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Agroforestry for biodiversity and climate change mitigation in Batutegi Protection Forest, Lampung, Indonesia

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Abstract. *Heryandi, Qurniati R, Darmawan A, Yuliasari V. 2022. Agroforestry for biodiversity and climate change mitigation in Batutegi Protection Forest, Lampung, Indonesia. Biodiversitas 23: 1611-1620.* The conversion of protected forests into farm areas decreases biodiversity and increases greenhouse gases. Planting trees using agroforestry patterns desire to overcome these problems. This study aimed to identify plant composition, biodiversity, and calculated carbon stock values to recommend a better agroforestry development. The data collection was carried out in June 2021 from four farmer group associations at Batutegi Protection Forest Management Unit, namely Mahardika, Sinar Harapan, Hijau Makmur, and Cempaka. The agroforestry pattern applied in four Gapoktans is agrisilviculture, with a combination of crops, plantation, and forest trees. The dominant plant species are coffee, pepper, rubber, and bananas. Based on the Importance Value Index, coffee becomes the dominant crop in Hijau Makmur, Mahardika, and Sinar Harapan, while rubber is the dominant crop in Cempaka. The agroforestry pattern applied by respondents has a higher carbon stock value than the average carbon stock of coffee-based agroforestry in Indonesia, but the diversity index value is lower. Improving biodiversity is necessary to optimize growing space in farmer land through species enrichment under existing land and plant conditions.

Keywords: carbon stock, important value index, plant composition, Shannon-Wiener Index, species enrichment

INTRODUCTION

Agroforestry systems also play an essential role in mitigating and adapting to climate change because they can increase the ability of carbon storage and carbon sequestration (Zomer et al. 2016). Climate change occurs due to the increase of concentration of CO_2 in the atmosphere so that the temperature on the earth's surface increases (Budiastuti 2020). Agroforestry systems reduce the rise of CO_2 by increasing carbon stocks above the ground level (De Stefano and Jacobson 2018). Therefore, it is necessary to manage sustainable agroforestry systems that can support target achievement of reducing emission by 29% in Indonesia based on the Paris Agreement in 2015.

Indonesia has a high rate of deforestation, which increased during 2001-2016 due to the development of smallholder agriculture and plantations (Austin et al. 2019). The conversion of forests to smallholder agriculture and plantations causes the loss of trees and biodiversity. Based on Indonesia Law No. 41 of 1999, it is mentioned that a forest is an ecosystem unit in the form of a stretch of land containing biological natural resources dominated by trees in their natural environment, which cannot be separated from one another. Stored carbon is then released into the atmosphere because of deforestation (Rai 2013). Therefore, it is crucial to maintain and increase trees diversity, particularly in forest areas, rather than exploit them.

Part of the Batutegi Protected Forest Management Unit (KPHL) area has become a garden managed by the community with an agroforestry pattern. Agroforestry is a practice combining land use with agriculture (perennial crops) and forestry (trees) to create an integrated and sustainable land-use system (Molla 2019). This combination creates a strong interaction between components based on the pattern and composition of the plant being developed. The application of agroforestry systems has economic value for farmer income (Notaro et al. 2020), and also ecological value that can ensure the sustainability of forest resources, reduce land degradation (Qurniati et al. 2017), provide ecosystem services, provide water resources, and prevent landslides and erosion (Rahman et al. 2017).

Previous research has shown that income from agroforestry gives an outstanding contribution compared to non-agroforestry (Asmi et al. 2014; Bhandari et al. 2021). The income is influenced by the cultivated species (Wanderi et al. 2019), for example, coffee agroforestry with *Senna siamea* and *Erythrina variegata* that combination creates shade trees that promote higher coffee productivity rather than those without shade (monoculture) or conversely, *Michelia champaca* as shade trees reduced coffee productivity (Evizal et al. 2012). Therefore, the selection of plant species needs to be considered, especially when combining the main tree with intercropping, because the distribution of light through the canopy of shade plants can be a limiting factor.

