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RESEARCH ARTICLE

The Role of Urban Forest in Providing Landscape Services: A Case Study from Bekasi City, West Java, Indonesia

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ABSTRACT

Urban forests are critical green infrastructures that provide multiple landscape services, including carbon sequestration, microclimate regulation, and biodiversity support, thereby contibuting to global climate adaption and urban sustainability. This study aimed to analyze the Patriot Bina Bangsa (PBB) Urban Forest's role in providing comfort through carbon storage and sequestration using the i-Tree Eco model, microclimate monitoring, and evaluating its contribution to landscape services. Data were collected from 12 sample plots using a stand inventory that refers to the i-Tree Eco data collection protocol. An estimated 750 trees, dominated by *Nauclea orientalis* and *Swietenia macrophylla*, with a moderate species diversity index (H' = 1.7). The urban forest stored 241 tons of carbon and sequestered 17.85 tons annually, valued at approximately 151 million rupiah. Temperature Humidity Index (THI) values indicate moderate thermal comfort, especially during peak hours. A multifunctional landscape service assessment shows high for regulation functions and landscape disservices, and medium for habitat, information, and production. These findings highlight the importance of urban forests and tree diversity in maintaining landscape services. The indicators outlined in this study provide a basic method for assessing the services provided by urban forest landscapes. It can be used as a tool to improve the management of urban forest systems and monitor the impact of urban greening policies on human well-being in urban landscapes.

Introduction

Urban forests include all trees growing in urban areas [1], both in public and private spaces that provide various landscape services to the community [2]. Urban forests provide diverse landscape services. They improve air quality and mitigate climate change by reducing air pollutants and greenhouse gas emissions through carbon sequestration [3,4]. They also regulate temperature by shading impervious surfaces and contribute to stormwater management. Additonal functions include noise reduction, as well as psychological, social, and recreational benefits. Urban forests also support wildlife and fulfil aesthetic needs [5]. To put it simply, these trees are environmental capital and key infrastructure in urban locations that need to be managed and maintained. Variations in spatial design and tree structures, such as tree density, species richness, and tree diameter, influence the quality of ecosystem services provided to urban areas [6]. However, it is necessary to consider reliable evaluation tools.

The i-Tree tool offers practical vegetation analysis and provides useful urban forest structure data for future management needs [7]. Monitoring the urban forest using this technique makes it easy to validate changes in urban forest structure and composition. As a result, important landscape services can be quantified and valued, enabling efficient urban forest management. The i-Tree Eco model supports decision-making in urban forest management in areas such as determining planting priorities, developing urban forest plan, managing

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environmental regulations, evaluating trade-offs between various landscape services, and promoting equity in urban forest benefits [8]. The i-Tree Eco model has been widely applied in diverse contexts worldwide. In Europe, it has been used to quantify park tree ecosystem services in Germany and to evaluate urban air quality impacts in Dublin by combining air monitoring with i-Tree modelling [9,10]. In Asia, applications have focused on planning strategies for carbon sequestration in South Korea and assessing green infrastructure to support ecosystem balance in China [11,12].

Meanwhile, studies on the assessment of ecological benefits of urban forests in Indonesia using the i-Tree Eco model have mostly been conducted in large cities. For example, urban tree management in the Jakarta urban forest using i-Tree Eco can improve the accuracy of the inventory in the long term [13] and tree inventory for urban forest landscape service assessment in Bandung City [14]. These studies demonstrate the versatility of i-Tree Eco in capturing ecological and planning dimensions of urban forest. However, few studies have integrated ecological metrics with multifunctional landscape service assessments, particularly in rapidly urbanizing contexts such as Indonesia. Therefore, it is necessary to conduct urban forest inventories in other urban areas to expand the database for urban forest management and improve the quality of life of the community.

This study responds to that gap by explicitly evaluating the ecological performance of the Patriot Bina Bangsa (PBB) Urban Forest in Bekasi City, Indonesia. Situated within the rapidly urbanizing *Jabodetabek* region, the forest represents a critical green space in a city where urban expansion has placed increasing pressure on ecological sustainability. This study aims to (1) quantify the carbon stock and annual sequestration potential of the PBB Urban Forest, (2) evaluate its microclimatic comfort using the temperature humidity index (THI), and (3) assess its performance across multiple landscape service functions, namely regulation, habitat, information, and production.

Materials and Methods

Study Area

Bekasi City spans 213.12 km² and is part of the Greater Jakarta (*Jabodetabek*) metropolitan region. As of 2020, only 2.43% of the city's land was allocated to green space, far below the 30% national target [15]. This research focused on the PBB Urban Forest, which is in Kayuringin Jaya Village, South Bekasi Subdistrict, at a latitude of 6°14'03.2"S, 106°59'32.6"E., as shown in Figure 1. The urban forest is managed by the *Dinas Lingkungan* Hidup (DLH Bekasi City), spans approximately 3 hectares (ha), and serves multifunctional roles as a public recreation space, biodiversity habitat with a collection of 72 plant species and 24 animal species, and carbon storage. It is equipped with various public facilities, including sports fields, prayer rooms, gazebos, and playgrounds.

