Estimation of carbon stocks from tree stands vegetation in Universitas Indonesia’s urban forest, Depok

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Abstract. Urban forest has a function as CO2 emissions absorbers derived from human activities around the city. Universitas Indonesia (UI) Urban’s Forest is one of the Urban Forest which has potential carbon stocks. A study has been conducted to analyze the potential of carbon stocks and tree stands that have the highest carbon stock in UI Urban’s Forest. Tree stands are woody vegetation with a diameter ≥ 20 cm. The research was conducted in October-November 2017 in UI Urban’s Forest area covering three locations, west Wallace, east Wallace, and natural vegetation. Method of collecting data of vegetation was done by nondestructive sampling by measuring Breast Height Diameter (DBH). Data processing uses allometric equations with the specific wood density of each tree species. Results showed that the potential of carbon stocks in UI Urban’s Forest is 468.02 ton/ha with west Wallace, east Wallace, and natural vegetation are 138.62 ton/ha, 162.75 ton/ha, and 182.64 ton/ha. Overall, potential carbon stocks in UI Urban’s Forest is 11752.48 ton/ha. Species of trees with the highest potential of carbon stocks is Delonix regia.

Keywords: Allometric equations, carbon stocks, DBH, wood density

1. Introduction

Urban forests have the ecological benefits by reducing rainwater and reducing urban heating [1]. Urban forests also have a function as carbon stocks and carbon sequestration that can be determined through carbon stock calculations. The calculation aims to determine the estimated potential of carbon stocks and the value of CO2 uptake form of biomass in forest vegetation. The vegetation inside the forest has a chlorophyll capable of absorbing CO2 and then storing it as organic matter in plant biomass [2].

Universitas Indonesia (UI) Urban’s Forest is one of the urban forest that has potential as a carbon stocks in Depok and surrounding areas. As an area capable of absorbing pollutants resulting from human activities in the vicinity of UI Urban’s Forest, the existence of urban forests surrounding UI campus is important as a carbon stocks from vegetation in the forest, because that area is surrounded by fairly dense settlements with various activity that produces pollutants, especially CO2 [3]. Studies of carbon stocks in UI Urban’s Forest which include Lubis, et al. [3] and Aisyah [4] that examined the number of carbon stock in UI Urban’s Forest was 172.86 ton/ha [3] and carbon sequestration 387 ton/ha [4].

However, there are not information available on the updated carbon stocks and which tree species provide the highest carbon stock. Therefore, a study on carbon stocks especially in UI Urban’s Forest is important to find out the amount of carbon stocks and the tree species that have carbon stock highest in UI Urban’s Forest area. Such study is important to provide information on the amount of potential carbon stock per year.
2. Study area and method

2.1. Study area
The study was conducted on October-November 2017 in UI Urban’s Forest area. The location is divided into three zones: West Wallace, East Wallace, and natural vegetation. West Wallace has native vegetation types from the western area of the Wallace Line, including *Shorea* spp. and *Tectona grandis*. East Wallace has selected types of vegetation originating from the eastern part of the Wallace Line, such as *Diospyros celebica*, *Pometia* sp., and *Syzygium aromaticum*. Natural Vegetation is the core of ‘Mahkota Hijau’ which contains a variety of local natural vegetation collections (Jakarta-Depok) and is also engineered for natural tropical forests. There were 75 total sample sites, each of which the urban forest zone was divided into 25 sample sites with a 20 m x 20 m square plot for tree [5]. The sample point is randomly assigned to the right and left along the forest path with a distance of 5 m each plot.

2.2. Determination of vegetation area
The UI Urban’s Forest area is determined using software ArcGIS 10.5 version based on coordinate data marked by GPS, then inserted in Google Earth map and then converted the form of file format into shapefile, then opened in ArcGIS software. UI Urban’s Forest area is based on area calculation by ArcGIS software (figure 1).

2.3. Vegetation data collection
Vegetation data were obtained using direct measurement method in the field of nondestructive sampling. The vegetation data in the form of trees with stem circumference of > 62 cm were collected. Then the Diameter BreastHeight (DBH) of each stand that goes into the plot was measured at 1.3 m from the surface of the soil by regular measuring tape which then converted into a diameter.

![Figure 1. Map of UI Urban’s Forest area.](image-url)
2.4. Environmental parameter data retrieval

Data collection of environmental parameters is required as complementary data to determine environmental factors and to be a supporting factor in analyzing the number of carbon stocks. Environmental parameters taken are the intensity of sunlight using Luxmeter, humidity and air temperature using Jumbo Thermohygrometer Display model E91502 taken at each sample sites which is in the middle of sample sites.

