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Estimating carbon stocks of three traditional agroforestry systems and their relationships with tree diversity and stand density

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Abstract. *Hartoyo APP, Khairunnisa S, Pamoengkas P, Solikhin A, Supriyanto, Siregar IZ, Prasetyo LB, Istomo. 2022. Estimating carbon stocks of three traditional agroforestry systems and their relationships with tree diversity and stand density. Biodiversitas 23: 6137-6146.* One of the important sectors as a strategy for climate resilience and low carbon development in Indonesia is Forestry and Other Land Uses (FOLU) including the agroforestry sector. Carbon stock and tree diversity in an ecosystem are dynamic over time and still need to be investigated. This study was aimed: i) to estimate aboveground carbon stocks in the traditional agroforestry of Mount Halimun Salak National Park (MHSNP), in Kampung Birang and Kampung Merabu, East Kalimantan, as well as ii) to analyze the correlation between carbon stock with tree diversity and stand density in traditional agroforestry of Mount Halimun Salak National Park (MHSNP), in Kampung Birang and Kampung Merabu, East Kalimantan. The total plots were 75 plots (a plot size of 50x50 m), and carbon stock estimation was focused on pole and tree levels. The average carbon stock in the traditional zone of MHSNP, Kampung Birang, and Kampung Merabu respectively was 51.02 Mg C/ha, 96.25 Mg C/ha, and 82.17 Mg C/ha. The carbon stock in traditional agroforestry of all study sites was very significantly affected by the basal area (m^2/ha) (p-val<0.05) with a strong correlation (r = 80% and 97%). The carbon stock was affected by stand density (p-val<0.1) with a very low correlation (r = 27.3%). The carbon stock was very significantly affected by total species (p-val<0.05). However, it had a weak correlation (r = 28.0%). In agroforestry systems, how to manage the agroforestry, socio-economic aspects, ecological site, and market are the main factor in species selection and species maintenance by landowners that indirectly influence biodiversity conservation effort and carbon stock value. The agroforestry system has the potential to become a target and priority location for Indonesia's FOLU Net Sink 2030 by providing non-timber forest products, which can avoid leakage in forest conservation efforts and carbon stock.

Keywords: East Kalimantan, FOLU Net Sink, forest garden, Mount Halimun Salak National Park

INTRODUCTION

Climate change is a world problem caused by increasing greenhouse gas emissions in the atmosphere, specifically carbon dioxide (CO_2). The Indonesian government has ratified Paris Agreement and committed to reducing greenhouse gas emissions up to 2030 by approximately 29-41% (MoEF 2022). It is declared through Law No. 16 in 2016. One of the important sectors as a strategy for climate resilience and low carbon development is Forestry and Other Land Uses (FOLU) including the agroforestry sector. Indonesia's FOLU Net Sink 2030 is a national program set through Presidential Regulation No. 98 in 2021 to achieve net zero emissions in the forestry and land sector 2030 of 140 million tons of CO_2. One of the mitigation actions in this program is to increase carbon stock and conserve biodiversity. FOLU Net Sink 2030 is started by REDD+. Indonesia also has a strong commitment to participate in the success of REDD+ implementation before.

Each ecosystem has a specific ecological dynamic that influences biodiversity and carbon stock. Forest ecosystems store at least 80% aboveground carbon and 70% belowground carbon (soil) in all terrestrials (Ameray et al. 2021). According to Chen et al. (2014), carbon storage and carbon fluxes very vary, which depend on forest types and biodiversity status. In addition, separate and independent studies related to the interlinkage between biodiversity and carbon stock were mostly conducted. The present procedure operational standard of FOLU Net Sink to estimate forest biomass is merely based on the quantitative perspective of carbon storage. However, the qualitative aspects of the design of forest biodiversity have not yet been considered, although biodiversity has significance for the sustainability of forest resilience and carbon stocks (Messier et al. 2019; Bauhus et al. 2017).

Agroforestry is a dynamic ecosystem, consisting of wood and non-wood plants that are grown alongside other farming activities (Dawson et al. 2013). Agroforestry gives advantages in economic aspects, such as diversified income, energy conservation, productivity enhancement, and social aspects including fulfilling people's needs and aesthetics (UNDP 2012). From an ecological aspect, agroforestry gives many advantages in increasing carbon stock and biodiversity (Hartoyo et al. 2019b), as well as reducing climate change effects through carbon sequestration (Gebremeskel et al. 2021; Subedi et al. 2022).

Tesfay et al. (2022) explained that the agroforestry system stores carbon larger than seasonal or annual-based plant farming. The presence of various quality trees, which have high biomass and high input of litter continuously. The biomass of stands will increase linearly in line with the ages of the agroforestry system established in the area. Woods that grow in the forest and agroforestry potentially have larger storage of carbon (carbon sink) than annual plants. Examples of agroforestry systems are windbreaks, alley cropping, silvopasture, riparian forest buffers, forest farming, *tembawang*, *talun*, rubber agroforest, and forest gardens to solve special concerns about natural resources and to enhance wildlife habitat (UNDP 2012; Hartoyo et al. 2019a). According to Hartoyo et al. (2016), agroforestry systems are classified into traditional and modern agroforestry. Traditional agroforestry has been applied by the Indonesian local community from ancestors with various practices depending on the location, tribe, and socio-culture. This study was classified into traditional agroforestry, specifically traditional agroforestry of *Poh-pohan* (*Pilea trinervia*) in the traditional zone of Mount Halimun Salak National Park (MHSNP), and forest gardens in two locations, namely Kampung Birang and Kampung Merabu, East Kalimantan.

