ASIAN JOURNAL OF FORESTRY
Volume 8, Number 1, June 2024
Pages: 63-71

E-ISSN: 2580-2844
DOI: 10.13057/asianjfor/r080106

Estimation of carbon sequestration in pine forest and agroforestry in Bategede Village, Jepara, Central Java, Indonesia

ALYA AFRA INAS NUR, AHMAD DWI SETYAWAN♥, LIA KUSUMANINGRUM
Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57 126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com, alyainas53@gmail.com

Manuscript received: 15 July 2023. Revision accepted: 12 February 2024.

Abstract. *Nur AAI, Setyawan AD, Kusumaningrum L. 2024. Estimation of carbon sequestration in pine forest and agroforestry in Bategede Village, Jepara, Central Java, Indonesia. Asian J For 8: 63-71.* The escalating rise in atmospheric carbon dioxide levels catalyzes accelerated global warming, profoundly impacting Earth's life. Within this context, forests emerge as crucial guardians of environmental equilibrium by actively absorbing atmospheric carbon dioxide. This process serves as a strategic mitigation measure against the perils of global warming. This study aims to determine the inherent potential of biomass, carbon stock, and carbon sequestration within tree stands and poles existing within pine forests and agroforestry landscapes in Bategede Village, Jepara, Central Java, Indonesia. Additionally, the study undertakes a comparative assessment of the biomass, carbon stock, and carbon sequestration attributes between two distinct forest types: homogeneous pine forests and heterogeneous forests represented by agroforestry systems within Bategede Village. The study was conducted in March in Bategede Village, Nalumsari District. Data was collected through non-destructive methods, focusing on tree stands with a diameter (at breast height) exceeding 20 cm and poles with a diameter (at breast height) ranging from 10 to 20 cm. Robust biomass calculations were computed through predetermined allometric equations. The results of this study show that the biomass, carbon stock, and carbon sequestration were recorded at 407.83 tons/ha, 191.68 tons/ha, and 703.46 tons/ha, respectively, in pine forests. Meanwhile, the biomass, carbon stock, and carbon sequestration values recorded in agroforestry landscapes in Bategede Village were 120.64 tons/ha, 56.41 tons/ha, and 207.01 tons/ha, respectively. The comparative analysis revealed that homogeneous forests, particularly in the tree category, have carbon sequestration values that are sixfold greater than their heterogeneous counterparts. A parallel evaluation within the pole category demonstrated a twofold rise in carbon sequestration within heterogeneous forests compared to their homogeneous counterparts. This difference may be due to the interplay of factors, including variations in stem diameter, species composition, and number of individuals, all cumulatively influencing carbon sequestration within the homogeneous and heterogeneous forest ecosystems.

Keywords: Allometric equation, carbon stock, environmental services, heterogeneous forest, homogenous forest

INTRODUCTION

Anthropogenic activities across various sectors can have a detrimental impact on the environment. Anthropogenic activities originate from various human actions such as industrial processes, transportation, etc., which can serve as sources of pollution to the environment (Sepriani et al. 2014). According to Singh and Purohit (2014), various anthropogenic activities, especially after the Industrial Revolution, have increased greenhouse gas levels in the atmosphere, including carbon dioxide (CO_2). Pirkko and Nyronen (1990) affirm that carbon dioxide emissions contribute more significantly to the greenhouse effect, accounting for approximately 48%. This high concentration of carbon dioxide is attributed to emissions from multiple anthropogenic sources, including industry, transportation, and deforestation. If proper controls are not implemented to curb carbon dioxide emissions, the acceleration of global warming could be exacerbated.

Global warming denotes the rise in the Earth's temperature brought about by the entrapment of solar heat by greenhouse gases in the atmosphere (Sulkam 2020). It has evolved into a pressing environmental concern due to its profound impact on Earth's biota. The ramifications of global warming include climate changes, which can lead to catastrophes such as coastal erosion, melting of ice and glaciers, altered rainfall patterns, and increased disease prevalence. A range of strategies can be adopted to mitigate the consequences of global warming, including measures to regulate atmospheric carbon concentrations through forest conservation.

Forests are paramount natural resources, endowing numerous environmental services that benefit human life. In mitigating accelerated global warming, forests play a crucial role in providing environmental services by helping absorb carbon dioxide from the atmosphere (Anggraeni et al. 2021). Plants facilitate this absorption of carbon dioxide through photosynthesis, whereby carbon is converted into organic carbon within the biomass (Nurfansyah et al. 2019). According to Rizki et al. (2016), trees exhibit the highest growth phase regarding carbon absorption and storage. The diversity of tree species within a forest community inherently influences the extent of carbon absorption capacity (Yastori et al. 2016).

