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Estimation of Above-ground Carbon Stocks in Green Areas of PT Sumatera Prima Fibreboard, North Indralaya, Ogan Ilir, South Sumatra

Ayu Wulandari[1], Hilda Zulkifli[1], Doni Setiawan[1], Agung Laksana[2*]

[1]*Biology Department, Faculty of Mathematics and Natural Science, Sriwijaya University, Indonesia*
[2]*HSE Deputy Manager, PT Sumatera Prima Fibreboard, South Sumatra, Indonesia*
[*]*Corresponding author: agung.laksana@spf.co.id*

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Abstract: PT Sumatera Prima Fibreboard (PT SPF) is a private company that produces medium-density fibreboard (MDF). PT SPF made a green area in several locations in the factory environment as an effort to reduce air pollution, especially CO_2 gas due to MDF production activities. The function of green areas as a carbon pool has an important role in reducing and suppressing the release of CO_2 emissions into the air. This research aims to determine the value of biomass and stored carbon reserves in saplings, poles, and trees rates, as well as understorey, and litter in PT SPF's green areas. This research used stratified purposive sampling methods. The saplings, poles, and trees biomass used a non-destructive method by recording the species, and the diameter at breast height. Understorey and litter biomass measurements used a destructive method by taking parts of the understorey and litter above the surface as samples. Based on this research, there were 13 saplings, poles, and tree rates species belonging to 9 families and 13 understory species belonging to 11 families in the research plots. The potential for saplings, poles, trees, understorey, and litter carbon storage in 5 green areas of PT SPF with a total area of 16,673 m^2 (1.67 ha) is 471.20 tons and classified as a good category.
Keyword: carbon stock, factory environment, green area, PT SPF, South Sumatra

1. Introduction

PT Sumatera Prima Fibreboard (PT SPF) is a private company that produces medium-density fibreboard (MDF) [1]. The manufacturing process involves the emission of dust and gas pollutants from treating and heating wood using production machinery, which is spread around the factory. Excessive concentrations of greenhouse gases such as CO_2, CH_4, and N_2O, can cause global warming and significant climate change [2].

One way to overcome the causes of global warming, especially greenhouse gases is to make a green area. Re-greening is an effort to repair, maintain, and improve the condition of land so that it can be used optimally [3]. Green open space has benefits in urban areas as a water storage and absorption area, filtering polluted air from industrial activities and vehicle pollution, cooling and supplying fresh air in the environment.

CO_2 gas from the air is absorbed by plants through the photosynthesis process. One of the photosynthesis results is carbohydrates which are then circulated and stored in the plant body, causing a process of carbon sequestration (C-sequestration) [4]. PT SPF has made a green area in the factory environment with a total area of more than 14.000 m^2 as an effort to reduce air pollution, especially CO_2 gas. The function of the green area as a carbon pool has an important role in reducing and suppressing the release of CO_2 emissions into the air, especially in the factory environment. Based on the description above, research was conducted to determine the value of carbon stocks of sapling, pole, and tree levels, as well as understorey and litter in PT SPF's green areas.

2. Material and Methods

2.1. Time and Place

This research was conducted from February to April 2023. The sampling location was at green areas of PT Sumatera Prima Fibreboard. Dry weight measurement of samples was carried out at The Physiology and Development Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Sriwijaya University.

2.1.1. Research location general condition

PT SPF's green area is currently divided into 8 locations planted with several types of trees and 1 location with natural vegetation. The MDF production area has 12 chimneys that produce emissions with chimney heights of 0.9 meters, 2.5 meters, 3.1 meters, 7.8 meters, 11.37 meters, 13.41 meters, 25 meters, 28 meters, and 30 meters (Figure 1).