In addition, it is known that the implementation of coffee agroforestry in KPHL Batutegi is low because farmers consider shade trees to reduce coffee productivity (Nawansih et al. 2020). In this regard, the selection of plant species in the agroforestry pattern implemented by farmers needs to be examined. Hence, the availability of information related to plant species composition and appropriate management techniques is also important for the community to adopt. The research aims to identify the composition and biodiversity in agroforestry land, calculate the contribution of agroforestry in maintaining carbon stocks, and develop recommendations for agroforestry management that can provide high benefits and become climate change mitigation efforts.

MATERIALS AND METHODS

Study area

The research carried out from June to November 2021 and involved four farmer group associations (Gapoktan) at KPHL Batutegi, namely Mahardika, Sinar Harapan, and Hijau Makmur Gapoktans in Air Naningan District, Tanggamus Regency, and Gapoktan of Cempaka in Pringsewu Regency (Figure 1). The four Gapoktans were chosen because they practiced different compositions of agroforestry plants that affected the farmers' economy and ecological of their environment.

Data collection

Primary data includes the identity of respondents, composition of agroforestry plants, and carbon values. Secondary data is additional data from reference libraries that support research, such as the gapoktan population. Primary data was obtained from interviews, Focus Group Discussion (FGD) with respondents, and vegetation analysis. The number of respondents involved in this study was 100 out of 3.812 potential respondents from four different groups: Gapoktan Mahardika, Sinar Harapan, Hijau Makmur, and Cempaka. The number of respondents involved in the study was based on the Slovin formula with a precision of 10% potential respondents. Variables, data, data collection techniques, and data analysis are detailed in Table 1.

Data analysis

The identification of ecological aspects in the agroforestry composition was analyzed using the vegetation analysis method to calculate the Important Value Index (IVI), the sum of relative density, relative frequency, and relative land cover area values. IVI was used to calculate the value of the Shannon-Wiener Diversity Index (H'). The criteria in the analysis of the species diversity index (the Shannon-Wiener Diversity Index) were if the value of H index is less than two: the value of species diversity is in a low category; if the value of H index is 2-3: it classified as moderate; and if the value of H index more than three: it classified as high.

Measurement of above-ground carbon stocks was carried out using the Rapid Carbon Stock Assessment (RaCSA) method developed by ICRAF (Hairiah et al. 2011; Siarudin et al. 2021) in two ways: non-destructive and destructive methods. The non-destructive method was utilized to measure tree biomass by recording each tree's local name and scientific name, trunk diameter, and tree height. Tree diameter and tree height were used to calculate tree biomass using allometric equations. Furthermore, destructive methods were used to measure understorey biomass. The understorey samples were all shrubs and grasses. A sampling of understorey plants is taken about 100-300 grams of plant samples. All samples were then dried in an oven at 80°C until completely dry and then weighed to obtain wood density.

