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RESEARCH ARTICLE

Estimating Vegetation Density Changes, Tree Diversity, and Carbon Stock in Eduforest, Bekasi Regency, West Java, Indonesia

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Abstract

Climate change poses a threat in the form of temperature elevation, which can alter weather patterns and ecological balance, necessitating urgent mitigation strategies, such as emission reduction and enhanced carbon sequestration in the urban forest. This research aimed to analyze vegetation density through the NDVI approach, assess tree stand structure and composition, and approximate aboveground carbon stocks in the urban forest, specifically in Eduforest, Bekasi Regency, Indonesia. The methodology involved vegetation analysis and carbon stock estimation, utilising allometric and destructive estimation for seedling and understory levels. The high-density class in Eduforest had the highest area increase in 2023, from 0.64 ha in 2013 to 1.31 ha in 2023. There are 36 species found in all growth levels and the understory. The dominant species, such as *Swietenia mahagony*, *Acacia mangium*, and *Falcataria falcata*, are fast-growing. The tree-growth level has the highest carbon stock (39.90 tons/Ha) of the other growth levels. Eduforest can be an alternative effort to maintain vegetation diversity and carbon stock in addressing climate change.

Keywords: aboveground biomass, carbon stock, normalized difference vegetation index, urban forest

1. Introduction

Climate change is characterised by comprehensive longterm temperature and precipitation trends and other components such as pressure and humidity levels in the surrounding environment [1]. It is a complex intergovernmental challenge globally, influencing various ecological, environmental, sociopolitical, and socioeconomic disciplines [2–4]. Climate change involves heightened temperatures across numerous worlds [5–8].

According to the document of Nationally Determined Contribution (NDC), Indonesia aims to reduce greenhouse gas (GHG) emissions by 29% and 41% with international assistance to prevent a global temperature rise of 2 °C and limit global temperature rise to 1.5 °C [9]. The forest and other land use (FOLU) sector is essential in efforts to reduce emissions in Indonesia. Aside from being a store of carbon stocks, forests also act as a giant carbon sink. Forests can store at least ten times more than other vegetation types [10]. Mitigation actions under the FOLU sector involve estimating and monitoring carbon stocks and biodiversity in green areas, such as urban forests. Remote sensing offers a valuable tool for monitoring land cover changes and vegetation density. One of the tools is the Normalized Difference Vegetation Index (NDVI), which is most frequently used to indicate forest quality, vegetated area, land cover changes, mapping species distribution, carbon stock estimation, and vegetation change condition [11].

Bekasi "Eduforest" Urban Forest is located in Setu Subdistrict, Bekasi Regency, Indonesia. This area is designated for urban forest development, providing cultural and environmental services. The cultural-environmental services that could be provided by Bekasi's "Eduforest" Urban Forest can consider the microclimatic conditions and biomass potential for urban forest development. Bekasi "Eduforest" Urban Forest had an average temperature of 30.88 °C, a relative humidity of 74.02%, and an average temperature humidity index (THI) of 27.27 [12]. It refers to an uncomfortable condition, as described in the THI calculation using the formula of [13]. This condition can be improved by planting trees that can prevent the penetration of solar radiation and decrease air temperature. Bekasi "Eduforest" Urban Forest had biomass potential from dominant species, 133.10 kg/ha, stored carbon stock 66.55 kg/ha, and CO_2 sequestration 244.25 kg/ha [12]. The potential for cultural-environmental services in the Bekasi "Eduforest" Urban Forest can provide massive information for improving the development of tourist attractions, which can be in the form of educational tours, culinary tours, landscape attractions, and health therapy tours. Based on this background, this research aimed to analyse vegetation density through the NDVI approach, assess tree stand structure and composition, and approximate aboveground carbon stocks in the Eduforest, Bekasi Regency, Indonesia.

2. Materials and Methods

2.1. Site and Period

The research was conducted from July to September 2023 at Eduforest in Bekasi Regency, West Java, Indonesia. The total study site covers an area of approximately 5 hectares. This area is composed of a 4-hectare forested section and a 1-hectare portion designated for public facilities. A map showing the boundaries of the research area is provided in **Figure 1**.

