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CARBON STORAGE IN FOREST AND COFFEE BASED LAND MANAGEMENT AT BATU TEGI

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ABSTRACT

Climate change is a global issue that requires mitigation strategies in various sectors, including forestry. Agroforestry, which combines trees with agricultural crops, is considered a strategy that can reduce greenhouse gas emissions by increasing carbon storage. This study aims to estimate and analyze the amount of carbon stored in three different land cover types found in a landscape of forest management unit (FMU), namely agroforestry coffee, monoculture coffee, and forest. Carbon stock analysis was conducted using a non-destructive approach on 36 sample plots evenly distributed across the three land cover types. The results showed that the highest carbon stock was found in forested area, followed by agroforestry coffee and monoculture coffee. However, the agroforestry system showed a fairly high carbon storage potential and was close to forest land, especially due to the presence of species such as Swietenia macrophylla and Coffea canephora. These findings indicate that the agroforestry system has great potential in climate change mitigation strategies by increasing carbon stocks, making it worthy of being an alternative to support forest conservation and rehabilitation.

Keywords: *Agroforestry System; Carbon Storage; Climate Mitigation; Land Cover Type*

INTRODUCTION

Global warming and climate change are not only experienced by one country but globally, including Indonesia. Indonesia is a large country with many islands and oceans that can have an effect on global warming and climate change. Indonesia has also experienced a fairly rapid change in lifestyle, which is the main cause of the increase in greenhouse gases (GHG), resulting in global warming (Ainurrohmah and Sudarti, 2022). The Intergovernmental Panel on Climate Change (IPCC) said that within 15 years (1990-2005) there had been an increase in global temperature on earth of around 0.15ºC-0.3ºC (Mulyani, 2021). Therefore, increased efforts to reduce GHG emissions need to be made to reduce the causes and effects of global warming massively as mandated by the Paris Agreement. One of these efforts is through increasing forest restoration activities.

According to Rahmani *et al.* (2021), restoration efforts can be carried out through the agroforestry scheme method. This method has the bargaining power to restore several essential functions of forests and land that have been lost due to increasing deforestation and degradation. There are at least three principles in forest and land restoration, namely: restore degraded lands at a huge scale; every tree count, engaging and empowering people to sustainable use forest is a key step towards positive change (Junarto, 2023). The contribution of agroforestry to reducing GHG in the atmosphere is quite significant through the large amount of carbon stored in the system (Wulandari *et al.,* 2021). The positive impact of agroforestry land can increase reforestation efforts for degraded land (Harsya *et* *al*., 2025). Studies on the role of agroforestry in adaptation efforts have been proven and have been conducted by Wulandari (2021), therefore the role of agroforestry in climate change mitigation is important.

According to Sari and Ariabhakti (2022), agroforestry systems have the potential to store carbon that varies greatly depending on the natural quality of the growing area and the agroforestry management method (cultivation techniques and level of product utilization). One way to obtain the value of forest carbon stocks can be done using a remote sensing technology approach (Cahyo *et al*., 2022). In addition, estimating aboveground forest carbon stocks in forest areas is important for biodiversity conservation and science in addressing REDD+ (Darmawan *et al*., 2022). Therefore, researchers tried to analyze information regarding the amount of carbon storage in three land covers, namely forests, agroforestry, and monocultures found in one forest management unit (KPH) landscape. Thus, it can be seen whether agroforestry land can be used effectively in efforts to mitigate climate change.

METHOD

This research was conducted from October to November 2024 in two locations, namely Pekon Sirna Galih, Ulubelu District and Pekon Sinar Jawa, Air Naningan District, Tanggamus Regency, Lampung (Figure 1). The tools used were measuring tape, Tallysheet, ATK (office stationery), raffia rope, ArcGIS software, laptop, GPS, cellphone and other supporting software such as Microsoft Office and Excel. The objects of the study were forested land, agroforestry, and monoculture in KPH Batu Tegi, Lampung Province. The condition of the forested land at the research location is secondary forests. Secondary forests are forests that grow and develop again naturally after experiencing damage or changes from previous primary forests, either due to natural factors or human activities such as logging, fires, or land clearing. The method used in this study is a quantitative approach. The primary data collected were documentation of location, type of plant, diameter, and circumference in each phase in the three land covers. Secondary data is used as supporting data obtained from scientific literature (scientific works).