2.5. Processing and data analysis

Data processing begins by converting the circumference of trees into diameters (DBH) which divided by 3.14. The obtained diameter will be used to estimate the biomass of each tree stand calculated using the allometric equation

\[ W = 0.11 \cdot D^2 + 0.62 \] (6)

where \( W \) = tree biomass (kg); \( D \) = wood density (g/cm³) refers to ICRAF website [7]; \( D \) = diameter of tree (cm). After the biomass is obtained, then the carbon stock is calculated by multiplying the biomass by 0.5 coefficient according to the equation

\[ C = W \times 0.5 \] (8)

with \( C \) = carbon stock (ton); \( W \) = tree biomass (kg).

Data will be processed by Microsoft Excel program with entering the value of biomass and carbon stock. Then, data will be analyzed by comparing the carbon stocks in UI Urban’s Forest on 2017 by 2013 and carbon stock in each tree species will be compared to understand which tree species have the highest carbon stock.

3. Results and discussion

3.1. Vegetation in Universitas Indonesia urban’s forest

In total, we recorded 641 individuals belonging to 57 species of trees from 28 families in the UI forest area. The previous studies in 2013 [4] found 45 species from 18 families and in 2009 [9] found 33 species from 16 families (see table 1).

The comparison of plant species yields is seen to be changing. The results of the study were not completely comparable with previous studies, as there were differences in the number of sample sites used. The number of sample sites in the 2009 study was 42 sample sites, while in the study of 2013 and 2017 using 75 sample sites. The difference in the number of sample sites is enough to make the tree species found in 2017 more than the previous year.

In this study, there were four plant species commonly found in UI Urban’s Forest, including Acacia mangium (Akasia), Falcataria moluccana (Sengon), Microcos tomentosa (Dluwak), and Macaranga tanarius (Mara). These are plant species found in UI Urban’s Forest because the species has adaptations to various environmental conditions so as to grow and develop properly [10]. Acacia mangium is a species that is able to adapt in almost all places, both humid areas and infertile soil is not fertile [11]. However, Acacia mangium also has invasive and allelopathic properties that can inhibit the growth of other nearby species [12]. Falcataria moluccana is a fast-growing species in the tropics. Neither do Microcos tomentosa and Macaranga tanarius are generally reside in secondary forest and relatively open areas [13, 14].

A large number of individuals from a tree species indicates high levels of dispersal and adaptability to the physical condition of the forest environment. The supporting physical conditions of the environment such as humidity, temperature, light intensity, nutrients and wind speed affect the growth and distribution of seeds [2]. Physical factors will create soil conditions that will provide moisture and nutrients so as to determine the quality of habitat in a vegetation. Tree seedling regeneration (seedling and sapling) is also influential in the successful growth of a tree [15].

3.2. Environmental parameter measurement

The temperature that has been obtained in 2017 was slightly increased from 2013 [4] in table 2. UI urban’s forest area has average temperature of 27 °C [3]. The increase of air temperature is probably due to the decrease in canopy coverage in the study area. The area which was enclosed by canopy has
low temperatures and high humidity as the effect of the lush tree canopy otherwise the areas with the open canopy, the temperature will be high and the humidity will decrease because of low canopy coverage [16].

The air humidity in UI Urban’s Forest tended to decrease when compare to the results obtained in 2013 [4] in table 2. It was predicted because of the effect of rain during data collection in 2013 so that the measured moisture becomes higher than year 2017. Humidity and temperature greatly affect to plant growth, and each of these factors is interrelated in creating the optimal environmental conditions for the plant. The growth of a plant will increase as the temperature decreases and the humidity increases, and otherwise [17]. The average annual air humidity in UI Urban’s Forest is 85 % and has an average rainfall of 2,478 mm/year, as well as the number of days of average annual rainfall of 75–155 days [3].

The light intensity also tended to decrease when compared to the results obtained in 2013 [4] in table 2. That means due to differences in tree canopy cover at the study sites (figure 2). Factors that affect the high intensity of sunlight is the closure of the tree canopy [17]. High sunlight intensity values indicate that there are many gaps (gaps) that allow sunlight to enter more into the forest floor, and otherwise [15]. The measurement of environmental parameters such as temperature, humidity, and intensity of sunlight are for supporting data in view of the growth of vegetation contained in the forest. Based on these growths will also affect the ability of a vegetation in storing carbon, this is because moist air and low temperatures allow the growth of vegetation to become abundant [15].