Poh-pohan (*P. trinervia*) is the main commodity in the traditional zone of MHSNP. *Langsat* (*Lansium domesticum*) is the main commodity for the local communities in the agroforestry of Kampung Birang. Many forest fruits, such as *durian* (*Durio zibethinus* and *Durio dulcis*), as well as *langsat* (*L. domesticum*) have been cultivated by the local communities through the agroforestry system in Kampung Merabu. All traditional agroforestry systems in this study have the main commodity and have been cultivated by the local communities from generation to generation with considering ecological, socio, and economic aspects. Therefore, a study on agroforestry systems to achieve sustainable management as a part of Indonesia's FOLU Net Sink mitigation action is necessary. Besides that, carbon stock and tree diversity in an ecosystem, both in the natural forest and agroecosystem, are dynamic over time and still need to be investigated. Therefore, it requires an assessment method to obtain information regarding tree diversity and carbon stock. This study was purposed to estimate aboveground carbon stocks in the traditional agroforestry of Mount Halimun Salak National Park (MHSNP), in Kampung Birang and Kampung Merabu, East Kalimantan, as well as to analyze the correlation between carbon stock with tree diversity and stand density in traditional agroforestry of MHSNP, in Kampung Birang and Kampung Merabu, East Kalimantan.

MATERIALS AND METHODS

Study area

This study was located in (i) the traditional agroforestry of *Poh-pohan* (*Pilea trinervia*), in the traditional zone of Mount Halimun Salak National Park (MHSNP), West Java, Indonesia (Figure 1.A); (ii) forest garden in Kampung Birang and Kampung Merabu, East Kalimantan, Indonesia (Figure 1.B).

Procedures

Plot establishment

Assessment of carbon stock, tree diversity, and stand density was conducted by establishing 15 plots in MHSNP, 30 plots in Kampung Birang, and 30 plots in Kampung Merabu. Selected sampling plots in this study using some criteria: i) representing an agroforestry system that consists of at least a woody plant, ii) the agroforestry system has been managed by the local communities from generation to generation, and iii) the agroforestry system that has at least a main commodity/species for the local community's income. The total plots were 75 plots with a plot size of 50 m x 50 m following Hartoyo et al. (2019b). The Landsat resolution image is 30 m x 30 m, hence the study plot has to be wider than that size. This study focused on tree species at the poles/medium trees (diameter of 10-20 cm) and trees/large trees (diameter of > 20 cm) level growth.

Carbon stock estimation

Carbon stock estimation was focused on pole and tree levels. According to Rahayu and Harja (2013), the total carbon reservoir (70%) exists at the tree level, while herbs, understorey, and grass only contribute no more than 5%. Tree level was classified into medium trees (poles) with diameters of 10-20 cm and large trees (trees) with diameters >20 cm. The diameter was measured at breast height (DBH) as high as 1.3 m above the surface of the ground. Tree species that have no allometric equation were estimated using the formula of Chave et al. (2005) as follows:

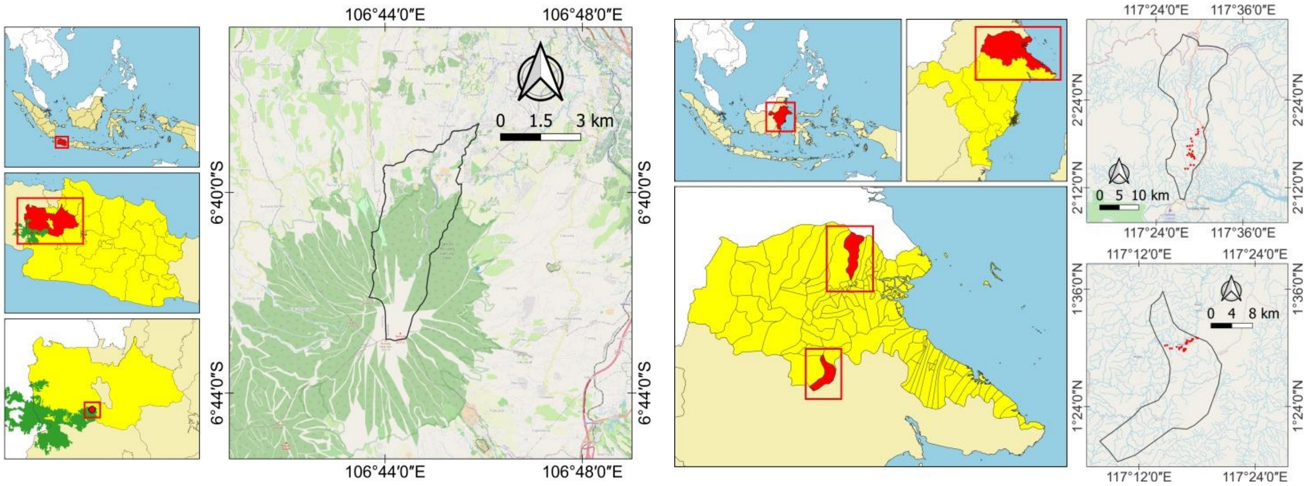
$$Y = \rho * \exp(-1.499 + 2.148 \ln(D) + 0.207 \ln(D^2) - 0.0281 \ln(D^3)) \quad (1)$$

Where:
Y : tree biomass (kg/tree)
ρ : wood density (g/cm^3)
D : tree diameter (cm)

The allometric equation was developed by Chave et al. (2005) using the diameter, and wood density parameters. For the species whose wood density is unknown, we used the other timber trees' allometric equation (Brown and Iverson 1992). While this study used allometric equations for some species that have been developed by other scientists (Table 1). Tree biomass was converted into carbon stock by multiplying 0.46 (Hairiah et al. 2010).

