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Research Article

Assessment of the Carbon Stock of Trees in Selected Urban Green Spaces of Davao City, Philippines

Daiseree M. Cuabo*, Yves Paul M. Montero, Daryl S. Salas, John Paullette M. Viernes

Natural Science Department, College of Arts and Sciences, University of Southeastern Philippines, Davao City, Philippines

*Corresponding Email: dmcuabo03191@usep.edu.ph

Abstract
The combined impacts of deforestation, tree cover loss, and urbanization in urban and suburban areas significantly reduce the capacity of natural carbon sinks to sequester and store carbon. Hence, this study assessed the aboveground biomass (AGB) and carbon stock of trees in the selected green spaces of Davao City. A purposive sampling technique was employed in placing quadrats, with data collected from 27 plots categorized by size. AGB was estimated via an allometric equation, and aboveground carbon (AGC) was derived from the AGB values. A total of 358 individual trees from 25 species, 24 genera, and 13 families were documented. Species contributing more than 2% to the total AGC were identified as major carbon stock contributors, with *Samanea saman* demonstrating the highest carbon stock, followed by Pterocarpus *indicus* f. *indicus* and *Acacia auriculiformis*, despite *Hibiscus tiliaceus* being the most abundant. Spearman's correlation was also used to find significant correlations between stem length, canopy area, and AGC, with a weak positive relationship between stem length and AGC (r_s = 0.166) and a strong positive relationship between canopy area and AGC (r_s = 0.631).

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Introduction
Urban trees are vital for climate change mitigation and adaptation because they provide essential ecosystem services, including carbon dioxide (CO_2) uptake through carbon sequestration, flood regulation, and urban heat island reduction [4, 19-21]. Despite these benefits, urban trees are often undervalued due to a lack of awareness and quantification of their contributions. Globally, approximately 60,065 tree species have been identified [1], with the Philippines contributing 8,120 species of angiosperms and 33 gymnosperms, over half of which are endemic [2]. Moreover, the composition of tree species within urban green spaces directly influences the range of biological, physical, and social services that urban forests can offer [3]. However, urban development projects, including the construction of highways and buildings, frequently result in tree removal, thereby diminishing their ecological benefits. Furthermore, the Philippines, which ranked 38th globally in terms of greenhouse gas emissions in 2021, is among the top 12 countries most vulnerable to climate change because of factors such as droughts, floods, and sea-level rise [5-6].

Urbanization is often associated with biodiversity loss due to significant habitat fragmentation and the conversion of natural landscapes into infrastructure, as well as the extensive introduction of nonnative species. However, the impact of urbanization on biodiversity is complex and can have various effects [7-8]. Research has shown that urban environments, including native species, can support high levels of tree diversity [9-14]. For example, 30% of wild plant species are found in some urban and suburban parks in Belgium [15]. Similarly, urban forests in Sweden have been found to host numerous rare and endangered tree species listed on the Swedish Red List [16]. These studies demonstrate that, despite the challenges posed by urbanization, urban areas can still play a significant role in supporting biodiversity. This diversity strengthens ecological productivity and stability in urban areas over time [24] and enhances the resilience of plant communities, helping them withstand environmental stressors, pests, and diseases [7].

The species composition of trees in urban green spaces shapes the ecological, physical, and social benefits they offer. Each species has distinct growth characteristics that influence its environment. For example, crown size and density play a role in climate regulation, whereas the depth and spread of roots impact soil stabilization and enrichment [68]. Woody biomass contributes to carbon storage, and tree litter supports soil nutrient cycling and organic matter. Combinations of species create varied landscapes, offering aesthetic and social value through ornamental features such as leaves, flowers, and fruits. Hence, selecting tree species for urban areas should align with the intended benefits of each green space [3].

The importance of urban species composition is increasingly recognized in academic research [17], urban planning [18], and urban sustainability initiatives. Strategically planted urban trees indirectly mitigate carbon emissions by reducing building cooling energy demand [25]. With increasing urban expansion and global warming driving elevated atmospheric carbon in cities, understanding the role of trees in carbon mitigation has become critical for urban planners and researchers. Consequently, numerous studies have investigated urban park and tree management for carbon emission mitigation [26-27]. The United Nations Sustainable Development Goals (UN SDGs) [69], particularly SDG 11 (Sustainable Cities and Communities) and SDG 15 (Life on Land), provide a crucial framework for recognizing and promoting the importance of urban tree biodiversity in enhancing the carbon stock and sequestration capacity of urban green spaces.