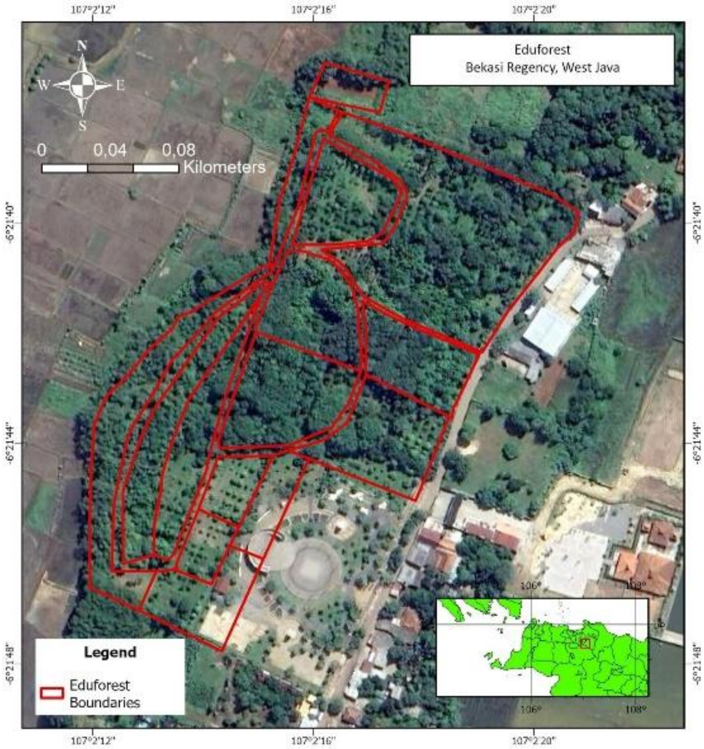

Figure 1. Geographical boundaries of the Eduforest study site in Bekasi Regency, West Java.

2.2. Tools and Materials

Field measurements were conducted using a Haga hypsometer (for tree height), measuring tape (for diameter), digital scale (for biomass weighing), and cutting tools (machete, sickles, and plant scissors) for sample collection. A laptop with ArcMap 10.8 was used for geospatial analysis, while Epicollect5 enabled real-time mobile data recording. Additional materials included markers, trash bags, flagging tape, plastic clips, and thread for sample labelling and organization. Sentinel-2 and Landsat 8 satellite imagery were incorporated for broader-scale assessment to support remote sensing analysis.

2.3. Research Procedure

2.3.1. Normalized difference vegetation index (NDVI) analysis

The NDVI was analysed using the Sentinel 2 image in ArcMap 10.8 software. The chosen image for processing was the image from May 2023. Furthermore, the image was analysed using NDVI and ArcMap 10.8 software; the bands used for processing were band 5 (NIR) and band 4 (Red). The main steps of image processing using ArcMap 10.8 were (i) image input, (ii) image pre-processing including clipping and compositing bands, (iii) classifying NDVI in the Area of Interest into three density levels using natural breaks (Jenks), namely low density, medium density, and high density, (iv) perform plot distribution. As a comparison, images from 2013 were used to determine changes in land cover in the study area. The NDVI value was obtained using the following equation [14]:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

Information:

NDVI = Normalized Difference Vegetation Index

NIR = Band Near Infrared

RED = Band Red

2.3.2. Plot establishment

Vegetation analysis was carried out by establishing a sample plot. The main plot had a 50 m x 50 m dimension consisting of three subplots, illustrated in **Figure 2**. The 50 m x 50 m plot was used to analyze the tree-level vegetation, the 25 m x 25 m subplot was used to analyze pole-level vegetation, the 12.5 m x 12.5 m subplot was used to analyze sapling-level vegetation, and the 6 m x 6 m subplot was used to analyze seedlings level and understory plants. The number of observation plots used was 16, and they were placed spread out in almost all the Eduforest area (refer to the area of Eduforest, which is only about ± 4 ha of forest area and 1 ha of public facilities).

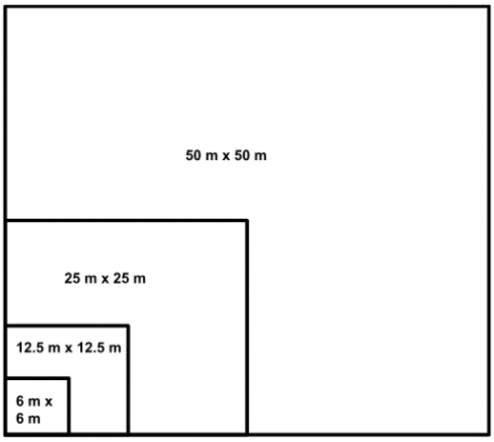

Figure 2. Schematic of sampling plot layout and dimensions at the Eduforest study site.

2.3.3. Tree species diversity study

The structure and composition of the vegetation were characterized by surveying five distinct life-form classes: trees, poles, saplings, understory, and seedlings. For each individual in the tree, pole, and sapling classes, we measured three structural parameters: diameter at breast height (DBH), total height, and clear bole height. In the understory and seedling classes, the assessment focused on floristic composition, wherein all individuals were identified to the species level and counted to determine abundance.