Tree diversity and stand density measurement

Tree diversity was species diversity shown by the Shannon-Wiener index and the total species or species richness, while stand density was calculated by basal area and total individuals per ha. Those parameters were analyzed to calculate the relationships between carbon stock, and species diversity using the Shannon-Wiener index value, species richness, basal area, and stand density in traditional agroforestry.



A B

A.1 B.1 B.2

Figure 1. A. Map of the study site in the traditional zone of Mount Halimun Salak National Park (MHSNP), West Java, Indonesia. A.1. traditional agroforestry of *Poh-pohan* (*Pilea trinervia*); B. Forest garden in Kampung Birang (B.1) and Kampung Merabu (B.2), East Kalimantan, Indonesia

Table 1. Biomass allometric equations for carbon estimation in aboveground

Species or plant type	Equation*	Source
Tectona grandis (Teak)	$Y = 0.20091*D^{2.30}$	Krisnawati et al. (2012)
Theobroma cacao (Cocoa)	$Y = 0.1208*D^{1.98}$	Yuliasmara (2009)
Coffea sp. (Coffee)	$Y = 0.281*D^{2.06}$	Arifin (2001)
Palm	$Y = \exp(-2.134+2.530*\ln(D))$	Brown (1997)
Hevea brasiliensis (Rubber)	$Y = -3.84+0.528*BA+0.001*BA^2$	ICRAF (2003)
Maesopsis eminii (Umbrella tree)	$Y = 0.0363 * D^{2.5131}$	Samsoedin et al. (2016)
Agathis dammara (*Damar*)	$Y = 0.4725 * D^{2.0112}$	Uthbah et al. (2017)
Paraserianthes falcataria (*Sengon*)	$Y = 0.113 * D^{2.345}$	Krisnawati et al. (2012)
Polyosma ilicifolia (*Ki menyan*)	$Y = 0.044 * D^{2.54}$	Alhamd (2014)
Pinus merkusii (Pine)	$Y = 0.094 * D^{2.432}$	Krisnawati et al. (2012)
Other timber trees	$Y = (21.3 - 6.95*(D)+0.74*(D^2))$	Brown and Iverson (1992)

Note: *Y: biomass (kg/tree); D: diameter at breast height (cm); ρ: wood density (g/cm^3); BA: basal area (cm^2).

RESULTS AND DISCUSSION

Carbon stocks in traditional agroforestry

Carbon reserves and tree diversity in the natural ecosystem (forest and agroecosystem) are dynamic over time. Agroforestry is a unique approach to land management that intentionally blends together agriculture and forestry to enhance productivity, profitability, and environmental stewardship (USDA 2012), which depends on the local culture and specific site. In the long period, the agroforestry system will become the potential carbon source although the amount of carbon stock unit area is relatively lower than the amount in natural forest. Natural succession is generally more effective for carbon sequestration than tree planting. When the factors of forest degradation can be well controlled, natural succession may provide great benefits for biodiversity. However, many interests are involved in forest management, such as the social and economic aspects of the local communities.

Traditional agroforestry systems in the traditional zone of Mount Halimunt Salak National Park (MHSNP), Kampung Birang, and Kampung Merabu are classified into complex agroforestry (agroforest). Complex agroforestry is characterized by the number of species being more than 2 species, and multilayers canopy that is almost similar to a natural forest. The local communities' welfare depends on the forest products, including ecosystem services.

Almost every local community in Kampung Birang and Kampung Merabu has forest gardens located at the edge of the river. These forest gardens have been developed a long time ago by their anxiety with the local name is *huma*. Kampung Birang is one of *langsat* (*Lansium parasitum*) producer. *Langsat* has hundreds of years old with big diameter trees that they classified into 2 types (*langsat roko* and *langsat telur*). *Langsat roko* is a superior trait with bigger tree diameter, wider leaves, sweeter fruit, thicker rind, easier to fall, and more resistant to rot than *langsat telur* (Hartoyo et al. 2018). *Langsat* is also a medicinal plant. Dayak Seberuang and other ethnic groups in Kalimantan, Sabah, Malaysia use this species for malaria treatment. Due to the many benefits of *langsat*, the local community in Kampung Birang really preserves this species from other disturbances, which indirectly increases species conservation and carbon stock in the forest garden of Kampung Birang. Most species are planted by the local community in Kampung Merabu including *D. dulcis, D. zibethinus, Durio kutejensis*, and *L. domesticum* for self-consumption. They are facing infrastructure problems to transport their forest fruits to the market.