Despite the acknowledged importance of urban trees in carbon storage, quantitative assessments, such as baseline carbon stock evaluations, are often lacking in specific urban contexts, such as Davao City. Therefore, this study determined the tree aboveground carbon (AGC) stock of trees in selected green spaces in Davao City. Specifically, this study quantified the AGC stock, identified dominant carbon-sequestering species, and analyzed the relationships between AGC and tree canopy area and stem length.

Materials and methods

1) Study area

This study was conducted within a highly urbanized area in the downtown area of Davao City, which is situated in the southern Philippines on the island of Mindanao (Figure 1). Despite its urban character, Davao City boasts substantial green spaces, with 60% of its total land area being approximately 145,000 hectares (ha) allocated for agricultural and forestry purposes [28].

Trees within five distinct urban green spaces in Davao City were assessed. Osmeña Park (0.60 ha in total, 0.39 ha in vegetation cover) features a variety of well-spaced trees, shrubs, and landscaped greenery, providing a shaded environment within the urban landscape. The Park (4.0 ha total area, 2.089 ha vegetation cover), a cultural-themed park, supports a diverse variety of trees, shrubs, flowering plants, and curated gardens, offering substantial green cover and shade. Ramon Magsaysay Park (3.05 ha land area), is situated along Leon Garcia Street and is proximate to Sta. Ana Wharf. The park features a diverse assemblage of tropical arboreal species of ornamental plants combined with open green spaces. This spatial configuration establishes a dynamic, shaded microclimate along the urban waterfront. The University of Southeast Philippines (USeP) – Obrero Campus, (6.5 ha total area), is situated amidst residential and commercial establishments, features dense stands of mature trees and maintained vegetation, supporting epiphytic flora on tree trunks and branches. The Ayala Land Incorporated (ALI) Davao Carbon Forest (54 ha total area), an urban green space located along the Maharlika National Road approximately 10–12 km from the other study sites, is bordered by residential areas encompassing secondary forest across flat terrain, swampy zones, streams, and grasslands. This green space was included because of its significance as a major carbon sink with the urbanized area of Davao City and its role as a nature park frequented by residents and tourists. Additionally, the park provides habitat for numerous endemic flora and fauna, and the accumulation of leaf litter within this forest likely contributes to soil organic matter formation and enhances net carbon storage [29].

2) Field sampling technique

The sites were categorized into three size classes: small (< 2.3 ha), medium (2.3 to 8 ha), and large (> 8 ha) [30]. The sampling plots were established as follows: two plots in Osmeña; five plots in each of People's Park, Ramon Magsaysay Park, and USeP – Obrero Campus; and ten plots in ALI Davao Carbon Forest. Each plot measured 20 × 20 m², resulting in a total of 27 sampling plots. A purposive sampling technique was used to determine the placement of quadrats, ensuring accessibility and the presence of trees; their locations were recorded via the Gaia mobile application.

3) Data collection

All the recorded species were photographed via a Canon EOS 70D camera and initially identified and classified via photographs from Co's Digital Flora [31] as a field guide and a taxonomic key [32]. The identified species were then consulted and confirmed by an expert. Moreover, the names of the recorded species were verified through the International Plant Names Index (IPNI).