| Table 1. Number of tree species and tree family in the 2009, 2013 and 2017 studies. |
|---------------------------------|-----------------|-----------------|
| No                             | Studies year    | Species         | Family |
|--------------------------------|-----------------|-----------------|
| 1                              | 2009            | 33              | 16     |
| 2                              | 2013            | 45              | 18     |
| 3                              | 2017            | 57              | 28     |

| Table 2. Comparison of environmental parameter data range 2013 and 2017. |
|---------------------------------|-----------------|-----------------|
| No.                            | Environmental parameter | Range          |
|--------------------------------|------------------------|----------------|
| 1                              | Temperature (°C)       | 27.3–35         | 29.2–34 |
| 2                              | Humidity (%)          | 71–93           | 44–82   |
| 3                              | Sunlight intensity (lux) | 350–17200    | 55–3134 |

**Figure 2.** A description of the research location in UI city forest, (a) west Wallace, (b) east Wallace and (c) natural vegetation.
3.3. Carbon stocks from tree stands in UI Urban’s forest
The potential of carbon stock in UI Urban’s Forest is 486.01 ton/ha (table 3). That result showing an increased carbon stocks in 2017 if compared to the year 2013 [3, 4] in the order of 172.86 ton/ha and 335.478 ton/ha. Increasing the amount of carbon stocks because carbon stocks in each stand are strongly influenced by the amount of biomass held by the stand. The magnitude of biomass is influenced by the diameter of the stand. The carbon stock of a stand will increase along with the increase in stem diameter [3]. In addition, the high low carbon stock is also determined by the specific wood density that will show the density of the constituent cells in a plant. The greater the density of a plant then the density of its constituent cells will be higher, thus will increasing the size circumference of the tree stalk. This will certainly affect the size of the diameter, given the diameter is obtained based on the stem circumference value of a plant, so that the stored carbon stock will be even higher [18].

3.4. Comparison of carbon stocks of tree stands in UI urban’s forest area
Table 4 showed that natural vegetation area has a potential carbon stocks of 182.64 ton/ha. Then, natural vegetation with an area of 18.042 hectares has carbon store capacity 3295.23 ton. East Wallace area is the area with the largest area compared with two other areas have carbon potential of 164.75 ton/ha. East Wallace of 28.750 hectares has 4736.59 tons of carbon. West Wallace has the smallest carbon reserves when compared with the other two areas that are 138.62 ton/ha. West Wallace area with an area of 26.849 hectare has a carbon store capacity of 3270.66 ton/ha.

The results of reserves obtained in 2017 which compared to carbon stocks in 2013 [4] in figure 3 has increased. Increased carbon stocks from 2013 to 2017 are suspected of being influenced by the value of biomass, wood density, number of individuals, and plant life.

There are ten species of tree stands that have the highest potential carbon stock in UI Urban’s Forest (see table 5). The carbon stock of each tree species will show different results when averaged according to the number of individuals. The highest carbon stock based on the average number of individuals in table 6. The calculation of carbon stocks based on the average individual is intended to determine the average capability of carbon stocks in each species, because the high ability of trees in carbon inserts is influenced by the number of individuals of the species [19].

| Table 3. Total biomass and carbon stocks in UI Urban’s Forest area. |
|----------------------|----------------------|----------------------|----------------------|----------------------|
| Total biomass (kg) | Total biomass (ton) | Total biomass (per plot) | Total biomass (per ha) | Carbon stocks (C) |
| 972033.54 kg | 972.03 ton | 38.88 ton/plot | 972.03 ton/ha | 486.01 ton/ha |

| Table 4. Carbon stocks in UI urban’s forest. |
|----------------------|----------------------|----------------------|
| UI Urban’s Forest area | Area (hectare) | Carbon stocks/hectare (ton/ha) | Total of carbon stocks (ton) |
|----------------------|----------------------|----------------------|----------------------|
| West Wallace | 26.840 | 138.62 | 3720.66 |
| East Wallace | 28.750 | 164.75 | 4736.59 |
| Natural vegetation | 18.042 | 182.64 | 3295.23 |
| Total | 73.63 | | 11752.48 |
| Average | | | 159.61 |
Figure 3. Differences of carbon stocks from tree stand in 2013 and 2017.