While in the traditional zone of MHSNP, the traditional agroforestry of *Poh-pohan* (*Pilea trinervia*) or *lalaban* has been developed a very long time ago by their ancestors. *Poh-pohan* is an herb that grows up to 2 m and usually is planted by combining with vegetables, shade trees, and fruit plants. This is an indigenous aromatic fresh vegetable with antioxidants and high economic value. Shade trees (e.g *Pinus merkusii*, and *Agathis dammara*) are a must and have an important role in *Poh-pohan*'s growth. The maximum shading that can be tolerated by *Poh-pohan* is 60%. Overshading trees should be removed by the local community due to it will affect the growth of *Poh-pohan*.

Based on the carbon stock measurement in this study, the average carbon stock in the traditional zone of MHSNP is lower than the average carbon stock in Kampung Birang and Kampung Merabu (Figure 3). The average carbon stock in Kampung Birang was higher (96.25 Mg C/ha) than in Kampung Merabu (82.17 Mg C/ha) and in the traditional zone of MHSNP (51.02 Mg C/ha). The carbon stocks in all these study sites are higher than Siarudin et al. (2014)'s report that the aboveground carbon stock of *Manglid*-based agroforestry in the community forest of West Java was 44 Mg C/ha. Wardah et al. (2011) reported an average of carbon stocks of living trees with a range of 30.32-45.05 Mg C/ha in simple agroforestry and 71.99-85.45 Mg C/ha in complex agroforestry. Based on its components, agroforestry systems in these study sites are classified into complex agroforestry (agroforest). *Huma* or forest garden commonly named for the complex agroforestry system in Kampung Birang and Kampung Merabu, East Kalimantan. Carbon stocks in Kampung Birang and Kampung Merabu were higher than Wardah et al. (2011)'s reported. Carbon stocks in this study were mostly higher than carbon stock in some ecosystems, such as in the secondary natural forest in Mandiangin University Forest of Lambung Mangkurat University (Unlam) (70.42 Mg C/ha), community forest in Kediri (36.67 Mg C/ha), *Acacia mangium* plantation forest in Cianjur (39.26 Mg C/ha), and rubber agroforests in Jambi (42.4 Mg C/ha) (Yamani 2013; Siregar 2007; Heriyanto and Siregar 2007). However, carbon stock in this study was still lower than carbon stock in Gunung Gede Pangrango National Park (275.56 Mg C/ha), Dipterocarpaceae natural forest in Central Kalimantan (253.33 Mg C/ha), and Damar agroforests in Lampung (102.7 Mg C/ha) (Siregar 2007; Siregar and Dharmawan 2011; Ginoga et al. 1999) (Table 4). With regard to those carbon comparisons, it can be noted that carbon stocks in the traditional zone of MHSNP, Kampung Birang and Kampung Merabu were still higher than carbon stock in the plantation forest but still lower than in the natural forest.

Carbon stocks vary greatly, depending on forest types, specifically species composition and age. However, there is growing proof that older primary forests maintain more carbon than intensive and extensive forest management (Smyth et al. 2014; Ameray et al. 2021). Tropical mixed-species plantations such as agroforestry systems have higher total biomass and carbon sequestration if compared to monocultures plantations (Castle et al. 2022; Graß et al. 2020; Jose and Bardhan 2012). Plantation structure and composition in agroforestry systems are affected strongly by species value. The increase and or decrease in carbon depends on its functional characteristic in carbon storage (Jia et al. 2022). The dynamic system in agroforestry is mostly due to human intervention in arranging vegetation composition and structure in agroforestry, especially for the species with high economic value. These activities will increase forest resilience in facing global climate change.

The relationships between carbon stock, tree diversity and stand density

Correlation between carbon stock, tree diversity, as well as stand density are still need to be investigated. According to Rahayu and Harja (2013), the dynamics of carbon reserves and tree diversity at landscape scale could be described as a degradation and restoration cycle. As there is a degradation, carbon reserves and species diversity will decrease because of ecosystem disturbances. These disturbances could be in form of legal and illegal logging and forest fires. After experiencing degradation, carbon reserves and biodiversity (restoration) will increase once time passes. The dynamic and fluctuations of carbon reserves and biodiversity depend on the type of disturbances (Rahayu and Harja 2013). In this study, tree diversity parameters used were Shannon-Wiener index and total species per ha. Stand density was obtained from total individuals per ha. The correlation between carbon stock and Shannon-Wiener index, total basal area (m^2/ha), stand density per ha, and total species per ha are shown in Table 2-3 and Figure 4.

Shannon-Wiener index had no significant affected on total carbon stock of all study sites (Table 2). Shannon-Wiener index formula was established from the total individual in each species and total individuals in all species found. This result in line with Birhane et al. (2022). They revealed correlation between carbon stock and woody species diversity was not significant. Total basal area (m^2/ha) had very significantly affected on total carbon stock of all study sites (Table 3). Stand density had significantly affected on total carbon stock of agroforestry in East Kalimantan. Tree species also significantly affected total carbon stock only in agroforestry of East Kalimantan.