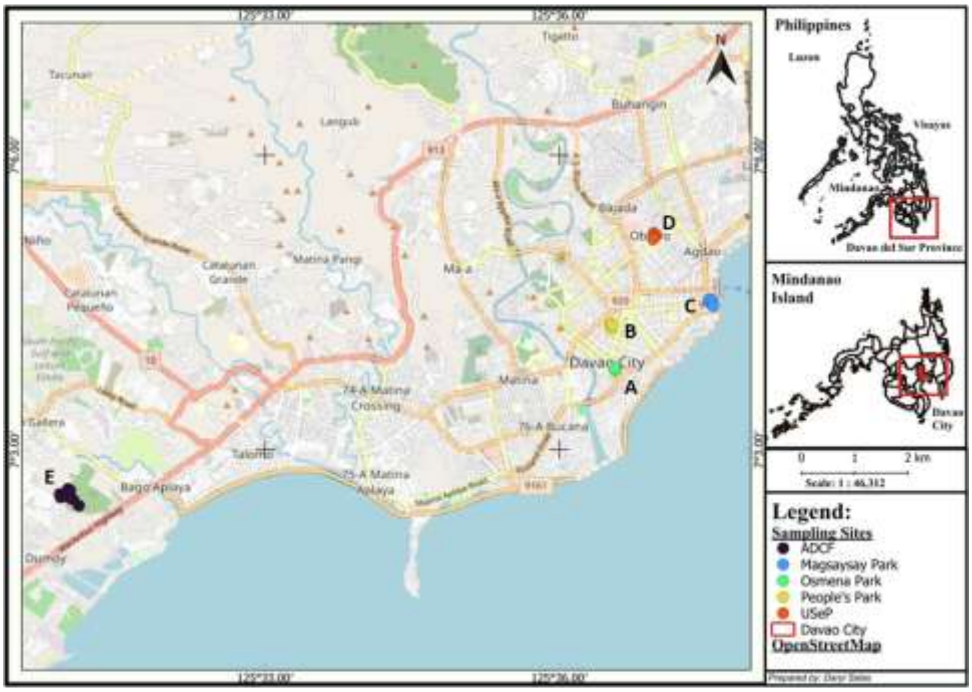

Figure 1 Map of Davao City, Mindanao Island, Philippines, with the sampling sites. A. Osmeña Park, B. People's Park, C. Ramon Magsaysay Park, D. USeP – Obrero Campus, and E. ALI Davao Carbon Forest.

The diameter at breast height (DBH), canopy height (CH), stem length, and canopy area were measured for each tree. The DBH of each tree trunk was measured with a Forestry Suppliers® diameter tape. For trunks with buttresses or deformities, the girth was measured above the deformation, typically at a height of 1.3 m from the ground. In the case of multiple stems, the overall DBH was calculated via Eq.1.

$$\mathrm{DBH} = \sqrt[2]{\sum_{i=1}^{n} \mathrm{DBH}_i^2} \qquad \text{(Eq. 1)}$$

where $\mathrm{DBH_i}$ is the DBH of the $\mathrm{i^{th}}$ stem of the same tree and where n refers to the total number of branched stems.

CH was defined as the distance from the nearest root of a tree to its highest visible point. Measurements, including the angle to the tree apex and the horizontal distance between the observer and the tree obtained via a laser rangefinder, were used to calculate the CH via Eq.2.

$$\mathrm{CH} = [\tan(\theta)(x)] + y \qquad \text{(Eq. 2)}$$

where θ is the angle to the top of the tree, x is the distance of the observer from the tree, and y is the height of the observer's eye above the ground. The canopy area was determined by averaging four crown radius measurements taken from the center of the trunk to the crown edges in the north, east, south, and west directions. Stem length was defined as the distance from the base of the tree to the first live branch or fork. Both canopy area and stem length were measured via a Mileseey® laser rangefinder.

4) Data analysis

4.1) Aboveground biomass calculation

The aboveground biomass (AGB) was estimated via Eq.3, which accounts for volume biomass carbon contributions from stems and branches ≥10 cm, as well as carbon stored in maller branches <10 cm and foliage, across species and sites [33].

4.2) Carbon stock measurement

The aboveground carbon stored (AGC) in kg was calculated via Eq. 4, where AGB represents the aboveground biomass.

The AGCwas aggregated by species and then at the plot level. This aggregation aimed to determine the carbon stock density by dividing the total AGC by the area of the 27 plots, each measuring 400 m2. Trees with more than 2% of the total AGC are considered major AGC-contributing species [34].

4.3) Statistical method for correlation

Tree AGC is strongly associated with DBH and canopy height [35-36]. However, the significance of canopy area and stem length as predictors of the carbon stock has not been evaluated. This study employed the Shapiro–Wilk test to assess data normality, revealing a nonnormal distribution [37]. Consequently, Spearman rank-order correlation, a nonparametric alternative suitable for nonlinear or ordinal variable relationships, was used via JASP software [38].

$$(\text{AGB})_{\text{est}} = 1.62 \times 10^{-2}(\text{DBH}^2 \times \text{CH})^{0.943} + 1.75 \times 10^{-2}(\text{DBH})^{2.20} + 1.71 \times 10^{-2}(\text{DBH})^{1.75} \quad \text{(Eq. 3)}$$

where CH represents the canopy height and DBH represents the diameter at breast height.