Jepara District in Central Java Province, Indonesia, has witnessed recent industrial development, prompting escalated anthropogenic activities contributing to global warming. A pertinent example is the furniture and carving industry, which entails deforestation for sourcing wood for production. Additionally, the machinery used in the production process generates emissions that further elevate the presence of greenhouse gases in the atmosphere. Bategede Village in Jepara District is characterized by diverse forest areas, offering the potential to contribute to global warming mitigation through carbon sequestration. The biomass quantity and capacity to absorb atmospheric carbon within a specific area are crucial in climate change mitigation (Munir 2017).

The literature presented substantiates the forests' pivotal role in attenuating global warming's acceleration. No published scientific work currently provides a comprehensive report on vegetation inventory and carbon sequestration potential across various forest land covers, particularly in Bategede Village, Nalumsari Sub-district, Jepara District, Indonesia. Information on vegetation's carbon-absorbing capacity is essential for effective area management and conservation efforts. Therefore, this study aims to estimate the carbon sequestration potential of homogeneous pine forests and heterogeneous agroforestry systems within Bategede Village, Nalumsari Sub-district, Jepara District.

MATERIALS AND METHODS

Study area

The study was conducted in Bategede Village, Nalumsari Sub-district, Jepara District, Central Java Province, Indonesia. Bategede Village is geographically located at 6°40'59"S and 110°49'12"E (Figure 1). This study is centered within a pine forest area located in the Wana Sreni Indah, which serves as a representative example of a homogeneous vegetation type. The study also encompasses a forest area with an agroforestry system, serving as a representative instance of heterogeneous vegetation type.

Data collection

Data collection was conducted in March 2023. Estimating carbon sequestration in pine forests and agroforestry areas in Bategede Village involved the calculation of Aboveground Biomass (AGB) and Belowground Biomass (BGB). Biomass calculations were performed using allometric equations, using a non-destructive sampling method. The sampling process involved both tree-level Diameter at Breast Height (DBH) > 20 cm and pole-level (DBH 10 to 20 cm) divisions. The sampling plots were divided into 20 × 20 m^2 for tree vegetation and 10 × 10 m^2 for pole vegetation. A total of 150 plots were used for the research purpose. Essential data, including the names of plant species and the corresponding diameters at breast height, were recorded in the datasheet. Complementary secondary data, such as pertinent allometric equations and specific gravity, were integrated into this study (Table 1).

Data analysis

The data analysis was conducted using a quantitative descriptive approach, where the field data acquired were subjected to calculations from several allometric equations. Subsequently, each species' total aboveground and belowground biomass was multiplied by 0.47 to obtain its carbon stock value (SNI 2011). Therefore, the derived carbon stock outcomes were further multiplied by a constant factor of 3.67 to derive the respective carbon sequestration values. The following are the allometric formulas used to calculate the aboveground biomass:

Conversely, the quantification of belowground biomass was done by applying the root-to-shoot ratio methodology. This approach involves evaluating the relationship between belowground biomass and aboveground biomass. The equation for estimating root biomass, proposed by Cairns et al. (1997), is as follows:

$$RDB = \exp(-1.0587 + 0.8836 \times \ln AGB)$$

Where RDB stands for root biomass or Belowground Biomass (BGB), and AGB represents aboveground biomass.

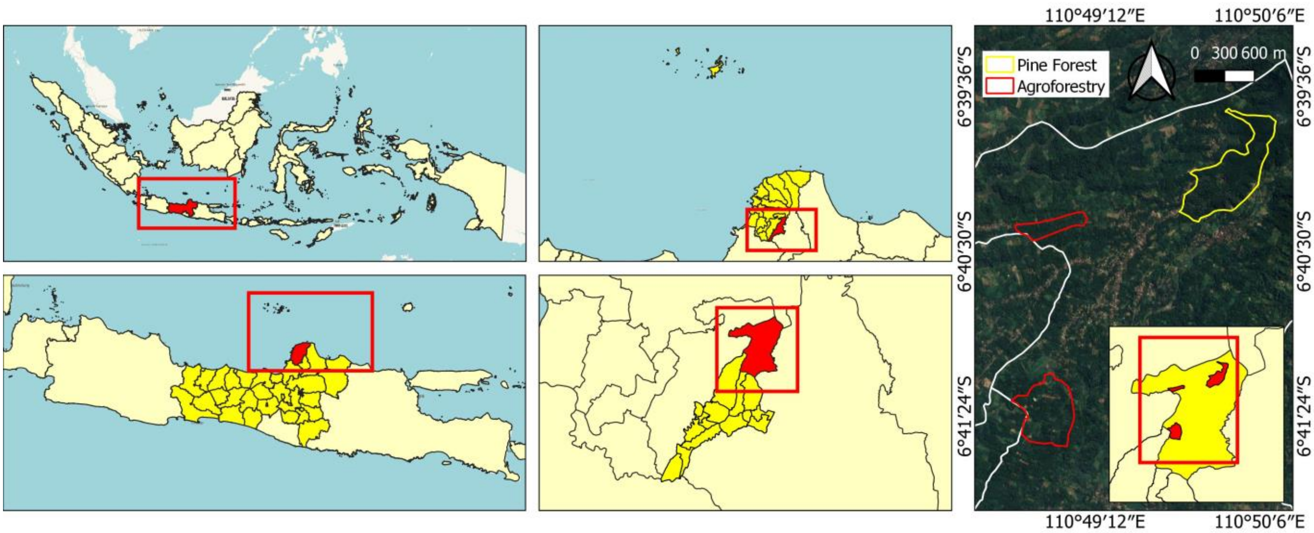

Figure 1. Location of the study area in Bategede Village, Jepara District, Central Java, Indonesia