The carbon stock was very significantly affected by basal area (m^2/ha) in traditional agroforestry of all study sites (p-val<0.05) (Table 2-3). Basal area and carbon stock had a strong correlation. It can be shown by r of 70% in traditional agroforestry of MHSNP and r of 97% in traditional agroforestry of Kampung Birang and Kampung Merabu, East Kalimantan (Figure 4-5). A higher basal area led to higher total carbon stock. The tree diameter is the main factor to calculate biomass and carbon in the allometric formula. This result was supported by Siregar (2007) which studying the carbon stock estimation at Pangrango Mountain National Park. This also is in accordance with the study result of Segura and Kanninen (2005), which described that the size of tree diameter was the main factor that affected aboveground biomass Costa Rica Forest.

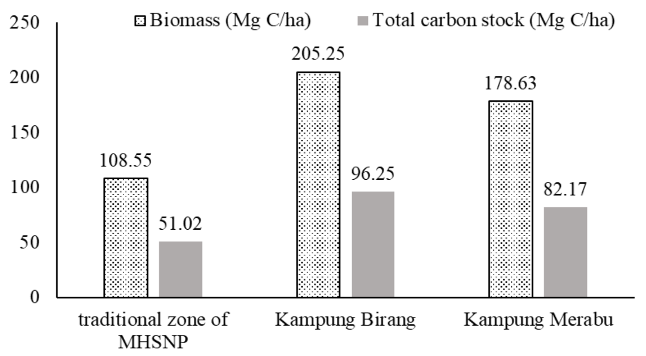


Figure 3. Comparison of carbon (Mg C/ha) and biomass (Mg C/ha) in the traditional zone of MHSNP, Kampung Birang and Kampung Merabu

Table 2. Pearson test between Shannon-wiener index, total basal area (m^2/ha), stand density per ha, total species per ha, and total carbon stock (Mg C/ha) of traditional agroforestry in traditional zone of MHSNP

Variable	Shannon-wiener index	Total basal area (m^2/ha)	Stand density (N/ha)	Species richness
Total basal area (m^2/ha)	-0.122	-	-	-
Stand density (N/ha)	0.263	0.379	-	-
Total species per ha	0.418	-0.215	0.796**	-
Total carbon (Mg C/ha)	-0.166	0.799**	0.139	-0.403

Note: * significantly different (p<0.1); ** very significantly different (p < 0.05).

Table 3. Pearson between Shannon-wiener index, total basal area (m^2/ha), stand density per ha, total species per ha, and total carbon stock (Mg C/ha) of traditional agroforestry in East Kalimantan

Variable	Shannon-Wiener index	Total basal area (m^2/ha)	Stand density (N/ha)	Species richness
Total basal area (m^2/ha)	0.196	-	-	-
Stand density (N/ha)	0.532**	0.415*	-	-
Total species per ha	0.897**	0.296*	0.687**	-
Total carbon (Mg C/ha)	0.214	0.965**	0.273*	0.280**

Note: * significantly different (p<0.1); ** very significantly different (p < 0.05)

Stand density significantly affected carbon stock (p-val<0.1) in traditional agroforestry of East Kalimantan with very low correlation (r = 27.3%) (Figure 5). While in agroforestry traditional of MHSNP, total species per ha very significantly affected the carbon stock (p-val<0.05) and also had a weak correlation (r = 28%) (Figure 4). The higher total species per ha (species richness) will generate higher total carbon stock. A species affects the carbon stock because every species has a various wood density, which is used for biomass allometric equation. Wood density in this studies area was in the range between 0.29 g/cm^3 and 1.07 g/cm^3. Chave et al. (2005) explained that wood density is an essential parameter to estimate biomass that follows diameter parameter although it is more important than tree height parameter. Wardle et al. (2012) reported that aboveground C stock significantly affected (p-val=0.05) the species richness in forested islands in lakes Hornavan and Uddjaure, Northern Sweden. Rahayu and Harja (2013) observed the relationships between aboveground carbon stock and tree species richness and in 1.500 plots located in various forest types, including lowland rainforest, mountain forest, and swamp forest. The results reported that high tree species richness resulted in a high aboveground total of carbon stock. However, tree species richness did not directly affect total carbon stock. In general, peat forests had lower species richness than lowland rainforests. Otherwise, in some conditions, species richness in peat forests was higher than in lowland rainforests. It describes that the correlation between biodiversity and carbon stock is so dynamic. According to Rahayu and Harja (2013), the diversity index and carbon stock at the site and landscape level did not have any direct relationship since the land cover area with high carbon stock is not always followed by high diversity.

Agroforestry systems are unique system that depends on each local culture and specific site. Agroforestry systems developed by the local community in MHSNP, Kampung Birang, and Kampung Merabu are still on the track to increasing biodiversity and carbon stock. It will result in an increase in forest resilience to recover its biodiversity and carbon stock in the future. The exploitation of a certain number of species in the agroforestry system will decrease the species richness gradually across the land use intensity. Extraction in agroforest systems must be carried out carefully in order to preserve the species richness and carbon stock.

Plant utilizations in traditional agroforestry of MHSNP is in form of fresh vegetable harvesting, fruit, medicine plant in rational quantity, *gondorukem*, and *terpentin* harvesting from pine trees. Species with economic value in MHSNP are *Poh-pohan* and pine products. Local communities prefer to plant *Poh-pohan* because besides being valuable, it is easy to harvest and can be propagated by stem cuttings. Local communities will plant what they need and are valuable in the traditional zone. Local communities make a living from the products and they can manage the agroforestry sustainably. The disturbances in the traditional zone of MHSNP are illegal logging and forest encroachment. Based on statistical data from Mount Halimun Salak National Park in 2021, illegal logging is the most frequent activity until now. Forest disturbances can cause a change in the vegetation cover in MHSNP.