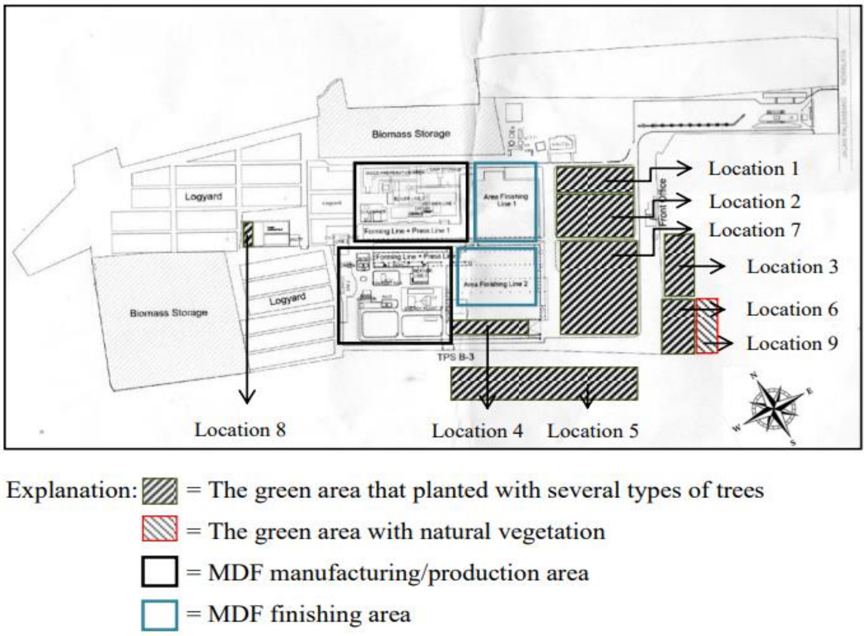

Figure 1. Location view of PT SPF's green area at a scale 1:1000
Source: PT Sumatera Prima Fibreboard (2022)

2.2. Tools and Materials

This research used stationery, GPS, pruning shears, a calculator, a digital camera, plastic bags, labels, a measuring meter, an oven, wooden stakes, measuring tape, permanent marker, rope, a tally sheet, and scales. The materials used were saplings, pole and tree stands, understorey, and litter samples.

2.3. *Methods*

The method used was stratified purposive sampling. The population in the green area was divided into several types of samples (sapling, pole and tree, understorey, and litter). Sampling was done by determining the minimum area and creating plots where in the main plot there are smaller plots.

The main plot is made with a size of 20×100 m or 20×50 m to measure trees ≥ 30 cm in diameter. Sub-main plots were made inside the main plot with a size of 10×50 m to measure trees 5 cm-30 cm in diameter. Subplots were set up inside the main subplot with a size of 0.5×0.5 m for understorey and litter sampling (Figure 2).

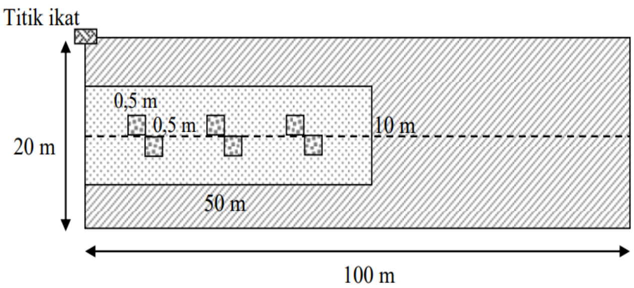

Figure 2. Biomass and carbon stock measurement plot

The sample plots were set up in the green areas with tree planting years 2004-2010 and the natural green areas adapted to field conditions. The measurement of sapling, pole, and tree biomass used non-destructive methods by recording the species, and diameter at breast height (dbh). The measurement of understorey and litter biomass used destructive methods by taking parts of the understorey and litter above the surface as samples.

2.4. Data Analysis

The primary data used are the diameter of saplings, poles, and trees as well as the name of the sample species, wet weight and dry weight of understorey and litter. Secondary data used are wood density, factory chimney height, wind direction, and wind speed.

2.4.1. Tree stands biomass analysis

The wood density can be found on ICRAF's wood density database website. Some sources such as Oey (1964), Abdurrochim *et al*. (2004), and Martawidjaya *et al*. (2005) have information on the wood density in Indonesia so that it can be used as a reference. If the wood density value for the suspected tree species is not available, then the average value of the specific gravity of that genus of trees can be used [5]. After the wood density of each type of tree was obtained, the next step was calculating the dry biomass of trees using the allometric formula.

