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Monitoring and analyzing tree diversity using i-Tree eco to strengthen urban forest management

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Abstract. *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: 4033-4039.* Inadequate data on vegetation growth makes it difficult for managers to determine the additional measures necessary for effective urban forest management. The management of urban forests in Jakarta also raises this issue. Collaborative research with multiple stakeholders was conducted in five Jakarta urban forests to assess the diversity and structure of the vegetation as a basis for long-term monitoring and management. Using 49 plots, we carried out a field inventory to gather information on tree number, diameter at breast height, tree height, and crown size. The i-Tree Eco programme was used to examine the data and information gathered. The widely used i-Tree Eco analysis was conducted to make viable evidence-based evaluation feasible and to help stakeholders with data processing. The results showed that the five urban forests had a moderate level of diversity, with an index value ranging from 2.1 to 3.0. The five most common tree species—*Swietenia macrophylla*, *Terminalia* sp., *Delonix regia*, *Ceiba pentandra*, and *Aleurites moluccanus*—dominate urban forests, whereas three of them are exotic and most native species have substantially lower values. Increasing tree diversity by enriching native species is recommended to be a top priority for urban forest management in Jakarta. Additionally, this research shows that adopting advanced and user-friendly tools to regularly monitor and analyze vegetation helps stakeholders achieve better urban forest management.

Keywords: Composition, diversity, Jakarta, native trees, urban forest, vegetation structure

INTRODUCTION

Urban ecosystem benefits greatly from the landscape services provided by urban forests. Urban forests, for instance, play a significant part in maintaining improved soil, water, air, and climatic quality. Urban forests can offer habitats to a diversity of organisms that can support the stabilization of the food web and food chain in the local ecosystem. Additionally, the products and services that urban forests may offer, such as non-timber forest products, education, tourism, and so on, have a significant potential to boost productivity. Aside from climate change impacting landscape services, urban forest management is also a critical success factor in improving its landscape services, such as ecological function and provision of recreational areas. (Sukiman et al. 2015; Noviandi et al. 2017; Roeland et al. 2019; Desta and Kaswanto 2021).

Urban forests are extremely important in Jakarta since it is the only megacity in Indonesia and has large cities surrounding it. With green cover at 2,372 ha, or 9.97% of its entire area, the Jakarta City, until 2021 has designated 34 urban forests with a combined size of 182.54 ha. According to the Jakarta green open space master plan 2018-2038, the ideal urban forest should cover 5,040.59 ha by 2038.

Urban forest management in Jakarta is regulated by Governor Regulation No. 17/2017 concerning the Management of Urban Forests. This governor regulation is a solid legal foundation for becoming one of the solutions for developing urban forests in DKI Jakarta, which necessitates a good achievement strategy, an appropriate approach, and rapid response to numerous environmental issues. Yet, the function of urban forests in improving landscape services has not yet been fully optimized (Markho et al. 2020). The Jakarta urban forest area is still far behind expectations in terms of the requirement from Minister of Forestry Regulation No. 71 of 2009 concerning Urban Forest Management Guidelines that urban forests at least 10% of total area. The relevant stakeholders have expressed concern and are actively working to find a solution. The lack of managers with the technical and conceptual understanding for the effective management of urban forests is another major barrier to Jakarta's urban forest management. It is presumably a result of the limited financial resources available for increasing institutional and human capabilities, particularly research-based management (Kurniastuti 2013).

As the cornerstone of policy, planning, and management to accomplish intended landscape functions, the evaluation of urban forests is certainly crucial, especially for comprehensive and accurate information regarding the structure of urban forests (Nowak et al. 2008). In reality, there hasn't been a lot of monitoring of tree growth in Jakarta's urban forests in Indonesia. It makes it difficult to assess the structure, composition, and health of trees and the urban forest's landscape functions and benefits (Kim 2016). Through this vegetation assessment, evidence-based information may help people appreciate the important benefits of well-managed urban forests. This is necessary for translating research findings into policies (Yannelli et al. 2022; Kaswanto 2017) for better urban forest management with a highly future perspective.