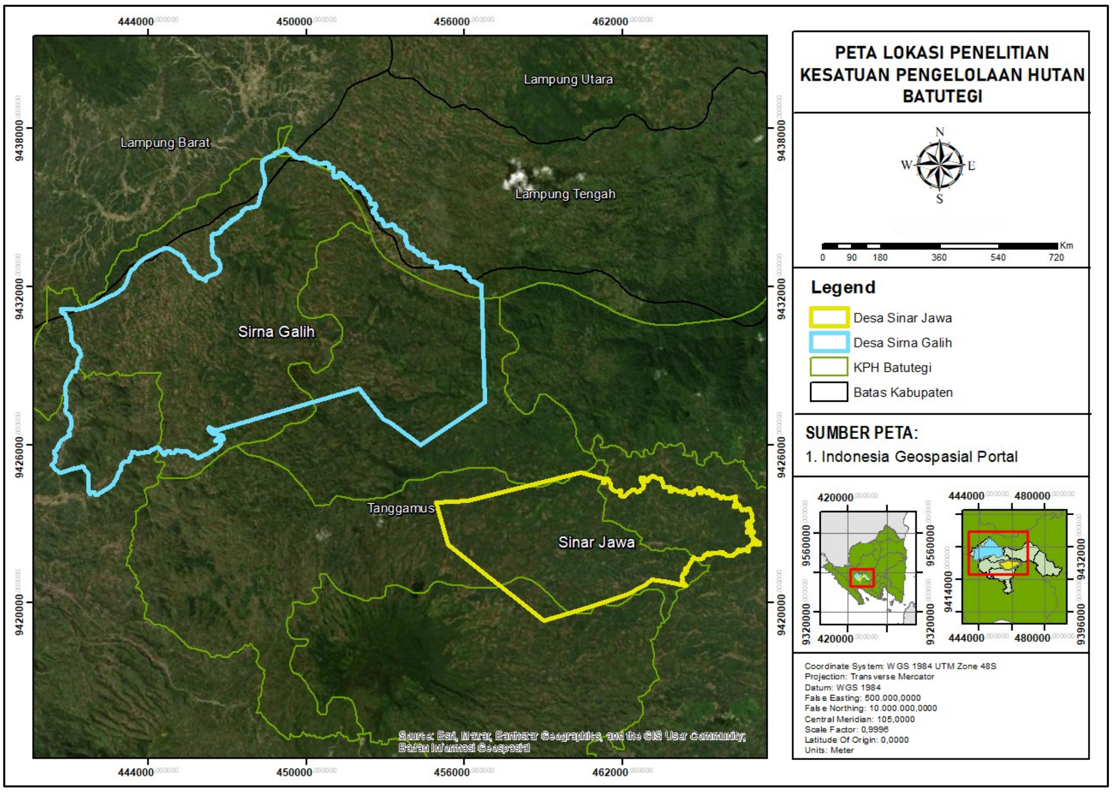

Figure 1. Study Location

Measurement of tree, pole and sapling biomass was carried out based on the allometric equation (dbh > 10 cm, height > 1.5 m) by measuring the tree diameter at breast height (DBH) in a sample that consists of three measurement plots, namely 20x50 (trees with DBH > 20 cm), 10x10 (poles with DBH 10-20 cm) and 5x5 (sapling with DBH 1.5-10 cm). Samples were collected using purposive sampling method to provide different data information on each land cover. In this study, researchers used the Cochran formula (Sugiyono, 2017) to determine the number of samples. Based on the calculation, the number of minimum samples that need to be collected were 35.25, so we rounded up to 36 sample plots from 6,615.2 ha of study area with a margin error of 16.5%. The Cochran formula is as follows:

$$n = \frac{\frac{t^2 x\ p\ x\ q}{d^2}}{1 + \frac{1}{\mathrm{N}}\left(\left(\frac{t^2 x\ p\ x\ q}{d^2}\right) - 1\right)}$$

Description:
n = Number of samples
t = level of confidence (t = 1.96)
p = proportion of certain characteristics (0.5)
N = Number of Population
d = level of error (0.165)
q = 1 – p (1 = constant number)

Vegetation Analysis Calculation

The density (K) for each type of plant can be calculated using the following formula:

$$\mathrm{K} = \frac{\text{Number of individuals of a species}}{\text{Total area of sample plot}} \qquad \mathrm{KR} = \frac{\text{Density of a species}}{\text{Frequency of all species}} \text{ x } 100\%$$

The frequency (F) of distribution of each plant population uses the following formula:

$$\mathrm{F} = \frac{\text{Number of plots where a species is found}}{\text{Number of all sample plots}} \qquad \mathrm{FR} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{ x } 100\%$$

The dominance of the dominant plant species is as follows:

$$\mathrm{D} = \frac{\text{Total area of the base of a species}}{\text{Area of the entire sample plot}} \qquad \mathrm{DR} = \frac{\text{Dominance of a species}}{\text{Dominance of all species}} \text{ x } 100\%$$

The important value index (INP) is based on the equation of density, frequency, and dominance, so the formula for finding the INP in the tree, pole, and sapling phases is as follows:

$$\text{INP} = \text{KR} + \text{FR} + \text{DR}$$

Description:
INP = Importance Value Index
KR = Relative Density
FR = Relative Frequency
DR = Relative Dominance

Species Diversity Index (Shannon-Wienner) uses the following formula:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

$$\text{Pi} = \frac{\text{Ni}}{\text{N}}$$

Description:
H' = Species diversity index
N = Number of individuals of all species
Ni = Number of individuals of species i
Pi = Proportion of individuals of species i

The category of species diversity index is divided into 3 categories, namely where H' < 1

Description:
H' = Species diversity index
N = Number of individuals of all species
Ni = Number of individuals of the i-th species
Pi = Proportion of individuals of species i
is low, 1 < H' < 3 is medium, and H' > 3 is high.