Table 1. Allometric equations used for calculating Aboveground Biomass (AGB)

Species	Equation	References
Arecaceae	exp{-2.134 + 2.530 × ln(D)}	Brown (1997)
Artocarpus heterophyllus Lam.	$0.179 \times D^{2.25112}$	Samsu (2019)
Branched tree	$0.11 \times \rho \times D^{2.62}$	Ketterings et al. (2001)
Gmelina arborea Roxb.	$0.153 \times D^{2.217}$	Banaticla et al. (2007)
Leucaena leucocephala (Lam.) de Wit	$0.206 \times D^{2.305}$	Banaticla et al. (2007)
Paraserianthes falcataria (L.) I.C.Nielsen	$0.049 \times D^{2.591}$	Banaticla et al. (2007)
Pinus merkusii Jungh. & de Vriese	$0.0936 \times D^{2.4323}$	Siregar (2007)
Swietenia macrophylla King in Hook.	$0.048 \times D^{2.68}$	Adinugroho and Sidiyasa (2006)
Tectona grandis L.f.	$0.290091 \times D^{2.3}$	Hendri (2001)
Theobroma cacao L.	$0.012088 \times D^{1.98}$	Yuliasmara et al. (2009)

Note: D stands for diameter, and ρ refers to wood density (World Agroforestry 2023)

RESULTS AND DISCUSSION

Pine forest

Pine, a prominent species within plantation forests, plays a crucial role in sustainably rehabilitating land. Apart from their utility in timber and sap production, pine forests also contribute to environmental services by absorbing one of the significant greenhouse gases, viz. carbon dioxide (CO_2) (Polosakan et al. 2014). Based on the findings of this study, the pine forest of Bategede Village was found to harbor a diverse array of tree species, namely pinus (*P. merkusii*), *sengon laut* (*P. faltacaria*), *mahoni* (*S. macrophylla*), *jati* (*T. grandis*), and *salam* (*S. polyanthum*). Meanwhile, at the pole level, the study identified two predominant species, namely *P. merkusii* and *P. faltacaria*.

The pine forests exhibited a tree density of 482 individuals/ha, with an average diameter measuring 35.52 cm. Notably, *P. merkusii* emerged as the prevalent species, with a density of 465 individuals/ha, constituting approximately 96% of the species' populace (Figure 2). This substantial figure highlights the dominance of *P. merkusii* within that area. Therefore, the pine forest qualifies as a homogeneous forest ecosystem, primarily due to the dominance of *P. merkusii*. This is in line with the delineation of a homogeneous forest by Agesti (2018), where a single species constitutes around 80% of the entire population. In this study, the *P. merkusii* species accounted for a remarkable 96% of all the species encountered at the tree level.

The results show that *P. merkusii* had the highest biomass value, including aboveground and belowground biomass, in carbon stock and sequestration values, among other species. This can be attributed to the significantly higher number of *P. merkusii* species than other species. As the predominant species within pine forests, *P. merkusii* demonstrates a higher rate of carbon absorption than other species. This follows the study of Komiyama et al. (2007), who elucidated how dominant species influence the quantum of biomass and carbon storage in an area. The values for aboveground and belowground biomass of *P. merkusii*, carbon stock, and carbon sequestration were 322.29 tons/ha, 50.26 tons/ha, 175.14 tons/ha, and 642.77 tons/ha, respectively (Table 2).

Moreover, at the pole level, the total species density within the pine forest reached 232 ind/ha, where *P. merkusii* was found at 200 ind/ha and 32 ind/ha was *P. falcataria* (Figure 3). The average diameter was about 17.45 cm. This value highlights the prevalence of tree stands compared to pole stands. Notably, *P. merkusii* was also dominant at the pole stands with a species density of *P. merkusii*, which is 200 ind/ha, accounting for 86% of the total species count. In contrast, the density of *P. falcataria* was only 32 ind/ha.

The *P. merkusii* maintained its dominance in the pole category in the study area. This shows the higher value of *P. merkusii* than *sengon laut* or *P. falcataria*. Specifically, the carbon sequestration value achieved by *P. merkusii* in the pole category was 44.2 tons/ha, whereas *P. falcataria* only absorbed carbon dioxide at a rate of 3.59 tons/ha. However, it's noteworthy that the value of carbon sequestration of *P. falcataria* at the pole level exceeded that of the tree level (Table 3). This may be attributed to the greater number of individuals at the pole level than the tree level (Figures 2 and 3).