Table 5. The highest carbon stock value on 10 tree species in UI urban’s forest.

| No | Species                  | Species biomass in area | Total biomass per species (ton/ha) | Carbon stocks per species (ton/ha) |
|----|--------------------------|-------------------------|-----------------------------------|-----------------------------------|
|    |                          | West Wallace            | East Wallace                      | Natural vegetation                |                                    |
| 1  | Acacia mangium           | 62.03                   | 31.34                             | 265.51                            | 358.88                            |
|    |                          |                         |                                   |                                   | 179.44                            |
| 2  | Falcataria moluccaana    | 122.94                  | 64.19                             | 59.74                             | 246.88                            |
| 3  | Delonix regia            | 0.19                    | 72.30                             | 0                                 | 72.49                             |
|    |                          |                         |                                   |                                   | 36.25                             |
| 4  | Dalbergia latifolia      | 44.94                   | 6.43                              | 0                                 | 51.37                             |
|    |                          |                         |                                   |                                   | 25.69                             |
| 5  | Enterolobium cyclocarpum | 4.84                    | 31.27                             | 0                                 | 36.11                             |
|    |                          |                         |                                   |                                   | 18.06                             |
| 6  | Macaranga tanarius       | 1.77                    | 16.90                             | 15.02                             | 33.69                             |
|    |                          |                         |                                   |                                   | 16.84                             |
| 7  | Adenanthera pavonina     | 6.01                    | 20.12                             | 1.70                              | 27.82                             |
|    |                          |                         |                                   |                                   | 13.91                             |
| 8  | Microcos tomentosa       | 2.83                    | 7.83                              | 15.20                             | 25.86                             |
|    |                          |                         |                                   |                                   | 12.93                             |
| 9  | Macaranga triloba        | 0                      | 20.76                             | 0                                 | 20.76                             |
|    |                          |                         |                                   |                                   | 10.38                             |
| 10 | Ceiba pentandra          | 0.35                    | 14.93                             | 0                                 | 15.28                             |
|    |                          |                         |                                   |                                   | 7.64                              |

The highest proportion of carbon stocks in UI Urban’s Forest is largely derived from the family tree Fabaceae because it has a fast enough diameter growth to store carbon in large quantities. Family Fabaceae is also a type of trees that has tolerance to environmental factors such as temperature, humidity, soil conditions, and nutrient competition. It greatly influences and allows plants to have good tree development and has a large diameter of stems [3].

The high or low ability of trees in storing carbon is influenced by biomass, wood density, and a large number of individual trees. Biomass will affect the size of the stem diameter. Similarly, the specific wood density will affect the density of plant cells. The increase in carbon stock will be followed by the size of the stem diameter [3]. Similarly, the specific wood density, if the weight value of wood from a large stand, the higher the density of its constituent cells, thus increasing the diameter of the stem. So, that’s mean will inevitably affect the carbon stocks it stores becomes increasing [18].
Table 6. The highest carbon stock based on the average number of individuals tree species in UI Urban’s Forest.

| No | Species                  | Total biomass per species (ton/ha) | Carbon stocks per species (ton/ha) | Number of tree stands | Average of carbon stocks (ton/ha) |
|----|--------------------------|-----------------------------------|-----------------------------------|-----------------------|----------------------------------|
| 1  | Delonix regia            | 72.49                             | 36.25                             | 3                     | 12.08                            |
| 2  | Falcataria moluccaana    | 246.88                            | 123.44                            | 80                    | 1.54                             |
| 3  | Enterolobium cyclocarpum | 36.11                             | 18.06                             | 12                    | 1.50                             |
| 4  | Adenanthera pavonina     | 27.82                             | 13.91                             | 12                    | 1.16                             |
| 5  | Acacia mangium           | 358.88                            | 179.44                            | 168                   | 1.07                             |
| 6  | Eucalyptus alba          | 1.79                              | 0.90                              | 1                     | 0.90                             |
| 7  | Dalbergia latifolia      | 51.37                             | 25.69                             | 32                    | 0.80                             |
| 8  | Macaranga tanarius       | 33.69                             | 16.84                             | 28                    | 0.60                             |
| 9  | Gmelina arborea          | 6.32                              | 3.16                              | 8                     | 0.40                             |
| 10 | Intsia bijuga            | 0.78                              | 0.39                              | 1                     | 0.39                             |

Each plant species has specific wood density. The wood density will affect the biomass of a plant. The greater the specific gravity, the higher the carbon stored in a plant. A tree stands to have a high wood density if its weight value is above 0.65 g/cm³, and otherwise if the wood density below 0.65 g/cm³ is included in low wood density [18].

4. Conclusion
The potential of carbon stocks in the UI Urban’s Forest area increased from the previous study in 2013 that is 468.02 ton/ha with west Wallace, east Wallace, and natural vegetation in sequential order of 138.62 ton/ha, 162.75 ton/ha, and 182.64 ton/ha. Overall, Potential carbon stocks in UI Urban’s Forest is 11752.48 ton/ha. The tree species that have the highest potential carbon stocks is Delonix regia.

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