Media Konservasi, 20 (1) 253-261

RESEARCH ARTICLE

MEDIA KONSERVASI
SCIENTIFIC JOURNAL IN CONSERVATION OF NATURAL RESOURCES AND ENVIRONMENT

Carbon Stock Estimation on Oil Palm Plantations and Oil Palm-Based Agroforestry in Gunung Mas Regency

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Article Info:
Received 23 June 2023,
Accepted 14 September 2023

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Abstract

Central Kalimantan has one of the highest rates of deforestation and palm oil production in Indonesia. These changes have ecological impacts, such as loss of wildlife, loss of water absorption functions, and increased carbon emissions. Agroforestry is a synergistic planting system between crops and forest stands to maintain the ecological balance. Planting sengon trees (*Paraserianthes falcataria* (L.) Nielsen) and oil palm plants (*Elaeis guineensis* Jacq.) is one of the agroforestry application systems of the researcher's research area. Sengon has easy maintenance, a high selling price, and can increase soil fertility and absorb N also CO_2. This study aimed to calculate the amount of aboveground carbon stocks on oil palm plantations and oil palm-based agroforestry with sengon trees in Manuhing and Rungan Barat Sub-Districts, Gunung Mas Regency, Central Kalimantan. The number of plots are 45, were used for each land use type. Litter and undergrowth carbon were measured using a destructive method, then tree stands vegetation was measured by the allometric equations using breast height diameter. The oil palm-based agroforestry has the highest aboveground carbon stocks, with an average of 63.14 tonC/ha, while the oil palm plantations with an average of 46.70 tonC/ha. The differences in their amounts can be caused by the differences in years of planting and fertilization by farmers; thus, they have different growth rates in increments of diameter.

Keyword: deforestation, litter carbon, sengon trees, tree stands vegetation

1. Introduction

The United Nations Convention (UNC) on United Nations Framework Convention on Climate Change (UNFCCC) defines that climate change as a change in the composition of the global atmosphere—in the form of GHGs (Greenhouse Gases) such as carbon dioxide, methane, nitrous oxide, and others, as well as—natural climate variability over a period of time due to human activities, either directly or indirectly. COP26, also known as the 26th Climate Conference, produced an agreement called the Glasgow Climate Pact, one of which was related to accelerating the mitigation of the climate crisis by reviewing the 2030 emission reduction commitments in the Nationally Determined Contribution (NDC) of each country by 2022.

Strategies for mitigating climate change are focused on reducing the GHGs, particularly carbon dioxide (CO_2). One of the main causes of CO_2 emissions is deforestation [1]. Deforestation is a permanent change from forested areas to non-forested areas as a result of human activities [2], such as the conversion of forests to oil palm plantations. Central Kalimantan is Indonesia's second-largest palm oil production province after Riau province [3].

Carlson et al. [4] stated that in the results of analysis of satellite imagery during the period 1990–2010, the rate of deforestation in Kalimantan showed that 90% of the forest area had been converted to oil palm plantations. The Central Kalimantan Plantation Service also states that, by 2020, the oil palm sector will target to plant 3.5 million ha of oil palm plant. Central Kalimantan, the third largest province in Indonesia, with an area of 15.3 million ha, 1,156 m^2 in 2014, has been converted into oil palm plantations and accounts for 11% of the total oil palm in Indonesia. Central Kalimantan has one of the highest rates of deforestation and oil palm development in Indonesia [5]. These changes have ecological impacts, such as loss of animals, loss of water absorption functions, and increased carbon emissions.

According to Hartati et al. [6], forest vegetation stores 50% of the total forest carbon. Therefore, if deforestation occurs, it can increase the amount of carbon dioxide in the atmosphere. Carbon stock estimation can be utilized as a metric of deforestation in an area and its changes over time [7]. Hence, forests are very important in the global carbon cycle. Several efforts to increase carbon stocks in the forestry sector include afforestation, agroforestry, forest improvement, mining land reclamation, forest protection, and urban forests.