To address this issue, various stakeholders including academics, urban forest managers, and technicians—conducted joint tree assessment research in the field. The goal was to improve technical expertise for doing practical vegetation analyses and to provide data on the structure of urban forests using i-Tree Eco that could be useful for future management needs. These data will be helpful for budgeting, tree planting, and other activities that can enhance the landscape services. Urban forests monitoring using this technique may make it easier to validate the monitoring of changes in the structure and composition of urban forests. As a result, important landscape or ecological services may also be quantified and valued, enabling efficient management of urban forests (Raum et al. 2019).

MATERIALS AND METHODS

Study area

This research was conducted in five urban forests which are representative of each region in Jakarta: Srengseng (SUF) in West Jakarta, Pondok Labu (PUF) in South Jakarta, Rawa Malang (RUF) in North Jakarta, Cipayung (CUF) and Munjul Urban Forest (MUF) in East Jakarta. Each urban forest has various areas: SUF 10.15 ha, PUF 2.02 ha, RUF 5.70 ha, CUF 1.32 ha, and MUF 3.74 ha. The field study was held from October to December 2021.

Procedures

There were 49 sample plots dispersed among five urban forests. The size of the urban forests determined the number of plots: SUF 20 plots, PUF 6 plots, RUF 15 plots, CUF 4 plots, and MUF 4 plots. The 0.4 ha circular plots were distributed around the sites at random. The i-Tree Eco model recommended the plots as a fundamental benchmark for additional investigation (Nowak et al. 2008). The inventory was examined to collect data of plot and tree information such as vegetation cover, tree DBH, crown size, geolocation, number of trees, and species name.

Tree data were collected only from the trees with DBH greater than 10 cm. The trees with the favored DBH were already established in the ecosystem and would continue to thrive and mature in the future (Magarik et al. 2020). Furthermore, the data that were collected in the field to determine the structure and composition of urban forests could effectively guide policy in management, planning, and strategic actions, including assessing environmental and economic landscape services (Morgenroth and Östberg 2017).