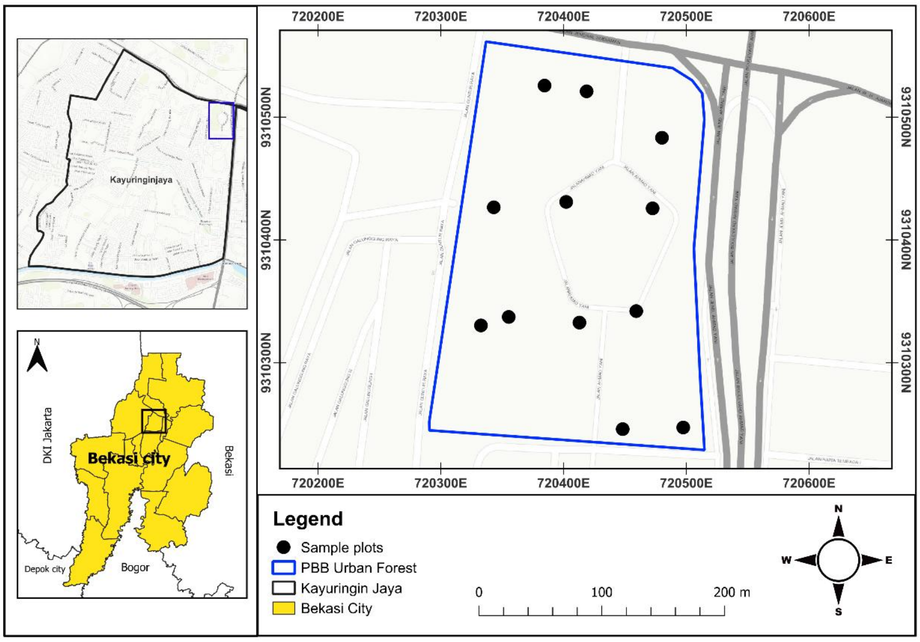

Figure 1. Study area.

Field Survey

The research was conducted from November 2023 to January 2024 for primary data collection. The number of samples and plots to be taken was determined by the detailed, statistically based sampling and data collection protocols in i-Tree Eco. Field data were drawn from 12 circular, randomly distributed plots (0.04 ha and 22.6 m in diameter). A total of 12 circular plots were randomly established across the forest using a stratified random sampling approach to ensure spatial representativeness. Each plot was 0.04 ha in size (radius of 11.28 m), covering a total sampled area of the urban forest. The number of plots used represents 10% of the total area, with increments of 5 to 10% to avoid data loss.

For each sample plot, the examined data collection was divided into plot data and tree data. The plot data included geolocation, percent cover, ground cover, and photo documentation. Meanwhile, the inventoried tree data included tree species (genus at a minimum), diameter breast height, distribution of tree diameters/DBH (cm), total height (m), crown width (m), percent crown missing (%), crown health condition (%), and crown light exposure (CLE) (1 to 5). This baseline information led to a comprehensive analysis of the ecology and physiology of the trees in the study area.

Field data on the structure of the urban forest was processed using i-Tree Eco software to quantify biophysical and economic landscape services, as the program already has all accessible data templates. i-Tree Eco performed tree condition checks and calculations to estimate the number of trees in the urban forest, canopy area, carbon storage and sequestration, and tree diversity was calculated by shannon-wiener index (H'), and species richness was calculated by evenness index. Species abundance was defined as the count of individuals of each species within a plot, while species richness referred to the total number of different species found per unit area. The diversity index criteria are as follows: $H' \leq 1$: low diversity; $1 < H' \leq 3$: moderate diversity; $H' \geq 3$: high diversity [16]. Species evenness index ranges from 0 to 1, where 1 indicates complete evenness [17]. All standard equations and calculation principles have been established in i-Tree Eco [7]. The economic valuation was derived as the present value of the discounted annual monetary benefits of the ecosystem service indicator over the tree's expected lifespan, which amounts to IDR 16,100 per metric ton of Carbon.

Thermal Comfort

Microclimate data were collected using Elitech RC-4HC data loggers, which were installed 1.5 meters above the ground. Air temperature and relative humidity were recorded at five-minute intervals over ten consecutive days. To assess thermal comfort, data were segmented into five periods of solar radiation exposure: morning (07:00 to 10:00), afternoon (11:00 to 16:00), evening (17:00 to 19:00), after sunset (20:00 to 23:00), and night (00:00 to 06:00) [18]. The THI was then calculated to evaluate perceived human comfort. The comfort index is calculated using equation 1 from [19]. The calculated THI values were interpreted based on the threshold classifications presented in Table 1, which define categories of thermal comfort according to Ige et al. [20].

$$THI = T - 0.55 \times (1 - RH) \times (T - 14.50) \quad (1)$$

where:

T : Air temperature (°C)

RH : Relative humidity (%)

THI : Temperature humidity index

Table 1. Thermal category thresholds of THI [20].

THI	Comfort index class category
≤ 21.10	Cold
21.11–23.80	Comfortable
23.81–26.60	Enough comfortable
≥ 26.61	Discomfort

Urban Landscape Services Indicator

Measuring landscape services in urban forests is challenging due to the complexities outlined in the introduction. A framework was employed to evaluate each site for urban forest sustainability. Indicators for urban forest landscape services are categorized into four function groups relevant to well-being, as identified by Dobbs et al. [21]: regulation, habitat, information, and production. Additionally, "ecosystem disservices" were incorporated as an indicator. The group indicator values represent the average of the landscape services within each of the four functional groups listed in Table 2.

Table 2. Indicator thresholds for assessing urban forest landscape services and disservices.

