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Assessing the benefits and management of urban forest in supporting low carbon city in Jakarta, Indonesia

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Abstract. *Aulia R, Kaswanto, Arifin HS, Mosyaftiani A, Syasita N, Wahyu A, Wiyoga H. 2023. Assessing the benefits and management of urban forest in supporting low carbon city in Jakarta, Indonesia. Biodiversitas 24: 6151-6159.* Climate change is a phenomenon that has become a global concern including in urban areas. Jakarta is one of the most populated cities in Indonesia, reaching 10.56 million people in 2020 with high emissions levels due to high human activities. Thus, efforts to reduce carbon emissions to mitigate climate change are necessary in Jakarta one of which is through the concept of low carbon city and manifested in the establishment of Green Open Space (GOS), including urban forests. Urban forests aim to sequester and store carbon, and improve the urban microclimate. This research aimed to assess the benefits of urban forests in Jakarta in term of their capacity in carbon sequestration using i-Tree Eco tool, and analyse the management of urban forests related to the applicable regulations. To collect data on trees, this study created 49 plots scattered across Srengseng Urban Forest, Cipayung Urban Forest, Munjul Urban Forest, Rawa Malang Urban Forest, and Pondok Labu Urban Forest. Tree species, Diameter at Breast Height (DBH), total tree height, live tree height, crown base height, crown width, percent crown loss, and crown light exposure were all gathered. Furthermore, in-depth interviews with urban forest managers were performed to gather additional information on present management, including questions derived from Jakarta's green open space legislation to assess management efficacy. The results of the analysis of urban forest quality show that the health status of trees is one of the factors that indicate the quality of urban forests at the five study sites, with more than 50% of the total trees in fair condition (75-90% health). The gross carbon sequestration of trees in five urban forests Jakarta is about 184.8 metric tons of carbon per year. Additionally, the in-depth interviews also test the mortality of the urban forest, a decent indicator of current management with estimates over the next 10 years, showing a slight increase in carbon sequestration and storage capacity. However, the mortality scenario leads to a trend toward a decrease in leaf area and the number of tree categories, especially in the Srengseng Urban Forest.

Keywords: Climate change, ecosystem service, i-Tree eco, Jakarta, urban forest, urban forest management

INTRODUCTION

The increase in population and human activities in urban areas can cause problems for the environment including climate change. Therefore, the direction and agenda of the development of cities must pay attention to environmental sustainability (Lehmann 2015). Urban development should apply an integrated approach that considers both environmental and human well-being aspects to deal with the increased urbanization and climate change impacts (Endreny 2018). This can be manifested by developing policies to mitigate climate change through urban development with low carbon emissions (low-carbon city) combined with carbon sequestration efforts. Such efforts are essential to limiting global warming to 1.5°C which requires at least 80% zero energy emissions by 2030 and 100% zero by 2050 (IPCC 2018; United Nations 2018).

Jakarta, the capital of Indonesia, had population of 10,609,681 people in 2021 based on the result of Interim Population Projection 2020-2023 (midyear/June) with the population growth rate of 0.57 percent per year (BPS Jakarta 2022). Jakarta is recognized as one of the most polluted cities in the world in term of air quality with level of pollutant of PM2.5 is currently 12.6 times higher than the WHO annual air quality guideline. PM2.5 refers to fine particles less than 2.5 microns in diameter and is one of the major pollutants to be considered when calculating a city's overall air quality rating since it has multiple detrimental effects on human health and the environment (IQAir 2023). Considering such problem, efforts are needed to mitigate the impacts of air pollution in Jakarta to improve the environmental quality of the city.

One strategy to solve both the problems of climate change and air pollution in urban areas is by increasing Green Open Space (GOS). GOS is often seen as a space with no economic value, so it is often converted into built-up area to meet society's need and improve the city's economy. GOS, including urban forests, are characterized by their proximity to human populations and numerous physical elements that constitute urban development. Characteristics of these forests are determined by their natural components and the anthropogenic elements in the landscapes in which they occur. In the context of Jakarta, GOS can be promoted as nature-based solution to tackle the problems of climate change and air pollution to improve the environmental quality of the city (Kurniastuti 2013). However, a previous study showed that the number of GOS in Jakarta decreased by 23% from 1983 to 2013 (Setiowati et al. 2018).

Urban forests contribute to climate change mitigation by capturing and storing atmospheric carbon dioxide in the biomass of vegetation it composed and moderated the microclimate which can lower the temperature in the surrounding environment including buildings (Safford et al. 2013). In order to reduce carbon emissions from human activities in each type of landscape, it can be realized by placing the landscape like a living being that metabolizes to meet the needs of the hardscape and softscape elements in it (Kaswanto 2017; Prasetiyo et al. 2018; Prasetiyo et al 2020: Kaswanto et al. 2022). For this purpose, the existence of urban forests is an important element in the sustainability of urban landscapes and as a potential means of global climate mitigation. On the top of that, urban forests also play an integral role in the delivery of ecosystem services in urban areas and make towns more livable. It eases people to breathe, think, exercise and relax; reduce extreme heat; and create pedestrian-friendly streets. Urban forests might also serve as source of livelihood and shelter of vulnerable populations such as the young, the elderly and the poor. These people are often disproportionately affected by multiple health threats related to climate change, especially near highways, industrial zones, rivers, landfills and other areas with little green space (Safford et al. 2013).

The stature, diversity, and health of the vegetation, including trees, are important determinants of ecosystem service provided by urban forest (Chambers-Ostler et al. 2023). Trees in urban forest must be in located in the proper place and maintained over time (Wilson et al. 2022). Other facilities might be integrated in urban forests, such as those in East Jakarta area which have been equipped with various facilities, such as fishing ponds, jogging tracks, outbound etc. These facilities are provided to attract people who live around the urban forest to visit it (Permata et al. 2018).

Despite the existence of urban forests in Jakarta, it is not clear whether the vegetation components, particularly trees, and other components in urban forests, are effective in delivering ecosystem services. Therefore, this research aimed to assess the the management of urban forests in Jakarta and to optimize strategies to achieve a low-carbon city. In doing so, the quality of urban forests in Jakarta was assessed using i-Tree Eco tool. A stakeholder analysis of urban forests was carried out through interviews with relevant managers and stakeholders on the value, benefits, and management of urban forests associated with the applicable regulations. The results of stakeholder analysis were to develop scenarios for the management of urban forests over the next decade. Eventually, recommendations were made for optimizing the management of Jakarta's urban forest landscape to support low-carbon city in Jakarta.