The measurement of tree biomass using the allometric formulation for branched trees was developed by Ketterings *et al*. (2001) [6] as below:

$$B = 0.11 \times \rho \times D^{2.62}$$

Where B= Biomass/dry weight (kg/tree); ρ= BJ/wood density (g/cm^3); D= dbh (cm)

Biomass of tree stand per unit area can be determined by dividing the total amount of tree biomass by the total area [7] as below:

$$\text{Total biomass of trees (kg)} = B_1 + B_2 + \cdots + B_n$$

$$\text{Biomass per unit area} = \frac{\text{Total biomass (kg)}}{\text{Area (m}^2)}$$

2.4.2. Understorey biomass and litter biomass analysis

Dry weight data of each understorey and litter component in each sub-plots were calculated using the formula [4] as follows:

$$\text{Total BK (g)} = \frac{BK_{sub-sample} \times \text{Total BB}}{BB_{sub-sample}}$$

Where BK= Biomass/dry weight (g); BB= Wet weight (g)

2.4.3. Carbon stock analysis

Based on the biomass values of each tree, understorey, and litter, the carbon stock of each sample per plot was calculated with a general formulation, assuming a carbon composition of 50% of the biomass weight as below [8]:

$$C = 0.5 \times B$$

Where C= Carbon stock (kg); B= Dry biomass (kg); 0.5= coefficient of carbon concentration in plants

3. Results and Discussion

Based on research in the green area of PT Sumatera Prima Fibreboard, the research plots obtained 13 species with growth stages of saplings, poles, and trees belonging to 9 families. Those 13 species are Anacardiaceae, Apocynaceae, Elaeocarpaceae, Euphorbiaceae, Fabaceae, Meliaceae, Myrtaceae, Theaceae, and Verbenaceae as can be seen in Table 1. The distribution of sapling, pole, and tree species and variation in stem diameter in plots at five green areas of PT SPF in 2023 can be seen in Figure 3 and Figure 4.

Table 1. Trees composition in PT SPF's green area

No	Family	Species	Number of Individual in Plot					Total
			L1	L2	L3	L4	L9	
1	Fabaceae	*Acacia crassicarpa*	-	-	1	17	2	20
2	Fabaceae	*Acacia mangium*	-	-	2	7	6	15
3	Apocynaceae	*Alstonia scholaris*	-	-	-	-	7	7
4	Myrtaceae	*Eucalyptus* sp.	-	-	18	4	6	28
5	Euphorbiaceae	*Hevea brasiliensis*	42	-	-	-	-	42
6	Euphorbiaceae	*Hura crepitans*	3	-	-	-	-	3
7	Anacardiaceae	*Mangifera indica*	-	-	-	3	-	3
8	Myrtaceae	*Melaleuca* sp.	-	-	2	-	-	2
9	Theaceae	*Schima wallichii*	-	-	-	-	4	4
10	Meliaceae	*Swietenia mahagoni*	3	46	20	-	-	69
11	Verbenaceae	*Tectona grandis*	-	-	-	-	14	14
12	Myrtaceae	*Syzygium* sp.	-	-	-	-	8	8
13	Elaeocarpaceae	*Muntingia calabura*	-	-	-	-	4	4

Explanation: L1 = Green area location 1
L2 = Green area location 2
L3 = Green area location 3
L4 = Green area location 4
L9 = Green area location 9 with natural vegetation
- = Species was not found at the plot location