Aboveground biomass was obtained from the measurement results analyzed using the allometric equation formula to calculate biomass which is presented in Table 1.

Table 1. Allometric Equations Used to Estimate Tree Biomass

Tree Types	Allometric Equations	Source
Campuran	$B = 0{,}206 (D^{2,56}) (\rho^{0,889})$	Manuri *et al* (2017)
Kopi pangkas	$B = 0{,}281 (D)^{2,06}$	Arifin (2001); Van Noordwijk *et al*. (2002)
Jati Putih	$B = 0{,}128 (D)^{2,35}$	Rifai (2024)
Jati	$B = 0{,}0944 (D)^{2,4578}$	Siregar (2012)
Mahoni Daun Lebar	$B = 0{,}048 (D)^{2,68}$	Adinugroho *et al* (2006)
Jabon Merah	$B = 0{,}014 (D)^{2,958}$	Siregar (2007)
Kakao	$B = 0{,}1208 (D)^{1,98}$	Hairiah & Rahayu (2007)
Meranti	$B = 0{,}067 (D)^{2,859}$	Yunita (2016)
Payung (Afrika)	$B = 0{,}0559 (D)^{2,464}$	Sukiman *et al* (2016)
Sengon	$B = 0{,}623 (D)^{1,471}$	Ohorella *et al* (2022)

Description: B = Biomass (kg/tree), ρ = Wood density (g/cm-3), D = Tree diameter at breast height (cm).

Belowground biomass is calculated using the equation prepared by (Cairns *et al.,* 1997) as follows:

$$BGB = \exp(-1{,}0587 + 0{,}8836 \times \ln AGB)$$

Description:
BGB = Belowground biomass (kg)
AGB = Aboveground biomass value (kg)

The carbon estimation (C) calculation is calculated using the following formula:

$$C = B \times 0{,}47 \qquad C = N \times 0{,}47$$

Description:
C = Carbon (kg) B = Biomass (kg)
N = Necromass (kg) 0.47 = International standard for carbon estimation

The calculation of carbon reserves per hectare in each plot is calculated using the following formula (SNI, 2011):

$$Cn = Cx/1000 \times 10000/(L\ plot)$$

Description:
Cn = Carbon per hectare in each carbon pool in each plot (ton/ha)
Cx = Carbon in each carbon pool in each plot (kg)
L plot = Plot area in each pool (m^2)

Statistical analysis of the uncertainty of the carbon stock factor can be calculated using the following formula.

Table 2. Statistical Analysis of Uncertainty Values of Carbon Stock Factors

Land Cover type	Statistical analysis							
	Mean (Mj)	Standard Deviation (SD)	Sampel Count (n)	t-stat 95% (t)	Confidence Interval (CI)	Lower Bound	Upper Bound	Uncertainty (%)
Land Cover type to-j	$\frac{1}{n}\sum_{i=1}^{n} M_i$	$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Mi + Mj)^2}$			$\frac{SD \times t}{\sqrt{n}}$	$Mj - CI$	$Mj + CI$	$\frac{CI}{Mj} \times 100\%$

Mi = total carbon stock (in tC/ha) of plot-i in crop type to-j, n is the number of plots in each crop type to-j.

RESULT AND DISCUSSION

Importance Value Index (IVI) in Three Land Covers

The types of vegetation and INP found from each land cover based on each phase are presented in the following table.

Table 3. Important value index in the research area

Phase	Land Cover Type					
	Forest		Agroforestry		Monoculture	
	Spesies	INP (%)	Spesies	INP (%)	Spesies	INP (%)
Sapling	*Coffea canephora*	196,9	*Coffea canephora*	256,71	*Coffea canephora*	249,52
	Gliricidia sepium	51,78	*Gliricidia sepium*	18,25	*Gliricidia sepium*	28,03
	Casuarina equisetifolia	39,8	*Parkia speciosa*	12,59	*Hevea brasiliensis*	11,56
	Mangifera indica	11,51	*Eugenia aromatica*	12,44	*Eugenia aromatica*	10,87
Pole	*Casuarina equisetifolia*	73,25	*Coffea canephora*	147,93	*Coffea canephora*	167,19
	Coffea canephora	60,27	*Gliricidia sepium*	44,5	*Gliricidia sepium*	81,7
	Gliricidia sepium	54,36	*Persea americana*	23,93	*Myristtica fragrans*	9,18
	Hevea brasiliensis	32,07	*Theobroma cacao*	16,21	*Durio zibethinus*	8,7
	Lithocarpus sundaicus	26,24	*Hevea brasiliensis*	14,74	*Hevea brasiliensis*	8,46
Tree	*Swietenia macrophylla*	63,54	*Swietenia macrophylla*	94	*Gmelina arborea*	88,69
	Casuarina equisetifolia	62,11	*Durio zibethinus*	36,67	*Swietenia macrophylla*	43,17
	Anthocephalus macrophyllus	49,91	*Maesopsis eminii*	34,7	*Anthocephalus macrophyllus*	38,37
	Gmelina arborea	43,51	*Shorea sp*	32,9	*Hevea brasiliensis*	35,71
	Lithocarpus sundaicus	35,8	*Gmelina arborea*	29,3	*Manilkara zapota*	22,03

Source: Data Processing by the Compilation Team, 2025.