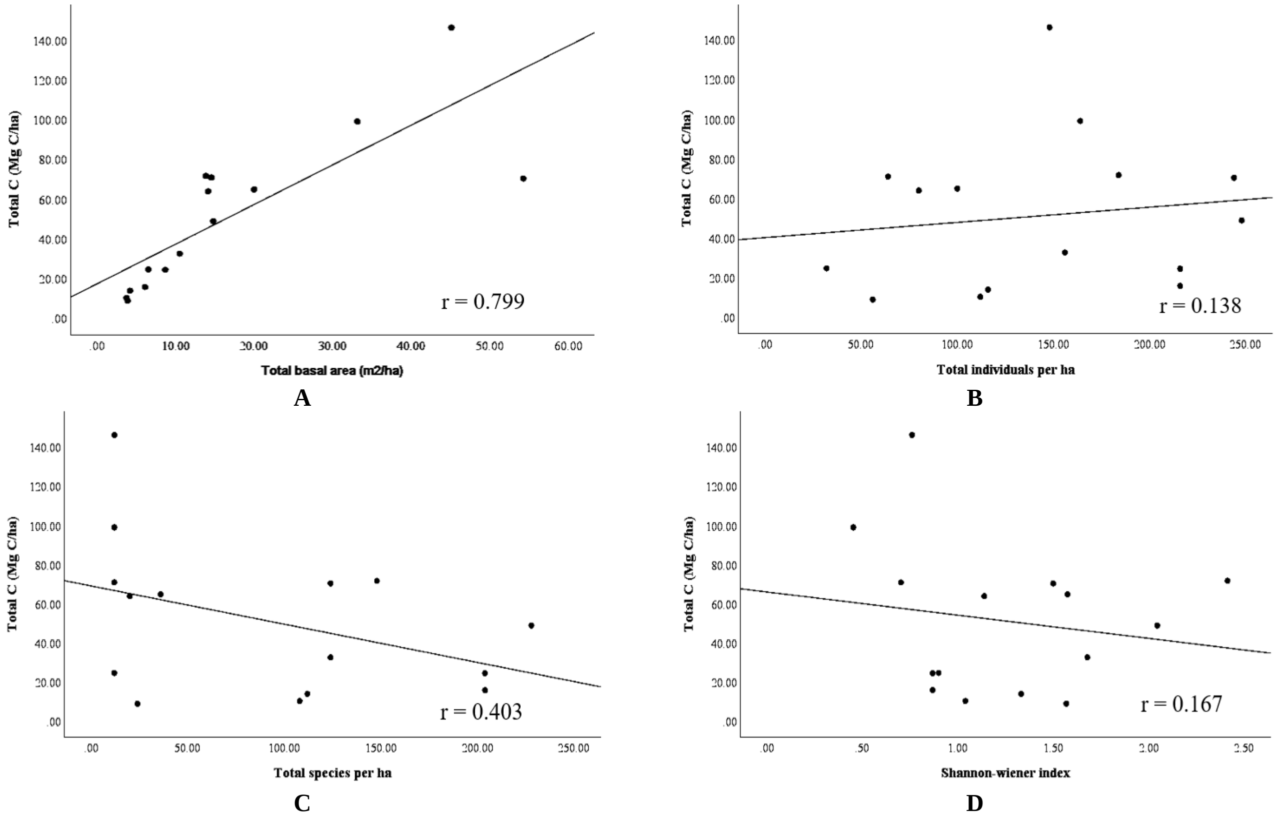


Figure 4. Correlation between total C stock (Mg C/ha) with a basal area (m^2/ha) (A), stand density (N/ha) (A), total species per ha (C), and Shannon-Wiener index (D) in traditional zone MHSNP