Landscape services	Value		
	Low	Fair	Good
Regulation function			
CO_2 Sequestration (ton/year)	0–0.05	0.05–0.2	> 0.2
Tree density (tree/plot)	0–2	2–4	> 4
Crown dieback (%)	> 50	25–50	0–25
Leaf area (ha)	< 0.1	0.1–0.2	> 0.2
Foliage	< 25% evergreen trees	25–50% evergreen trees	> 50% evergreen trees
Habitat function			
Shannon index	< 1	1–3.0	> 3.0
Evenness index	0–0.5	0.5–0.75	0.75–1.0
Ratio of native trees	< 25% of native trees	25–75% of native trees	> 75% of native trees
Information function			
Forest recreation	No tree cover	1–25% of tree cover	25–75% of tree cover
Production function			
Tree biomass (kg)	< 1	1–10	> 10
Green waste biomass (kg)	> 0.1	0.01–0.1	< 0.01
Ecosystem disservices			
Damage to infrastructure and risk to human safety	> 75% of the tree species have branches or trunks susceptible to breakage, and on average, they have good, fair, or poor conditions	< 25% of the tree species have branches or trunks susceptible to breakage and poor average tree condition	< 25% of the tree species have branches or trunks susceptible to breakage, and excellent, good, or fair average tree condition
VOC tree emissions (ton/year)	> 0.01	0.001–0.01	0–0.001
Emission CO_2 (ton/year)	> 0.01	0.001–0.01	0–0.001

The regulation function encompasses the benefits derived from managing ecological processes. These include climate regulation through carbon sequestration, air quality improvement, prevention of negative impacts from natural disasters, pest and disease control, erosion prevention, and maintenance of soil fertility, pollination, water purification, waste treatment, and flood control [22]. The habitat function refers to the provision of living spaces and the preservation of biological and genetic diversity. Habitats refer to the places that provide all of these things for a plant or animal—food, water, and shelter. Each landscape provides different habitats that can be critical to a species' life cycle.

Production function refers to an ecosystem's ability to provide biomass, food, and raw materials essential for humans and other living organisms. The production function refers to the potential of urban wood to provide a sustainable supply of biomass as an energy source, as well as a cost-effective ecosystem good [23]. Meanwhile, the information functions refer to the non-material benefits people derive from ecosystems, including spiritual enrichment, cognitive growth, reflection, recreation, and aesthetic experiences [22].

Ecosystem disservices, or costs, negatively affect well-being. Ecosystem disservices are the additional costs involved in urban forest management. For example, costs spent to address tree failures that negatively impact infrastructure and human safety [24]. Indicators like VOC and CO_2 emissions were not directly measured but inferred from i-Tree Eco simulations. These estimates depend heavily on tree species, condition, and modeled physiological parameters. Therefore, the emission estimates are treated as approximations and are primarily useful for comparative rather than absolute interpretation.

Specific methods for quantifying landscape services and disservices are listed by functional group and summarized in Table 2. Trees with no indicator value, or plots below the recommended values in the literature, were ranked as “low” and assigned a number value of 1. A moderate provision of landscape services was ranked as “medium” or fair and assigned a number value 2. A high provision of landscape services was ranked as “high” or good and assigned a number value 3.

The evaluation of the urban forest was conducted by considering the value of the landscape service function, based on the total score generated. The scores were calculated by summing the indicator values to produce a landscape service ranking. This ranking is used to standardize the indicators, group landscape services by function, and make the variables comparable. The landscape service rankings were categorized into low (1.00–1.50), low-medium (1.51–2.00), medium (2.01–2.50), and high (2.51–3.00), as presented in Table 3.

Table 3. Categories of urban forest landscape service levels based on indicator scoring results.

Score	Category
1.00–1.50	Low
1.51–2.00	Low-Medium
2.01–2.50	Medium
2.51–3.00	High

Results

Vegetation Composition and Structure

PBB Urban Forest is located in the South Bekasi Administrative City area, inaugurated in 2012, offering a combination of conservation and recreation. This urban forest is often used as a tourist spot, playground, jogging track, and even a camping ground due to its strategic location, size, and comprehensive public facilities. More than 750 trees are estimated to be growing in the forest area, with a tree cover of approximately 21.8%. More than 90% of the trees are in fair to very good condition. Nine target tree species were identified, dominated by *Nauclea orientalis* (30.4%), followed by *Swietenia macrophylla* (28.0%), *Terminalia catappa* (16.0%), *Cerbera manghas* (12.0%), *Acacia mangium* (4.8%), and other species (less than 4.5%) (Figure 2). This dominance contributes significantly to ecological functions such as carbon sequestration, though it may limit biodiversity resilience.

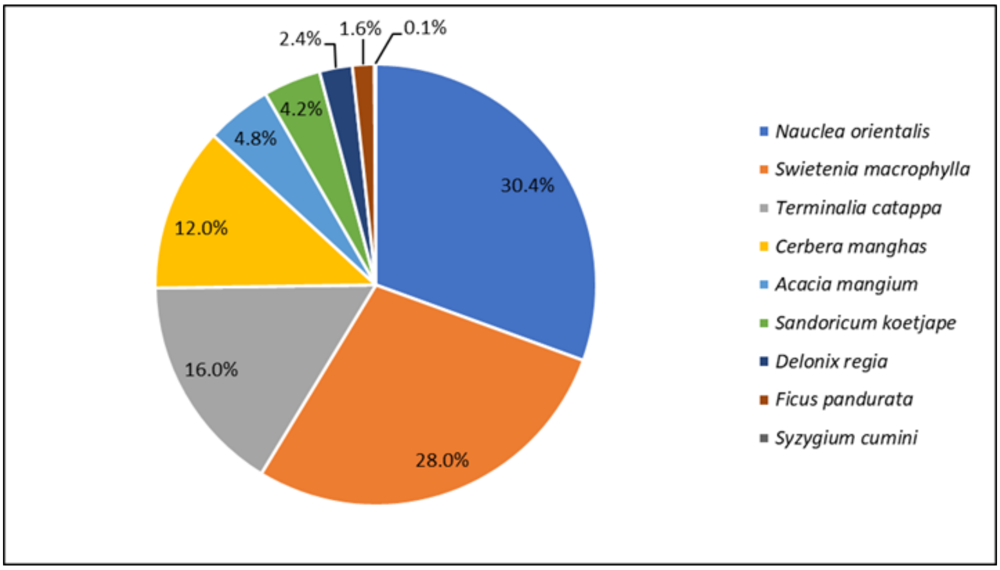

Figure 2. Proportion of target tree species.