MATERIALS AND METHODS

Study area and period

This research was conducted at five urban forests in Jakarta, Indonesia, namely Srengseng Urban Forest (SUF), located in West Jakarta, with an area of 10.15 ha; Cipayung Urban Forest (CUF), located in East Jakarta, with an area of 1.32 ha; Rawa Malang Urban Forest (RUF) in North Jakarta with an area of about 5.7 ha; Munjul Urban Forest (MUF) in East Jakarta with an area of 3.74; and Pondok Labu Urban Forest (PUF) in South Jakarta with an area of 2.02 ha (Figure 1).

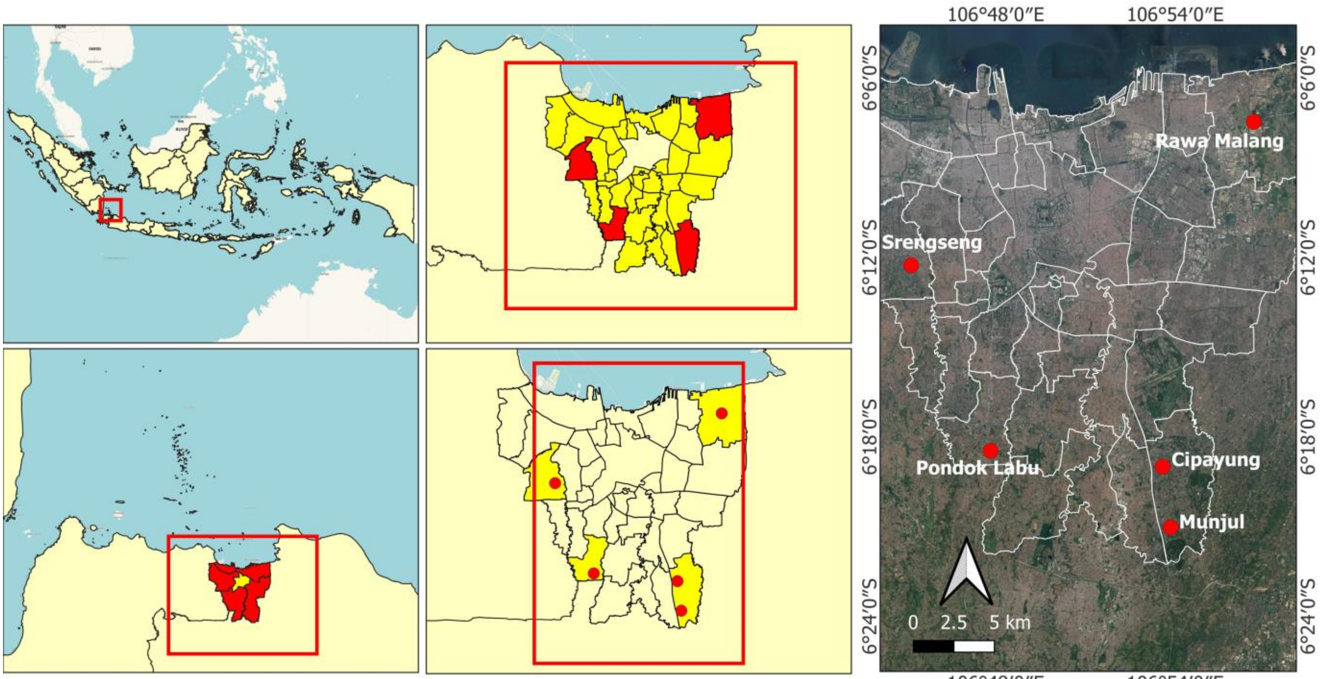

Figure 1. Five urban forests in Jakarta as the study sites: Rawa Malang in North Jakarta, Cipayung and Munjul in East Jakarta, Pondok Labu in South Jakarta, and Srengseng in West Jakarta, Indonesia

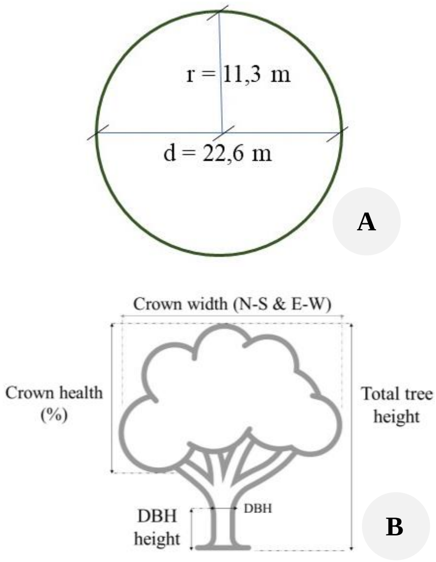

Figure 2. Vegetation sampling showing: A. Plot size, and B. Data measurement for tree

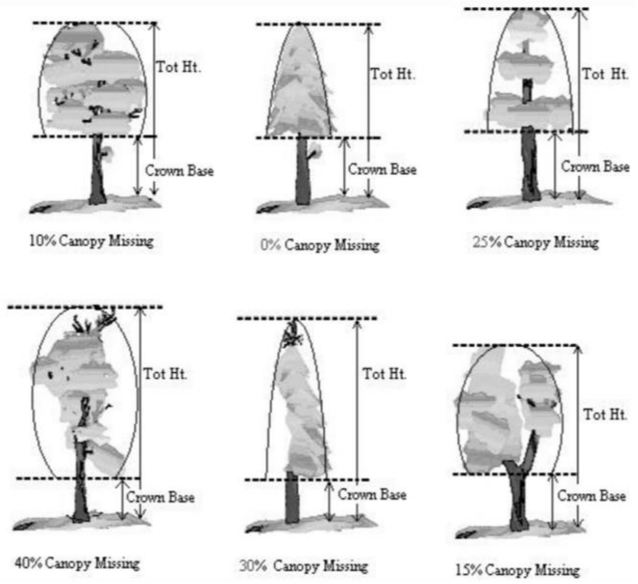

Figure 3. Illustration of how to measure height to crown base and percent canopy missing (i-Tree Eco Manual 2021)

Table 1. Information from five urban forests in Jakarta, Indonesia investigated in this study

Name of urban forest	City	UF area (ha)	Number of plots
Srengseng	West Jakarta	15.0	20
Rawa Malang	North Jakarta	5.7	15
Munjul	East Jakarta	1.3	4
Cipayung	East Jakarta	1.4	4
Pondok Labu	South Jakarta	2.2	4
Total		25.5	49

These urban forests were chosen based on the age of the urban forest, which is more than ten years and represents each region in Jakarta. The five urban forests also cover different biogeographical regions and regional types of forest management and maintenance systems. The research was conducted from January 2022 to August 2022.