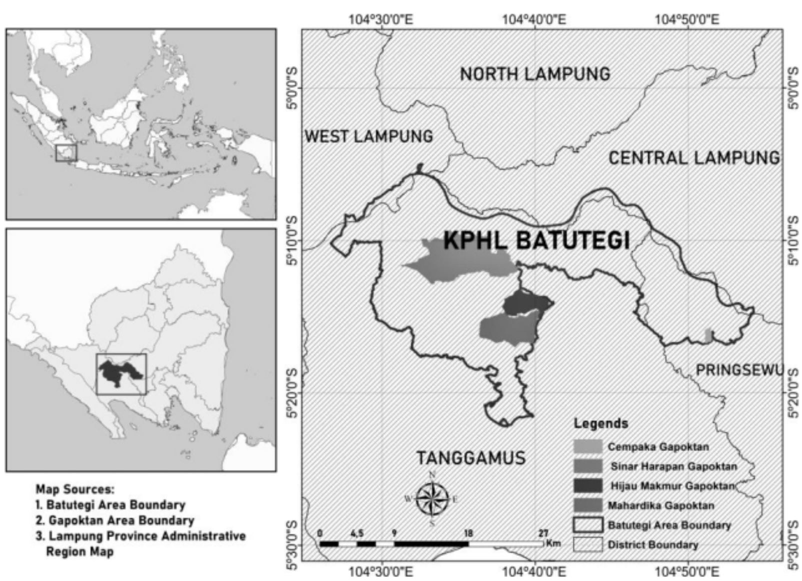

Figure 1. Map of the research area in KPHL Batutegi, Lampung Province, Indonesia

Table 1. Variables, data, data collection techniques, and data analysis

Research objectives	Variable and data	Data collection techniques	Data analysis
Identify the composition and diversity of vegetation developed by farmers using agroforestry systems	Composition and diversity of vegetation (species, diameter, height, and number of vegetation per hectare)	Structured interviews with 100 members of Gapoktan, FGD, and made 36 plots. The plots are rectangular in areas of 20 m x 20 m (trees), 10 m x 10 m (poles), 5 m x 5 m (saplings), and 2 m x 2 m (seedlings)	Vegetation analysis (important value index, values of relative density, relative frequency, and relative land cover area). Analysis of the Diversity Index (H')-Shannon-Wiener
Calculate the contribution of coffee agroforestry in maintaining above-ground carbon stocks	Tree height, tree diameter, canopy cover, dry and wet weight of undergrowth and litter, as well as disturbed and undisturbed soil samples	Making 36 sample plots. The plots are rectangular in area of 20 m x 20 m (trees), 10m x 10m (poles), 5m x 5m (saplings), and 2m x 2m (seedlings)	Carbon stock measurement is carried out using the Rapid Carbon Stock Assessment (RaCSA) method
Prepare recommendations for agroforestry management capable of providing high economic and ecological benefits and being an effort to mitigate climate change	Important Value Index Shannon-Wiener Diversity Index (H') Number of trees/ha Carbon value		Inter-case analysis of the four Gapoktans. Regulation of the Minister of Environment and Forestry Number 2 in 2020 concerning Procedures for Implementation, Supporting Activities, Providing Incentives, and Guiding and Controlling Forest and Land Rehabilitation Activities

Total carbon storage is obtained from the sum of the carbon stored in all trees and understorey and then converted into tons. The wood density value of each tree species is assumed to be 0.47 of the weight of the biomass so that the total biomass is multiplied by the value of 46% (IPCC 2006). Then to get the potential for carbon storage per hectare of all tree species, the size of the biomass obtained is divided by the total area. In addition, the ecological aspect was analyzed based on the Regulation of the Minister of Environment and Forestry Number 2 in 2020 concerning procedures for implementation, supporting activities, providing incentives, guiding and controlling forest and land rehabilitation activities.

RESULTS AND DISCUSSION

Composition of plants in agroforestry land

Agroforestry practices in Indonesia have various local terms based on plant composition, vegetation structure, management practices, and the overall agroforestry system developed in several places (Parikesit et al. 2021). The agroforestry pattern applied in the four Gapoktans is agrisilviculture, a combination of the agricultural, plantation, and forestry crops in one plot of land in each Gapoktan. As written by Asmi et al. (2014), the composition of plants creates agroforestry generally consists of crops (*Theobroma cacao*, *Coffea canephora*, *Eugenia aromatica*), woody plants, and fruit trees (*Cocos nucifera*, *Musa* sp., Multi-purpose Trees Species/MPTS). The benefits of agroforestry for farmers depend on tree-crop interaction and the system's adaptation to local economic, social, and environmental conditions (Borek 2015). Based on interviews with respondents, there are similarities in the main plant species in Cempaka, Hijau Makmur, Mahardika, and Sinar Harapan Gapoktans. The main crops are the plants with the highest number planted by the community in the KPHL Batutegi, namely *C. canephora*, *Piper nigrum*, *Hevea brasiliensis*, and *Musa* sp. (Table 2). People tend to plant crops that have high economic value to meet their economic needs.