Table 2. Biomass, carbon stock, and carbon sequestration for tree category in the pine forest

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Pinus	*Pinus merkusii* Jungh. & de Vriese	322.29±156.01	50.26±20.76	175.14±83.1	642.77±304.96
Mahoni	*Swietenia macrophylla* King in Hook.	3.95±7.73	0.67±1.29	2.17±2.98	7.97±15.55
Jati	*Tectona grandis* L.f.	0.93±4.47	0.15±0.70	0.51±2.53	1.85±9.27
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	0.78±2.36	0.15±0.44	0.43±1.31	1.59±4.82
Salam	*Syzygium polyanthum* (Wight) Walp.	0.73±2.66	0.13±0.46	0.40±1.47	1.48±5.38

Table 3. Biomass, carbon stock, and carbon sequestration for pole category in the pine forest

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Pinus	*Pinus merkusii* Jungh. & de Vriese	21.34±19.30	4.29±3.88	12.04±10.89	44.2±39.98
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	1.71±4.44	0.37±0.95	0.98±2.54	3.59±9.31

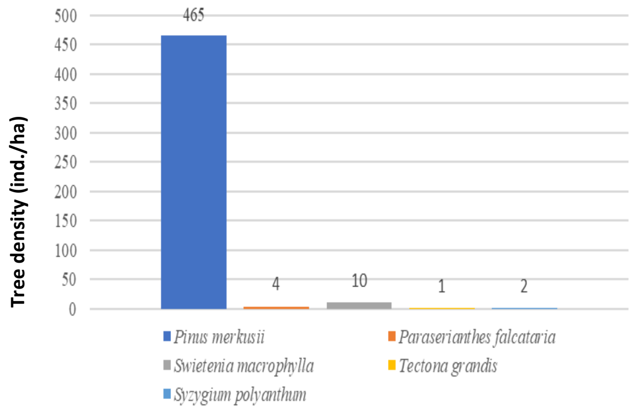

Figure 2. The density of tree species in pine forest

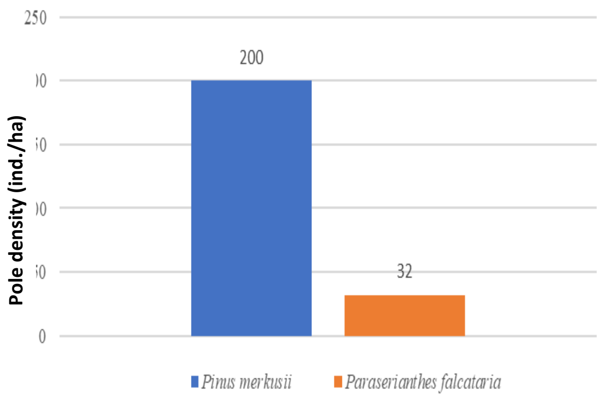

Figure 3. Density of pole species in pine forest

Table 4. Total biomass, carbon stock, and carbon sequestration in the pine forest

Category	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
	Above ground	Below ground		
Tree	328.68	51.44	178.66	655.67
Pole	23.05	4.66	13.02	47.79
Total	407.83		191.68	703.46

Based on the calculations, the tree species in the pine forest had an aboveground and belowground biomass of 328.68 tons/ha and 51.44 tons/ha (Table 4). Therefore, using these biomass values, the carbon stock and carbon dioxide absorption in the pine forest in the tree category was estimated at 655.67 tons/ha. Meanwhile, the pole category had smaller aboveground and belowground biomass values than the tree category. The low value of pole-level biomass compared to trees may be ascribed to the larger tree diameter than the pole. This is in line with the study of (Yamani 2013), who reported an increase in diameter with the increase in the tree's biomass.

The total biomass within the pine forest, as assessed across both tree and pole categories, amounted to 407.83 tons/ha. This biomass value was determined by calculating the total biomass above and below ground or root biomass. Notably, this value surpasses that of the study of Ramadhan et al. (2014), wherein the biomass within Pine Forest Taman Hutan Raya (Tahura) Pocut Meurah Intan across the tree, pole and root categories stood at 117.92 ton/ha. The carbon stock value attributed to the pine forest in Bategede Village was 191.68 tons/ha. According to Table 4, the pine forest in this study demonstrates the capacity to absorb 703.46 tons/ha of carbon. This quantity notably exceeds the study by Syabana et al. (2015) conducted in the pine forest composition of Taman Wisata Alam (TWA) Punti Kayu, where carbon reserves at the tree level were measured at 103.21 tons/ha, and carbon dioxide absorption amounted to 378.79 tons/ha. These differences may arise from variations in diameter and the presence of diverse species. Furthermore, it's important to note that the study by Syabana et al. (2015), exclusively focused on carbon reserves and carbon dioxide absorption within the tree category.