Data collection procedure

To assess the ecosystem services of urban forests, 49 circular sampling plots were created in five urban forests. The size of the urban forest determines the number of plots, approximately 10-15% of the total area: i.e. SUF 20 plots, PUF 4 plots, RUF 15 plots with the size of area as shown in Table 1, CUF 4 plots, and MUF 4 plots. Each circular plot had an area of 0.4 hectares with diameter 22.6 m (Figure 2.A) which was distributed using website randomizer.

Data related to trees within the plots were collected (Figure 2.B) including species name, Diameter at Breast Height (DBH), land use, crown health (%), total tree height, crown width (north to south and east to west), percent crown missing (Figure 3), and crown light exposure. This research only measured trees with DBH of more than 10 cm because trees these size are considered well-established in the ecosystem and will continue to thrive and mature in the future (Magarik et al. 2020). In addition, vegetation structures of trees at such ages can be monitored in the future. Variables collected in situ to determine the structure and composition of urban forests can fundamentally inform policy for management, planning, and strategic actions, including the estimation of ecological and economic benefits of a landscape (Morgenroth and Östberg 2017).

In this study, the carbon storage and sequestration capacity of urban forest vegetation within the studied urban forests were estimated using the i-Tree Eco model. i-Tree Eco refers to a software developed by the United States Department of Agriculture (USDA) Forest Service. i-Tree Eco is a tool designed to assess and analyze the structure and functions of urban and community forest. It quantifies ecosystem services provided by trees, such as carbon storage and sequestration, air pollution removal, and stormwater interception. Carbon storage has been used to measure the amount of carbon stored in trees. Carbon sequestration is the amount of atmospheric carbon (from carbon dioxide) sequestered annually in tree tissue (i-Tree 2021). Although carbon sequestration can be measured as Gross Carbon Sequestration (GCS) and net carbon sequestration density, this study only considered the GCS of urban forests in Jakarta.

In-depth interview

In-depth interviews were conducted with forest managers of the five urban forests studied. Questions about the type, history, and management of urban forests were asked to gain the needed information. All interviews were conducted in person. If a personal meeting was impossible, video-phone interviews were conducted. The interview length varied between 45 minutes and 1.5 hours. Members of the research team conducted all interviews. The format of the in-depth, semi-structured allows the researcher and participant to engage in a somewhat free-flowing dialogue. The researcher might have a set purpose for speaking to each participant and an agenda of themes they plan to discuss. Nonetheless, the flexible nature of this research method encourages the researcher to listen closely for any unexpected issues that arise and follow the lead of the interviewee as they bring new themes to light (Barrick 2020).

Data analysis

After collecting biophysical data of the urban forests, including the data from interviews, all information was transferred into the i-Tree Eco software, which already has all data templates. In the i-Tree Eco, the five urban forests were defined as a stratum. They can be analyzed concurrently and possibly compared. i-Tree Eco ran the calculations based on the field data to analyze vegetation diversity indices, the critical values of the species, the estimated tree numbers in urban forests, and leaf area information. In i-Tree Eco, all standard equations and the calculation principle have been defined (Martin et al. 2011; Nowak et al 2018). i-Tree Eco calculated the data in its server, and before the process, users were required to provide an email address and other relevant information. Once the calculations are completed, the i-Tree server will notify the users. It took at least 30 minutes for the results to be completed. The information about vegetation structure was displayed entirely in the i-Tree Eco Reports.

RESULTS AND DISCUSSION

Type and function of urban forest in Jakarta

According to the Jakarta Governor Regulation No. 17 of 2007 concerning Urban Forests, there are five types of urban forest: (i) urban forest in residential area, which has the functions as oxygen generators, carbon dioxide absorbers, water absorbers, windbreaks, and noise reducers, in the form of tall trees vegetation combined with shrubs and grasses; (ii) urban forest in industrial area, which has the function to reduces air pollution and noise generated by industrial activities; (iii) urban forest for recreation, which is functioned for recreational and landscape aesthetic purposes, and composed by beautiful and unique tree species; (iv) urban forest for conservation, which functions as the area to conserve germplasm of flora and fauna species; (v) urban forest for protection, which functions to protect soil and water to mitigate disasters such as erosion and landslides in areas with a steep slope, abrasion to protects coastal areas from sea waves, and to serve as water catchment areas.

SUF, established in 1995, is the oldest urban forest in Jakarta which has functions of recreation, education, and protection. SUF is close to Central Jakarta and its easy access makes it more crowded than other urban forests. There are many visitor attractions in this urban forest, such as spots for taking photos and a stage for performances, and tree information. SUF has also become a favorite natural-based recreation for students and communities. Besides that, SUF provides WiFi that is available for visitors. It attracts the children surrounding to enjoy its facilities and the lake is used by the local community for fishing. The various functions and facilities in SUF indicate the important role of green open space beyond its ecological functions.

PUF, built in 2008, is an urban forest which has functions of green space in residential area and germplasm conservation. PUF is located in a densely populated area. The entrance gate is positioned on a narrow road and seems challenging to find. Even though this urban forest is more focused on conservation, a playground and hall were built in this place, which also attracts the local community to come and do activities for example, vaccination activities and others.

MUF and CUF were established in 2010 and 2016, and are located in East Jakarta, so they are under similar management. This urban forest has function for recreational and protection. Uniquely, MUF has GOS that are artfully arranged and have aesthetic value to attract visitors. In addition, MUF also has quite a large lake, but this urban forest is still in the land acquisition process because some lands in the area are still privately owned by residents. The location of the private lands is unique because it is between an urban forest lake with a clear difference. In addition, MUF is a nursery center for the East Jakarta area.