$$\text{AGC} = \text{AGB}\,(0.521) \quad \text{(Eq. 4)}$$

Results

1) Species composition

A total of 358 trees belonging to 25 species, 24 genera, and 13 families were documented across the five study sites in the downtown areas of Davao City. Among the families, Fabaceae had the greatest number of species with six, followed by Euphorbiaceae and Moraceae with three species each, whereas Lamiaceae and Meliaceae had two species each. Moreover, Bignoniaceae, Rubiaceae, Myrtaceae, Sterculiaceae, Bombacaceae, Malvaceae, Anacardiaceae, and Combretaceae were represented by one species each. Among the total species documented, 12 were native to the area, such as *Terminalia catappa*, *Homalanthus populneus*, *Macaranga tanarius*, *Melanolepis multiglandulosa*, *Pterocarpus indicus* f. *indicus*, *Vitex parviflora*, *Hibiscus tiliaceus*, *Didymocheton gaudichaudianus*, *Ficus benjamina*, *Ficus nota*, *Nauclea orientalis*, and *Sterculia foetida*. Moreover, 13 species were exotic, including *Mangifera indica*, *Spathodea campanulata*, *Ceiba pentandra*, *Samanea saman*, *Acacia auriculiformis*, *Delonix regia*, *Leucaena leucocephala*, *Senna siamea*, *Gmelina arborea*, *Swietenia macrophylla*, *Azadirachta indica*, *Artocarpus camansi*, and *Syzygium cumini* (Table 1).

This study highlights a global trend in which exotic species often dominate urban ecosystems due to historical factors, aesthetic appeal, and resilience to urbanization and climate change [39-41]. While exotic trees contribute to biodiversity and urban greening, concerns about their potential invasiveness persist [42-43]. However, in this study, native species accounted for a greater percentage of the total stem count (56%) than did exotics (44%), likely due to the predominance of *H. tiliaceus* (Table 1). Native species make up most of the urban tree stock, and exotic trees currently pose no threat to local flora. This contrasts with findings from Sokoto and Zaria, Nigeria, and is consistent with the findings of Sahiwal, Pakistan, where native populations were also more numerous despite the prevalence of exotics [44-45]. In addition to *H. tiliaceus*, other dominant species in urban green spaces include *A. auriculiformis*, *M. tanarius*, *P. indicus* f. *indicus*, *A. camansi*, *S. saman*, *T. catappa*, *V. parviflora*, *S. macrophylla*, and *G. arborea* (Table 1). These species are commonly planted in urban areas such as Bacolod and Iloilo City, Philippines, due to their adaptability to urban conditions [46-47].

Similar findings were reported from urban green spaces in Metropolitan Manila, where native species such as *P. indicus forma indicus*, *T. catappa*, and *V. parviflora*, along with exotic species such as *S. saman* and *S. macrophylla*, ranked among the 10 most common species identified in at least 50% of the study sites. *T. catappa* is widely planted for its broad crown, which provides ample shade and helps reduce urban temperatures. The prevalence of *S. saman*, *P. indicus* forma *indicus*, and *S. macrophylla* can be attributed to their fast growth, low maintenance needs, and high transplant survival rates. Additionally, *V. parviflora* is frequently planted for its cultural importance as a native species, as well as for its ornamental appeal and shade-providing qualities. Hence, these species collectively contribute to the ecological and social benefits of urban green spaces, offering shade, enhancing biodiversity, and promoting cultural heritage within cities [3].

2) Total carbon stock

The average vegetation carbon stock of the selected urban green spaces in Davao City was 35.43 megagrams of carbon per hectare (Mg C ha^{-1}), surpassing similar studies in Helsinki, Finland, which recorded 22.1 Mg C ha^{-1} and 28.1 Mg C ha^{-1} [30]. This difference in Davao City is attributed to the prevalence of fast-growing, larger tropical tree species exhibiting high carbon sequestration potential compared with the smaller, slow-growing trees adapted to temperate climates such as those in Helsinki [48]. Additionally, the current study integrated both DBH and CH in AGB calculations and yielded slightly higher carbon stock values than studies in Shenyang (33.22 Mg C ha^{-1}) and Hangzhou (30.25 Mg C ha^{-1}), which relied solely on DBH [49-50].

However, the carbon stock recorded in this study is lower than the average carbon stock of 87.81 Mg C ha^{-1} reported for urban trees in Cebu City, Philippines [4]. This difference is attributed to methodological variations, as the previous study included root biomass (RB), whereas this study excluded RB, as it required destructive approaches such as excavation. Additionally, the previous study analyzed 409 trees across 24 species, whereas 358 trees were analyzed in the present study, allowing for a more extensive carbon stock assessment in Cebu City.