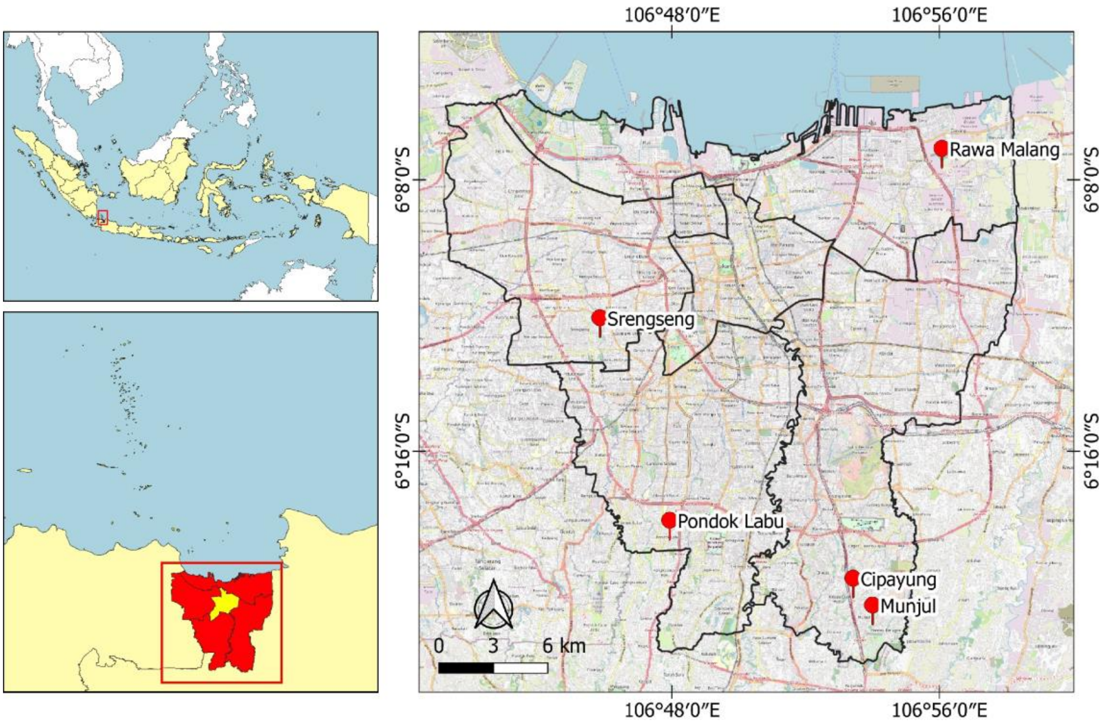

Figure 1. Five urban forests in Jakarta as the site locations for this study: Rawa Malang in North Jakarta, Cipayung and Munjul in East Jakarta, Pondok Labu in South Jakarta, and Srengseng in West Jakarta

Data analysis

The i-Tree Eco programme was used to input all of the data and information from the field survey because it already had all of the data templates accessible. The five urban forests were designated as stratum in the i-Tree Eco, which could be simultaneously examined and compared. In order to examine tree diversity indices, species richness, estimated tree counts in urban forests, and leaf area data, i-Tree Eco performed computations based on field data. All standard equations and the calculation principle have been specified in i-Tree Eco (Martin et al. 2011; Nowak et al. 2018). Users had to supply an email address and other necessary details before the data could be computed on i-Tree Eco's server. The users would be informed by the i-Tree server once the computations are finished. The completion of the findings took close to an hour. The i-Tree Eco Reports Tab (sub-tab Composition and Structure) provided information about vegetation structure and diversity.

RESULTS AND DISCUSSION

General overview

Five urban forests were sampled and estimated to have 10,509 trees with a tree cover of 73.9%: 742 trees were found in CUF, 1,848 trees in MUF, 973 trees in PUF, 3,033 trees in RUF, and 3,913 trees in SUF. *Swietenia macrophylla* (15.0 %), *Terminalia* (9.0 %), and *Delonix regia* (6.4 %) were the three most common species found in the five urban forests. This measurement could also identify the tree density providing information about how close the trees grow in the area. The average density of trees in those five urban forests was 458 trees per hectare. CUF had the highest tree density, followed by RUF and MUF. Common ground cover classes (including cover types beneath trees and shrubs) were duff/mulch, bare soil, other impervious, buildings, unmaintained grass, rock, and water, impervious covers like cement, and tar, and herbaceous covers like grass, and herbs. Duff/mulch and bare soil were the most dominant ground cover types in all urban forests.

Urban forests consist of a variety of native and non-native tree species. About 19% of the trees in these five urban forests are native to Asia. The majority of trees originate in North and South America (30 % of the trees). Thus, urban forests typically have a greater tree diversity than the surrounding natural landscapes. The harm brought on by a species-specific pest or disease can be lessened by increased tree diversity, but it can also put native plants in danger if any of the exotic species are invasive ones that may potentially outcompete and replace them. To counter the threat of invasive species, native plant selection is crucial.

Vegetation Structure

In order to better understanding the structure and vegetation that will be stable enough to thrive in the next 10-20 years, the trees with DBH greater than 10 cm were measured. The distribution of trees by DBH in the five urban forests is depicted in Figure 2. In all five urban forests, it can be seen that the tree composition is quite normal. It demonstrates that there are much more low DBH class trees than high DBH class trees. However, RUF and CUF, didn't have more trees, especially in high DBH classes. The natural regeneration of the woods will be hampered by the absence or low density of old-growth trees (high DBH).

Therefore, the process of forest structure regeneration and normalization must be a focus of urban forest management. The SUF, on the other hand, contains a quarter of the ecosystem's population of young trees and a relatively substantial majority of old trees with large tree diameters. Natural tree regeneration and supporting their healthy development should also be a short-term goal in order to stop the ageing distribution from shifting toward maturity. The health of trees is improved through tree management, which also enhances the ecological functions and landscape services they offer (Morgenroth et al. 2020). Tree health may be identified by the diversity of diameter distributions (Morgenroth and Östberg 2017; Pretzsch et al. 2021). To maintain the long-term viability of urban forests and to avert any dangers in the future, planning, management, and policy should be implemented.

