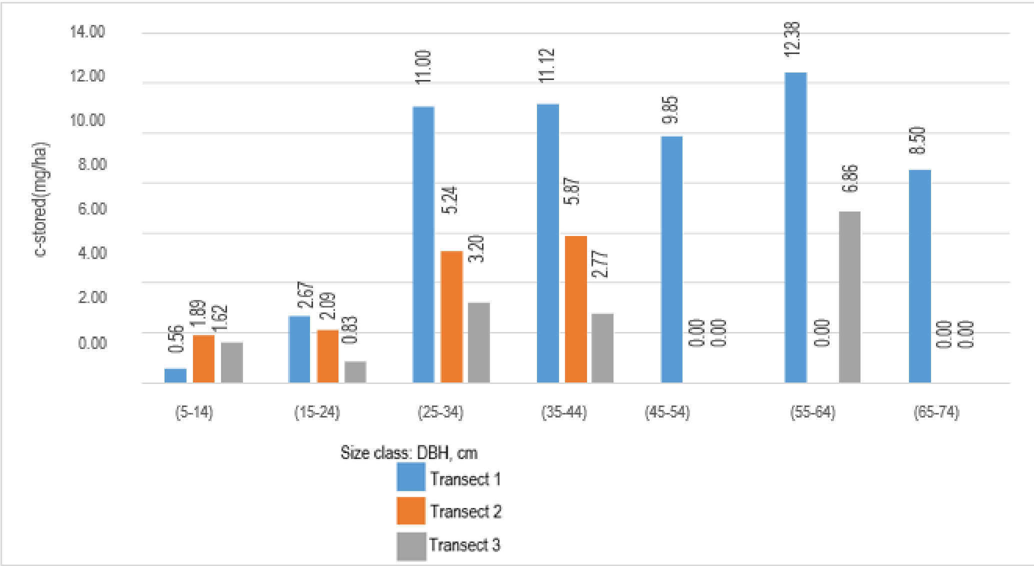


Figure 2: Aboveground biomass in different tree-size classes



3.5 Total aboveground biomass and carbon stored

Table 3 compares aboveground biomass (AGB) and carbon sequestration potential across different diameter size classes (DBH) in three KRAEFI-Sumile Botanical and Zoological Garden transects. The total AGB for all transects was 53,219.6 kg, giving an estimated carbon stock of 86.46 Mg/ha.

In general, the data show a clear link between tree size and carbon storage potential. Larger DBH classes make an unduly enormous contribution to total AGB and carbon sequestration. This pattern aligns with global findings emphasizing the importance of mature trees in forest carbon dynamics (Stephenson et al., 2014). These results underline the ecological importance of protecting and maintaining older trees while also promoting the growth and regeneration of younger trees. The mixture of structural diversity and species composition in the botanical garden supports biodiversity and improves its role in fighting climate change through carbon sequestration.

4. CONCLUSION

This study revealed that the KRAEFI-Sumile Botanical and Zoological Garden's tree composition comprises indigenous and exotic species, representing 16 identified tree species and 115 individuals with DBH values ranging from 7 cm to 80 cm. These trees were recorded across 18 sample plots, each with a 7-meter radius. Most trees belonged to the 5-15 cm diameter class, while the 35-45 cm class had the fewest individuals. This distribution pattern is characteristic of tropical secondary forests, where high population density, species competition for nutrients, water, light, and space often result in slender but tall trees. Due to their protective conservation management, some trees in the garden have successfully grown beyond 20 meters in height.

Table 3: Total AGB and carbon stored

Size class (cm)	Transect 1		Transect 2		Transect 3	
	AGB (kg)	C-stored (mg/ha)	AGB (kg)	C-stored (mg/ha)	AGB (kg)	C-stored (mg/ha)
(5-14)	344.72	0.56	1165.38	1.89	995.72	1.62
(15-24)	1644.52	2.67	1288.83	2.09	513.06	0.83
(25-34)	6773.59	11.00	3227.04	5.24	1971.39	3.20
(35-44)	6842.31	11.12	3611.45	5.87	1702.75	2.77
(45-54)	6060.73	9.85	0.00	0.00	0.00	0.00
(55-64)	7623.32	12.38	0.00	0.00	4222.28	6.86
(65-74)	5232.49	8.50	0.00	0.00	0.00	0.00
Total	34521.69	56.08	9292.70	15.10	9405.21	15.28
TOTAL AGB	53,219.6 kg					
TOTAL Carbon Stored	86.46 Mg/ha					

The dominance of exotic species, such as *Swietenia macrophylla, Gmelina arborea, and Acacia mangium,* was notable, as these species recorded importance values of 180.76, 47.26, and 14.84, respectively. Despite their prominence, the botanical garden remains rich in indigenous species, which outnumber the exotic species. This highlights the garden's potential role in conserving native biodiversity while accommodating introduced species with ecological or economic benefits. Each species, whether native or exotic, contributed uniquely to the environmental functions of the site and served both conservation and community purposes. The recorded total aboveground biomass (AGB) was 53,219.6 kg. This amount corresponds to a carbon stock of 86.46 Mg/ha. Transect 1 contributed the most biomass and carbon due to the presence of larger trees, especially those in 35 to 74 cm DBH classes. In contrast, transects 2 and 3 showed lower values because they had younger, smaller-diameter trees.

The forest area under study primarily consists of small and young trees, with a few newly planted ones. These characteristics suggest that the area is a secondary forest, formed through past disturbances and ongoing natural regeneration. The carbon sequestration potential of the area is closely linked to the size of the tree species. Larger and older trees stored substantially more carbon due to their increased aboveground biomass, emphasizing the necessity of retaining mature individuals within the stand. Although younger trees currently contribute less to carbon storage, they represent future biomass and carbon stock if the site continues to be protected and managed sustainably.

In conclusion, tree size classes are crucial in determining biomass accumulation and the potential for carbon sequestration.

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