Tree measurements were carried out on trees with DBH of more than 10 cm, which is related to the structure and vegetation that is considered quite stable within the next 10 to 20 years. The distribution of tree diameter classes indicates the condition and capacity of the urban forest ecosystem to support landscape services. This distribution shows that most trees fall into small to medium diameter classes, with only a few in larger diameter classes. The distribution shows that the majority of the trees are in the medium size (21–30 cm DBH), while the number of large-sized trees (41 cm and above) is much less. Trees in the 21–30 cm diameter class had the highest frequency of about 45 trees. The frequency of trees decreased as the DBH size increased. The largest diameter class trees (61 cm and above) had the lowest frequency of about 5 trees. In contrast, the 12–20 cm diameter class has a relatively moderate number of trees with a frequency of about 20 trees which can be seen in Figure 3. This distribution is often found in urban forests or rehabilitation areas consisting of young or growing trees, with fewer large old trees.

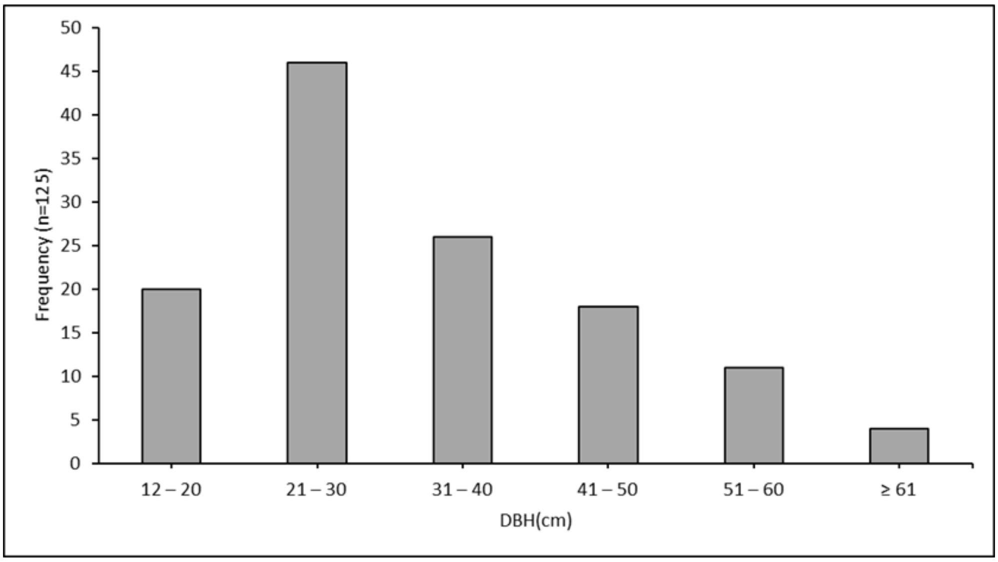

Figure 3. DBH in the PBB Urban Forest shows varying frequencies across size classes.

The importance value (IV) is determined by summing the population percentage and the leaf area percentage. Importance values rank species within a site based on three criteria: (1) the occurrence rate of a species within the urban forest area, (2) the total number of individuals of the species, and (3) the area of the urban forest [25]. In the current study, four tree species have importance values greater than 10, i.e. *Nauclea orientalis*, *Swietenia macrophylla, Terminalia catappa,* and *Cerbera manghas* as shown in Table 4. The species IV analysis confirmed *N. orientalis* as the ecologically dominant species with an IV of 81.2. Diversity indices such as the shannon index measure biodiversity by accounting for the number of species present and their relative abundance. These indices are useful metrics for making comparisons across different spatial scales [17]. The shannon index shows that the study site's value of 1.7 is lower than that reported in Jakarta City [13]. The value is in a moderate range, suggesting that the strict conservation of trees increases the diversity and abundance of trees. The evenness index using i-Tree Eco shows a value of 0.8, or stable ecosystem conditions and high uniformity.

Table 4. Importance value and diversity indices of PBB Urban Forest.

Species	Status	*Growth rate**	Percent population	Percent leaf area	IV*	Shannon	Evenness
Nauclea orientalis	Exotic	SG	30.4	50.8	81.2		
Swietenia macrophylla	Exotic	SG	28.0	19.8	47.8		
Terminalia catappa	Native	SG	16.0	12.0	28.0		
Cerbera manghas	Native	SG	12.0	6.4	18.4		
Acacia mangium	Native	FG	4.8	3.7	8.5	1.7	0.8
Sandoricum koetjape	Native	FG	4.0	3.6	7.6		
Delonix regia	Exotic	FG	1.6	2.1	3.7		
Ficus pandurata	Exotic	SG	2.4	0.9	3.3		
Syzygium cumini	Exotic	SG	0.8	0.6	1.4		

*FG: fast growing, SG: slow growing, IV: importance value.