The distribution in tree height in these five urban forests were similarly very broad. Except for SUF and PUF, the urban forests generally contained a large number of trees that ranged in height from 5 to 10 meters. The height and vertical growth of tree species are influenced by competition and cohabitation. Additionally, the normal stratification of existing trees may be brought on through the management of tree planting and the urban forest age. Tree height might provide urban forest stratification that serves as a vital habitat for species that live in cities, since the vertical distribution of the crown interferes with the availability of adequate habitat to accommodate diverse plant and animal species (Marziliano et al. 2013). Naturally, larger and taller trees improve landscape services better. Despite the fact that local environmental stressors may influence a tree's height and the study discovered an irregular relationship between tree height and tree diameter at breast height (DBH) (Chen and Brockway 2017), this data offers insight into the direction of urban forest management for maximizing and enhancing stratification in order to provide habitat availability and additional benefits.

Species composition

The amount of healthy leaf area on a tree directly relates to the number of advantages it provides. With 161.5 hectares of leaf area, trees cover around 73.9 percent of Jakarta's urban forests. The largest total leaf area is seen in SUF, followed by RUF and MUF. The species with the largest leaf area in five Jakarta Urban Forests were *Ceiba pentandra*, *Swietenia macrophylla*, and *Delonix regia*. According to the i-Tree Eco study report, *Swietenia macrophylla*, *Ceiba pentandra*, *Terminalia* sp., *Delonix regia*, and *Aleurites moluccanus* were the five species with the most important values across all five urban forests.

All urban forests have their own significant species that contribute to each urban forest's maximum leaf area and population density (Table 1), which result in among the most important value above 10% in the community. In the tree community of CUF, there were six most significant species viz. *Swietenia macrophylla*, *Eucalyptus globulus*, *Calophyllum inophyllum*, *Pterospermum* sp., *Adenanthera pavonina*, and *Khaya anthotheca*. With the exception of *S. macrophylla*, *E. globulus* and *K. anthotheca*, the other three species are native species. In order to establish if these exotic species would have detrimental impacts on the existing native species, the conditions at CUF must be taken into account. Native species may face difficulties thriving if unmonitored ecological processes take place because exotic species dominate the structure of urban forests.

In the RUF, *Terminalia* sp., *Samanea saman, Swietenia macrophylla, Cerbera manghas,* and *Aleurites moluccanus* were the five species with an important value above 10%. The first, fourth, and fifth species are native, but the other two are exotic. Although the likelihood of native species in an urban forest is fairly high, the presence of exotic species might potentially outweigh that of native species. This might be interpreted as a cautionary note for management in the future.