Agroforestry systems offer simultaneous opportunities to meet water, food, energy, and income needs in rural and peri-urban areas in Indonesia [8]. Agroforestry can maintain carbon stocks on land even though they are still lower than in natural forests, but this system can provide hope for increasing carbon stocks in degraded lands. In general, agroforestry is a synergistic planting system between crops and forest stands to maintain the ecological balance due to soil damage [9]. Amin et al. [10] also stated that applying an agroforestry system is a land management system to overcome the consequences of land use change and food problems.

Sengon (*Paraserianthes falcataria* (L.) Nielsen) are legume plants that can be utilized in agroforestry systems. *Sengon* can grow quickly so that it can absorb more carbon than other slow-growing trees, and can grow in various types of soil such as dry soil, moist soil, and even in soil containing salt and acid as long as the drainage is sufficient [11]. *Sengon* can also improve soil fertility through soil atmospheric nitrogen fixation [12].

Fairventures Worldwide (FVW) is a Germany-based non-profit organization primarily focusing on improving degraded land and promoting sustainable development. FVW has been actively working in Central Kalimantan since 2014 to support local farmers in developing sustainable livelihoods. One of the programs carried out by FVW to deal with degraded land was the program to plant 1 million trees in 2015−2019 in two regencies there are Gunung Mas Regency (Manuhing Sub-District, Rungan Barat Sub-District, Manuhing Raya Sub-District, and Rungan Sub-District) and Katingan Regency (Katingan Hilir Sub-District, Tewang Sangalang Garing Sub-District, Katingan Tengah Sub-District, and Sanaman Mantikel Sub-District).

This program focuses on smallholder farmers planted in other land-use areas (APL), conversion production forests (HPK), limited production forests (HPT), production forests (HP), protected forests (HL), and forests nature reserves and tourism (HAS). The main commodity of this program is *sengon* tree. In addition, *sengon* trees are planted alternately with farmers' plants such as oil palm plant. This activity has aims in addition to the interests of the ecological aspect and can also be beneficial from social and economic aspects. This study aimed to calculate the amount of aboveground carbon stocks on oil palm plantations and oil palm-based agroforestry with *sengon* tree.

2. Research Methodology

Gunung Mas Regency is in the province of Central Kalimantan with coordinates of ±0°18'00" South Latitude to 01°40'30" South Latitude and ±113°01'00" East Longitude to 114°01'00" East Longitude. The area of Gunung Mas regency is 10,804 km^2 or 1,080,400 ha, with the boundaries of Murung Raya Regency in the north, Kapuas Regency in the east, Pulang Pisau Regency and Palangka Raya City in the south, and Katingan Regency and West Kalimantan province in the west. The plantation is one of the potentials of the Gunung Mas regency because the northern area has hilly areas with an altitude between 100–500 mamsl, a slope of 8−15°, and mountainous areas with a slope of 15−25°.

Data collection for this research was carried out from February to March 2023, located in Manuhing and Rungan Barat Sub-District, Gunung Mas Regency, Central Kalimantan (Figure 1), on two land uses: oil palm plantations and oil palm-based agroforestry. Litter and undergrowth samples were processed at the UPT CIMTROP Peatland Laboratory, University of Palangka Raya, Palangka Raya. The soil samples were processed at the Biotechnology Laboratory, Indonesian Center for Biodiversity and Biotechnology (ICBB), Bogor.