RUF was formed in 2012 and inaugurated in 2015 in the North Jakarta area. It has functions for recreational, protection and germplasm conservation. In the entrance of the urban forest, a tunnel is decorated with leaves to raise the aesthetic value. Like other urban forests, RUF establishes nurseries consisting of several species of trees that will be planted on the GOS in the surrounding area. In addition, RUF also has a hectare of pond for fishing site. Unfortunately, being close to the Jakarta Port and warehouse area makes RUF challenging. Some roads are damaged with wet clay roads and damaged paved lanes during the rainy season.

This study discovered that urban forests in Jakarta are not equally attractive and convenient for tourism and recreation purposes. Recent study by Weng et al. (2023) points out that nature-based tourism destinations such as urban forest are increasingly important for outdoor leisure and recreation. In the context of Jakarta, the regulation should be clear to be implemented optimally to achieve the better quality of the urban forests.

Existing management of urban forest in Jakarta

Urban forest management is important to maintain the forest to become more resilient to climate change, mitigating the urban heat island effect, reducing stormwater runoff, reducing nutrient loss, and promoting community well-being. An urban forest masterplan will guide the future development of the urban forest. The initial planning ought to assist the future direction of the urban forest to keep it on track. Unfortunately, most urban forests in Jakarta did not have an initial plan at their establishment. Budget planning is only provided according to the incidental needs and uses. SUF charges an entrance fee for visitor to help with management costs, but other urban forests have no funding other than the budget from the government and voluntary grants. The urban forest budget has decreased over the past few years, especially during the Covid-19 pandemic. This limits the ability of managers to plant and maintain trees. However, some urban forests, such as RUF and MUF, are earning additional incomes by selling fertilizer which comes from its organic wastes. Organic waste recycling, as practiced in some urban forests in Jakarta, is economically and ecologically beneficial and is an effective alternative to non-organic fertilizers. Furthermore, recycling organic waste is also beneficial for rejuvenating and restoring soil productivity by increasing microbial activity (Sharma et al. 2019).

This study noted an imbalance in the number of workers employed in the urban forests studied. SUF with an area of approximately 10 Ha, has 22 human resources; PUF with an area of 2 Ha, has only five human resources, while in the RUF with an area of approximately 5 Ha there is 30 personnel. SUF is managed technically and operated daily by a person in charge who is assisted by a forest ranger (Kurniastuti 2013). The workers include the cleaning team, security, driver, and urban forest managers. Moreover, this study found inconsistency of regulation in some urban forests in which the rules and management keep changing when the managers also change. The unspecific organization arrangements in each urban forest cause unclear coordination. In addition, uneven human resources may put the urban forests of abandoned and degraded. Therefore, obtaining funding sources for continuing maintenance is critical to ensuring the health of urban forests.

The information from a national survey (not only Jakarta) is necessary to understand better the resources of urban forest, and how these are changing through time, so that better management plans and policies can be developed to sustain and enhance urban forest benefits for future generations. This understanding, in turn, will enable us to disseminate improved best practices, identify emergent threats, and devise national and regional policies and partnerships to improve stewardship of these valuable resources. However, the Government of Jakarta, through the Parks and Urban Forest Service, has made efforts to manage urban forests well by placing several employees with various disciplines in the agency to manage urban forests.

Community's involvement

A community group can consist of people from different backgrounds working towards the same goal. A key aspect of the engagement process is the emphasis on horizontal networks and engagement-based processes. In other words, all group members are equal. It is believed that this condition can lead to social transformation (Leknoi 2018). There is a global shift towards sharing authority and responsibility between governments and local stakeholders with the aim of reducing the costs related to coordination, implementatio and monitoring (Ward et al. 2018). Lack of public support hinders urban forest conservation programs because local communities fail to understand the ecological and socioeconomic value of urban forests. Lagbas (2019) proposes that attitudinal and socioeconomic factors influence pro-environmental behavior. Socio-demographic factors may affect the community attitudes toward environment and sustainable resource management (Okumah et al. 2021).

Based on the interview results, community participation is quite high in activities related to the urban forest. For example, in SUF there is a forest farmer group (*Kelompok Tani Hutan*/KTH) that rearing bees and managing nurseries in the urban forest with the incomes are shared equally. KTH is a group of farmers or individual Indonesian citizens and their families who manage businesses in the forestry sector inside and outside the forest area, which includes timber forest products, non-timber forest products and environmental services, both upstream and downstream (Regulation of the Minister of Forestry Republic Indonesia 2014). In this study, there are 4 urban forests with KTH with PUF has no KTH. KTH members usually are the residents living around the urban forest and other people from other areas. In some areas, citizens participate in advisory commissions that supply input to local officials on policies and regulations governing urban forests. In other areas, partnerships promote innovative greening strategies that complement or augment existing programs (Connolly et al. 2013). In the context of climate change, Leknoi (2018) indicates that the public and government institutions do not yet have sufficient knowledge, action, and awareness. Therefore, raising awareness of climate change issues is important that affects the number of participants (Leknoi et al. 2022). In other words, raising environmental and political awareness in communities can enable society to tackle more complex issues such as climate change.

The condition of trees in urban forests

Urban green spaces provide immense ecosystem services to urban community. Similarly, forests play a key role in the global carbon cycle and should be properly protected and managed (Bellassen and Luyssaert 2014). Urban forests are considered as nature-based solutions to tackle climate change adaptation and mitigation, biodiversity conservation, human health, and social cohesion. To this end, local governments develop urban forest strategies and plans based on evidences to guide these efforts (Niu et al. 2023).

The results of this study show that more than half of the trees in the five urban forests assessed were in fair condition, while three percent were in critical and dying (Table 2).

Leaf area density and carbon sequestration of trees in urban forests

By using i-Tree Eco, the leaf area density of the five urban forests was calculated. The leaf area density was estimated to each urban forest with the results are presented in Table 3 and Figure 2. The result shows that SUF and SUF has the highest leaf area density, followed by MUF and PUF. However, this figure might dynamically change as a response to management practices, thus the long-term monitoring is essential to improve the accuracy of inventories (Mosyaftiani et al. 2022).