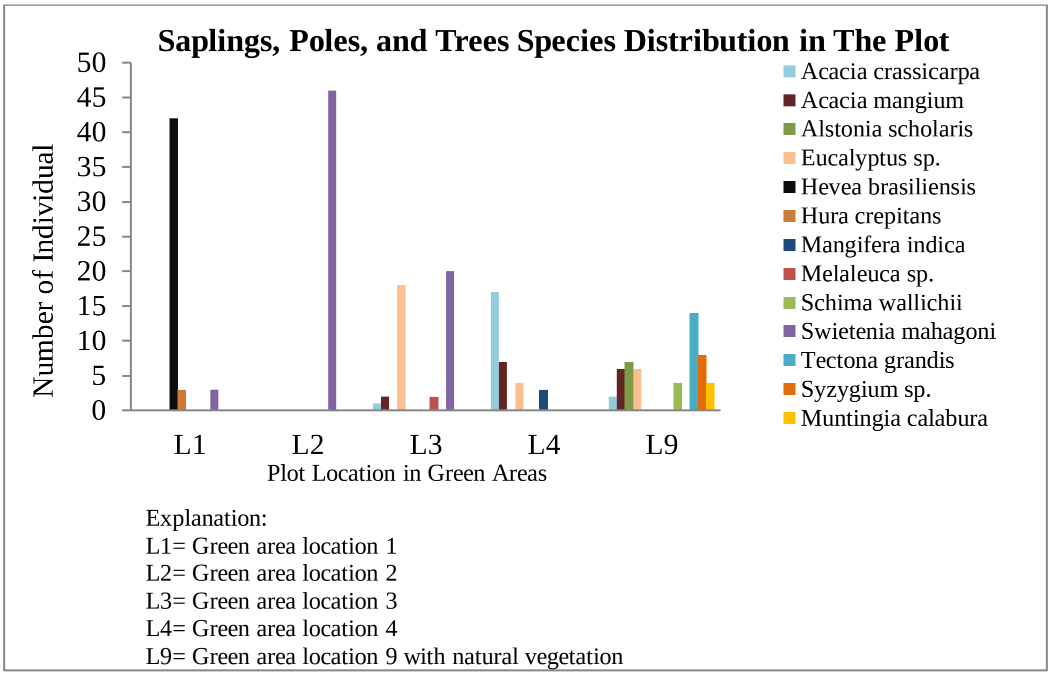

Figure 3. Species distribution at research plots in PT SPF's green area

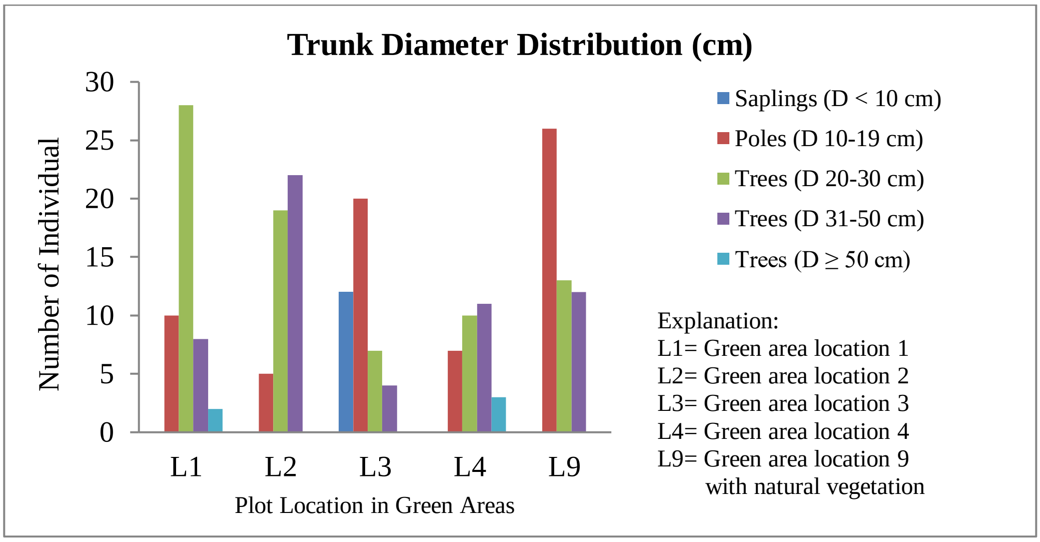

Figure 4. Distribution of tree growth stages based on diameter at research plots in PT SPF's green area

As for understorey at the research plot, 13 species were found belonging to 11 families which are Acanthaceae, Asteraceae, Euphorbiaceae, Fabaceae, Malvaceae, Myrtaceae, Poaceae, Rubiaceae, Rutaceae, Urticaceae, and Verbenaceae (Table 2).