The Importance Value Index (IVI) is used to identify the most dominant species in a plant community, because species with high IVI contribute the most to biomass and carbon stocks in an area. By knowing the dominant species through IVI, we can determine the species that play the most role in the process of carbon absorption and storage in the ecosystem being studied (Hidayat *et al*., 2020). Based on table 3. the IVI values in the three land covers show different results, but the highest IVI percentage in the three land cover types comes from the same plant, namely the Coffea canephora plant. The highest IVI value in forest land is 196.9% in the sapling phase, then in agroforestry land it is 256.71% in the sapling phase, and in monoculture land it is 249.52% in the sapling phase. The highest average IVI value comes from the sapling phase, this is because Coffea canephora plants are often found in sapling plots. The highest overall INP value percentage was in Coffea canephora plants with a value of 256.71% in agroforestry land. The high INP value of a species in a community indicates that the species is able to survive and grow well and the conditions are very suitable for developing well in the place where it grows (Hanafi *et al*., 2021).

Biodiversity Index (H')

Biodiversity index serves to assess the variation and diversity of organism types in an ecosystem or community. A commonly used index is the *Shannon-wiener* index (H').

Table 4. Biodiversity index in The Wanajaya Forest Farmers Group

No	Growth Phase	Land Cover		
		Agroforestry	Forest	Monoculture
1.	Sapling	0,68	0,22	0,27
2.	Pole	1,88	1,08	0,76
3.	Tree	1,87	1,88	1,94

Source: Data Processing by the Compilation Team, 2025.

According to Adelina *et al*., (2016) the Shannon-Wienner biodiversity index is used to measure the level of species diversity in a community. The H' value provides an overview of how many and balanced species are present, which is related to the stability and sustainability of ecosystem functions, including carbon storage capacity. High diversity can reflect a healthy ecosystem and has the potential to store carbon sustainably, although the relationship between diversity and carbon stock can vary depending on the type of ecosystem and its species composition. Based on table 4. in forest land in the sampling phase it is categorized as low diversity (0.68), the pole and sapling phases are respectively categorized as medium diversity, namely (1.88 and 1.87). Agroforestry land in the sapling phase has a low level of diversity (0.68) and for the pole and sapling phases the diversity levels are moderate (1.08 and 1.88). Then on monoculture land in the sapling and pole phase it is categorized as low diversity, namely (0.27 and 0.76) and in the tree phase it has a moderate level of diversity (1.94). The average sapling phase in each type of land cover has a low level of diversity. This indicates that the level of ecosystem stability in the research location is relatively low. One of the factors causing low biodiversity is caused by various human activities and environmental factors that damage habitats and ecosystems such as the conversion of forest land into agricultural land, settlements or industry.

Aboveground Biomass

Aboveground biomass after calculations were carried out, the biomass value per land cover was found, as presented in the table below.

Table 5. Aboveground Biomass Values in Three Land Covers

Species Name	Scientific Name	Agroforestry (kg)	Forest (kg)	Monoculture (kg)
Afrika	*Maesopsis eminii*	19.536,29	-	-
Alpukat	*Persea americana*	2.474,47	-	1.864,99
Bendo	*Artocarpus elasticus*		3.615,31	-
Cemara	*Casuarina equisetifolia*	10.761,52	95.470,90	-
Cengkeh	*Eugenia aromatica*	2,87	-	1,23
Cokelat	*Theobroma cacao*	179,77	18,71	-
Dadap	*Erythrina variegata*	584,02	-	468,90
Durian	*Durio zibethinus*	10.150,72	575,69	1.193,50
Gamal	*Gliricidia sepium*	2.065,67	565,61	2.414,99
Jabon Merah	*Anthocephalus macrophyllus*	-	67.156,81	11.584,77
Jambu	*Psidium guajava*	-	-	192,27
Jati	*Tectona grandis*	-	2.080,46	-
Jati Putih	*Gmelina arborea*	11.523,42	20.799,70	6.366,42
Karet	*Hevea brasiliensis*	2.118,57	5.704,09	2.180,52
Kemiri	*Aleurites moluccana*	1.891,78	-	-
Kopi	*Coffea canephora*	3.447,11	405,11	3.565,49
Mahoni Daun Lebar	*Swietenia macrophylla*	36.547,36	39.923,82	6.729,70

Mangga	*Mangifera indica*	-	3,28	-
Medang	*Phoebe hunanensis*	-	14.137,51	-
Mengkirai	*Trema orientalis*	150,15	-	-
Meranti	*Shorea sp*	52.666,74	-	-
Nangka	*Artocarpus heterophyllus*	3.014,46	-	3.162,65
Pala	*Myristtica fragrans*	-	-	233,30
Pasang	*Lithocarpus sundaicus*	728,09	42.055,93	-
Petai	*Parkia speciosa*	1.460,30	-	-
Randu	*Ceiba pentandra*	20.761,65	-	-
Sawo	*Manilkara zapota*	-	-	2.961,28
Sengon	*Paraserianthes falcataria*	-	19,52	-
Sonokeling	*Dalbergia latifolia*	4.619,99	-	-
Suren	*Toona sureni*	-	862,98	-
Timbalun	*Parashorea lucida*	-	1.227,38	-
Total above ground biomass of trees per land cover type		**184.684,97**	**294.622,82**	**42.920,01**

Source: Data Processing by Compilation Team, 2025.