2.3.4. Carbon stock measurement

Carbon stock was measured using both destructive and non-destructive methods, depending on vegetation type. The destructive approach was applied to undergrowth, seedlings, and litter, while the non-destructive method, involving allometric equations, was used for saplings, poles, and trees. **Figure 3** illustrates the step-by-step process for assessing carbon stock.

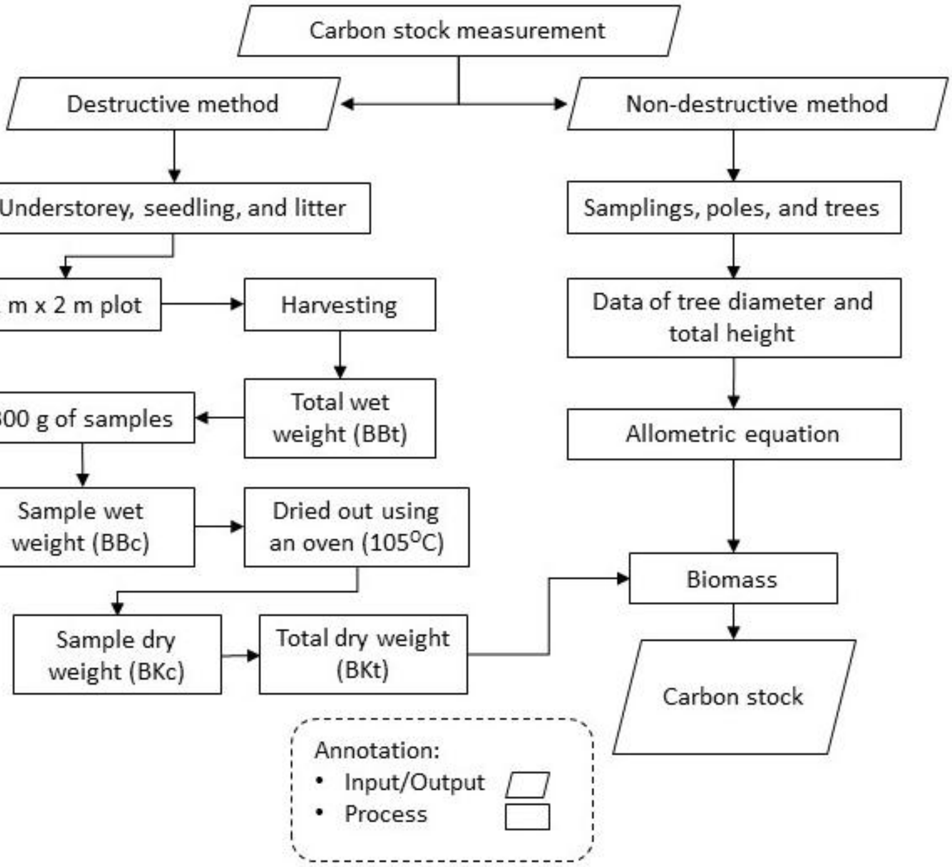

Figure 3. Flowchart illustrating the sequential steps taken to assess carbon stocks at the study site.

2.4. Data Analysis

2.4.1. Importance value index (IVI)

The IVI values at the pole and tree levels were calculated by adding up the relative density (RD), relative frequency (RF), and relative dominance (RDo). Meanwhile, it was acceptable to add RD and RF to obtain IVI at the level of undergrowth, seedlings, and saplings. RF, RD, and RDo values were obtained from the following formula:

$$\text{Density (D)} = \frac{Total\ number\ of\ individuals}{Plot\ size} \quad (1)$$

$$\text{Relative Density (RD)} = \frac{Number\ of\ individuals\ of\ the\ species}{Number\ of\ individuals\ of\ all\ species} \times 100 \quad (3)$$

$$\text{Frequency (F)} = \frac{Number\ of\ plot\ where\ species\ found}{Total\ plot\ size} \quad (4)$$

$$\text{Relative Frequency (RF)} = \frac{Frequency\ of\ the\ species}{Total\ frequency\ of\ all\ species} \times 100 \quad (5)$$

$$\text{Dominance (Dm)} = \frac{Total\ basal\ area\ of\ the\ species}{Total\ plot\ size} \quad (6)$$

$$\text{Relative Dominance (RDo)} = \frac{\textit{Total basal area of the species}}{\textit{Total basal area of all species}} \times 100 \quad (7)$$

$$\text{Important Value Index (IVI)} = \textit{RD} + \textit{RF (For undergrowth, seedling, and sapling} \quad (8)$$

$$\text{Important Value Index (IVI)} = \textit{RD} + \textit{RF} + \textit{RDo (For pole and tree)} \quad (9)$$