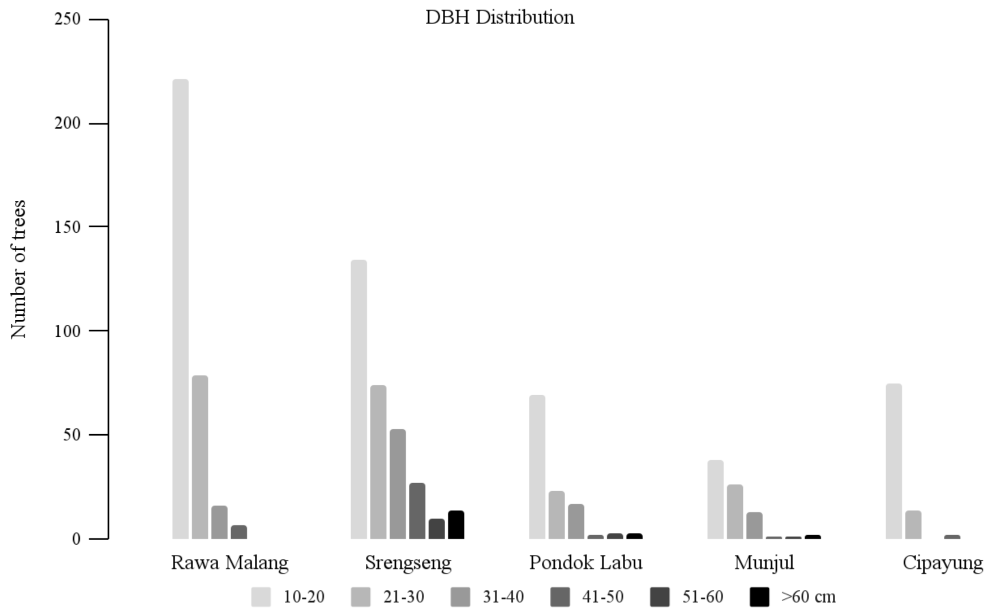

Figure 2. Tree DBH in five urban forests

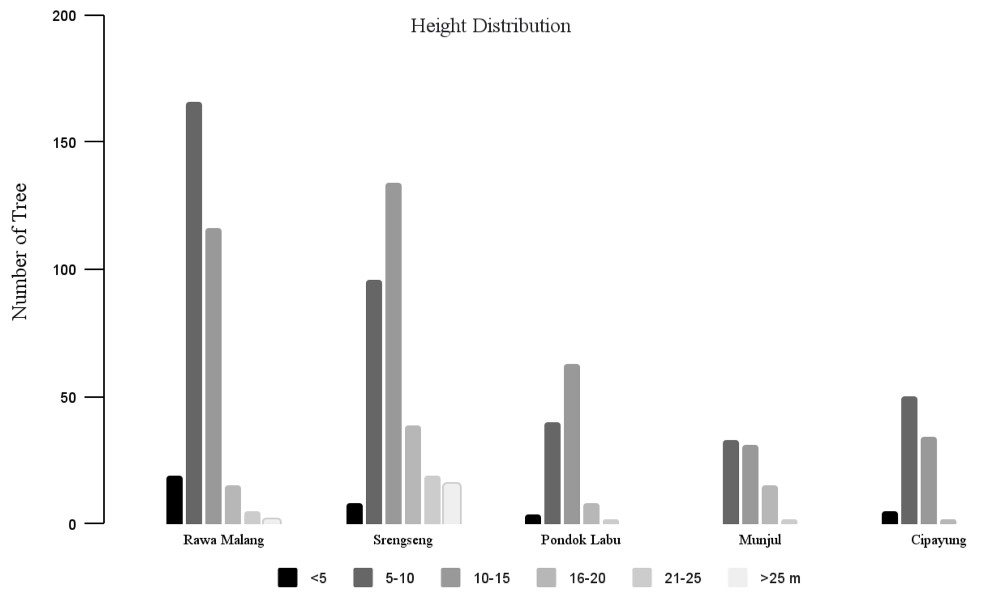

Figure 3. Tree height distribution in five urban forests

Table 1. The highest importance of species greater than 10% in urban forests

Urban forests	Species	Origin	Percent population	Percent leaf area	Important Value
Cipayung (CUF)	*Swietenia macrophylla* King in Hook.	Exotic	18.7	28.9	47.6
	Eucalyptus globulus Labill.	Exotic	19.8	18.5	38.3
	Calophyllum inophyllum L.	Native	16.5	9.6	26.1
	Pterospermum sp.	Native	7.7	8.6	16.3
	Adenanthera pavonina L.	Native	7.7	7.3	15.0
	Khaya anthotheca C.DC.	Exotic	5.5	5.3	10.8
Rawa Malang (RUF)	*Terminalia* sp.	Native	30.3	21.6	51.9
	Samanea saman (Jacq.) Merr.	Exotic	15.2	25.9	41.1
	Swietenia macrophylla King in Hook.	Exotic	14.2	11.2	25.5
	Cerbera manghas L.	Native	14.2	7.5	21.7
	Aleurites moluccanus Willd.	Native	8.4	10.8	19.2
Munjul (MUF)	*Aleurites moluccanus* Willd.	Native	13.7	20.3	34.1
	Nephelium lappaceum L.	Native	7.5	13.5	21.0
	Tectona grandis L.f.	Native	7.5	7.9	15.4
	Canarium ovatum Engl.	Native	5.0	7.7	12.7
	Roystonea regia O.F.Cook	Exotic	8.8	4.0	12.7
	Paraserianthes sp.	Exotic	3.8	7.0	10.8
Pondok Labu (PUF)	*Antidesma bunius* (L.) Spreng.	Native	17.1	13.5	30.6
	Artocarpus heterophyllus Lam.	Native	6.0	13.8	19.8
	Tectona grandis L.f.	Native	9.4	9.6	19.0
	Sandoricum koetjape Merr.	Native	5.1	11.1	16.2
	Mimusops elengi L.	Native	13.7	2.2	15.9
	Swietenia macrophylla King in Hook.	Exotic	7.7	7.6	15.3
	Aleurites moluccanus Willd.	Native	6.8	3.8	10.7
	Mangifera sp.	Exotic	1.7	8.6	10.3
Srengseng (SUF)	*Ceiba pentandra* (L.) Gaertn.	Exotic	13.8	28.1	41.9
	Swietenia macrophylla King in Hook.	Exotic	20.8	19.4	40.2
	Delonix regia (Bojer ex Hook.) Raf.	Exotic	13.5	8.8	22.3
	Leucaena leucocephala (Lam.) de Wit	Exotic	11.5	8.0	19.5
	Dialium sp.	Native	7.4	4.7	12.1