Based on the table above, the total aboveground biomass in the samples taken, the highest value is in forest land of 294,622.82 kg and agroforestry land of 184,684.97 kg. This is because in forest land there are many types of plants that have large plant diameters, so they can produce high biomass. This is supported by Tuah *et al.* (2017) the larger the diameter of the plant, the greater the biomass, and vice versa.

Belowground Biomass

After calculating the belowground biomass, the biomass value per land cover is found, which is presented in the table below.

Table 6. Subsurvace Biomass Values in Three Land Covers

Species Name	Scientific Name	Agroforestry (kg)	Forest (kg)	Monoculture (kg)
Afrika	*Maesopsis eminii*	57,18	-	-
Alpukat	*Persea americana*	35,50	-	10,95
Bendo	*Artocarpus elasticus*	-	12,57	-
Cemara	*Casuarina equisetifolia*	7,79	384,54	-
Cengkeh	*Eugenia aromatica*	0,88	-	0,17
Cokelat	*Theobroma cacao*	18,50	5,06	-
Dadap	*Erythrina variegata*	15,67	-	12,66
Durian	*Durio zibethinus*	73,89	9,51	17,77
Gamal	*Gliricidia sepium*	93,18	34,43	146,66
Jabon Merah	*Anthocephalus macrophyllus*	-	209,00	32,47
Jambu	*Psidium guajava*	-	-	6,96
Jati	*Tectona grandis*	-	11,48	-
Jati Putih	*Gmelina arborea*	69,62	213,94	73,91
Karet	*Hevea brasiliensis*	35,63	53,64	28,34
Kemiri	*Aleurites moluccana*	16,86	-	-
Kopi	*Coffea canephora*	463,43	60,45	537,39

Species Name	Scientific Name	Agroforestry (kg)	Forest (kg)	Monoculture (kg)
Mahoni Daun Lebar	*Swietenia macrophylla*	307,19	340,52	28,81
Mangga	*Mangifera indica*	-	1,00	-
Medang	*Phoebe hunanensis*	-	58,24	-
Mengkirai	*Trema orientalis*	4,21	-	-
Meranti	*Shorea sp*	111,87	-	-
Nangka	*Artocarpus heterophyllus*	11,06	-	12,23
Pala	*Myristtica fragrans*	-	-	9,03
Pasang	*Lithocarpus sundaicus*	9,90	127,76	-
Petai	*Parkia speciosa*	6,84	-	-
Randu	*Ceiba pentandra*	17,27	-	-
Sawo	*Manilkara zapota*	-	-	17,26
Sengon	*Paraserianthes falcataria*	-	3,82	-
Sonokeling	*Dalbergia latifolia*	7,08	-	-
Suren	*Toona sureni*	-	5,67	-
Timbalun	*Parashorea lucida*	-	5,97	-
Total tree root biomass per land cover type		**1.363,56**	**1.537,61**	**934,62**

Source: Data Processing by Compilation Team, 2025.

The total biomass of tree roots in the samples taken the highest value was in forest land of 1,537.61 kg and in agroforestry land of 1,363.56 kg. The decreasing amount of biomass will have a negative impact on the sustainability of the forest ecosystem and affect the carbon cycle in the atmosphere because almost 50% of plant biomass consists of carbon elements and these elements can be released into the atmosphere (Brown, 1997).

Estimated Carbon Stored

The carbon estimation calculation is presented in the following table.

Table 7. Estimated Value of Carbon Stored in Three Land Covers

Species Name	Scientific Name	Total Tree Carbon Stock (tC)	Total Root Carbon Stock (tC)
Afrika	*Maesopsis eminii*	9.182,06	26,88
Alpukat	*Persea americana*	2.039,55	21,83
Bendo	*Artocarpus elasticus*	1.699,20	5,91
Cemara	*Casuarina equisetifolia*	49.929,24	184,40
Cengkeh	*Eugenia aromatica*	1,93	0,50
Cokelat	*Theobroma cacao*	93,28	11,07
Dadap	*Erythrina variegata*	494,87	13,32
Durian	*Durio zibethinus*	5.602,36	47,55
Gamal	*Gliricidia sepium*	2.371,75	128,91
Jabon Merah	*Anthocephalus macrophyllus*	37.008,54	113,49
Jambu	*Psidium guajava*	90,37	3,27
Jati	*Tectona grandis*	977,82	5,39
Jati Putih	*Gmelina arborea*	18.184,09	168,01
Karet	*Hevea brasiliensis*	4.701,50	55,28
Kemiri	*Aleurites moluccana*	889,14	7,93
Kopi	*Coffea canephora*	3.486,33	498,80