2.4.2. Species diversity index

To quantify the plant community structure, the vegetation data were analyzed to calculate several ecological indices, including species richness index, species dominance index, species evenness index, and species diversity index. Species diversity index was specifically evaluated using the Shannon index (H'). Following the criteria established by Ludwig and Reynolds [15], the resulting H' values were then classified into three categories: low diversity (H'<1), medium diversity (1≤H'≤3), or high diversity (H'>3).

$$\mathrm{H'} = -\sum_{i=1}^{n} pi \, \ln pi \quad (10)$$

Where:

H' = Species diversity index

Pi = ni/N

Ni = total number of individuals of type-i

N = total number of individuals of all types

$$\mathrm{C} = \sum \left(\frac{ni}{N}\right)^2 \quad (11)$$

Where:

C = Species dominance index

Ni = Number of individuals per species

N = Number of individuals of all species

$$R = \frac{(S-1)}{\ln(N)} \quad (12)$$

Where:

R = Species richness index

S = Number of types found

N = Total number of individuals encountered

$$\mathrm{E} = \frac{H'}{H_{max}} \quad (13)$$

Where:

E =Species evenness index

H_{max} = ln S

S = Number of species

2.4.3. Biomass measurement

Standing biomass measurements were carried out using the allometric method. The allometric method measures plant growth, expressed in exponential or logarithmic relationships between plant organs that occur harmoniously and change proportionally [16]. The allometric model used in this study is presented in Table 1.

Table 1. Allometric equations used for biomass estimation at the Eduforest study site.

Type of Forest	Species	Allometric Model	Source
Plantation Forest	*Falcataria falcata*	AGB = 0.1126*D^2.3445	Krisnawati et al. [17]
Moist stands of forest	Mixture	AGB = BJ*exp(-1.499+2.148*ln(D)+0,207(ln(D)) ^2-0.0281(ln(D)) ^3)	Chave et al. [18]

AGB: Above-ground biomass, D: diameter, BJ: wood density

2.4.4. Understory, seedling, and litter biomass measurements

The carbon pool biomass for the undergrowth, seedling, and litter layers was quantified via destructive sampling. Following collection, the total wet weight (BBt) of each component was recorded in the field. A representative subsample was then taken to the laboratory to determine its wet weight (BBc) and oven-dry weight (BKc), which were used to calculate the total dry weight with the formula below:

$$\mathrm{BKt} = \frac{BKc}{BBc} \times BBt \quad (14)$$

Where:

BKt = Total dry weight (g)

BBc = wet weight of sample (g)

BKc = Dry weight of sample (g)

BBt = Total wet weight (g)

2.4.5. Carbon calculation

Carbon stock was calculated by multiplying the biomass value by a conversion factor of 0.47. This factor represents the carbon concentration in organic material, which averages 47%. Thus, 0.47 was applied to convert total biomass to carbon stock [19]. The method aligns with standard protocols for carbon estimation in forest ecosystems.

$$\mathrm{C} = B \times 0.47 \quad (15)$$

Where:

C = Carbon stock (ton C/ha)

B = Biomass (ton/ha)

3. Results and Discussion

3.1. Results

3.1.1. Vegetation Cover Dynamics in Eduforest

Eduforest vegetation density maps can be seen in **Figure 4**. The result shows a vegetation area change in all vegetation cover classes. The high-density class had the highest area increase in 2023 (**Table 2**). The high-density class increased from 0.64 ha to 1.31 ha, with the percentage of vegetation cover changing from 18% to 38% (**Figure 5**). Meanwhile, the moderate class decreased from 1.62 ha to 1.61 ha, and the low class decreased from 1.22 ha to 0.53 ha. The increase in the high-density class is likely due to the lower classes, such as the moderate class and low class, having grown well and covered the empty area, so that in 2023, the vegetation density has changed.