Table 2. Tree condition in five urban forests in Jakarta, Indonesia

Tree condition	CUF (%)	MUF (%)	PUF (%)	RUF (%)	SUF (%)	All Urban forests (%)
Excellent (100%)	19.8	0	26.5	38.1	14.4	20.5
Good (90-99%)	23.1	1.3	10.3	13.9	17.9	15
Fair (75-90%)	39.6	96.3	45.3	31	64.1	55.3
Poor (50-75%)	11	1.3	12.8	9.9	2.9	5.9
Critical (25-50%)	5.5	1.3	4.3	5.6	0.6	2.6
Dying (1-25%)	11	0	1.7	1.5	0	0.6
Dead (0%)	0	0	0	0	0	0

Table 3. Leaf area of tree canopy in urban forests in Jakarta, Indonesia

Urban forest	Leaf Area Density (m^2/ha)
CUF	48,584.65
MUF	69,450.90
PUF	54,429.28
RUF	52,890.31
SUF	86,668.09
All urban forests	70,430.84

Leaf Area Density (LAD) is an important index characterizing vertical and horizontal canopy structure. It is defined as the total leaf area on one side per unit volume (Oshio et al. 2015) and an important parameter affecting light utilization efficiency, photosynthetic capacity and trace gas exchange within the canopy (Li H et al. 2017; Li S et al. 2017). The number of leaves and stems and their spatial distribution in the tree play an essential role in the interaction processes between the forest canopy and the atmosphere. Trees can block solar radiation without significantly increasing leaf surface temperatures due to their transpiration and high leaf convective heat transfer coefficient (Oshio et al. 2021). Therefore, given differences in leaf physiology and morphology, a better understanding of how these properties vary vertically and horizontally within the canopy should allow us to estimate carbon stocks more accurately (Niinemets et al. 2015).

This study measured leaf area of the 20 most common species in five urban forests in Jakartat assessed using i-Tree Eco as presented in Table 4. *Swietenia macrophylla* (Mahogany) has the largest number of trees in the five urban forests. The gross carbon sequestration of trees in five urban forests Jakarta is about 184.8 metric tons of carbon per year, or if tagged with carbon price it has a value of IDR 499 million. Net carbon sequestration in the urban forests is about 182.2 metric tons per year. The benefits of trees in term of carbon sequestration and oxygen production equate directly to the leaf surface area. Trees cover about 74 percent of the five urban forests in Jakarta with a total of 161.5 hectares of leaf area. The greatest leaf area is in Srengseng Urban Forest, followed by Rawa Malang Urban Forest and Munjul Urban Forest. All leaves on the tree contribute to the entire surface of a side. Leaf area is estimated from measurements of crown dimensions and percentage of crown lost. Oxygen production by trees during photosynthesis, taking into account the amount used during plant respiration, is calculated from carbon sequestration based on atomic weight. Total sequestration is a measure of carbon sequestered by trees, calculated as the difference between 2022 and 2023 carbon stock estimates. Net carbon sequestration, a measure of the carbon sequestered by a tree, calculated as the total carbon sequestered by the tree minus the carbon emissions from decomposition after the tree dies. Carbon stock is a measure of carbon stored in trees. This is the amount of carbon sequestered in both the above-ground and below-ground part of woody plants.

Urban public green spaces, situated in urban areas, serve as near-natural ecological environments crucial for advancing carbon neutrality. These spaces offer various ecosystem services that enhance human health and well-being, with a particular focus on carbon sequestration. This aspect has gained considerable attention as an ecosystem regulation service aimed at counteracting CO_2 emissions (Zhao 2023). In addition to serving as a carbon sink by storing substantial amounts of carbon in solid wood and other organic matter, forest vegetation also reduces the atmospheric CO_2 content by increasing biomass and organic matter accumulation (Ni 2013). There, it is reasonable that global effort has been made to address climate change by increasing forest areas to store more carbon in forests and thereby offset emissions (Ma et al. 2021).

Oxygen production is one of the most cited benefits of urban trees. Annual oxygen production by a tree is directly related to the amount of carbon sequestered by the tree, which is strongly correlated with the accumulation of tree biomass (Ning et al. 2016). Trees in five urban forests in Jakarta are estimated to produce 485.8 metric tons of oxygen per year. However, this oxygen benefit is relatively insignificant compared to the large and relatively stable amount of oxygen in the atmosphere and the great amount of oxygen production by aquatic systems (Khanal and Straka 2021). Nonetheless, trees in cities help combat climate change by sequestering carbon dioxide in the atmosphere especially those emitted from fossil fuel-based energy sources into the tissue and changing energy use in buildings (Khanal and Straka 2021). The amount of carbon sequestered each year increases with tree size and health (US National Park Service 2022).

Table 4. The benefits of urban forest in term of oxygen produced and net carbon sequestration

Species	Oxygen (metric ton)	Net Carbon Sequestration (metric ton/yr)	Number of Trees	Leaf Area (hectare)
Swietenia macrophylla	54.74	20.53	1,576	23.86
Ceiba pentandra	49.29	18.48	599	27.79
Delonix regia	41.01	15.38	676	9.29
Terminalia	39.24	14.72	945	6.84
Cerbera manghas	22.92	8.59	570	4.6
Roystonea regia	21	7.88	162	1.03
Aleurites moluccanus	18.88	7.08	574	8.97
Leucaena leucocephala	17.46	6.55	501	7.48
Guazuma ulmifolia	15.38	5.77	188	3.69
Tectona grandis	13.55	5.08	277	3.92
Dialium sp.	13.34	5	305	4.32
Samanea sp.	11.75	4.4	107	2.78
Hymenaea courbaril	10.82	4.06	100	4.05
Albizia saman	9.51	3.57	460	7.82
Adenanthera pavonina	8.83	3.31	174	1.87
Ehretia anacua	8.25	3.09	126	1.01
Nephelium lappaceum	8.14	3.05	164	4.01
Pterocarpus indicus	7.99	3	71	1.66
Bryonia chinensis	7.76	2.91	66	1.08
Falcataria falcata	6.57	2.46	23	1.11

Mortality analysis of trees in urban forest

Based on comprehensive interviews, this study undertook estimations of leaf area, tree count, carbon storage, and carbon sequestration within each urban forest landscape under investigation. Emphasizing the crucial role of carbon storage and atmospheric carbon sequestration in the global carbon balance (Lin et al. 2011), the substantial impact of urban forest vegetation on this balance is underscored, given their potential to facilitate carbon storage, reduce energy consumption, and mitigate carbon emissions.