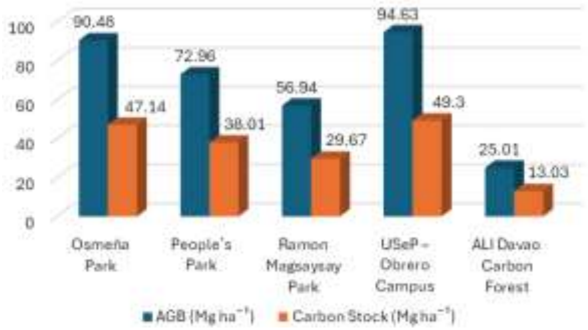

Figure 2 Aboveground biomass and carbon content of urban trees.

Table 1 Species composition, aboveground biomass and carbon stock of tree species across study sites

Family	Species	Common name	AGB (Mg)	AGC stored in Mg C (contribution in %)
Anacardiaceae	*Mangifera indica* L.	Mango	0.32	0.17 (0.5)
Bignoniaceae	*Spathodea campanulata* P. Beauv.	African Tulip	2.33	1.22 (3.8)
Bombacaceae	*Ceiba pentandra* (L.) Gaertn.	Silk Cotton Tree	0.14	0.07 (0.2)
Combretaceae	*Terminalia catappa* L.	Tropical Almond	3.52	1.83 (5.7)
Euphorbiaceae	*Homalanthus populneus* (Geiseler) Kuntze	Mouse Deer's Poplar	0.06	0.03 (0.1)
	Macaranga tanarius Müll.Arg.	Parasol Leaf Tree	1.28	0.66 (2.1)
	Melanolepis multiglandulosa Rchb. & Zoll.	Alim	0.07	0.04 (0.1)
Fabaceae	*Samanea saman* (Jacq.) Merr.	Rain Tree	22.74	11.85 (36.7)
	Acacia auriculiformis A.Cunn. ex Benth.	Earleaf Acacia	4.45	2.32 (7.2)
	Delonix regia (Bojer) Raf.	Fire Tree	2.28	1.19 (3.7)
	Leucaena leucocephala (Lam.) de Wit	Lead Tree	0.34	0.18 (0.6)
	Senna siamea (Lam.) H.S. Irwin & Barneby	Kassod Tree	0.08	0.04 (0.1)
	Pterocarpus indicus f. *indicus* Willd.	Narra	5.99	3.12 (9.7)
Lamiaceae	*Gmelina arborea* Roxb.	Gmelina	1.90	1 (3.1)
	Vitex parviflora Juss.	Molave	3.48	1.81 (5.6)
Malvaceae	*Hibiscus tiliaceus* L.	Sea Hibiscus	2.15	1.12 (3.5)
Meliaceae	*Didymocheton gaudichaudianus* A.Juss.	Ivory Mahogany	0.36	0.19 (0.6)
	Swietenia macrophylla King in Hook.	Mahogany	3.02	1.57 (4.9)
	Azadirachta indica A. Juss.	Neem Tree	0.98	0.51 (1.6)
Moraceae	*Artocarpus camansi* Blanco	Breadfruit	2.29	1.19 (3.7)
	Ficus benjamina L.	Weeping Fig	0.82	0.43 (1.3)
	Ficus nota Merr.	Sacking Tree	0.07	0.03 (0.1)
Myrtaceae	*Syzygium cumini* (L.) Skeels	Black Plum	2.19	1.14 (3.5)
Rubiaceae	*Nauclea orientalis* L.	Yellow Cheesewood	0.80	0.42 (1.3)
Sterculiaceae	*Sterculia foetida* L.	Hazel Sterculia	0.32	0.17 (0.5)
Total			**61.97**	**32.32**

The results also revealed that the medium-sized USeP – Obrero Campus had the highest recorded carbon stock content at 49.30 Mg C ha^{-1}, surpassing that of the larger ALI Davao Carbon Forest (Figure 2). This substantial carbon stock can be attributed to species-specific differences in biomass and carbon contributions, as tree species vary in their overall net productivity, allocation of carbon both above- and belowground, and rates of tissue turnover [51]. The number of tree stems in an area is a critical factor in determining the overall AGB [52]. However, in the present study, while the ALI Davao Carbon Forest recorded a greater stem count with 190 individuals than with 36 individuals at the USeP – Obrero Campus, the latter presented a greater total biomass and carbon stock due to the prevalence of larger-diameter trees, particularly *Samanea saman*, which had the highest average DBH (Table 2). This finding is consistent with studies indicating that trees with larger diameters store more carbon than smaller-diameter trees do [53-55]. Despite being the smallest in size, Osmeña Park presented the second highest AGB (90.48 Mg ha^{-1}) and carbon storage (47.14 Mg C ha^{-1}), whereas the USeP-Obrero campus presented the highest AGB (94.63 Mg ha^{-1} and 49.3 Mg ha^{-1}) (Figure 2). This suggests a direct relationship between the quantity of living plant material (age, size and count) and its carbon content. In contrast, ALI Davao Carbon Forest, despite being the largest in area, has the lowest AGB (25.01 Mg ha^{-1}) and carbon stock (13.03 Mg C ha^{-1}), potentially because of factors such as vegetation age and type. Consequently, the intensity of carbon storage is not solely determined by the overall size of the urban green space. Factors such as species composition, tree density, age structure, and ecological conditions likely play critical roles in influencing the amount of AGB and stored carbon across different sites.