The most frequent occurrences of trees and having the highest important values in the MUF are *Aleurites moluccanus, Nephelium lappaceum, Tectona grandis, Canarium ovatum, Roystonea regia, Paraserianthes* sp.. The four highest important species are native, while the fifth and sixth species are exotic. According to this, MUF management could effectively regulate the vegetation structure. Native species may grow and thrive unrestrictedly in this urban forest since invasive species have no influence over the composition of the vegetation.

The PUF tree community has eight species that are the most significant species. They include *Antidesma bunius*, *Artocarpus heterophyllus*, *Tectona grandis*, *Sandoricum koetjape*, *Mimusops elengi*, *Swietenia macrophylla*, *Aleurites moluccanus*, and *Mangifera* sp. It is interesting to observe that eight species, six of which are native, can coexist and grow next to one another, with an important value of more than 10%.

The five most significant species in the SUF are *Ceiba pentandra*, *Swietenia macrophylla*, *Delonix regia*, *Leucaena leucocephala*, and *Dialium* sp. The first four species are exotic, while the last is indigenous. The abundance of exotic species that predominate the tree community in SUF raises concerns about how future management of urban forests might allow more space for the establishment of various native species, thereby benefiting both local species and the tree structure and composition of the urban forest. These findings highlight the critical importance of plantation management and species mix in creating habitats for native species in urban forests.

Vegetation diversity

Several vegetation diversity indices could be investigated using i-Tree Eco. Shannon-Wiener, Menhinick, and Simpson diversity indices were assessed. The Shannon-Wiener diversity index revealed that all five urban forests are in the moderate range, to somewhat varying degrees: The MUF had the highest value (3.0), followed by PUF, SUF, CUF, and RUF. It's interesting to note that the rankings for those five urban forests in Menhinick's and Simpson's indices (Table 2) of tree diversity were the same. To pinpoint the steadily developing trees that aid in the growth of urban forests, the assessment focused on tree species with a diameter of greater than 10 cm.