Species Name	Scientific Name	Total Tree Carbon Stock (tC)	Total Root Carbon Stock (tC)
Mahoni Daun Lebar	*Swietenia macrophylla*	39.104,41	317,97
Mangga	*Mangifera indica*	1,54	0,47
Medang	*Phoebe hunanensis*	6.644,63	27,37
Mengkirai	*Trema orientalis*	70,57	1,98
Meranti	*Shorea sp*	24.753,37	52,58
Nangka	*Artocarpus heterophyllus*	2.903,24	10,95
Pala	*Myristtica fragrans*	109,65	4,24
Pasang	*Lithocarpus sundaicus*	20.108,49	64,70
Petai	*Parkia speciosa*	686,34	3,22
Randu	*Ceiba pentandra*	9.757,98	8,12
Sawo	*Manilkara zapota*	1.391,80	8,11
Sengon	*Paraserianthes falcataria*	9,17	1,80
Sonokeling	*Dalbergia latifolia*	2.171,40	3,33
Suren	*Toona sureni*	405,60	2,67
Timbalun	*Parashorea lucida*	576,87	2,81

Source: Data Processing by the Compilation Team, 2025.

The total carbon stock of trees obtained from each plant is the largest in the cypress plant (*Casuarina equisetifolia*) with a value of 49.929,24 Ton carbon (tc) and the total root carbon stock obtained a value of 498.80 tc in the coffee plant (*Coffea canephora*). This is because the cypress tree (*Casuarina equisetifolia*) consists of 75 individuals, so it is able to store high carbon reserves. Therefore, plants with high carbon reserves are expected to reduce damage to the forest. This is supported by Hidayah *et al*. (2023), the more forests that are damaged, the less the forest's ability to absorb carbon.

Carbon Stock Per Hectare in Each Plot

The magnitude of carbon values in the three land covers can be seen in the table below.

Table 8. Carbon Stock Values per Hectare in The Samples Taken

Land Type	Plot	Karbon per Plot (tC/ha)	Basal Area (m2/ha)
Forest	SD-H-1	71,81	4,83
	SD-H-2	60,29	3,30
	SD-H-3	217,02	5,41
	SD-H-4	60,52	4,53
	SD-H-5	156,47	8,27
	SD-H-6	83,28	6,19
	WJ-H-1	141,31	4,52
	WJ-H-2	215,55	6,70
	WJ-H-3	131,45	4,35
	WJ-H-4	184,15	5,48
	WJ-H-5	90,69	3,35
	WJ-H-6	137,06	5,55
Agroforestry	SD-AGF-1	66,37	4,12
	SD-AGF-2	65,66	5,37
	SD-AGF-3	67,89	5,36
	SD-AGF-4	218,51	4,93
	SD-AGF-5	82,05	5,45
	SD-AGF-6	94,87	5,06
	WJ-AGF-1	138,32	8,91

	WJ-AGF-2	173,74	10,05
	WJ-AGF-3	94,96	7,57
	WJ-AGF-4	78,80	6,01
	WJ-AGF-5	105,59	7,00
	WJ-AGF-6	69,04	4,25
Monoculture	SD-M-1	61,91	4,20
	SD-M-2	39,95	3,43
	SD-M-3	65,17	4,00
	SD-M-4	42,17	3,11
	SD-M-5	54,78	2,17
	SD-M-6	63,87	4,21
	WJ-M-1	56,01	4,91
	WJ-M-2	52,84	4,73
	WJ-M-3	45,97	4,08
	WJ-M-4	26,28	2,34
	WJ-M-5	42,07	3,53
	WJ-M-6	45,19	4,38

Source: Data Processing by the Compilation Team, 2025.

Table 8 shows the results of the total carbon stock of each plot in three types of land cover. The highest carbon stock for forest land in plot SD-H-3 with a total carbon stock of 217.02 tC/ha. Then, on agroforestry land, the highest results were obtained on the SD-AGF-4 plot with a total carbon stock of 218.51 tC/ha. In the monoculture land type, the highest results were obtained in the SD-M-3 plot with a total carbon stock of 65.17 tC/ha. The high carbon stock in the plot was due to several factors, namely dense vegetation cover, especially with high tree density and large stem diameter (DBH> 30 cm). According to a study conducted by Wang *et al* (2024), the large carbon stock in a plot due to the diversity of tree species (tree species diversity) can contribute significantly to carbon accumulation. Plots with high diversity tend to have greater biomass due to the variation in tree size, age, and growth type which enriches the total biomass and carbon storage.