Carbon stock assessments across various ecosystems in the Philippines reveal diverse storage capacities and the influence of land-use change and tree characteristics. Watershed studies in Laguna [70] demonstrated a decline in carbon stock between 2010 and 2018 in both the Silang-Stanta Rosa (120,113 Mg C to 82,228 Mg C) and Pagsanjan (1,612,309 Mg C to 1,374,340 Mg C) watersheds, attributed to urbanization and agriculture. In contrast, a reforestation site on Mt. Arayat [74] stored 542.32 Mg C ha^{-1}, with larger-diameter mango and *Syzygium cumini* being key contributors, notably higher than the urban green spaces in Davao City. Similarly, AGB estimation at the University of the Philippines Los Baños [71] highlighted the positive correlation between tree DBH and total AGB (15,074.54 Mg), with *Pterocarpus indicus*, *Swietenia macrophylla*, and *Samanea saman* as dominant biomass contributors, which was particularly greater than the AGB in USeP-Obrero. Species-specific studies at the University of San Carlos, Cebu City [75], indicated greater carbon storage in older mahogany (207.76 Mg C ha^{-1}) than in younger molave (36.21 Mg C ha^{-1}), although molave presented a slightly higher carbon sequestration rate. Notably, the Arroceros Forest Park in Metro Manila [73] had considerable AGB and carbon stocks (640.21 Mg ha^{-1} and 130.95 Mg^{-1}, respectively), exceeding the AGB and carbon stock of the ALI Carbon Forest (present study), emphasizing the importance of even small urban green spaces. In Mindanao, a 20-year-old eco-park in Butuan city [72] presented a relatively low AGB (2.48 Mg), with acacia, eucalyptus, coconut, *Ficus*, and gmelina as primary contributors.

3) Major AGC-contributing tree species

Among the 25 identified species, 13 were classified as major AGC contributors (Figure 3). These include *S. saman*, *S. campanulata*, *M. tanarius*, *S. cumini*, *A. auriculiformis*, *D. regia*, *G. arborea*, *A. camansi*, *H. tiliaceus*, *S. macrophylla*, *V. parviflora*, *P. indicus* f. *indicus*, and *T. catappa* (Figure 3).

Notably, *S. saman* emerged as the dominant contributor to the total carbon stock, accounting for 36.7% of the total AGC (Figure 3). This dominance is attributed to its large mean DBH of 66.3 cm (Table 2), which resulted in the highest aboveground biomass and a substantial carbon stock contribution of 11.85 Mg C (Table 1). This finding is supported by earlier studies, which revealed that DBH is strongly correlated with aboveground biomass, making it one of the most reliable predictors of AGC [56-57]. This observation is consistent with findings from Bilaspur city, India, where *D. regia*, *S. saman* and *T. catappa* were among the top contributors to AGC, primarily due to their large DBH values [58]. Similarly, in Kolhapur city, Maharashtra, India, *S. saman* was reported to have the highest carbon stock of 0.99 Mg C per tree because of its large average DBH of 58 cm [59].

Despite being the most abundant species, *H. tiliaceus* contributed only 3.5% (Figure 3) of the total AGC due to its smaller mean DBH than *S. saman* (Table 2). This finding underscores the significant role of tree size in carbon storage, where species with larger diameters and greater biomass accumulation, such as *S. saman*, contribute disproportionately to the overall carbon stock. These results are consistent with earlier studies, which emphasized that relatively large trees with faster growth rates in natural environments sequester more carbon than do medium-sized trees, which grow at moderate rates and accumulate less carbon at a slower pace [60-61].

Moreover, in this study, species-specific differences in AGC were also influenced by site conditions, particularly tree spacing. Wider spacing promotes greater growth, resulting in higher carbon stocks [62-63]. For example, *S. saman* was found at sites such as People's Park and the USeP – Obrero Campus, where wider spacing allowed for optimal growth, whereas the ALI Davao Carbon Forest, characterized by narrower spacing, exhibited reduced carbon storage. This spatial variation emphasizes the interplay between site management and carbon sequestration. While fast-growing, large-diameter species such as *S. saman* should be prioritized for maximizing carbon stocks, urban forest management must balance this approach with the need to maintain biodiversity and ecological stability [61].