Carbon Storage and Sequestration

Carbon storage refers to the total amount of carbon that a tree has stored over the years of its growth. Carbon is captured in the form of carbon dioxide through the process of photosynthesis. This is the process of producing organic matter needed for growth [11]. Carbon sequestration refers to the process of capturing and storing carbon in a material over time, thereby reducing the amount of carbon dioxide that the material releases into the atmosphere. Carbon sequestration is the process by which atmospheric carbon dioxide is transformed into organic compounds through photosynthesis in trees, plants, phytoplankton, and algae [26].

The total carbon storage of the PBB urban forest was estimated at 241 tons, dominated by *Nauclea orientalis*, which has the highest carbon storage (> 100 tons) with an economic value reaching IDR 80 million, followed by *Swietenia macrophylla* (> 50 tons), and *Terminalia catappa* (< 40 tons) (Figure 4a). Annual carbon sequestration was 17 tons/year, with an estimated economic value of IDR 11 million/year. *Terminalia catappa* and *Swietenia macrophylla* achieved the highest annual carbon sequestration, around 3 to 4 tons/year, with an economic value of approximately IDR 4 million/year for each tree. In contrast, trees such as *Delonix regia*, *Syzygium cumini*, and *Ficus pandurata* sequester the least annual carbon (< 0.5 tons/year), with small economic value (< IDR 200.000/year) (Figure 4b).

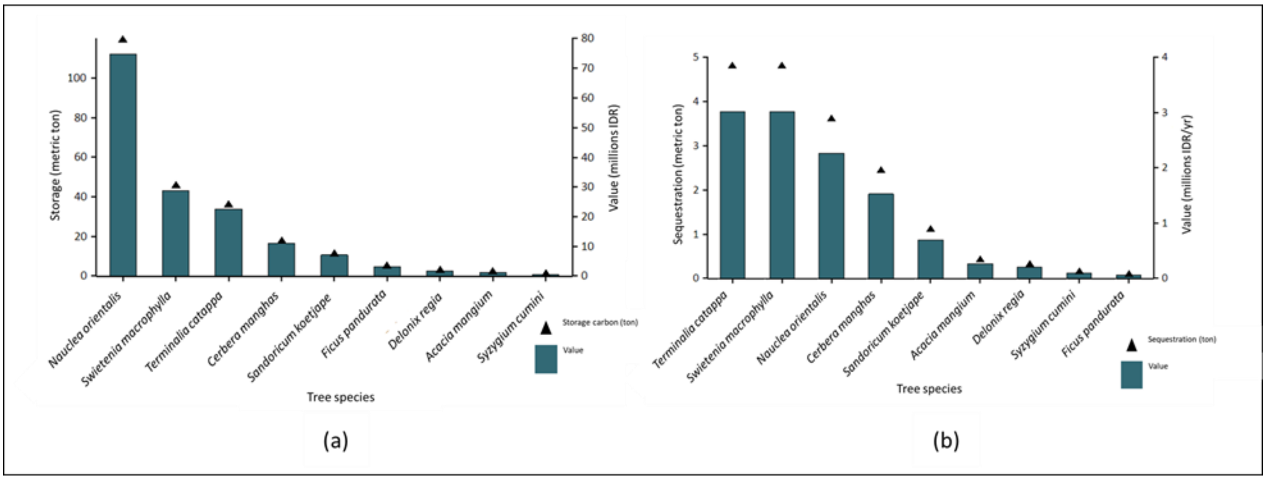

Figure 4. (a) Total carbon storage and (b) annual carbon sequestration by tree species.

Thermal Comfort

Figure 5 illustrates the distribution of weather variables over the ten measurement days. Results are presented for different periods of the day: morning (07:00 to 10:00), afternoon (11:00 to 16:00), evening (17:00 to 19:00), after sunset (20:00 to 23:00), and night (0:00 to 6:00). In Figure 5a, which shows the air temperature, the lowest temperatures are observed in the morning and at night, ranging from approximately 26 to 28 °C. This trend is consistent with typical daily temperature patterns where temperatures peak in the afternoon, with a median of about 31 °C and reaching up to 32 °C. The lower whiskers on the box plots in the afternoon are longer compared to other times of the day, indicating a consistent drop in air temperature, most likely related to the usual rainfall. After the afternoon peak, the temperature gradually declines during the evening and stabilizes between 27 °C and 29 °C after sunset. Meanwhile, Figure 5b illustrates the changes in relative humidity throughout the day. In the morning, the humidity level is around 77%. When the temperatures are highest in the afternoon, the humidity levels are at their lowest (67.94%), as humidity decreases with increasing temperature. As the day shifts to evening and night, the humidity increases again to around 78% in the evening and peaks at almost 90% at night.