Coffee (*C. canephora*) is a plant species with the highest average number per hectare in the Hijau Makmur (2,103 plants/ha), Mahardika (2,444 plants/ha), and Sinar Harapan (2,074 plants/ha) Gapoktans. In comparison, the Gapoktan of Cempaka is dominated by rubber (*H. brasiliensis*) (513 plants/ha). Coffee and rubber are grown with high crown species such as MPTS and woody plants, medium crown crops such as cocoa and bananas, and low crown crops (underground crops) such as chili and lemongrass, thus forming an agroforestry pattern (Figure 2). Coffee and rubber-based agroforestry have been widely developed in Indonesia. This pattern is considered capable of providing ecosystem services that resemble forest functions. Most coffee species cultivated by farmers in the four Gapoktans are robusta coffee. Coffee agroforestry with shade trees is considered suitable for development because it will complement each other from economic and ecological aspects. Shade trees also improve local climatic conditions and reduce microclimate variability and soil moisture (Wagner et al. 2019). The composition of shade trees was dynamic according to farmers' knowledge and local wisdom to sustain the productivity of coffee farms (Evizal et al. 2016). In addition to shade trees, they have planted understorey crops such as chilies to take advantage of the growing space for farmers in the Cempaka, Hijau Makmur, and Sinar Harapan Gapoktans. In the Gapoktan of Cempaka, farmers have also planted lemongrass.

Table 2. Species and number of plants developed by farmers in the study site

Scientific name	Local name	The average number of plants/ha			
		Cempaka	Hijau Makmur	Mahardika	Sinar Harapan
Coffea canephora	*Kopi*	374	2103	2444	2074
Piper nigrum	*Lada*	182	419	128	208
Hevea brasiliensis	*Karet*	513	500	0	0
Durio zibethinus	*Durian*	7	9	14	6
Persea americana	*Alpukat*	5	25	23	12
Eugenia aromatica	*Cengkeh*	63	0	44	13
Pithecellobium lobatum	*Jengkol*	12	33	16	13
Parkia spesiosa	*Petai*	7	5	8	3
Artocarpus heterophylla	*Nangka*	4	0	4	0
Theobroma cacao	*Kakao*	59	171	30	25
Myristica fragrans	*Pala*	66	0	0	6
Garcinia mangostana	*Manggis*	6	0	0	0
Aleurites molucana	*Kemiri*	4	4	0	27
Agathis damara	*Damar*	14	0	0	0
Swietenia mahagoni	*Mahoni*	0	21	8	10
Ceiba pentandra	*Randu*	9	28	0	0
Maesopsis eminii	*Afrika*	0	0	2	2
Erythrina variegata	*Dadap*	250	0	13	0
Senna siamea	*Gamal/Johar*	159	352	156	33
Dalbergia latifolia	*Sonokeling*	0	13	2	3
Aegle marmelos	*Maja*	29	0	0	0
Melia azedarach	*Mindi*	0	1	0	0
Musa sp.	*Pisang*	124	500	174	0
Cymbopogon citratus	*Sereh*	12	0	0	0
Piper retrofractum	*Cabai Jawa*	111	300	0	0
Arenga pinnata	*Aren*	0	10	0	0
Cocos nucifera	*Kelapa*	5	0	0	0
Archidendron bubalinum	*Jailing*	0	3	0	0
Pinanga kuhlii	*Pinang*	0	108	175	58
Leucaena leucocephala	*Lamtoro*	0	250	0	0
Gnetum gnemon	*Melinjo*	0	5	0	0
Santalum album	*Cendana*	0	0	2	0
Paraserianthes falcataria	*Sengon*	0	0	3	0

Figure 2. A. Combination of coffee (*Coffea arabica*), *Senna siamea* (*johar*), *Dalbergia latifolia* (*sonokeling*), and pepper (*Piper nigrum*). B. The combination of rubber (*Hevea brasiliensis*), coffee (*Coffea arabica*), and *Aleurites molucana* (*kemiri*). C. Combination of rubber (*Hevea brasiliensis*), coffee (*Coffea arabica*), *Pithecellobium lobatum* (*jengkol*), *Myristica fragrans* (*pala*)

The second dominant plant in all Gapoktan is pepper (*P. nigrum*). Farmers of Gapoktan Hijau Makmur mainly develop pepper. Peppers that grow vines are planted with *S. siamea* (*gamal/johar*) as woody perennial support trees.