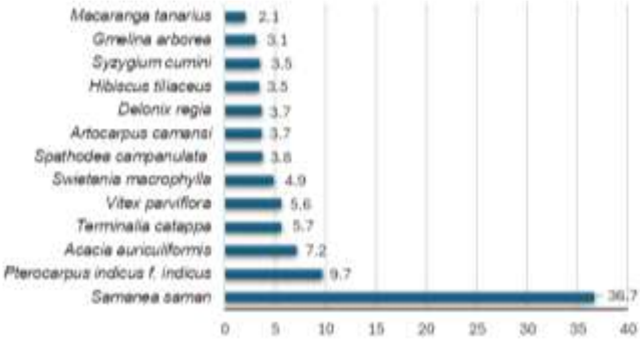

Figure 3 Major contributors to AGC.

Table 2 Average DBH (cm) of urban trees

Species	Average DBH
Mangifera indica L.	22.2
Spathodea campanulata P. Beauv.	31.3
Ceiba pentandra (L.) Gaertn.	17
Terminalia catappa L.	25
Homalanthus populneus (Geiseler) Kuntze	11.4
Macaranga tanarius Müll.Arg.	16.5
Melanolepis multiglandulosa Rchb. & Zoll.	18
Samanea saman (Jacq.) Merr.	66.3
Acacia auriculiformis A.Cunn. ex Benth.	25.7
Delonix regia (Bojer) Raf.	39.1
Leucaena leucocephala (Lam.) de Wit	57.7
Senna siamea (Lam.) H.S. Irwin & Barneby	23.5
Pterocarpus indicus f. *indicus* Willd.	36
Gmelina arborea Roxb.	23.7
Vitex parviflora Juss.	31
Hibiscus tiliaceus L.	15
Didymocheton gaudichaudianus A.Juss.	13
Swietenia macrophylla King in Hook.	32
Azadirachta indica A. Juss.	44
Artocarpus camansi Blanco	21
Ficus benjamina L.	27
Ficus nota Merr.	14.9
Syzygium cumini (L.) Skeels	53.8
Nauclea orientalis L.	27.9
Sterculia foetida L.	26

4) Relationships of stem length and canopy area with AGC

Evaluating the relationships between the canopy area and stem length and cumulative AGC is important, as this relationship may improve the accuracy of AGC estimates and help reveal potential underestimations, particularly for trees that are not fully represented by DBH and canopy height alone.

In the present study, with p values less than the significance level of 0.05, it was concluded that there was a significant relationship between stem length, canopy area, and AGC. A weak positive relationship exists between stem length and AGC, as evidenced by $r_s = 0.166$ (Table 3), suggesting that although AGC remains similar across trees, stem length varies widely (Figure 4). This variability observed in stem length without corresponding increases in AGC can be attributed to species-specific growth patterns, age, and architectural traits [64]. Previous studies emphasized that tropical tree species often display trade-offs between growth rates and structural attributes, such as stem diameter and height, which influence carbon storage.

For example, trees that prioritize rapid height growth to gain light access may show substantial increases in stem length without proportional biomass gains, reflecting an adaptation to highly competitive environments. This growth strategy is more typical of pioneer or shade-intolerant species, which invest in elongation early in their life cycle to surpass competing vegetation [65]. Furthermore, variations in stem length can be linked to nutrient availability; a reduced nutrient supply can decrease photosynthetic capacity [66], thereby limiting the carbon available for wood growth and contributing to the observed differences in AGC across species [67].

In contrast, a strong positive relationship exists between canopy area and AGC, as evidenced by $r_s = 0.631$ (Table 3), indicating that larger canopy areas generally correspond to higher AGC (Figure 5). However, this relationship was substantially influenced by the presence of several trees with exceptionally large canopy areas. Specifically, out of the 358 trees surveyed, 73 individuals (20.4%) had canopy areas ranging from 5.3 to 14.1 m^2, disproportionately impacting the overall results. This can be supported by a previous study that stated that a larger canopy area may help balance lower biomass estimates in certain forests with shorter trees, as even relatively short trees can develop wide, sunlit crowns that extend into or above the forest canopy [68]. Even though these trees are relatively short, their large canopy area can help them store as much biomass as taller trees might. Moreover, their study suggested that adding crown dimensions to allometric equations for estimating tropical tree biomass can significantly increase accuracy, reducing the long-standing uncertainty in forest biomass calculations.