Annual data on tree planting, transplanting, and mortality were collected, acknowledging the practical challenge of urban forests lacking specific counts of new plantings. A pragmatic approach utilizing average planting values was employed based on weekly and monthly planting estimates, ranging from 250 to 1,000 tree seedlings across different urban forests.

Estimates and scenarios were processed using i-Tree Eco, relying on more than 20 field measurements and assumptions, incorporating adjustments for tree condition, light, land use, and modeled logging and decomposition rates (Ma et al. 2021). Scenarios depicting carbon sequestration, carbon storage, leaf area, and tree count for future years were illustrated for each urban forest (Figures 4-7), relying on structural estimates provided by i-Tree Eco. Tree carbon sequestration estimates were contingent on species type, mortality, growth characteristics, and overall condition (Lawrence et al. 2012).

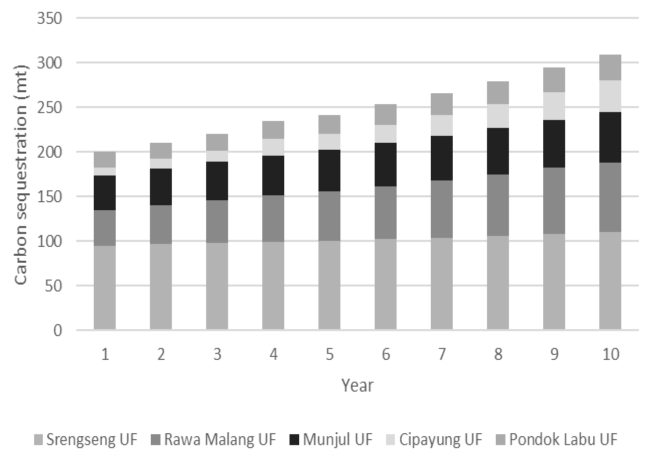

Figure 4. Carbon sequestration scenarios in five urban forests in Jakarta, Indonesia in the next ten years. Year 0 refers to the year of 2022

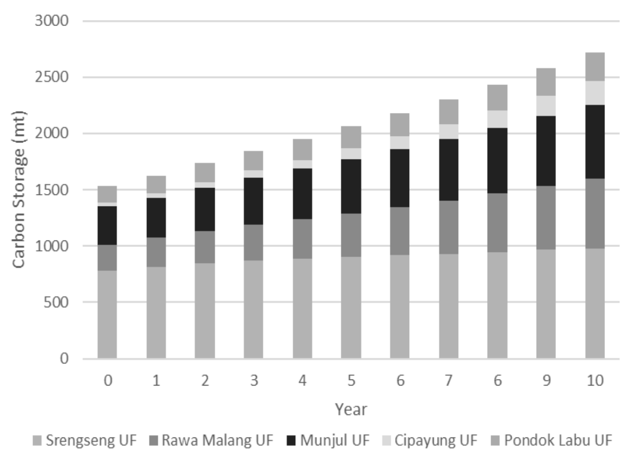

Figure 5. Carbon storage scenario in five urban forests in Jakarta, Indonesia in the next ten years. Year 0 refers to the year of 2022

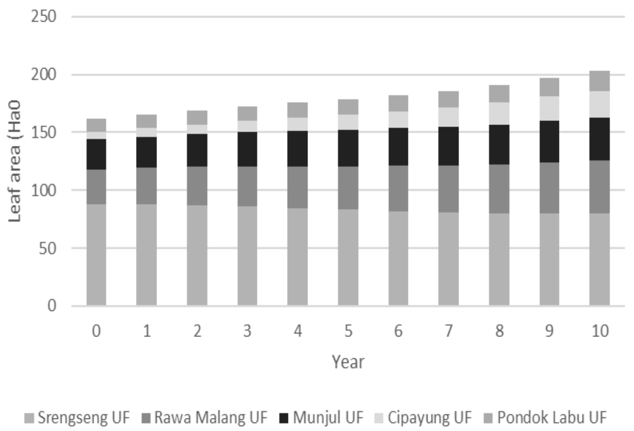

Figure 6. Leaf area scenario in five urban forests in Jakarta, Indonesia in the next ten years. Year 0 refers to the year of 2022

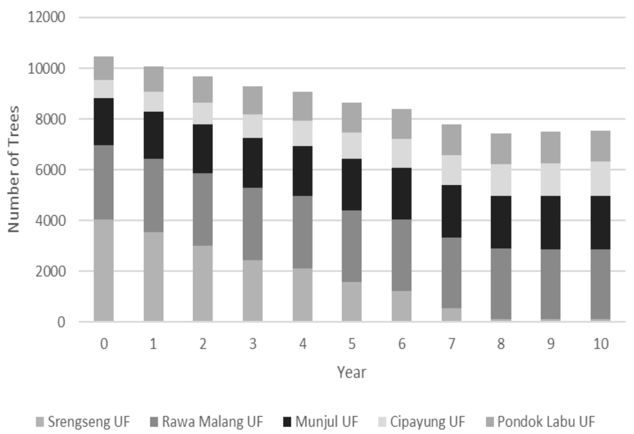

Figure 7. Number of tree scenario in five urban forests in Jakarta, Indonesia in the next ten years. Year 0 refers to the year of 2022

While three of the four scenarios demonstrated an increasing trend, a notable decrease in the number of trees was observed in Figure 6 and Figure 7. The increase in ecosystem services was relatively modest for Srengseng Urban Forest, where carbon sequestration after 10 years increased by approximately 16 metric tons, compared to Munjul Urban Forest, which exhibited an increase of over 37 metric tons. Leaf area in the four urban forests generally exhibited an increasing trend over the next decade, with the exception of Srengseng Urban Forest, which experienced a decrease from 87.97 Ha to 80 Ha between year 0 and year 10. These projections, analyzed by i-Tree Eco, are contingent on current tree conditions and annual planting data.