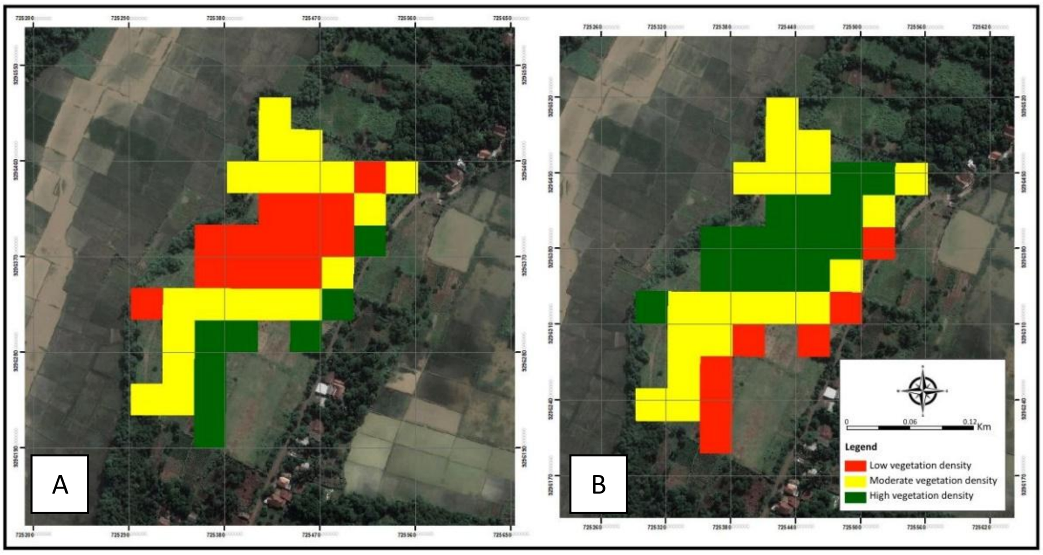

Figure 4. Temporal changes in the Normalized Difference Vegetation Index (NDVI) at the Eduforest study site from 2013 (A) to 2023 (B).

Table 2. A comparison of land area by vegetation density class at the Eduforest site for 2013 and 2023.

Density	Large area (Ha)	
	2013	2023
Low dense	1.22	0.53
Moderately Dense	1.62	1.61
Highly Dense	0.64	1.31

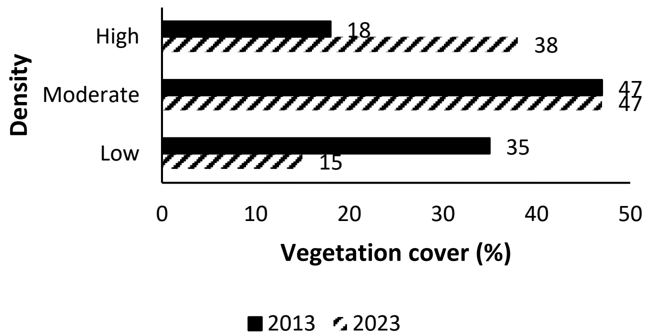

Figure 5. Changes in the proportional area of vegetation cover density classes at the Eduforest site between 2013 and 2023.

3.1.2. Vegetation Diversity

This study found 36 species in all growth levels and the understorey. The greatest number of species found was at the sapling-growth level, with 35 species in the study area. The species found in the sapling growth level are *Swietenia mahagoni, Agathis dammara, Adenanthera pavonia,* etc. The seedling-growth level is the lowest number of species found, and there is only one in this growth level, *Acacia mangium*. According to

Table 3, *P. purpureum* (understorey), *A. mangium* (seedling), *S. mahagony* (sapling), *F. falcata* (pole), and *A. mangium* (tree) have the highest species density on each growth level.

Table 3. The three most abundant tree species based on stem density (individuals/ha) at the Eduforest study site.

Growth level	Local name	Scientific name	Individual plant density (individuals/ha)
Understorey*	*Rumput Gajah*	*Pennisetum purpureum*	8,334
	Rumput Kerbau	*Paspalum conjugatum*	8,264
	Bandotan	*Ageratum conyzoides*	5,417
Seedling	*Akasia*	*Acacia mangium*	18
Sapling	*Mahoni*	*Swietenia mahagony*	96
	Damar	*Agathis dammara*	28
	Saga	*Adenanthera pavonina*	32
Pole	*Sengon*	*Falcataria falcata*	10
	Mahoni	*Swietenia mahagony*	6
	Kecrutan	*Spathodea campanulata*	4
Tree	*Akasia*	*Acacia mangium*	8
	Kecrutan	*Spathodea campanulata*	6
	Sengon	*Falcataria falcata*	3

* not include growth level

Table 4 shows the top three species with the highest IVI value in the study area. *P. purpureum* dominated the understorey layer, while *A. mangium* had the highest IVI at both the seedling and tree growth levels. *S. mahagony* was the leading species at the sapling-growth level, and *F. falcata* showed the highest IVI at the pole-growth level.

Table 4. The three most important tree species determined by the Importance Value Index (IVI) at the Eduforest study site.