This finding is also consistent with a study conducted in the urban area of Auckland city, New Zealand, where stem length was identified as the least effective indicator of AGC, whereas canopy area emerged as a more reliable predictor [34]. The emphasis on canopy area as a predictor underscores the importance of tree canopy area in assessing AGC, highlighting that larger canopies contribute more directly to the carbon sequestration potential of trees in urban environments.

Table 3 Spearman correlations

X	Y	r_s	p
Stem Length	AGC	0.166	0.002
Canopy Area		0.631	< 0.001

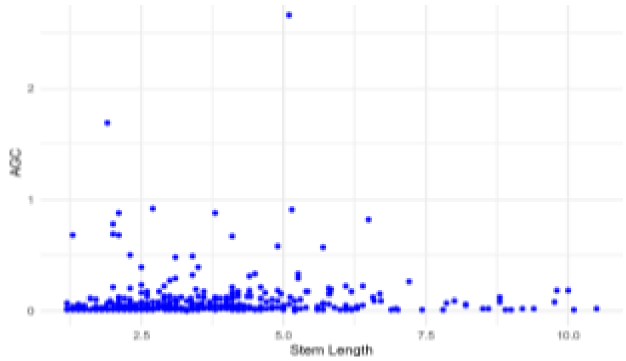

Figure 4 Relationship between AGC and stem length.

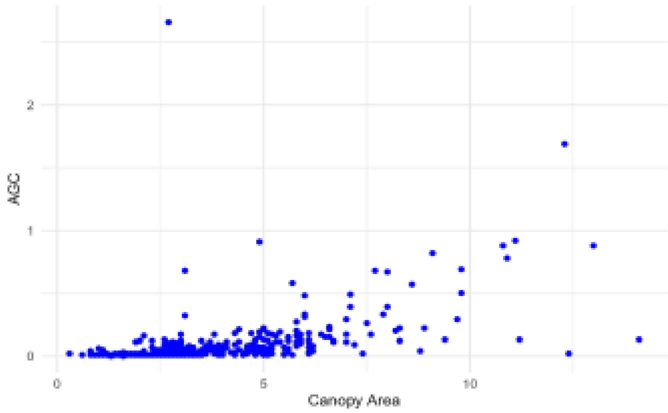

Figure 5 Relationship between AGC and canopy area.

5) Importance of carbon stock monitoring in achieving the SDGs

Monitoring the urban carbon stock is crucial for achieving the SDGs, particularly in mitigating climate change and promoting a sustainable urban environment. This contributes to the UN REDD+ program [76], supporting climate policy implementation in Davao City. Southeast Asia faces rapid forest shrinkage, making land conversion for agriculture and urbanization major CO_2 emission sources [77]. Urbanization exacerbates pressures on green spaces, impacting urban health [78], necessitating adherence to UN SDG 11 for inclusive, resilient, and sustainable cities with accessible green spaces [79] and SDG 15 for the protection, restoration and promotion of the sustainable use of terrestrial ecosystems. This goal requires prioritizing tree preservation and green space development, considering that tree density is vital for environmental health [80]. A 2022 characterization of Davao City green spaces [81] revealed varying tree densities, highlighting the potential for increased planting, as successfully demonstrated by the reforestation of the ALI Davao Carbon Forest. Carbon stock management, as employed in this study, provides crucial insights into the carbon storage capacity of tree species, which is essential for quantifying urban trees and their role in climate change mitigation and advancing the Philippine 2021 Local Climate Change Action Plan and the United Nations Framework Convention on Climate Change (UNFCCC) climate action commitments, thereby informing evidence-based policymaking.

Conclusions

This study demonstrated that urban green spaces in Davao City, which are mostly dominated by large canopy trees such as *Samanea saman*, possess significant carbon sequestration potential. The strong correlation between tree size and carbon stock stresses the importance of conserving existing mature trees and prioritizing the planting of fast-growing, large-canopy species in urban reforestation efforts. Furthermore, the size of urban green spaces may not be the primary determinant of carbon sequestration efficiency; rather, focusing on planting and managing appropriate tree species and ensuring healthy ecosystem conditions within these spaces is likely more crucial for enhancing carbon storage per unit area.

For future research, it is recommended to include quantification of belowground carbon stock and to conduct temporal monitoring of both aboveground and belowground biomass. The use of more economical methods employing geospatial technology is also suggested.

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