3.1. Biomass and Carbon Stock of Trees

The biomass value and carbon stock potential of trees (at sapling, pole, and tree growth stages) in PT SPF's green area can be seen in Table 3 as follows. Based on the results of the estimation of biomass and carbon stock of trees with diameters of 5-30 cm and ≥ 30 cm in 5 green areas, the green areas from the highest biomass values in sequence are L1, L2, L9, L4 and L3 with biomass values of 274.17 tons/ha, 235.96 tons/ha, 205.80 tons/ha, 139.49 tons/ha, and 82.83 tons/ha. Biomass is directly proportional to carbon stocks so the value of carbon stocks in the 5 green areas from the highest are 137.08 tons/ha, 117.98 tons/ha, 102.90 tons/ha, 69.74 tons/ha, and 41.41 tons/ha, in sequence. The difference in carbon stock value in PT SPF's green areas is alleged due to the effect of wind direction and speed that carries emission gases from chimneys with a certain height to the direction of the wind blowing, tree planting year, diameter, tree species, planting distance, and nutrients.

Table 2. Understorey composition in PT SPF's green area

No	Family	Species	Research location				
			L1	L2	L3	L4	L9
1	Poaceae	*Imperata cylindrica*	√	-	√	√	-
		Panicum repens	-	√	√	-	-
		Panicum capillare	-	-	√	-	-
2	Verbenaceae	*Stachytarpheta indica*	-	-	-	√	-
3	Rubiaceae	*Borreria* sp.	√	-	-	-	-
4	Asteraceae	*Ageratum conyzoides*	√	-	-	-	-
5	Acanthaceae	*Asystasia* sp.	-	√	-	-	-
6	Urticaceae	*Elatostema strigosum*	-	-	-	-	√
7	Fabaceae	*Ormosia* sp.	-	-	-	-	√
8	Rutaceae	*Clausena excavata*	-	-	-	-	√
9	Euphorbiaceae	*Mallotus* sp.	-	-	-	-	√
10	Malvaceae	*Microcos* sp.	-	-	-	-	√
11	Myrtaceae	*Syzygium* sp.	-	-	-	-	√

Explanation: L1 = Green area location 1
L2 = Green area location 2
L3 = Green area location 3
L4 = Green area location 4
L9 = Green area location 9 with natural vegetation
\- = Species was not found at the plot location

Table 3. Biomass and carbon stock of trees in PT SPF's green area

Location	Dominating species	Tree planting year	Diameter average of all trees in the plot (cm)		Biomass (ton/ha)	Carbon stock (ton/ha)
			5 to 30	≥30		
L1	*Hevea brasiliensis*	2004	22 ± 4.02	41 ± 8.13	274.17	137.08
L2	*Swietenia mahagoni*	2010	23 ± 5.41	36 ± 5.14	235.96	117.98
L3	*Eucalyptus* sp. *Swietenia mahagoni*	2010	13 ± 5.85	34 ± 2.94	82.83	41.41
L4	*Acacia crassicarpa*	2010	21 ± 7.07	39 ± 11.82	139.49	69.74
L9	*Tectona grandis* *Syzygium* sp.	-	17 ± 4.96	40 ± 6.26	205.80	102.90
		Total			938.25	469.11

Explanation: L1 = Green area location 1
L2 = Green area location 2
L3 = Green area location 3
L4 = Green area location 4
L9 = Green area location 9 with natural vegetation
\- = Unknown

Wind speed and wind direction can affect the level of a pollutant gas in the air because wind speed and wind direction can determine the rate of spread of pollutants when carried by the wind direction [9]. Wind causes pollutant dispersion to other places according to the direction of the wind. Wind speed causes a decrease of 83% in CO_2 concentration while due to other factors as much as 17%, which means that it can be concluded that CO_2 concentration will decrease with the increasing of wind speed [10]. According to the South Sumatra Climatology Station, the wind direction during November [11], December [12] 2022 and January [13] 2023 was dominant from the west with the average of wind direction from southwest, southeast, and west. The average wind speed was 0.75 m/s, 0.92 m/s, and 1.03 m/s.

The green areas of locations 1 and 2 are located to the east of the chimney location in the factory area so that they can be directly exposed to wind-borne emissions coming from the west, while location 4 is to the south, location 3 and location 9 are to the southeast of the chimney location so they are not directly exposed to wind-borne emissions from the west. The average wind speed of 1.953 m/s is a weak wind, but with this wind speed, the dispersion process of pollutants in the air will be slow and cause the concentration of pollutant compounds near the emission source [14].