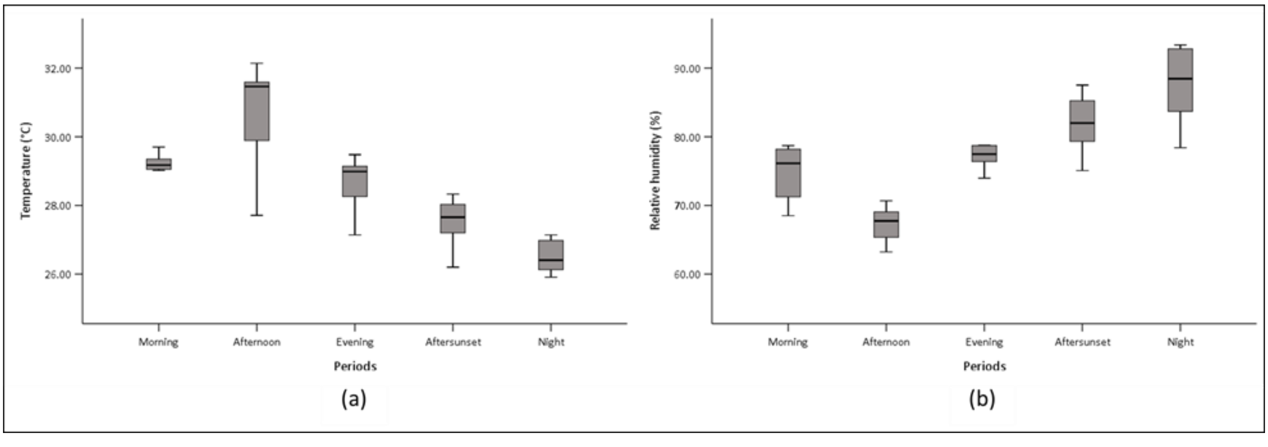

Figure 5. Observed (a) period means air temperature and (b) mean relative humidity at the site over all ten fieldwork days in which data were collected.

The THI is used to assess the daily comfort level, which can help the development of urban planning to be more comfortable and environmentally friendly, as shown in Table 5. The mean air temperature and relative humidity measurements for ten days in the morning from 07:00 to 10:00 is 29.20 °C and 74.76%, in the afternoon at 11:00 to 16:00 is 30.82 °C and 67.94%, in the evening at 17:00 to 19:00 is 28.57 °C and 77.36%, in the after sunset 20:00 to 23:00 is 27.51 °C and 82.38% and in the night at 00:00 to 06:00 is 26.49 °C and 87.64%. The daily air temperature was obtained with an average of 25.22 to 32.69 °C, and relative humidity of 67.94 to 87.65%. The THI values range from 25.68 to 27.94. THI is a measure that combines temperature and humidity to assess human comfort. Higher THI values generally indicate discomfort. Morning, afternoon, and evening are classified as "Discomfort", indicating that both temperature and humidity levels are high enough to create significant discomfort for individuals. After sunset and at night, the comfort level shifts to "Enough Comfortable", because temperatures decrease, the high relative humidity continues to affect comfort, though not as severely as during the day. However, the high canopy cover (21.8%) and evergreen tree ratio (48.8%) suggest the forest contributes to moderating microclimate extremes. A paired-site control comparison is recommended for future studies.

Table 5. Summary of air temperature, relative humidity, and THI values for different time periods across ten observation days in the study area.

Period	Temperature (°C)			Relative humidity (%)	THI	Comfort index class category
	T min	T max	T Av			
Morning	26.48	31.63	29.20	74.76	27.16	Discomfort
Afternoon	26.26	32.69	30.82	67.94	27.94	Discomfort
Evening	26.19	30.13	28.57	77.36	26.82	Discomfort
After sunset	26.14	28.58	27.51	82.38	26.25	Enough comfortable
Night	25.22	27.81	26.49	87.65	25.68	Enough comfortable

Urban Landscape Services

An integrated scoring system based on i-Tree data and functional indicators (Table 2–3) was used to evaluate the PBB Urban Forest's landscape service levels. Scores were assigned based on indicator thresholds and grouped into five functions: regulation, habitat, information, production, and ecosystem disservices (Table 6). Each value is based on field data and i-Tree Eco analysis, assigned to performance classifications.

Table 6. Summary of urban forest landscape services and disservices across five functional categories.

Landscape services		Value		Category
Regulation function	CO_2 Sequestration	0.52 ton/year	Good	High
	Tree density	10 trees/plot	Good	
	Crown Dieback	16.86%	Good	
	Leaf area	0.23 ha	Good	
	Foliage	48.80% evergreen trees	Fair	
Habitat function	Shannon index	1.7	Fair	Medium
	Evenness index	0.8	Good	
	Ratio of native trees	37.6% of trees are native	Fair	
Information function	Forest recreation	21.8% of tree cover	Fair	Medium
Production function	Tree biomass	50.67	Good	Medium
	Green waste biomass	0.66	Fair	
Ecosystem disservices	Damage to infrastructure and risk to human safety	83.14% on average, they have good, fair, or poor conditions	Good	High
	VOC tree emissions	0.0034 ton/year	Fair	
	Emission CO_2	0.0001 ton/year	Good	

Regulation Function

In general, the production function exhibited high indicator values due to strong performance in CO_2 sequestration (0.52 ton/year), tree density (10 trees/plot), crown condition (16.86% dieback), and leaf area (0.23 ha). CO_2 sequestration indicates that the urban forest effectively absorbs carbon dioxide, helping mitigate climate change, and this is attributed to the higher tree density and the presence of older, closed-canopy trees. Evergreen foliage composition (48.8%) was rated fair, suggesting potential improvement through species selection.

Habitat and Information Function

Habitat function is medium**.** The shannon index (1.7) and native species ratio (37.6%) indicate moderate ecological value. Although the evenness index (0.8) suggests stable diversity, a higher proportion of native species would improve resilience. The information function is medium due to the low tree cover (21.8%) in recreational zones. While the area supports various public functions, more tree cover could be dedicated to improving the recreational experience for the public.

Production Function and Ecosystem Disservices

Overall, the production function varied from medium to good with healthy biomass (50.67 kg/plot) but moderate green waste levels. This indicates a relatively healthy and productive forest in terms of biomass, contributing positively to carbon sequestration and ecosystem services. A moderate amount of green waste is generated in the forest. Efficient management of this waste is essential for sustainability. Overall, the indicator values for ecosystem disservices are relatively high, indicating low negative impacts. This implies a lower probability of trees causing damage to infrastructure or posing risks to human safety. CO_2 emission indicator values were good, showing minimal emissions, which is positive as the urban forest helps mitigate rather than exacerbate carbon emissions.