Growth level	Local Name	Scientific Name	RF	RD	RDo	IVI (%)
Understorey*	Rumput Gajah	*Pennisetum purpureum*	8.80	15.35	-	24.10
	Rumput Kerbau	*Paspalum conjugatum*	8.80	15.22	-	23.97
	Bandotan	*Ageratum conyzoides*	11.3	9.97	-	21.22
Seedling	Akasia	*Acacia mangium*	100	100	-	200
Sapling	Mahoni	*Swietenia mahagony*	6.78	22.22	-	29.00
	Damar	*Agathis dammara*	5.08	6.48	-	11.57
	Saga	*Adenanthera pavonina*	3.39	7.41	-	10.80
Pole	Sengon	*Falcataria falcata*	8.11	16.39	19.86	44.40
	Mahoni	*Swietenia mahagony*	8.11	9.84	8.53	26.50
	Kecrutan	*Spathodea campanulata*	8.11	6.56	10.21	24.90
Tree	Akasia	*Acacia mangium*	17.86	38.55	31.00	87.41
	Kecrutan	*Spathodea campanulata*	17.86	25.30	39.99	83.15
	Sengon	*Falcataria falcata*	21.43	14.46	11.05	46.94

* does not include growth level. RF: Relative Frequency. RD: Relative Density. RDo: Relative Dominance. IVI: Important Value Index

Table 5 shows that the highest species dominance index (C) value occurs at the pole-growth level, with a value of 0.90. The species richness index (R) is highest at the sapling-growth level, reaching a value of 7.26. The species evenness index (E) reaches its highest value of 1.00 at the seedling-growth level.

Table 5. A comparison of community structure indices across five vegetation life-form classes at the Eduforest study site.

Growth level	H'	C	R	E
Understory	2.36	0.72	3.01	0.12
Seedling	1.00	0.00	0.00	1.00
Sapling	3.08	0.86	7.26	0.07
Pole	2.89	0.90	5.59	0.07
Tree	1.77	0.69	2.71	0.24

H': species diversity index. C: species dominance index. R: species richness index. E: species evenness index

3.1.3. Vegetation structure

Figure 6 presents the density of individual trees for each regeneration. The results show that the vegetation did not exhibit an inverted J curve. The highest density was found at the sapling-growth level, which does not present the normal distribution of forest vegetation. Hence, enrichment planting with the adaptive species can be an option to increase the diversity in the Eduforest.

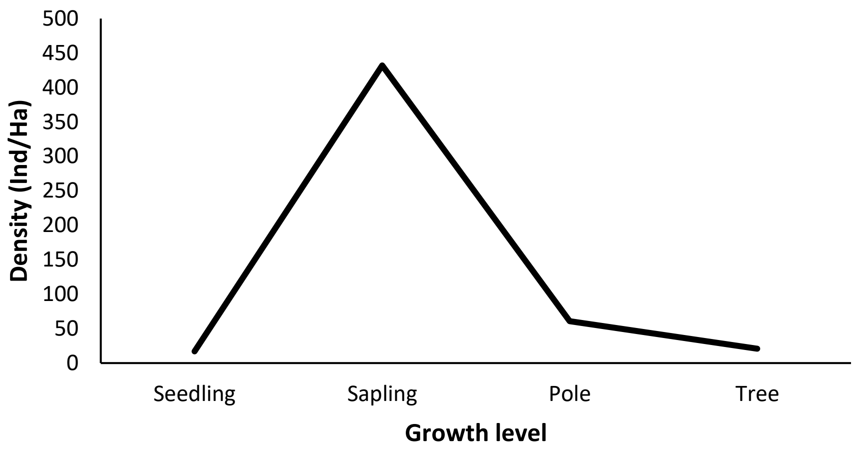

Figure 6. Stem density across different vegetation life-form classes at the Eduforest study site.

Table 6 and **Figure 7** show vegetation density across various diameter classes, revealing a distinct inverted-J curve pattern. This pattern is indicative of a forest structure dominated by a high frequency of individuals in the smaller diameter classes (particularly 10-19 cm), with a progressive and consistent decline as diameter increases. Such a distribution is commonly associated with uneven-aged or regenerating forest stands, where natural regeneration is ongoing. The predominance of smaller-diameter trees shows dynamic stand development and potentially favourable regeneration conditions. Conversely, the reduced frequency of larger diameter stems reflects limited regeneration, anthropogenic disturbance, and or the early successional stage of the forest. This tree structure is usually found in secondary forests or disturbed forest ecosystems. Monitoring the dynamics in this distribution can serve as a valuable indicator for forest recovery and stand regeneration.

Table 6. Stem density distribution across Diameter at Breast Height (DBH) classes at the Eduforest study site.