Agroforestry

From an ecological standpoint, agroforestry contributes to the quality of the local ecological conditions (Adinugroho et al. 2013). This contribution is attributed crucial role of vegetation present within agroforestry systems in effectively sequestering carbon within an area. This highlights the vital contribution of agroforestry in mitigating climate change through the absorption of atmospheric CO_2 (Lorenz and Lal 2014). According to Pandey (2002), agroforestry stands out as a superior climate change mitigation option compared to marine and other terrestrial alternatives, given its manifold advantages such as bolstering food security, augmenting income in the agricultural sector, conservation of biological diversity, maintenance of watershed hydrology, and safeguarding soil integrity.

In the Bategede Village, agroforestry emerged as a potent contributor to the absorption of carbon dioxide through its diverse constituent plants. According to Asmi et al. (2013), agroforestry's plant composition usually consists of crops, timber plants, and fruit plants. Noteworthy crops in the Bategede Village agroforestry include *kencur*, galangal, and cassava, besides timber plants like *T. grandis*, *C. pentandra*, *P. falcataria*, among others. The fruit-bearing plants, including *A. heterophyllus*, *M. indica*, and *C. nucifera*, further enrich the agroforestry landscape.

In the context of agroforestry, the tree level density was 158.5 ind/ha, with an average diameter of 30.3 cm. The species with the highest density was *P. falcataria*, 36 ind/ha, followed by *S. macrophylla*, 34 ind/ha. Meanwhile, the species with the lowest density were *A. procera*, *M. foetida*, *M. indica*, *T. indica*, and *S. polyanthum*, each with a 0.5 ind/ha density (Figure 4). The higher the density value, the greater the number of species found. Conversely, the lower the density value, the rarer the species was found in the research location.

Based on Table 5, *C. pentandra* exhibited the highest biomass values above and below ground, surpassing the values of other species, with measurements of 19.56 tons/ha and 3.14 tons/ha, respectively. Furthermore, the findings also indicate that *C. pentandra* had larger carbon stock and carbon sequestration values than other species, specifically 10.67 tons/ha and 39.15 tons/ha, respectively. This was because of the direct influence of biomass values on carbon stock and carbon sequestration metrics. A direct correlation emerged between greater biomass values and augmented carbon stock and sequestration values compared to other species, corroborating prior research findings (Chanan 2012; Manafe et al. 2016). This trend also aligns with the insights shared by Pambudi (2019), who highlighted a positive relationship between biomass and carbon stock values.

The density of poles within the agroforestry system stands at 634 ind/ha, with an average diameter of 14.43 cm. Remarkably, this density exceeded that observed at the tree level within the agroforestry. Compared to trees, the abundant presence of pole-level species suggests an ongoing ecological evolution, as these poles are poised to develop into trees and reshape the agroforestry structure. Among the species, *sengon laut* (*P. falcataria*) has the highest density, reaching 222 ind/ha, accounting for 35% of the total species composition. Sengon laut has a significantly higher value than other species, thus reinstating its prominence at the study site. On the other hand, species such as *mindi* (*M. azedarach*), *pakel* (*M. foetida*), *alpukat* (*P. americana*), *salam* (*Syzygium aromaticum*), and *jambu air* (*Syzygium aqueum*) had the lowest density at 2 ind/ha, indicating their relatively lower prevalence within the studied ecosystem (Figure 5).

According to Suwardi et al. (2013), trees characterized by small diameters, such as poles, are anticipated to contribute to future carbon stocks substantially. This study shows that the pole category, *P. falcataria*, had the highest carbon sequestration value, surpassing other species at 25.92 tons/ha (Table 6). Interestingly, this value is also higher at the tree level (Table 5). This can be attributed to the notably higher number of individuals at the pole level than the tree level. This follows the study by Widyasari and Saharjo (2010); it is evident that poles' density and growth rate play crucial roles in augmenting the potential for carbon sequestration.

Table 5. Estimation of biomass, carbon stock, and carbon sequestration for tree category in agroforestry