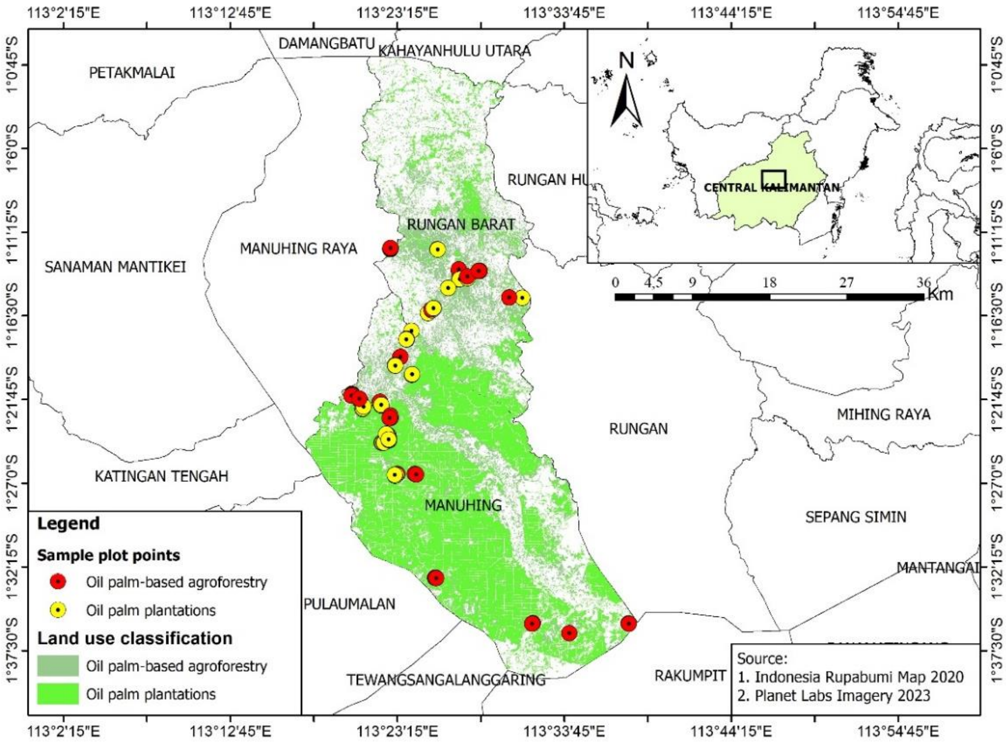

Figure 1. Research site map

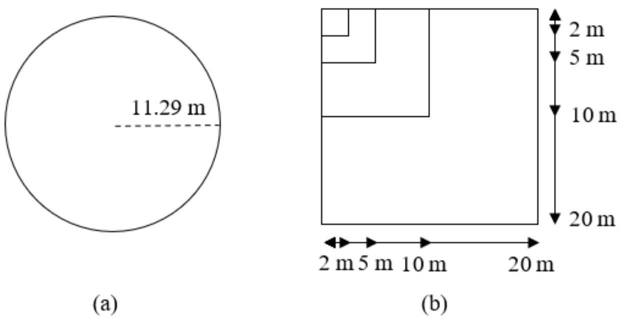

Figure 2. Plot size for (a) oil palm plantations and (b) oil palm-based agroforestry

GPS and position maps, measuring tapes, phi bands, tally sheets, stationery, scales in grams, raffia rope, stakes, machetes, and soil sample rings were all employed in this investigation. The resources used included primary data such as field measurement data and sample plot coordinates, as well as secondary data such as allometric equations derived from linked periodicals.

This study used purposive sampling with systematic sampling with random start to ensure research illustrations. In this study, 45 plots were used for each land use type. The distribution of sampling plot locations was carried out by purposive sampling. Plot distribution is based on consideration of representative variations of stand conditions such as elevation, slope, stand density, and ease of accessibility. Systematic sampling with a random start using intervals between sub-plots. In general, farmers own 1 hectare of land, and the desired sample plots are 2 plots per 1 ha, thus the distance between sub-plots is 50 m.

In oil palm plantations, circular plots with a radius of 11.29 m (0.04 ha) were used which contain one sub-plot with a radius of 0.56 m for measuring litter and undergrowth [13]. It differ from oil palm-based agroforestry, which had a square plot of size 20×20 m for the tree level, 10×10 m for the pole level, and 2×2 m for litter and undergrowth (Figure 2).

Aboveground samples consisting of litter and undergrowth were taken using the destructive method, by taking a 100 g sample and then testing it in the laboratory to obtain the wet weight sample, after which it was placed in an oven at 85 °C for 2×24 h [13], while at the tree stands vegetation, it was carried out using a non-destructive method with an allometric equations approach.