Then in Table 8, the results of the basal area density (BSD) in three types of land cover are obtained. The highest BSD in the forest land type is in the SD-H-5 plot with a BSD of 8.27 m2/ha. In agroforestry land, the highest basal area (BA) is found in plot WJ-AGF-2 with a basal area (BA) of 10.05 m2/ha. In the monoculture land type, the highest basal area (BA) is found in plot WJ-M-1 with a basal area (BA) of 4.91 m2/ha. According to Al-Reza *et al*. (2017) basal area density (basal area (BA)) has a significant relationship with carbon stock because high basal area (BA) indicates a larger tree trunk cross-sectional area per unit area, dominance of large-diameter trees, and dense canopy cover. These factors increase carbon storage capacity through the accumulation of woody biomass. The following is a graph related to the relationship between basal area density and carbon stock per hectare and a graph of the relationship between basal area and carbon stock per hectare. The following is a graph related to the relationship between basal area density and carbon stock per hectare and a graph of the relationship between basal area and carbon stock per hectare.

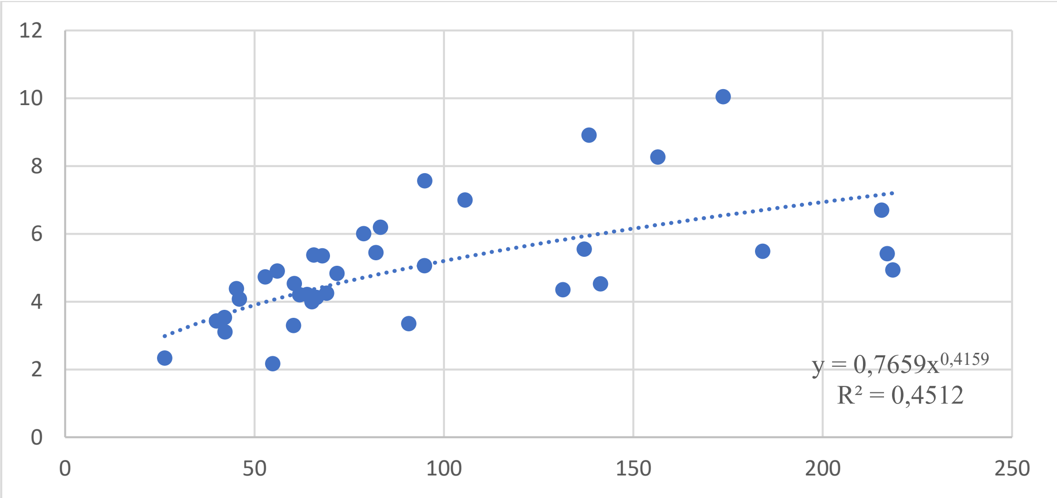

Figure 2. Relationship Between Basal Area Density and Carbon Stock per Hectare

Based on the graph, the equation of the line that approaches the data is y = $0.7659x^{0.4159}$ with an R^2 value of 0.4512. This R^2 value indicates that about 45.12% of the variation in carbon stock can be explained by the density of the basal plane, while the rest is influenced by other factors.

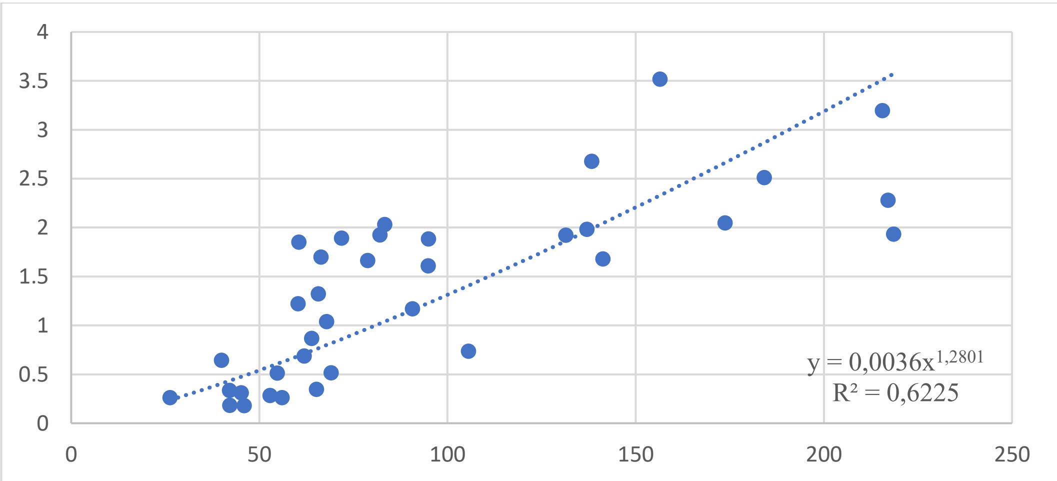

Figure 3. Relationship Between Basal Area and Carbon Stock per Hectare

The graph shows the relationship between basal area and carbon stock per hectare. The horizontal axis shows basal area, while the vertical axis shows carbon stock per hectare. Based on the graph above, it can be seen that there is a positive correlation between basal area and carbon stock per hectare, which is indicated by a trend line with the equation y = $0.0036x^{1.2801}$ and an R^2 value of 0.6225. The R^2 value indicates that approximately 62.25% of the variation in carbon stock per hectare can be explained by variations in basal area.

In general, this graph indicates that the larger the basal area, the higher the carbon stock per hectare. This can be explained because areas with wider vegetation tend to have greater biomass, so they are able to store more carbon. It should be noted that this relationship is not perfect, because there are still other factors that can affect carbon stock, such as vegetation type, environmental conditions, and land management.