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Randu	*Ceiba pentandra* (L.) Gaertn.	19.56±25.04	3.14±3.83	10.67±13.57	39.15±49.78
Mahoni	*Swietenia macrophylla* King in Hook.	11.83±15.90	1.93±2.49	6.21±8.64	22.81±31.69
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	6.63±6.17	1.24±1.14	3.70±3.43	13.60±12.60
Jati	*Tectona grandis* L.f.	8.43±18.27	1.33±2.67	4.59±9.84	16.84±36.11
Petai Cina	*Leucaena leucocephala* (Lam.) de Wit	1.99±5.24	0.34±0.89	1.09±2.88	4.02±10.58
Nangka	*Artocarpus heterophyllus* Lam.	1.69±4.23	0.31±0.76	0.94±2.34	3.44±8.60
Waru	*Hibiscus tiliaceus* L.	1.43±3.77	0.26±0.68	0.79±2.09	2.91±7.67
Mindi	*Melia azedarach* L.	1.34±3.01	0.25±0.54	0.75±1.67	2.74±6.13
Durian	*Durio zibethinus* L.	1.28±3.15	0.23±0.56	0.71±1.75	2.61±6.41
Gmelina	*Gmelina arborea* Roxb.	0.95±2.87	0.18±0.54	0.53±1.60	1.95±5.88
Petai	*Parkia speciosa* Hassk.	0.79±2.70	0.14±0.48	0.44±1.94	1.60±5.48
Kelapa	*Cocos nucifera* L.	0.77±2.67	0.13±0.46	0.43±1.47	1.57±5.41
Mangga	*Mangifera indica* L.	0.44±3.11	0.07±0.49	0.24±1.69	0.88±6.21
Jati Londo	*Guazuma ulmifolia* Lam.	0.41±1.69	0.07±0.30	0.23±0.93	0.83±3.43
Weru	*Albizia procera* (Roxb.) Benth.	0.40±2.83	0.06±0.45	0.22±1.54	0.80±5.66
Jengkol	*Archidendron pauciflorum* (Benth.) I.C.Nielsen	0.19±0.94	0.04±0.18	0.11±0.53	0.39±1.93
Salam	*Syzygium polyanthum* (Wight) Walp.	0.12±0.86	0.02±0.16	0.07±0.48	0.25±1.75
Pakel	*Mangifera foetida* Lour.	0.09±0.62	0.02±0.12	0.05±0.35	0.18±1.27
Asam Jawa	*Tamarindus indica* L.	0.003±0.02	0.001±0.01	0.002±0.01	0.01±0.05

Table 6. Biomass estimation, carbon stock, and carbon sequestration for poles category in agroforestry

Local name	Scientific name	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
		Above ground	Below ground		
Sengon Laut	*Paraserianthes falcataria* (L.) I.C.Nielsen	12.19±8.93	2.84±2.61	7.06±5.23	25.92±19.19
Jati	*Tectona grandis* L.f.	6.98±14.30	1.33±2.72	3.91±8.00	14.33±29.35
Nangka	*Artocarpus heterophyllus* Lam.	4.81±6.91	0.99±1.40	2.73±3.91	10.00±14.33
Mahoni	*Swietenia macrophylla* King in Hook.	4.22±5.45	0.89±1.13	2.40±3.09	8.81±11.34
Mangga	*Mangifera indica* L.	3.67±5.56	0.76±1.11	2.08±3.09	7.65±11.33
Jengkol	*Archidendron pauciflorum* (Benth.) I.C.Nielsen	3.40±5.29	0.76±1.10	1.94±3.00	7.13±11.03
Waru	*Hibiscus tiliaceus* L.	1.57±3.54	0.34±0.75	0.90±2.02	3.29±7.40
Petai	*Parkia speciosa* Hassk.	1.36±4.30	0.28±0.87	0.77±2.43	2.84±8.93
Gmelina	*Gmelina arborea* Roxb.	1.07±2.72	0.23±0.57	0.61±1.55	2.24±5.68
Petai Cina	*Leucaena leucocephala* (Lam.) de Wit	0.81±6.39	0.16±0.64	0.45±1.84	1.66±6.75
Rambutan	*Nephelium lappaceum* L.	0.75±2.18	0.16±0.46	0.43±1.24	1.57±4.54
Durian	*Durio zibethinus* L.	0.74±2.21	0.16±0.46	0.42±1.25	1.54±4.61
Jati Londo	*Guazuma ulmifolia* Lam.	0.04±2.28	0.08±0.45	0.23±1.28	0.85±4.70
Sirsak	*Annona muricata* L.	0.29±1.26	0.06±0.27	0.17±0.72	0.62±2.64
Randu	*Ceiba pentandra* (L.) Gaertn.	0.19±0.72	0.04±0.16	0.11±0.42	0.40±1.53
Alpukat	*Persea americana* Mill.	0.17±1.07	0.03±0.22	0.09±0.61	0.34±2.22
Salam	*Syzygium polyanthum* (Wight) Walp.	0.13±0.62	0.03±0.14	0.07±0.36	0.27±1.32
Mindi	*Melia azedarach* L.	0.07±0.53	0.02±0.01	0.04±0.31	0.16±1.12
Pakel	*Mangifera foetida* Lour.	0.07±0.49	0.02±0.11	0.04±0.29	0.15±1.05