To calculate the biomass of litter and undergrowth, the dry weight of the sample, the wet weight of the sample, and the total weight of the wet sample were calculated using [14]:

$$Btb = \frac{BKC}{BBC} \times TBB \quad (1)$$

Where:

Btb : litter/undergrowth biomass (kg)

BKC : dry weight sample (kg)

BBC : wet weight sample (kg)

TBB : total wet sample (kg)

The allometric equation used to estimate biomass in oil palm plantations (*Elaeis guineensis* Jacq.) used the results of Muhdi et al. [15], which was carried out destructively and had a coefficient of determination of 0.899 or 89.99%. This value indicates a diameter of 89.99% can explain the magnitude of carbon diversity:

$$W = 0.003D^{2.761} \quad (2)$$

Where:

W : aboveground biomass (kg/tree)

D : breast height diameter with palm fronds (cm)

Estimating the value of *sengon* tree (*Paraserianthes falcataria* (L.) Nielsen) biomass uses an allometric equation from Siregar [16] study, which was conducted destructively and has a coefficient of determination of 0.91 or 91% and this equation has been used by [17] in estimating the amount of *sengon* tree biomass stored in South Barito Regency, Central Kalimantan.

$$B = 0.2831D^{2.063} \quad (3)$$

Where:

B : aboveground and belowground biomass (kg/tree)

D : breast height diameter (cm)

According to the [14], the potential for storing carbon stocks is 47% or equivalent to 0.47 of the total biomass.

$$Cb = B \times \%C \quad (4)$$

Where:

Cb : biomass carbon proportion (ton/ha)

B : biomass total (ton/ha)

%C: biomass carbon values (0.47)

After obtaining the carbon stock value, the carbon value per hectare was calculated using an equation from the [14].

$$C_h = \left(\frac{C_x}{1000}\right) \times \left(\frac{10000}{L\ plot}\right) \quad (5)$$

Where:

Ch : carbon value per hectar (tonC/ha)

Cx : carbon value per pool carbon on every plot (kg)

Lplot: plot area in each pool (m^2)

3. Result and Discussion

3.1. Litter and undergrowth carbon stock

Litter is one of the carbon pools of dead plants aboveground. Litter is the upper layer, consisting of plant parts that have died before decomposition, such as fallen leaves, twigs, branches, flowers, fruit, bark, and others parts that spread on the ground beneath the forest. The litter found in the oil palm plantations plots was in the form of fallen leaves, twigs, and fronds of oil palm plants, whereas in oil palm-based agroforestry, it was in the form of fallen leaves, twigs, and fronds of oil palm plants, and fallen leaves and twigs from *sengon* trees.

Undergrowth is one of the carbon pools in plants living aboveground. Undergrowth is characterized by herbaceous plants and lower shrubs that covering the forest area's upper part. In general, the research plots on oil palm plantations and oil palm-based agroforestry (oil palm and *sengon* trees) had a fairly clean forest floor; therefore, the undergrowth was rarely found, but several plots had high-intensity undergrowth. This difference can be attributed to the different treatment systems used by each farmer.

Table 1. Litter and undergrowth carbon stock

Carbon stock (tonC/ha)		Manuhing		Rungan Barat	
		Oil palm plantations	Oil palm-based agroforestry	Oil palm plantations	Oil palm-based agroforestry
Litter	Minimum	0.11	0.05	0.10	0.11
	Maximum	0.68	0.68	0.87	0.46
	Average	0.35	0.32	0.30	0.27
	Standard deviation	0.15	0.15	0.24	0.13
Undergrowth	Minimum	0.03	0.03	0.04	0.04
	Maximum	0.35	0.68	0.61	0.16
	Average	0.14	0.19	0.20	0.10
	Standard deviation	0.09	0.10	0.18	0.04

Based on Table 1, the high and low values of litter and undergrowth carbon stocks do not have a sufficiently large difference for each land-use type. This is because in research locations such as oil palm plantations and oil palm-based agroforestry with oil palm and *sengon* tree commodities, the vegetation cover and vegetation density tend to be the same. The Manuhing Sub-District has the highest potential for litter carbon stocks in oil palm plantations (0.35 tonC/ha) while for the highest undergrowth carbon stocks in oil palm-based agroforestry (0.19 tonC/ha). The Rungan Barat Sub-District has the highest potential for undergrowth (0.20 tonC/ha) and litter (0.30 tonC/ha) carbon stocks in oil palm plantations.