Diameter (cm)					Tree Basal Area (m^2/ha)
10-19	20-29	30-39	40-49	50-59	
59	58	16	7	2	6.78

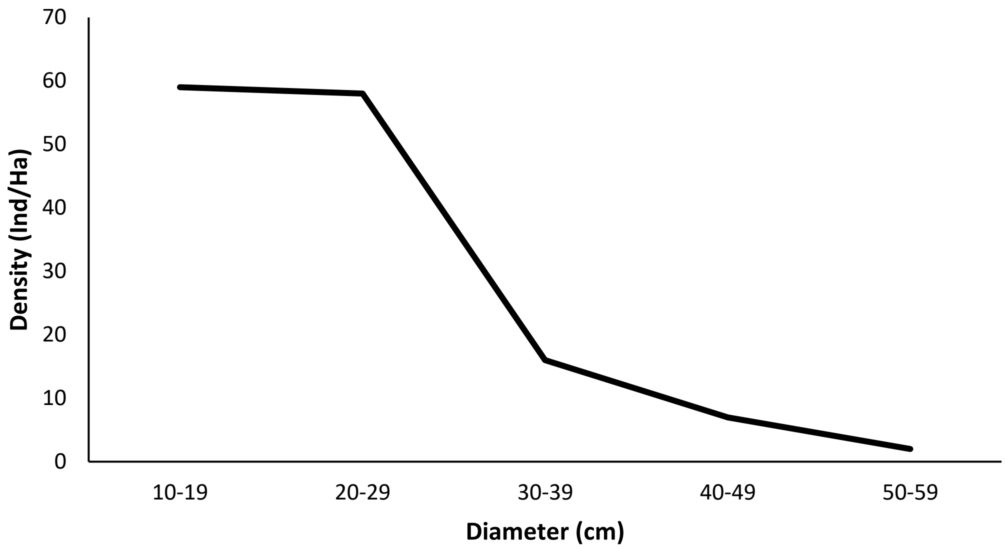

Figure 7. Stem density distribution across Diameter at Breast Height (DBH) classes at the Eduforest study site.

3.1.4. Carbon stock

Figure 8 shows that the tree-growth level has the highest carbon stock of the other growth levels. The tree-growth level has the highest carbon stock at 39.90 tons/Ha, surpassing all other growth levels. This level alone holds over five times the average carbon stock of Eduforest, which stands at 7.37 tons/Ha.

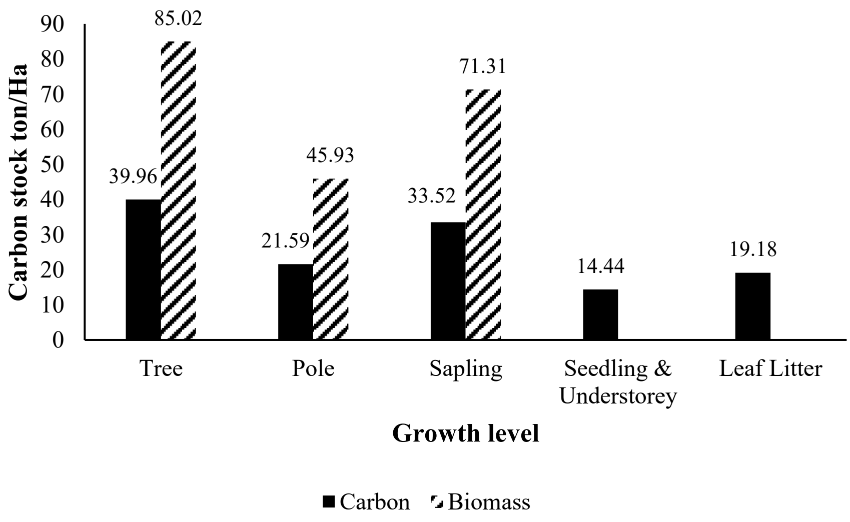

Figure 8. Carbon and biomass stocks are distributed across different growth levels at the Eduforest site.

3.2. Discussion

3.2.1. Vegetation Cover Dynamics in Eduforest

Individual plant density refers to the number of plants per unit area (plants/ha). Generally, a higher individual plant density indicates a denser vegetation cover. The importance value index (IVI) evaluates a species' ecological significance in a specific ecosystem. The Normalized Difference Vegetation Index (NDVI) is an index used to quantify vegetation health and biomass by measuring the reflectance of near-infrared (NIR) and red light. Higher NDVI values show denser and healthier vegetation.