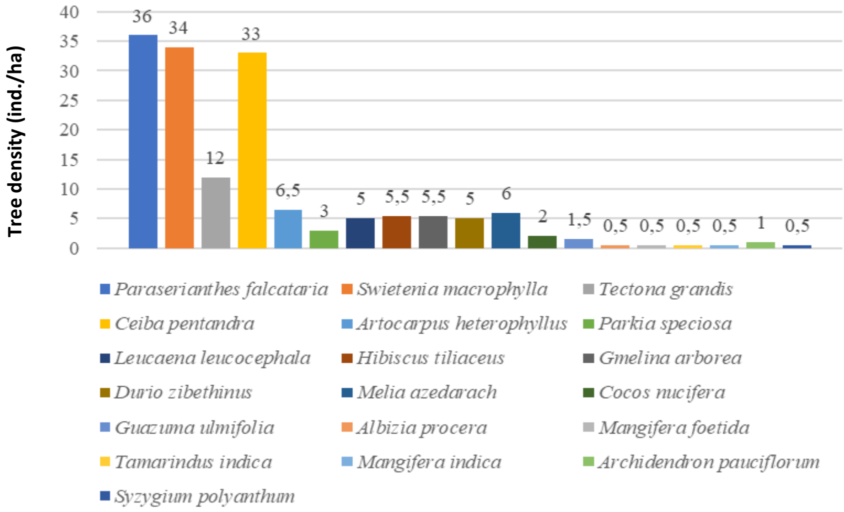

Figure 4. Density of tree species in agroforestry

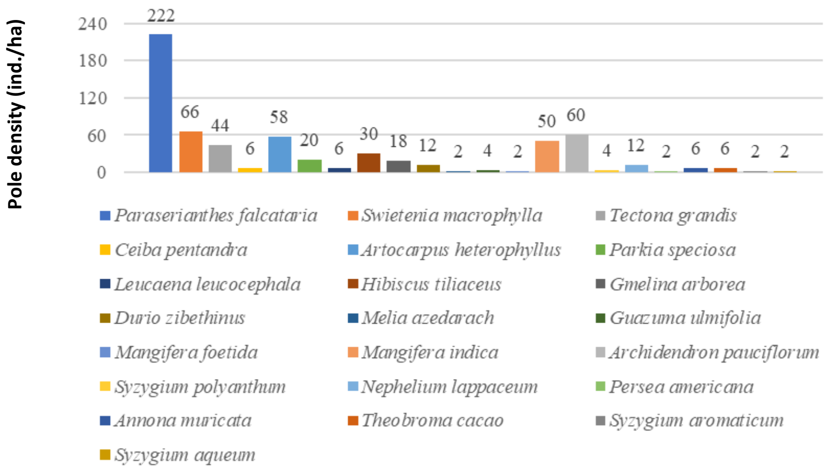

Figure 5. Density of pole species in agroforestry

Table 7. Estimation of biomass, carbon stock, and carbon sequestration in agroforestry

Category	Biomass (ton/ha)		Carbon stock (ton/ha)	Carbon sequestration (ton/ha)
	Above ground	Below ground		
Tree	58.34	9.85	31.76	116.07
Pole	43.23	9.22	24.65	90.46
Total	120.64		56.41	207.01

In the agroforestry within Bategede Village, the combined biomass value for trees and pole categories amounts to 120.64 tons/ha. Correspondingly, the carbon stock had a value of 56.41 tons/ha. This value is consistent with the findings of Murthy et al. (2013), who asserted that Southeast Asian agroforestry systems have the potential to sequester carbon within the range of 12 to 228 MgC/ha. Moreover, the established carbon stock value in the agroforestry framework of West Java is documented to span from 37 to 108Mg/ha, as indicated by Siarudin et al. (2021). Notably, the carbon stock value in the agroforestry system of Bategede Village is also comparable to the study by Malau et al. (2013), which identified carbon stock values of 58.438 tons/ha, 63.005 tons/ha, and 56.76 tons/ha in agroforestry stands within Sei Binga Sub-district, Bahorok Sub-district, and Wampu Sub-district, respectively. The dynamic spectrum of carbon stock across agroforestry landscapes was further evidenced by Paembonan et al. (2019) observations in Toraja, South Sulawesi, where a carbon stock value of 79.246 tons/ha was recorded. Moreover, the projected potential of agroforestry at the tree and pole level in Bategede Village to absorb carbon could be established at 207.01 tons/ha (Table 7).

Pine forest (homogenous forest) vs agroforestry (heterogenous forest)

Forests offer invaluable environmental services, including their role as carbon sinks. Within this intricate ecosystem, the vegetation takes part in sequestering atmospheric CO_2 through the process of photosynthesis. Acknowledging that the carbon-absorbing potential varies among distinct plant species is important. As a result, the mosaic of plant diversity within a forest ecosystem increases the divergent capacities for carbon dioxide assimilation. Azzahra et al. (2020) findings show that the carbon content variations are intricately linked to specific plant species. That study explored the carbon dioxide absorption capabilities at both tree and pole levels, comparing these dynamics within homogeneous and heterogeneous forests.