The high biomass value in location 1 and location 9 is influenced by the age of the tree stand where the trees in location 1 were planted in 2004, while location 9 is a natural so it has more diversity of tree species and a quite dense tree growth distance compared to other green areas. In addition, the diameter of trees in location 1 and location 9 also affects the biomass value and carbon stock value. As the age of the tree increases, the diameter of the tree will also get bigger until it reaches the maximum growth limit.

This assumption is by research conducted by Uthbah *et al.* (2017) [15], on damar stands where the diameter of damar tree stands with older ages has bigger diameter. This is due to the amount of CO_2 absorbed from the air and stored by tree stands in their trunks. In addition to the age of the stand, the density and intensity of sunlight entering the stand can also affect the diameter size. Diana *et al.* (2022) [16], stated that as the age of a tree increases, the volume of the tree will also increase, resulting increasing biomass of the tree.

Location L2 is a green area that is only planted with mahogany trees where mahogany trees themselves have been widely used as road shade trees and good carbon sinks. Mahogany trees can reduce air pollution by around 47% to 69%. Mahogany trees have a biomass percentage value for the trunk of 54.07%, branches and twigs of 22.02%, roots of 13.21%, and leaves of 10.70% [17].

The low value of carbon stocks at location L3 is assumed due to location factors that have low nutrients, waterlogged land conditions when it rains, and plant spacing that is quite far apart. The average diameter of trees found in plot L3 is 13 cm and 34 cm where the diameter is smaller than other locations. Based on research by Hilwan and Nurjannah (2014) [18], in revegetation stands on post-mining land at PT Jorong Barutama Greston South Kalimantan, low CO_2 uptake in revegetation stands is due to nutrient-poor land conditions that slow plant growth. The difference in the amount of CO_2 uptake in the air is influenced by several factors such as climate, topography, soil characteristics, species and age composition of tree stands, and tree growth stages.

The amount of forest biomass is also highly depend on the results obtained during the photosynthesis process. Trees need sunlight and water nutrients absorbed from the soil and CO_2 gas absorbed from the air for their continuance [19]. All living things need material supplies as energy supplies for growth, and green plants carry out the photosynthesis process to convert sunlight energy into chemical energy in the form of organic carbon compounds derived from carbon dioxide and water molecules. Plants are reservoirs of CO_2 gas from the air because they have a CO_2 binding mechanism that has an impact on reducing CO_2 levels in the air globally [20].

The species and the number of individual trees that were intentionally planted and those that grew naturally at locations L1 to L9 gave different carbon stock results as presented in Figure 5. Plant species diversity, diameter of constituent trees, and individual density affect the value of carbon storage in land use. The greater the number of individuals and the diameter of the tree, the absorption process of carbon dioxide will be greater so that the value of carbon storage will also be greater [21].

Based on Figure 5, the average carbon stock of tree stands in PT SPF's green area in a row from the largest is produced by *Hura crepitans*, *Acacia mangium*, *Mangifera indica*, *Swietenia mahagoni*, *Alstonia scholaris*, *Tectona grandis*, *Acacia crassicarpa*, *Hevea brasiliensis*, *Schima wallichii*, *Eucalyptus* sp., *Melaleuca* sp., *Syzygium* sp., and *Muntingia calabura*.