In conclusion, the strong desire to develop a sustainable urban environment that delivers ecosystem services has encouraged policymakers and stakeholder in Jakarta to establish urban forests. Our study revealed that these urban forests are essential in sequestering and storing carbon. There is an intention by the governments to continuously increase the number and total area of urban forests. However, there is a need to improve the manpower and budget to manage such urban forests. The study suggests that planting 1,000 trees annually for Srengseng Urban Forest, spanning an area of 15 Ha, proves ineffective in mitigating forest mortality. Factors such as high tree mortality rates and uneven landscape management are likely contributors. Encouragingly, all surveyed urban forests exhibited a commitment to replanting every deceased plant to counteract reductions in plant numbers. Moreover, natural processes like succession play a pivotal role in plant growth within urban forests, emphasizing the importance of a balanced relationship between organisms and their environment for community stability and longevity (Wang et al. 2021; Schwartz et al. 2022).

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REFERENCES

Barrick L. 2020. Interviews: In-Depth, Semistructured. International Encyclopedia of Human Geography 5: 403–408. DOI: 10.1016/B978-0-08-102295-5.10832-7

Bellassen V, Luyssaert S. 2014. Carbon sequestration: Managing forests in uncertain times. Nature 506 (7487): 153-155. DOI: 10.1038/506153a.

BPS Jakarta. 2022. Jakarta dalam Angka 2022. Badan Pusat Statistik & Dinas Kependudukan dan Pencatatan Sipil Provinsi DKI Jakarta. https://kependudukancapil.jakarta.go.id›statistik_2022. [Indonesian]

Chambers-Ostler A, Walker H, Doick KJ. 2023. The role of the private tree in bringing diversity and resilience to the urban forest. Urban For Urban Green 2023: 127973. DOI: 10.1016/j.ufug.2023.127973

Connolly JJ, Svendsen ES, Fisher DR, Campbell LK. 2013. Organizing urban ecosystem services through environmental stewardship governance in New York City. Landsc Urban Plan 109 (1): 76-84. DOI: 10.1016/j.landurbplan.2012.07.001.

Endreny TA. 2018. Strategically growing the urban forest will improve our world. Nat Commun 9: 1160. DOI: 10.1038/s41467-018-03622-0.

Escobedo F, Varela S, Zhao M, Wagner J, & Zipperer W. 2010. Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. Environ Sci Pol 13: 362-372.

Fang J. 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. Science 292: 2320–2322. Doi: 10.1126/science.1058629.

IPCC [Intergovernmental Panel on Climate Change]. 2018. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C. Nature 562: 172-173. DOI: 10.1038/d41586-018-06876-2.

IQAir Staaf Writers. 2023. Air Quality in Jakarta. www.iqair.com/indonesia/jakarta.

i-Tree. 2021. i-Tree Eco User's Manual. Retrieved from https://www.itreetools.org/documents/275/EcoV6_UsersManual.2021.09.22.pdf

Kaswanto RL. 2017. Management of landscape services for improving community welfare in West Java, Indonesia. In: Hong SK, Nakagoshi

N (eds.) Landscape Ecology for Sustainable Society. Springer, Cham. DOI: 10.1007/978-3-319-74328-8_15

Kaswanto RL. 2022. Landscape metabolism management realizes low-carbon landscape. In: Yusfiandani R (ed.) Ragam Aktualisasi Agromaritim Indonesia: Bunga Rampai Pemikiran Dosen Muda IPB University. IPB University Press, Bogor. [Indonesian]

Khanal PN, Straka TJ. 2021. Benefits of urban forests and determining their value. Clemson (SC): Clemson Cooperative Extension, Land-Grant Press by Clemson Extension; 2021. LGP 1108. http://lgpress.clemson.edu/publication/benefits-of-urban-forests-and-determining-their-value

Kurniastuti AE. 2013. Pengelolaan hutan kota di Jakarta (studi kasus hutan kota Srengseng di Jakarta Barat). Jurnal Pembangunan Wilayah dan Kota 9: 439-450. DOI: 10.14710/pwk.v9i4.6681. [Indonesian]

Lagbas AJ. 2019. Social valuation of regulating and cultural ecosystem services of Arroceros Forest Park: A man-made forest in the city of Manila, Philippines. J Urban Manag 8 (1): 159-177. DOI: 10.1016/j.jum.2018.09.002.

Lawrence AB, Escobedo FJ, Staudhammer CL, Zipperer W. 2012. Analyzing growth and mortality in a subtropical urban forest ecosystem. Landsc Urban Plan 104 (1): 85-94. DOI: 10.1016/j.landurbplan.2011.10.004.

Lehmann S. 2015. A new urban agenda: Introduction to the special issue on "sustainable urban development". Sustainability 7 (8): 10000-10006. DOI: 10.3390/su70810000.

Leknoi U, Yiengthaisong A, Likitlersuang S. 2022. Community engagement initiative amid climate change crisis: Empirical evidence from a survey across Bangkok Metropolis of Thailand. Cities 131: 103995. DOI: 10.1016/j.cities.2022.103995.

Leknoi U. 2018. Guideline for building community engagement towards low carbon community in Bangkok metropolitan. J Environ Manag 14 (2): 78-95. DOI: 10.14456/jem.2018.12. [Thailand]

Leknoi U. 2018. Guideline for building community engagement towards low carbon community in Bangkok Metropolitan. NIDA J Environ Manag 14 (2): 78-95.

Li S, Dai L, Wang H, Wang Y, He Z, Lin S. 2017. Estimating leaf area density of individual trees using the point cloud segmentation of terrestrial LiDAR Data and a Voxel-Based Model. Remote Sens 9 (11): 1202. DOI: 10.3390/rs9111202.

Lin W, Wu T, Zhang C, Yu T. 2011. Carbon savings resulting from the cooling effect of green areas: A case study in Beijing. Environ Pollut 159 (8-9): 2148-2154: DOI: 10.1016/j.envpol.2011.02.035.

Ma J, Li X, Jia B, Liu X, Li T, Zhang W, Liu W. 2021 Spatial variation analysis of urban forest vegetation carbon storage and sequestration in built-up areas of Beijing based on i-Tree Eco and Kriging. Urban For Urban Green 66: 127413. DOI: 10.1016/j.ufug.2021.127413.

Magarik YAS, Roman LA, Henning JG. 2020. How should we measure the DBH of multi-stemmed urban trees? Urban For Urban Greening 47: 126481. DOI: 10.1016/j.ufug.2019.126481.