Discussion

Vegetation Composition and Structure

The high dominance of *Nauclea orientalis* and *Swietenia macrophylla* provides benefits in terms of their large biomass for carbon sequestration. However, this condition may reduce biodiversity and increase the site's vulnerability to ecosystem disturbances, such as pest or disease attacks. *Naucluea orientalis* and *Terminalia catappa* have a wide canopy that effectively provides shade and regulates the urban microclimate, enhancing thermal comfort for visitors to the urban forest. *Nauclea orientalis* is classified as a multipurpose tree species (MPTS) due to its ability to serve ecological, social, and economic purposes. In ecological purposes, this species offers a wide crown that can provide shade, making it an ideal choice for urban areas. Its large crown diameter is particularly beneficial for creating shaded spaces in urban environments [27]. Meanwhile, *Delonix regia* and *Cerbera manghas* have high aesthetic value with their striking flowers, adding visual appeal to the urban landscape. *Delonix regia* is commonly found in gardens and parks, both in private and public green spaces, and is frequently used for shading along roads and highways in Indonesia [28].

The abundance of small and medium-sized trees indicates that they are relatively young and have high growth rates, optimizing carbon sequestration potential to support urban ecosystems in the coming years. Meanwhile, the presence of large trees enhances ecosystem stability and contributes to environmental resilience against climate change, playing an important role as carbon storage. It is essential to maintain the health and longevity of these large trees to ensure optimal landscape service provision in urban areas [29]. Large trees provide much greater landscape services, including air pollution removal, carbon sequestration and storage, energy savings, rainwater harvesting, and climate change adaptation, compared to smaller trees [30].

High importance values do not mean that these trees should be recommended for future planting, but rather that these species currently dominate the urban forest structure, but the importance of dominant trees can affect carbon stocks in urban forest areas. According to Briantama and Basukriadi [31], the higher IV is positively correlated with the carbon stock value. The complexity of vegetation is important for improving the landscape services provided by urban forests. A high level of diversity can reduce the potential damage from natural pests or diseases, but it may also pose a threat to native species if exotic species dominate and invade, replacing the native ones. Urban forests consisting of a mix of native and introduced tree species have higher species diversity [32]. Istomo and Sari [33] added that a high diversity index value indicates a greater environmental capacity to support survival, leading to more stable forest communities. A high evenness value means that there is a uniform distribution among species in a given ecological environment [25]. Previous studies [34] state that the evenness value reflects the uniform distribution of each species in relation to dominance. A higher evenness value indicates a more balanced distribution, meaning the evenness index is inversely proportional to the dominance index.

Carbon Storage and Sequestration

Trees such as *Nauclea orientalis* and *Swietenia macrophylla* have large biomass and long lifespans, which can store large amounts of carbon, whereas *Terminalia catappa* demonstrates high annual sequestration rates due to its fast growth, making it a good option for enhancing carbon sequestration. Trees with high carbon storage generally also have high annual carbon sequestration rates, but this pattern is not always consistent. It depends on the tree's age, growth rate, and biomass. The amount of carbon sequestered annually increases with the size and health of each tree [35]. In addition, a tree's biomass and carbon sequestration depend on its leaf area, importance value, and canopy cover [36]. Annual carbon sequestration efficiency reflects the tree's yearly capacity to absorb carbon, which is influenced by factors such as tree size, health, canopy coverage, and spatial distribution [12]. Trees such as *Nauclea orientalis* and *Swietenia macrophylla* are suitable for long-term conservation programs, while *Terminalia catappa* is ideal for rapid rehabilitation purposes. On the other hand, trees with low sequestration can be maintained to increase biodiversity, despite their limited carbon contribution. Total carbon storage and sequestration in the study area is lower compared to the estimates for Babakan Siliwangi Urban Forest, which are 381 tons and 25 tons/year, respectively [14]. However, carbon sequestration in the study area is only about ten percent of the total carbon sequestration of five urban forests in Jakarta, Indonesia, which is 184.4 tons/year [37].

Thermal Comfort

The highest humidity levels are a result of solar radiation, where the temperature drops and humidity rises from sunset to sunrise. The lower air temperature in the urban forest proves that the urban forest plays a role in reducing the surrounding air temperature. This aligns with previous studies showing that urban forests improve air quality [38]. Vegetation cover can block sunlight, reducing temperatures under the canopy [39]. Vegetation is also able to cool itself and its surroundings through the evapotranspiration process. The presence of vegetation also influences the humidity levels due to transpiration/evaporation, which adds moisture to the air [40].

This level of discomfort is likely to be high, especially during the peak afternoon hours when temperatures are highest. The high temperatures in city parks are caused by the lack of surrounding vegetation, which prevents the creation of a comfortable microclimate [41]. THI can be improved by planting more trees, which help block solar radiation and lower air temperature through transpiration, thus absorbing significant heat from the surroundings [42]. In addition, tropical urban parks with high heterogeneity in land use and land cover types can enhance evapotranspirative cooling from vegetation, helping to improve thermal comfort [43]. This study didn’t include repeatability across multiple sites or the use of control areas (non-forested or open), which limits the ability to identify specific cooling effects of the PBB Urban Forest. Future studies should include comparisons of separate sites and repeatability of data to control for daily variability and site bias.