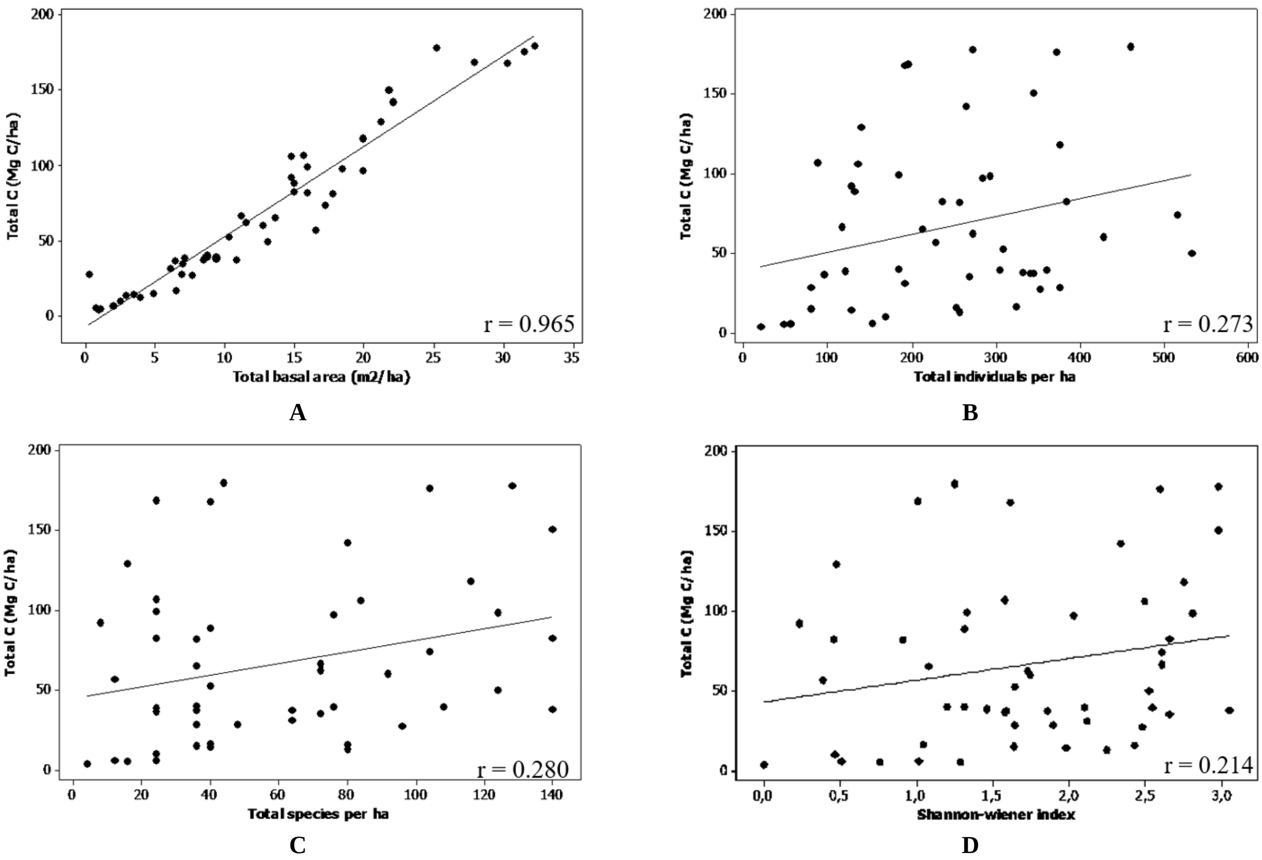


Figure 5. Correlation between total C stock (Mg C/ha) with a basal area (m^2/ha) (A), stand density (N/ha) (B), total species per ha (C), and Shannon-Wiener index (D)

The disturbances in Kampung Birang are mining activity, oil and natural gas exploration. Meanwhile, the possible disturbance in Kampung Merabu is due to oil palm plantation. Loss of resilience or increased vulnerability implies the loss of opportunities for redevelopment. Plant utilizations in traditional agroforestry of Kampung Birang and Kampung Merabu are in form of fruit harvesting, firewood, timber for housing, and medicine plant in rational quantity. It means the local community understood about the sustainability of agroforestry. In Kampung Birang, species with economic value was able to be economically utilized for a longer period time. Therefore, only specific species with large trees diameter and high total carbon stock that were remained to grow. Other species that disturbed *Langsat* growth was removed by local communities. Otherwise, in Kampung Merabu there is no forest garden management performed by local communities. They only cultivate the plants and go to forest garden when the harvest of fruit comes or when they need to use the part of plants for firewood, medical treatment, and building materials. They do not recognize the economic value of some of the tree species very well. Based on that phenomenon, it might result in high basal area, stand density, and total species per ha that are affected positively by carbon stock.

In agroforestry systems (including agroforest), the farmers will maintain the most valuable species for a long period of time, and turning it will affect the amount of carbon stock. The use of wood for non-firewood purpose in agroforestry will reduce the logging activities in the natural forest, and will fulfill the needs of fuel made of non-renewable sources. Agroforestry could provide ecosystem resilience because of its value and position in the community. In agroforest systems, how to manage the agroforestry, socio-economic aspects, ecological site, and market is the main factor in species selection and species maintenance that should be performed by a forest garden manager. For example, Bucagu et al. (2012) reported that farmers preferred to grow *Grevellia robusta* because it can growth quickly with less competitive and it may be grown alongside the other crops whereas Eucalyptus planting in Rwanda was preferred as collateral for loans.

Trees preferences planted in agroforestry practices are mostly determined by individuals, groups, institutions, societies, and cultures due to socio-economic need, management, and environmental factors (de Souza et al. 2012; Bucagu et al. 2012). The diverse agroforestry systems are applied in the tropics because of different climate, socio-economic aspects, comprising a huge human population, multiple benefits, smaller land size, markets, and complex land tenure (Nair et al. 2009; Roy et al. 2011; Mbow et al. 2014). Hence, carbon stock in agroforestry system strongly depends on component and composition of species, and landowners' management that are influenced by socio-economic and ecological factors.

Tree diversity status and carbon stock across land use types

Carbon stock dynamics and plant diversity do not only occur in the landscape but also in each land use types (Table 4). Carbon stocks are caused by stand mortality, and are followed by seedlings growth. Regeneration rate produces a seedling that will contribute to the increase of carbon reserve as well as the increasing of local diversity index (Rahayu and Harja 2013).

Plant diversity in Indonesia spreads out in various forest types, starting from coastal forest, mangrove forest, peatland forest, lowland forest, karst, mountainous forest to community forest managed by local communities. Based on those various forest types, lowland forests in East Kalimantan had the highest tree diversity with approximately 200 species per ha, and was followed by lowland forests in Sumatra that has approximately 180 species, lowland forests in Sulawesi with approximately 176 species, and mountainous forest in Java with 80 species (Kartawinata 2010).