Martin NA, Chappelka AH, Keever GJ, Loewenstein EF. 2011. A 100% tree inventory using i-Tree Eco protocol: A case study at Auburn University, Alabama, U.S. Arboric Urban For 37: 207-212. DOI: 10.48044/jauf.2011.027.

Morgenroth J, Östberg J. 2017. Measuring and monitoring urban trees and urban forests. In: Ferrini F, van den Bosch CCK, Fini A (eds). Routledge Handbook of Urban Forestry. Routledge, London. DOI: 10.4324/9781315627106.ch3.

Mosyaftiani A, Wahyu A, Kaswanto, Wiyoga H, Syasita N, Septa AF, Djauhari D. 2022. Monitoring and analyzing tree diversity using i-Tree Eco to strengthen urban forest management. Biodiversitas 23 (8): 4033-4039. DOI: 10.13057/biodiv/d230822.

Ni J. 2013. Carbon storage in Chinese terrestrial ecosystems: Approaching a more accurate estimate. Clim Change 119: 905-917. DOI: 10.1007/s10584-013-0767-7.

Niinemets Ü, Keenan TF, Hallik L. 2015. A worldwide analysis of within-canopy variations in leaf structural, chemical and physiological traits across plant functional types. New Phytol 205 (3): 973-993. DOI: 10.1111/nph.13096.

Ning ZH, Chambers R, Abdollahi K. 2016. Modeling air pollutant removal, carbon storage, and CO_2 sequestration potential of urban forests in Scotlandville, Louisiana, USA. iForest 9 (6): 860-867. 10.3832/ifor1845-009.

Niu H, Rehling F, Chen Z, Yue X, Zhao H, Wang X, Zhang H, Schabo DG, Farwig N. 2023. Regeneration of urban forests as influenced by fragmentation, seed dispersal mode and the legacy effect of reforestation interventions. Landsc Urban Plan 233: 104712. DOI: 10.1016/j.landurbplan.2023.104712.

Nowak DJ, Maco S, Binkley M. 2018. i-Tree: Global tools to assess tree benefits and risks to improve forest management. Arboricultural Consultant 51 (4): 10-13.

Okumah M, Ankomah-Hackman P, Yeboah AS. 2021. Do socio-demographic groups report different attitudes towards water resource management? Evidence from a Ghanaian case study. GeoJournal 86: 2447-2456. DOI: 10.1007/s10708-020-10173-9.

Oshio H, Asawa T, Hoyano A, Miyasaka S. 2015. Estimation of the leaf area density distribution of individual trees using high-resolution and multi-return airborne LiDAR data. Remote Sens Environ 166: 116-125. DOI: 10.1016/j.rse.2015.05.001.

Oshio H, Kiyono T, Asawa T. 2021. Numerical simulation of the nocturnal cooling effect of urban trees considering the leaf area density distribution. Urban For Urban Green 66: 127391. DOI: 10.1016/j.ufug.2021.127391.

Permata ND, Syartinilia, Munandar A. 2018. The actual use of urban forest for Jakarta's dwellers. IOP Conf Ser: Earth Environ Sci 179: 012036. DOI: 10.1088/1755-1315/179/1/012036.

Regulation of the Minister of Forestry Republic Indonesia. 2014. Guidelines for Development of Forest Farming. Permenhut 57/Menhut-II/2014, Jakarta. [Indonesian]

Safford H, Larry E, McPherson EG, Nowak DJ, Westphal LM. 2013. Urban Forests and Climate Change. U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. www.fs.usda.gov/ccrc/topics/urban-forests.

Schwartz N, Oguz I, Wang J, Pouch A, Yushkevich N, Parameshwaran S, Gee J, Yushkevich P, Oguz B. 2022. Fully automated placental volume quantification from 3D US for prediction of small-for-gestational-age infants. J Ultrasound Med 41 (6): 1509-524.

Setiowati R, Hasibuan HS, Koestoer RH. 2018. Green open space masterplan at Jakarta Capital City, Indonesia for climate change mitigation. IOP Conf Ser: Earth Environ Sci 200 (1): 012042. DOI: 10.1088/1755-1315/200/1/012042.

Sharma B, Vaish B, Monika, Singh UK, Singh P, Singh RP. 2019. Recycling of organic wastes in agriculture: An environmental perspective. Intl J Environ Res 13: 409-429. DOI: 10.1007/s41742-019-00175-y.

United Nations. 2018. UN climate report: It's 'now or never' to limit global warming to 1.5 degrees. UN News. news.un.org/.

US National Park Service. 2022. Carbon Storage by Urban Forests. National Park Service U.S. Department of the Interior. https://www.nps.gov/articles/000/uerla-trees-carbon-storage.htm

US National Park Service. 2022. Carbon Storage by Urban Forests. https://www.nps.gov/articles/000/uerla-trees-carbon-storage.htm#:~:text=The%20amount%20of%20carbon%20annually,naturally%20growing%20in%20forested%20areas.

Wang S, Jiménez-Alfaro B, Pan S, Yu J, Sanaei A, Emma J, Sayer, Ye J, Hao Z, Fang S, Lin F, Yuan Z, Wang X. 2021. Differential responses of forest strata species richness to paleoclimate and forest structure, Forest Ecology and Management, Volume 499, DOI: 10.1016/j.foreco.2021.119605.

Ward C, Stringer LC, Holmes G. 2018. Protected area co-management and perceived livelihood impacts. J Environ Manag 228: 1-12. DOI: 10.1016/j.jenvman.2018.09.018.

Weng L, Zhu Y, Xu X, Yang J, Zheng S, Liu H, Wang H, Zhu L. 2023. The influence of visitors' recreation experience and environmental attitude on environmentally responsible behavior: A case study of an urban forest park, China. Forests 14 (1): 24. DOI: 10.3390/f14010024.

Wilson S, Pool J-R, Phillips M, Alexander S. 2022. How Forests Near and Far Benefit People in Cities. World Research Institute (WRI). www.wri.org.

Zhao D, Cai J, Xu Y, Liu Y, Yao M. 2023, Carbon sinks in urban public green spaces under carbon neutrality: A bibliometric analysis and systematic literature review, Urban For Urban Green 86: 12803. DOI: 10.1016/j.ufug.2023.128037.