The standard deviation is a statistical metric used to determine how evenly dispersed the data is in the sample and how close the individual data points are to the average sample value. A data set's standard deviation is zero, suggesting that all values in the set are the same, but a bigger deviation value shows that individual data points are significantly different from the average value [18]. If the standard deviation is less than the average, it suggests that the data is less varied or diverse. The largest standard deviation value was found in oil palm plantations in Rungan Barat Sub-District (0.24 tonC/ha), however it was still less than the average (0.30 tonC/ha). This reflects the fact that individual data on oil palm plantations in Rungan Barat Sub-District is significantly higher (0.24 tonC/ha) than the average (0.30 tonC/ha).

Based on the results of Budiman et al. [19], physical conditions such as water content in litter tended to be different each year. This is also due to the fact that in the litter, the existing water potential has evaporated due to the influence of temperature and sunlight. This condition causes the water content stored in the litter to be lower. In addition, the effect of high temperatures is negatively correlated with air humidity, so transpiration increases and more leaves fall. Fertile soil with sufficient water availability will enable undergrowth to thrive in sufficient quantities.

3.2. Tree Stands Vegetation Carbon Stock

One of the carbon pools of other living plants is the tree stands vegetation, consisting of poles with a diameter of 10–20 cm and trees with a diameter of >20 cm. The amount of carbon can be determined from the value of biomass, which is influenced by binding variables, such as tree diameter. In the present study, oil palm plant and *sengon* tree were planted at different times. Oil palm plantations were grown by farmers in 2015, whereas *sengon* tree were planted by farmers in 2015–2017. Planting oil palm-based agroforestry systems was carried out by farmers by planting *sengon* trees between oil palm plantations to simultaneously provide ecological, economic, and social benefits.

The standard deviation values of the diameters show the average growing diameter of oil palm plant and *sengon* trees. The standard deviation value found in Table 2 is substantially smaller than the average diameter value of each stand. This demonstrates that the diameter of each stand has the same diameter value and does not have different individual diameter data. In contrast to the standard deviation value of carbon stock (Table 3), which is near to the average value, this demonstrates that carbon stock value varies between plots.

Carbon stock potential is strongly influenced by tree diameter. The carbon stock of the stand increases with an increase in stem diameter, and a decrease in carbon stock can occur if the number of stands or density found in that diameter class is low [20]. Table 2 shows the average growth diameters of oil palm plants in oil palm plantations and oil palm-based agroforestry, while *sengon* tree in oil palm-based agroforestry. Differences in the planting year can cause this difference in diameter; It can also be caused by differences in the treatment of each farmer on their land, such as differences in fertilization, land clearing, and pruning. The carbon stock of the tree stands vegetation was affected by the diameter and number of individual trees in one study plot (Table 3). As a result, it can be seen that oil palm-based agroforestry has a higher potential for tree stands vegetation carbon stock than oil palm plantations.

Table 2. Diameter of each plant

Diameter (cm)	Manuhing Sub-District			Rungan Barat Sub-District		
	Oil palm plantations	Oil palm-based agroforestry		Oil palm plantations	Oil palm-based agroforestry	
		Oil palm	*Sengon* tree		Oil palm	*Sengon* tree
Minimum	44.30	36.00	4.00	44.60	46.00	10.90
Maximum	108.30	150.00	43.70	136.00	92.00	40.00
Average	68.60	70.60	18.90	68.10	65.40	22.50
Standard deviation	11.08	19.26	6.99	13.24	9.59	6.83