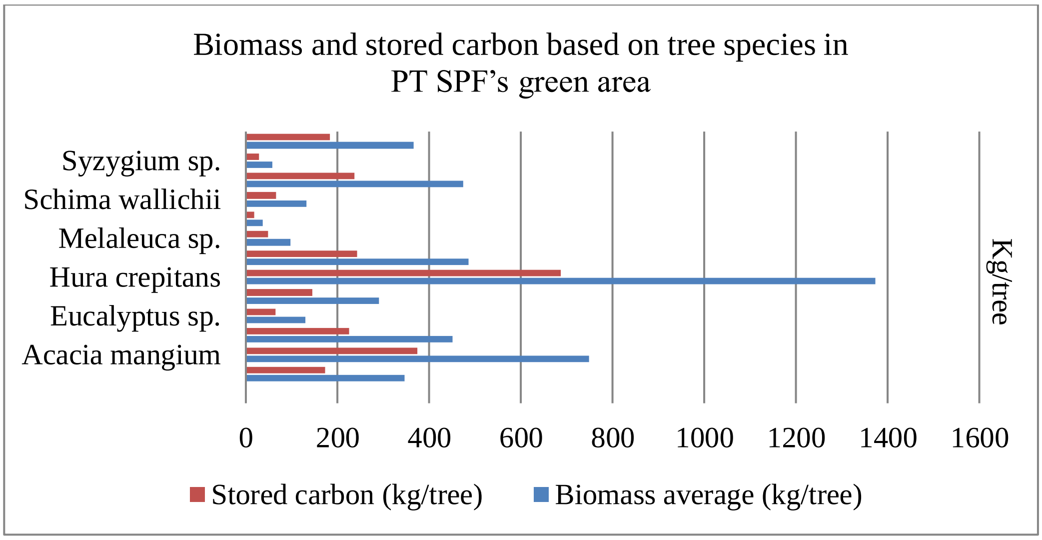

Figure 5. Biomass and stored carbon based on tree species in PT SPF's green area

The highest average biomass was owned by *H. crepitans* and *A. mangium* stands, which amounted to 1372.97 kg/tree and 748.45 kg/tree with an average trunk diameter of 51 cm and 36 cm, while the lowest average biomass was owned by *Syzygium* sp. and *M. calabura* stands, which amounted to 57.33 kg/tree and 36.87 kg/tree with an average trunk diameter of 12 cm and 14 cm.

Based on research by Olajide *et al*. (2021) [22], in Uyo town, the diameter of *Hura crepitans* encountered and randomly selected (30 trees) reached 27-76 cm (average diameter 49 cm) with aboveground biomass values ranging from 0.25-3.77 tons and carbon stocks ranging from 0.13-1.88 tons. The lowest biomass and carbon stock results obtained are in line with the research of Agumanis *et al*. (2021) [23], where the *Syzygium aqueum* and *Muntingia calabura* species have the lowest carbon stock from 32 tree species obtained at 0.01 tons/ha.

The amount of carbon sequestration in a tree stand can be influenced by several internal and external factors. The factors that determine the size of potential CO_2 uptake in a plant are leaf width, leaf thickness, chlorophyll content, and the number of leaves. External factors that affect the CO_2 uptake potential of a plant are the place where the plant lives, the availability of water, light, temperature, and the availability of mineral nutrients [24]. The surface area of the leaf blade itself does not really affect CO_2 uptake in shade plants but a combination of leaf surface area, the number of stomata, and the activity of opening and closing stomata greatly affects the level of CO_2 absorption [25].

3.2. Biomass and Carbon Stock of Understorey and Litter

The biomass values and potential carbon stocks in understorey and litter found in five green areas of PT SPF can be seen in Table 4. Based on Table 4, the biomass and carbon stocks total in litter throughout the PT SPF's green area are higher than the biomass and carbon stocks in understorey. Locations L1, L2, and L9 had the same values of litter biomass and carbon stock and were higher than locations L3 and L4 of 0.80 tons/ha for biomass and 0.40 tons/ha for carbon stock. Biomass and carbon stocks of understorey at location L4 were higher than the other locations at 0.27 tons/ha and 0.13 tons/ha.

Table 4. Biomass and carbon stock of Understorey and litter in PT SPF's green area

Location	Understorey		Litter	
	Biomass (ton/ha)	Carbon stock (ton/ha)	Biomass (ton/ha)	Carbon stock (ton/ha)
L1	0.13	0.06	0.80	0.40
L2	0.16	0.08	0.80	0.40
L3	0.13	0.06	0.40	0.20
L4	0.27	0.13	0.53	0.26
L9	0.20	0.10	0.80	0.40
Total	0.89	0.43	3.33	1.66

Explanation: L1 = Green area location 1
L2 = Green area location 2
L3 = Green area location 3
L4 = Green area location 4
L9 = Green area location 9 with natural vegetation

Biomass and carbon stock values can be influenced by litter components from trees and understorey found at the location, the number of samples obtained, and the density of understorey in each green area. Location L1 is a green area planted with *Hevea brasiliensis*, *Hura crepitans*, and *Swietenia mahagoni*, location L2 is only planted with *Swietenia mahagoni* while location L9 is a natural green area. Locations L2 and L9 have a fairly thick layer of litter but at location L9 it is rare to find grass or herbaceous.