Figure 6.A. illustrates a clear distinction between tree-level metrics within homogeneous forests, primarily pine forests, and their counterparts in heterogeneous or agroforestry forests; homogeneous forests exhibited significantly higher values in comparison. Biomass, carbon stock, and CO_2 absorption values in homogeneous forests stand at 380.12 tons/ha, 178.66 tons/ha, and 655.67 tons/ha, respectively. On the contrary, within heterogeneous forests, the corresponding values for carbon stock biomass and carbon sequestration were 68.19 tons/ha, 31.76 tons/ha, and 116.55 tons/ha, respectively. Notably, a conspicuous sixfold difference surfaced in carbon absorption, favoring homogeneous forests. This disparity increases due to the higher number of individual trees present in pine forests, resulting in a larger diameter distribution compared to the agroforestry system.

At the pole level (Figure 6.B), pine forests exhibited comparatively lower biomass, carbon stock, and carbon dioxide absorption values than agroforestry, quantified at 27.71 tons/ha, 13.02 tons/ha, and 47.79 tons/ha, respectively. Meanwhile, agroforestry had a biomass value of 52.45 tons/ha, a carbon stock of 24.65 tons/ha, and a carbon dioxide absorption of 90.46 tons/ha. This value notably surged to nearly twice that of biomass, carbon stock, and carbon dioxide absorption observed at the pole level within pine forests. The variance in carbon sequestration values can be attributed to several factors, including stem diameter, species type, and population density. A greater stem diameter corresponds to a greater biomass value within a stand (Hairiah and Rahayu 2007; Yamani 2013; Manafe et al. 2016; Azizah et al. 2019).

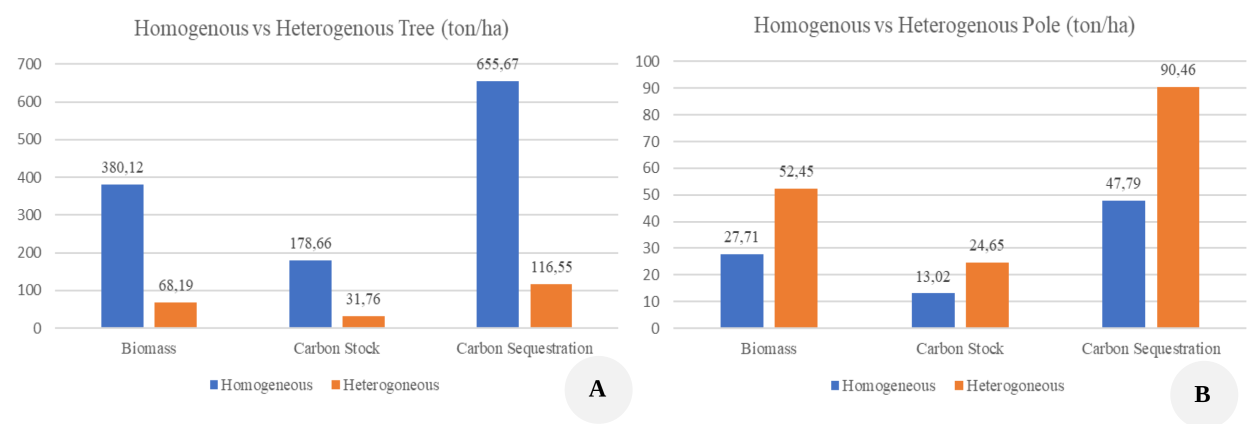

Figure 6. Comparison of biomass, carbon stock and carbon sequestration at: A. The tree level, and B. The pole level

Besides diameter, the species type also significantly contributes to carbon absorption potential (Suwardi et al. 2013; Zulkarnaen 2020). Each species exhibits distinct specific gravity or allometric formulas, resulting in distinct biomass values for each species, thereby influencing the total carbon absorption estimate. According to the study by Adinugroho et al. (2013), the plant's categorization shapes carbon reserves within a stand due to the variations of wood-specific gravity values inherent to each plant species. Furthermore, the number of individuals further impacts the biomass value within a designated area. This is in line with the findings of Hartoyo et al. (2022), which highlight the significant influence of species population on the carbon reserves quantification.

In conclusion, the present study has yielded notable findings regarding biomass, carbon stock, and carbon sequestration values within the pine forests, amounting to 407.83 tons/ha, 191.68 tons/ha, and 703.46 tons/ha, respectively. Conversely, the agroforestry system in Bategede Village showed distinct figures within biomass, carbon stock, and carbon sequestration, reaching 120.64 tons/ha, 56.41 tons/ha, and 207.01 tons/ha, respectively. The comparisons highlight that the carbon sequestration value within the homogeneous forest, specifically within the tree category of Bategede Village, significantly surpasses its heterogeneous counterparts, exhibiting a remarkable sixfold increment. Notably, the pole category in the heterogeneous forest demonstrates a twofold augmentation in carbon sequestration compared to the homogeneous forest. This difference may be attributed to variations in stem diameter, species composition and population density, factors that influence the carbon sequestration dynamics within these forests.

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