This study resulted in three vegetation densities, as determined by NDVI analysis, which are low, moderate, and high. The NDVI method calculates the greenness of vegetation derived from satellite image-based indices, which measure the relative abundance and spatial distribution of vegetation with a value interval of -1 to 1 [20-23]. Urban forests, such as Eduforest in Bekasi, are essential assets in addressing the global issue of climate change and protecting ecosystem services. Bekasi is one of the cities in Indonesia that has rapid urbanization. Eduforest represents a model for the green infrastructure development in an urban context and showcasing how cities of Bekasi can integrate environmental solutions to enhance resilience. Trees in Eduforest can store carbon, which directly reduces greenhouse gas emissions and improves air quality, while also contributing to biodiversity conservation.

3.2.2. Vegetation Diversity

The species with a higher IVI value have more dominance and importance than the other species, which means that *P. purpureum* (understorey), *A. mangium* (seedling), *S. mahagony* (sapling), *F. falcata* (pole), and *A. mangium* (tree) were the species that were dominant and important in this study. The IVI indicates the structural importance of species in each ecosystem [24], thus, species with high IVI values are deemed to be more important than those with low values [25], and it also indicates dominance and ecological success [26].

Species diversity is related to the species dominance index (C). A high C value indicates dominance is centred on a particular type. Conversely, dominance is not centred on a particular type if the C value is low. The study result shows that there was a dominant species at the pole-growth level. The value range $0<C<0.5$ indicates that no type dominates. Meanwhile, the value range $0.5<C<1$ indicates that there is a type that dominates.

The species richness index (R) describes the number of species in a community. The R-value will be higher if the number of types increases. The R-value determines the species richness index depending on the number of species in the ecosystem [27]. An R-value <3.5 indicates low species richness. Meanwhile, if the R-value is in the range of $3.5<R<5$, then species richness is high.

The species evenness index (E) determines the' evenness of individuals between species in a community. The E value ranges from 0-1. Several things, such as the suitability of the growing place and species enrichment activities can influence Evenness [28]. The seedling growth stage exhibited perfect species evenness ($E = 1$), indicating uniform abundance across all species in this stratum.

3.2.3. Vegetation structure

Vegetation structure can be observed from two different perspectives, vertical and horizontal. Horizontal stand structure describes the distribution of individual species within their habitat. Meanwhile, the vertical stand structure describes the distribution of trees across various canopy layers.

A classic inverse-J curve distribution suggests that the woody plant species have good regeneration, that it is a healthy forest, and that sustainable utilisation is taking place [25]. Several factors, including environmental conditions, can influence this condition. This also could be due to anthropogenic activities such as firewood extraction, grazing, charcoal burning, and the removal of poles [25].

The density distribution on each diameter indicates that the vegetation in the study area exhibited good regeneration. The density distribution shows a classic inverted J-curve. A classic inverse-J curve distribution suggests that the woody plant species have good regeneration, that it is a healthy forest, and that sustainable utilisation is taking place [25].

3.2.4. Carbon stock

The existence of forests provides benefits for many living creatures on Earth. Some advantages of forests include wood, non-timber forest products, and the presence of animals. Indirectly, forests act as providers of environmental services, regulating water management, enhancing aesthetics, and absorbing carbon. Forests draw carbon from the atmosphere in photosynthesis, and the carbon may remain stored for long periods in trees and other forest vegetation (in above and below-ground biomass) and in forest products in use or landfills [29]. The normal carbon cycle in the forest is initiated when carbon is fixed via photosynthesis [30]. Organic compounds are immobilised in tissue formation and transformed into biomass, and they are degraded through the respiration process by microbes, plants, and animals. Forest carbon sequestration can be classified into five categories within each forest ecosystem: aboveground biomass, belowground biomass, scrap biomass, ground cover plants, and soil carbon storage [30].

According to [31], the average carbon stock in the US urban forest is 7.69 kg C/m², equal to 76.9 tons C/ha. This is similar to the carbon stock in Eduforest, which was planted four years ago (7.37 tons/ha). However, the mean diameter and vegetation density affect carbon stocks [32]. A higher mean diameter and number of individuals will result in a higher carbon stock.

4. Conclusions

Eduforest's high-density vegetation class expanded significantly from 0.64 ha to 1.31 ha in 2023. There are 36 species found in all growth levels and the understory. The dominant species, such as *Swietenia mahagony*, *Acacia mangium*, and *Falcataria falcata*, are fast-growing. The tree-growth level has the highest carbon stock (39.90 tons/Ha), rather than the other growth levels, with an average carbon stock is 7.37 tons/Ha. Eduforest can serve as an alternative approach to maintaining vegetation diversity and carbon stock, addressing climate change, and providing a blueprint for sustainable urban planning in tropical cities.

Author Contributions

APPH: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing; **DNM**: Investigation, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing; **HNM**: Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing.

Conflicts of interest

There are no conflicts to declare

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