The greater the biomass of the stand, the higher the litter biomass so that the litter biomass storage is directly proportional to the tree stand biomass. Meanwhile, the understorey will be found more in stands with a younger age so that the biomass of the understorey is inversely proportional to the biomass of tree stands [18].

The understorey found in plots L1 are *Imperata cylindrica*, *Borreria* sp., and *Ageratum conyzoides*, L2 are *Asystasia* sp. and *Panicum repens*. The understorey found in plot L9 are mostly seedlings, those are *Elatostema strigosum*, *Ormosia* sp., *Clausena excavata*, *Mallotus* sp., *Microcos* sp., and *Syzygium* sp. Location L4 has an equi-spreading understorey, on the plot, *Imperata cylindrica*, and *Stachytarpheta indica* were found. The diversity of plant vegetation in an area can be influenced by environmental factors such as temperature, humidity, light intensity, rainfall, soil pH, and topography.

Herbaceous vegetation distribution patterns are also influenced by differences in environmental conditions such as resources, pH, temperature, light intensity, and interspecies or intraspecies competition [26].

3.3. Total Carbon Stock of PT SPF's Green Area

The aboveground carbon stock potential in five green areas of PT SPF with an area of 16,673 m^2 (1.67 ha) from the largest is in locations L1, L2, L9, L4, and L3 with total carbon stock values of 137,54 tons/ha, 118,46 tons/ha, 103.40 tons/ha, 70.13 tons/ha, and 41.67 tons/ha (Figure 6). The carbon stock value obtained when totaled is 471.20 tons and included as a good category.

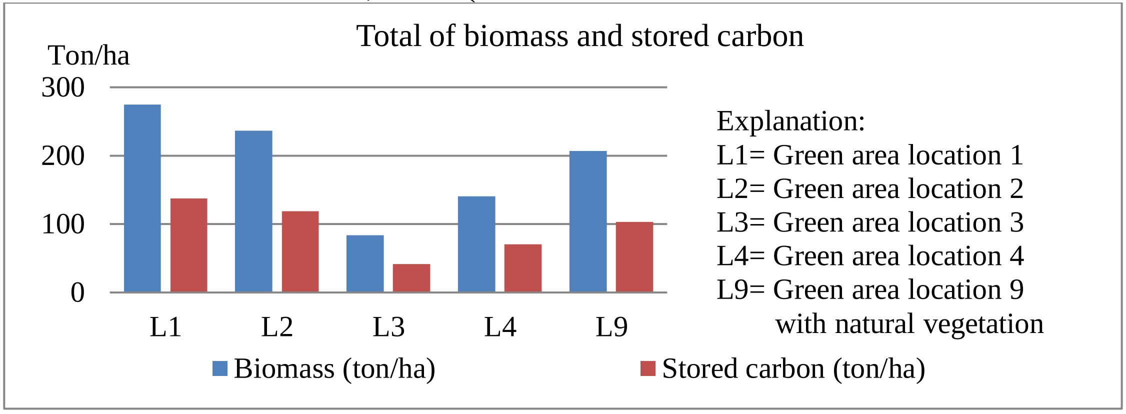

Figure 6. Total biomass and carbon stock in PT SPF's green area

Based on research by Sardi *et al*., on carbon stocks in Gunung Tumpa H. V. Worang Botanical Forest Park with an area of 208.81 ha, the carbon storage value found is 838.35 tons/ha and this value can be categorized into an area with a good category based on the recommendation of the IPCC carbon stock number in 2006 in the category of primary forest land, agroforestry, and secondary is 138 tons/ha. If the value of carbon storage in the three areas is less than 138 tons/ha, the carbon stock is said to be poor so maintenance or improvement of the area is needed [27]. Biomass and carbon are directly proportional so that if there is an increase or decrease in biomass, the stored carbon content will also increase or decrease [28].

4. Conclusion

Based on the results obtained, it can be concluded that the total value of saplings, poles, trees, understorey, and litter dry biomass in five green areas of PT SPF is 942.47 tons and the total value of carbon stock is 471.20 tons, which is included as a good category.

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