Table 4 shows that agroforestry systems can be the target in Indonesia's FOLU Net Sink 2030 program to produce high carbon stock compared to other ecosystems eventhough the carbon stock is still lower than that of primary forest. This result is also supported by Schroth et al. (2004). They explained that carbon stock in agroforestry systems is generally lower than that of natural forests. Additionally, biodiversity and carbon stocks in production systems are commonly higher in complex structure, diversified, and less intensively managed in systems, including complex agroforests (Schroth et al. 2004).

Table 4. Biodiversity and total carbon stock in various land use types

Land uses*	Carbon stock (Mg C/ha)	Species richness	Source
Agroforestry systems			
Agroforest in MHSNP	51.02	32	*This study*
Agroforest practice in Kampung Birang(s)	82.17	26	*This study*
Agroforest practice in Kampung Merabu(s)	96.25	88	*This study*
Agroforestry oil palm (25 years) and agarwood (7 years) in Tawau, Sabah(s)	37.88	-	Suardi et al. (2016)
Damar agroforests in Lampung, Sumatra(s)	102.7	-	Ginoga et al. (1999)
Parkland agroforestry in the Sahel(s)	46	-	Luedeling and Neufeldt (2012)
Homegarden agroforestry system in Southern Tigray, Northern Ethiopia (s,g)	38.57	-	Siyum GE and Tassew (2019)
Mix garden in Bekasi, West Java(s)	62.34	-	Adinugroho et al. (2013)
Community forest in Kediri, East Java(s)	36.67	-	Siregar (2007)
Simple agroforestry in Ciamis, West Java(s)	25-42	-	Ginoga et al. (1999)
Primary, secondary, and natural forests			
Mineral primary forest in Seturan, East Kalimantan(agb)	300	221	Kartawinata et al. (2008)
Mineral primary forest in Sebulu, East Kalimantan(agb)	300	276	Kartawinata et al. (2008)
Natural forest in Gunung Gede Pangrango National Park(s)	275.56	-	Siregar (2007)
Dipterocarpaceae natural forest in Central Kalimantan(s,b,tw,lv)	204.92	-	Siregar and Dharmawan (2011)
Primary forest in China(s)	142.2	-	Liu et al. (2016)
Natural forests in Zhejiang, China(s)	32.2	-	Xu et al. (2018)
Undisturbed peat forest(abg)	190	-	Rahayu and Harja (2013)
Secondary natural forest in Mandiangin University Forest Unlam(s)	70.42	-	Yamani (2013)
Secondary forests in China(s)	70.3	-	Liu et al. (2016)
Monoculture plantation forest			
20 *Acacia mangium* (8-year-old) plantation forest in Cianjur, West Java(s)	39.26	-	Roesyane and Saharjo (2011)
Other land uses			
High degraded lowland in West Kalimantan(s,n,l,g)	107.14	-	Astiani et al. (2016)
High degraded peatland West Kalimantan(s,n,l,g)	142.72	-	Astiani et al. (2016)
High degraded swamp West Kalimantan(s,n,l,g)	161.47	-	Astiani et al. (2016)
Logged-over forest (after 5 years) in Malinau, East Kalimantan(s)	343.61	-	Dharmawan and Samsoedin (2012)
Logged-over forest (after 30 years) in Malinau, East Kalimantan(s)	498,19	-	Dharmawan and Samsoedin (2012)
Grasslands in China	1.70	-	Liu et al. (2016)
Shrublands in China	4.15	-	Liu et al. (2016)
Shrub forests in China	22.3	-	Liu et al. (2016)
Shrub forest in West Kalimantan	46.31	-	Astiani et al. (2016)
Agriculture in West Kalimantan	47.41	-	Astiani et al. (2016)

Note: *Necromass (n), litter (l), ground storey (g), crop (c), stem at pole & tree level (s), branch (b), twig (tw), leaves (lv), aboveground biomass (abg).

In conclusion, the average carbon stock in the traditional zone of MHSNP, Kampung Birang, and Kampung Merabu respectively was 51.02 Mg C/ha, 96.25 Mg C/ha, and 82.17 Mg C/ha. The carbon stock in traditional agroforestry of all study sites was very significantly affected by the basal area (m^2/ha) (p-val<0.05). Basal area and carbon stock had a strong correlation. It can be shown by r of 80% in the traditional agroforestry of MHSNP and r of 97% in the traditional agroforestry of East Kalimantan. The carbon stock was affected by stand density (p-val<0.1) with a very low correlation (r = 27.3%). The carbon stock was very significantly affected by total species (p-val<0.05). However, it had a weak correlation (r = 28.0%). In agroforestry systems, how to manage the agroforestry system, socio-economic aspects, ecological site, and market are the main factor in species selection and species maintenance by landowners that indirectly influence biodiversity conservation effort and carbon stock value. However, carbon stocks in those locations were still higher than carbon stock in the plantation forest but still lower than in the natural forest. The agroforestry system can be a target and priority location for Indonesia's FOLU Net Sink 2030 by providing non-timber forest products, which can avoid leakage in forest conservation efforts and carbon stock.

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