Uncertainty Test of Carbon Stock Factor

The uncertainty values of the stored carbon factors are presented in the following table.

Table 9. Uncertainty Values of Carbon Stock Factors

Types of land cover	Average (tC/ha)	(SD)	n	Level of confidence 95% (t)	CI	LB	UB	Level of doubt (%)
Agroforestry	104,65	48,47	12	2,179	30,49	74,16	135,14	29,14
Forest	129,13	56,81	12	2,179	35,73	93,40	164,87	27,67
Monoculture	49,68	11,51	12	2,179	7,24	42,44	56,92	14,57

Source: Data Processing by the Compilation Team, 2025.

Description:
SD : Standard deviation LB : Minimum value n : Sample
CI : Convidenti UB : Highest value

Based on the statistical analysis of the sampling error test in the table above, the highest average value of the amount of carbon stored is in the forest land cover type, which is 129.13 (tC/ha) with a standard deviation of 56.81 and a confidence interval of 35.73. So it can be seen that the range of estimated carbon stored values in the forest land cover type is 93.40 tC/ha to 164.87 tC/ha with a sampling error value of 27.67%. Then in the agroforestry land cover, the average carbon stored value is 104.65 tC/ha, with a standard deviation of 48.47, and a confidence interval of 30.49. Thus it can be seen that the range of estimated carbon stored values in the agroforestry land cover type is 74.16 tC/ha to 135.14 tC/ha with a sampling error value of 29.14%. The average value of carbon stored in monoculture land cover is 49.68 tC/ha, with a standard deviation of 11.51, and a confidence interval of 7.24. This means that the range of estimated carbon stored in the monoculture land cover type is 42.44 tC/ha to 56.92 tC/ha with a sampling error value of 14.57%. Based on the results obtained, it is known that the carbon content value in each land cover is different, this is because the higher the biomass contained in the tree, the higher the carbon contained in the tree (Yaqin *et al*., 2022). The highest carbon content is found in forest type land cover while the lowest carbon value is found in monoculture land cover type (Wulandari *et al*., 2021)

The difference in stored carbon value occurs because the density of vegetation in forest land cover is greater than that of agroforestry and monoculture land cover located near community plantations. The same thing was also expressed by Rahayu (2007) who stated that the difference in biomass acquisition is influenced by vegetation density, diversity of diameter sizes and distribution of vegetation specific gravity, where land use consisting of trees with species that have high wood density values, the biomass will be higher when compared to land that has species with low wood density values. The value of carbon stored in forest land can result in a large accumulation of CO2 absorption (Ristiara *et al.,* 2017). This is because forest land has diverse vegetation and has a large population. However, with the high rate of forest degradation and deforestation to date, CO2 absorption has decreased. Forests that are increasingly degraded will gradually lose their function as CO2 absorbers (Junaedi, 2008). Then on monoculture land it cannot be a guarantee that it can absorb more CO2. This is because monoculture land only plants one type of plant that can absorb lower CO2. This is supported by the results of Sahuri (2019) study entitled "carbon reserve potential in rubber-based agroforestry systems" that the average value of carbon reserves in real agroforestry systems is higher than the carbon reserves produced by monoculture systems. So that the agroforestry system can be a reference in supporting carbon.

When viewed from the average value of the amount of carbon stored in agroforestry land, the carbon value is not much different from forest land. This is because agroforestry includes a system of use or management of forest land and agricultural land (mixed). Well-managed agroforestry practices can increase plant productivity by creating favorable microclimate conditions (Febryano *et al*., 2023). Of course, this has a positive impact on climate change mitigation efforts. In addition, agroforestry has benefits, especially in improving the economy and food security (Herwanti *et al*., 2022). One of the climate change mitigation efforts that can be carried out is by optimizing carbon dioxide absorption and storing high carbon stocks (Nedhisa and Tjahjaningrum, 2020). This mitigation functions to reduce the risk of increasing greenhouse gas emissions in the atmosphere and climate change. According to Diana *et al*. (2024) climate change is a difficult problem to manage so mitigation needs to be carried out to reduce its causes. Thus, the agroforestry system can be used as an effort to mitigate climate change and contribute high carbon stocks.

CONCLUSION AND RECOMMENDATIONS

The estimated value of carbon stored in the three land covers in KPH Batu Tegi varies, the highest carbon stored is in the forest land cover type, which is 129.13 (tC/ha), agroforestry land is obtained at 104.65 tC/ha, and monoculture land at 49.68 tC/ha. The high value of carbon stored in forest land is because forest land has a high-density value, a large number of trees with large diameters. So that the stored carbon owned is very high compared to agroforestry land and monoculture land. If you look at the average value of the amount of carbon stored in agroforestry land, it has a value that is not much different from forest land. So, it can be concluded that agroforestry land can offer efforts in mitigating climate change and is able to maintain a balance between conservation and socio-economic benefits, where agroforestry is one system that can be applied in social forestry programs that aim to improve community welfare.

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