Table 3. Tree stands vegetation carbon stock

Carbon stock (tonC/ha)	Manuhing Sub-District		Rungan Barat Sub-District	
	Oil palm plantations	Oil palm-based agroforestry	Oil palm plantations	Oil palm-based agroforestry
Minimum	26.86	23.58	14.47	27.73
Maximum	106.51	189.83	96.50	95.25
Average	45.23	74.20	47.18	51.20
Standard deviation	18.20	41.67	20.27	20.40

3.3. Total Carbon Stock

Based on the previous explanations, Table 4 shows the total carbon pools for each land-use type for each sub-district. Table 4 shows the total aboveground carbon, which is the sum of the litter carbon, undergrowth carbon, and tree stands vegetation carbon. As a result of aboveground carbon, oil palm-based agroforestry has a higher carbon stock than oil palm plantations, with 74.71 tonC/ha in the Manuhing Sub-District, while 51.57 tonC/ha in the Rungan Barat Sub-District. Table 5 also shows that the carbon stock of oil palm-based agroforestry (63.14 tonC/ha) was higher than of oil palm plantations (46.70 tonC/ha). This can be caused, in addition to the large differences in the carbon stocks of litter and undergrowth in each land use, by the different diameters and the greater number of stands in oil palm-based agroforestry consisting of oil palm plant and sengon trees, compared to only oil palm in oil palm plantations.

According to Astuti et al. [21] at the same research location in the province of Central Kalimantan. The total carbon stock in Manuhing Sub-District in 2017 in community forests was 45.94 tonC/ha, while in secondary forests was 371.23 tonC/ha. In contrast, the Rungan Barat Sub-District, which has a higher carbon stock in community forests was 51.39 tonC/ha, and in secondary forests was 418.62 tonC/ha. When compared to the results of this study, community forest carbon stocks have lower carbon stocks than carbon stocks in agroforestry lands but have a higher value when compared to carbon stocks in oil palm plantations. This difference could be caused by differences in the average measured tree diameter, the measured tree species, and the number of trees in 2017 that did not have growth in diameter and the number of individuals as much as in 2023.

Table 4. Carbon stock for each carbon pools

Carbon stock (tonC/ha)	Manuhing Sub-District		Rungan Barat Sub-District	
	Oil palm plantations	Oil palm-based agroforestry	Oil palm plantations	Oil palm-based agroforestry
Litter	0.35	0.32	0.30	0.27
Undergrowth	0.14	0.19	0.20	0.10
Tree stands vegetation	45.23	74.20	47.18	51.20
Total AGC	45.72	74.71	47.68	51.57

Table 5. The comparison for oil palm plantations and oil palm-based agroforestry

Land cover	Sub-District	Carbon stock (tonC/ha)	The average of carbon stock (tonC/ha)
Oil palm plantations	Manuhing	45.72	46.70
	Rungan Barat	47.68	
Oil palm-based agroforestry	Manuhing	74.71	63.14
	Rungan Barat	51.57	

4. Conclusion

Oil palm-based agroforestry have the highest aboveground carbon stocks, with an average of 63.14 tonC/ha; 74.71 tonC/ha in Manuhing Sub-District and 51.57 tonC/ha in Rungan Barat Sub-District. Oil palm plantations have lower aboveground carbon stocks than oil palm-based agroforestry, with an average of 46.70 tonC/ha; 45.72 tonC/ha in Manuhing Sub-District and 47.68 tonC/ha in Rungan Barat Sub-District. The differences in their amounts can be caused by the differences in years of planting and fertilization by farmers; thus, they have different growth rates in increments of diameter.

Author Contributions

WR: Conceptualization, Acquisition of Data, Analysis & Interpretation Data, Writing - Review & Editing; **BK:** Acquisition of Data, Review, Supervision; **NP:** Acquisition of Data, Review, Supervision**.**

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

The researcher would like to thank Fairventures Worldwide Indonesia a nonprofit organization located in Palangka Raya, Central Kalimantan. Thank you for all support since collecting data from the field, serving the database, and funding this research.

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