Table 2. Diversity indices in five urban forests

Urban forests	Area (ha)	Species richness	Shannon-Wiener	Menhinick	Simpson
Munjul (MUF)	3.74	29	3.0	3.2	20.1
Pondok Labu (PUF)	2.02	26	2.8	2.4	13.7
Srengseng (SUF)	10.51	35	2.7	2.0	9.7
Cipayung (CUF)	1.32	18	2.4	1.9	8.8
Rawa Malang (RUF)	5.70	20	2.1	1.1	6.1

Because of its moderate sensitivity to sample size, the Shannon-Wiener index is unreliable for comparing urban forests. The Menhinick and Simpson diversity indices, on the other hand, are both reliable for assessing the diversity of urban vegetation because of their low sensitivity to sample size (i-Tree 2021). These results suggest that MUF has more tree diversity than other urban forests. The largest urban forests were in SUF, which had lower diversity than MUF and PUF, but a higher diversity than RUF and CUF. The sample-wise species count revealed that species richness was independent of geographic location.

The findings were all at a moderate level, suggesting that management practices can be enhanced to achieve more effective action that can boost vegetation diversity. The complexity of vegetation is important for improving the landscape services provided by urban forests. It will be extremely beneficial for the surrounding areas in urban ecosystems, such as air quality regulation, water regulation, local-climate regulation, cultural heritage, aesthetic value, scientific activities, recreation, and education, to strengthen the landscape services provided by a range of plants to lead to ecosystem stability (Wright 2007). According to the study by Edwards (2017), urban forests with more than 90% tree coverage can lower the temperature to -1.7°C. In addition, the rate of decomposition in urban forests is higher than in vegetation with shrub management. Urban forests can nevertheless have a high tree diversity even when they are limited in size and as well urban forests with a wide variety of trees may provide maximum benefits. However, because the importance values (IV) are calculated by multiplying the population and leaf area percentages regardless of whether a species is native or exotic, the species that currently dominate the structure of the urban forest shouldn't necessarily be encouraged in the future (e.g. *Swietenia macrophylla* in CUF and *Ceiba pentandra* in SUF).

This is crucial for determining the species that comprise the vegetation, both in terms of the significance of their growth and population as well as their health. This is an important directive that Jakarta's urban forest managers may follow in order to conserve, improve, and sustain the urban forests. The total plant abundance in the plots was more steady, with the exception of sapling reduction. Given the high rates of attrition, an ecosystem's structural resilience indicates that diversity serves an important functional role (Templeton et al. 2019). The study of Sjöman et al. (2012) suggested maintaining an urban tree species population that does not exceed 10% of the entire tree population for more diversity. However, urban forest managers must plant native species which are adept to local conditions, and in consideration that the experimental introduction of exotic species might result in a rise in mortality and a decrease in longevity, thus increasing management expenses. Traditional Ecological Knowledge (TEK) for planting native species had already existed such as in the landscape agroforestry model (Prastiyo et al. 2018). It may also be applied in the tropical urban context, such as Jakarta urban forests.

The i-Tree Eco programme is useful for visualizing the general structure and composition of vegetation, especially urban forests. It combines field investigations with the outcomes of data analysis. For evaluating urban forest structure, landscape services, and its benefits, the i-Tree Eco model's key advantages are its use of standardized, peer-reviewed methodologies and locally observed field data. The application is freely accessible, and i-Tree offers technical support (Nowak et al. 2008). However, i-Tree Eco is not free from limitations. Urban forest effects and values must often be quantified and demonstrated through modeling approaches since urban forest ecosystem functions are usually difficult to define and display in the field (Nowak et al. 2008). Because urban forest conditions are dynamic, model outputs depend on precise field and auxiliary data inputs (such as pollution), thus model values are not absolute (Kim 2016).

In order to build sustainable urban forest management that is based in scientific knowledge, inventories and vegetation assessments of urban forests conducted using i-Tree are still very important (Morgenroth and Östberg 2017). Additionally, the shift from one-time inventories to ongoing monitoring is essential for establishing a long-term perspective and improving the accuracy of urban forest management over time. It could also cover landscape maintenance for urban forests (Klobucar et al. 2020). In conclusion, i-Tree Eco analysis in conjunction with field data collection is highly useful for monitoring the structure and composition of urban forests in order to assist management decisions.

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