Urban Landscape Services

Regulation Function

Urban forest areas have higher carbon sequestration capabilities due to their tree density. High tree density plays an important role in increasing the ability to sequester CO_2 through photosynthesis. However, the presence of more dead crowns indicates that urban forest areas are experiencing greater ecological pressures, such as pollution or sub-optimal management. Urban forests with more species with high tolerance and evergreen leaves can adapt to warmer and drier environments and respond to climate change [44].

Habitat and Information Function

Non-native species can also enhance diversity, which in turn can boost ecosystem function and productivity [32]. Tree diversity in urban forest ecosystems helps preserve fauna biodiversity and provides local communities with more opportunities to connect with nature [45]. High native tree ratios support the ecological sustainability of urban forests, but the introduction of fast-growing trees must be done carefully to avoid the dominance of non-native species that can reduce native tree ratios and protect local biodiversity.

Fast-growing trees are introduced to accelerate canopy cover in urban areas, but require ongoing management in the form of thinning to control invasive species and promote the establishment of desirable species [46]. Forests offer numerous opportunities for both active outdoor recreation and peaceful relaxation, providing a refuge from the stresses of urban life [47]. Specifically, the existential and non-use values of urban trees, or the value people attribute to various urban forest structures, could be utilized to more accurately quantify the connection between urban forests and well-being [21].

Production Function and Ecosystem Disservices

The potential of utilizing urban tree waste is diminished due to production costs, leading to underutilized products and revenue. In addition, landscape services' benefits can be derived through tree waste utilization, that reduces the use of fertilizers and fossil fuels in energy production [48]. More regular tree maintenance is still required to minimize potential negative impacts. The highest indicator values were attributed to the decline in air quality caused by VOCs and CO_2 emissions from trees and associated maintenance activities, which stemmed from the presence of a larger number of low-VOC-emitting tree species. For example, Storm damage was linked to the aging of trees, which increased the risk of falling branches or tree trunks [49].

Relationship of urban forest service impact with *Peraturan Menteri Agraria dan Tata Ruang/Kepala Badan Pertahanan Nasional* (ATR/KBPN) Number 14 Year 2022

The PBB Urban Forest constitutes one of the strategic RTH (*Ruang Terbuka Hijau*) in Bekasi City, delivering significant ecological, social, and aesthetic contributions to the surrounding community. *Peraturan Menteri Agraria dan Tata Ruang/Kepala Badan Pertahanan Nasional* No. 14 of 2022, concerning the provision and utilization of green open spaces, provides a regulatory framework for managing the fulfillment of RTH to at least 30% of the total urban area. However, Bekasi City currently fails to meet this requirement, with only approximately 16.32% of its total area classified as RTH [50]. The provision and utilization of RTH considers multiple aspects, including ecological functionality, water absorption capacity, economic value, aesthetic appeal, socio-cultural benefits, and disaster mitigation.

The existing vegetation in the area has far exceeded the prescribed standards for providing shade, carbon sequestration, and air pollution mitigation, particularly when assessed from an ecological function. Nevertheless, species diversity remains limited due to the predominance of *Swietenia macrophylla* and *Nauclea orientalis*. Notably, the presence of *Delonix regia*, characterized by its wide and umbrella-shaped crown, creates a distinctive lushness and provides cool shade and comfort for anyone sheltering beneath it. Vegetation diversity further enhances the aesthetic function of urban forests, as a higher species richness and stratification amplify the visual and ecological appeal of the landscape [38]. The regulation emphasizes the importance of urban forests as centers for recreation, education, and social community. The PBB Urban Forest is an active public space that facilitates opportunities for recreation, academic research, and visual or psychological enjoyment. It also provides space for active activities (i.e., sports, jogging, aerobics) and passive activities (i.e., sitting, resting, relaxing, and reading). The PBB Urban Forest fulfils a social function by fostering connections between community groups.

Various activities conducted by visitors can promote high social awareness in urban environments, helping to mitigate individualistic attitudes. As a hub for social engagement, the PBB Urban Forest is equipped with various sports facilities, including roller-skating rinks, running tracks, basketball courts, playgrounds, and entertainment amenities, which collectively enhance its appeal as a prominent urban attraction [51]. A multifunctional plaza located at the center of the PBB Urban Forest serves as a shared communal space, accommodating both individual and group activities. Visitors frequently utilize this space for a range of purposes, including commercial transactions, exercises, and government-organized events, such as weekly pop-up markets coinciding with Car-Free Day (CFD) events. Furthermore, the plaza can also be used as an emergency evacuation site. However, it is not equipped with visible direction signs or supporting elements such as assembly points or clearly marked evacuation routes, which could enhance its utility during disaster scenarios.

Conclusions

The PBB Urban Forest significantly contributes to landscape services in Bekasi City through carbon storage (241 tons) and annual sequestration (17 tons), despite discomfort-level microclimatic conditions (THI 25.68 to 27.94). It ranks high in regulation functions and disservices, but only moderate in habitat, information, and production. Future research should expand its temporal and spatial coverage and incorporate community perceptions. Recommendations include enhancing tree species composition by prioritizing native and fast-growing shade trees to improve thermal comfort and biodiversity, integrating forest functions into urban planning, and strengthening long-term monitoring. PBB Urban Forest holds strong potential as a model for multifunctional urban green infrastructure.

Author Contributions

YF: Writing - Review & Editing, Analysis and Interpretation of data; **LKS:** Conceptualization design of research, Writing - Review & Editing, Supervision; **RLK:** Conceptualization methodology, Writing - Review & Editing, Supervision; and **IZS:** Critical review/revision, Supervision.

Conflicts of Interest

There are no conflicts to declare.

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