Based on the study, the farmers have the same tendency to select plant species, especially the main crop on each farmer's land. This is because of the consideration of the economic value of the selected plants and the suitability of the arable land. Likewise, farmers' choice of filler crops by farmers is conducted by considering the growth prospect of particular plant species. Usually, if there are farmers who succeed in developing certain species of plants on their land, it will encourage other farmers to plant the same plant species.

The diversity of plant species found in each forest has a different structure and composition of vegetation. If the structure and composition of vegetation in an agroforestry system can resemble a forest ecosystem, then agroforestry can play an optimal role in biodiversity conservation (Lestari et al. 2019). Trees play an essential role in most ecosystems and provide a wide range of products and services to rural and urban communities (Wijayanto 2011). The status of land managed by the four Gapoktan in KPHL Batutegi is a protected forest with primary functions of protecting life support systems to regulate water systems, prevent flooding, control erosion, prevent seawater intrusion, and maintain soil fertility. Based on the Regulation of the Minister of Environment and Forestry Number 2 in 2020, it is mentioned that to maintain its function, community agricultural activities carried out in protected forests should at least plant 400 trees/ha consisting of timber and MPTS with agroforestry patterns. Referring to the regulation, the average number of trees found in Cempaka and Hijau Makmur Gapoktans already met the minimum number. However, the number of trees grown by Mahardika and Sinar Harapan is still lacking (Figure 3).

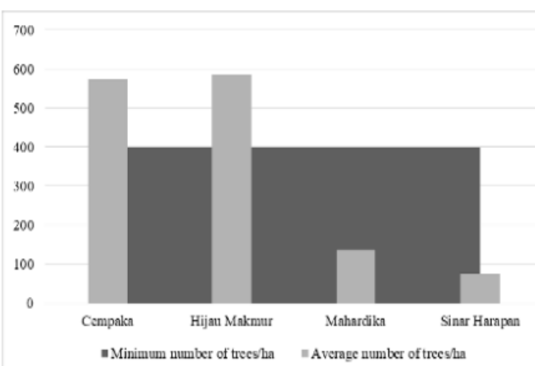

Figure 3. Comparison between the minimum number of trees/ha and average number of trees/ha in each Gapoktan

Most Cempaka Gapoktan members grow *Myristica fragrans* (*pala*), collaborating with the KPHL of Batutegi and the Asian Forest Cooperation (AfoCo) organization. Its collaboration is carried out in a partnership by providing the seeds for the farmers and a profit-sharing system both for farmers and KPH parties. The collaboration in Cempaka started in 2015. The average age of nutmeg plants is 3-5 years. In addition to *M. fragrans*, other plants that assisted the Cempaka were *E. aromatica* (*cengkeh*), *Garcinia mangostana* (*manggis*), and other species of MPTS. The existence of this partnership is what drives the high average number of trees on the lands of Cempaka members. In addition, Cempaka and Hijau Makmur have the highest number of plant species compared to other Gapoktans (Table 2). In Cempaka, the number of trees and the high number of plant species result from new planting activities in the partnership program. At the same time, in Hijau Makmur the trees (woody plants) on the land are new plants and old plants that are 20-40 years old, which are maintained and used as shelters for coffee plants and pepper plants. Those plants are the dominant plant in Hijau Makmur. In addition, the community in Hijau Makmur believes that the existence of these trees can maintain the sustainability of existing springs so that they can take advantage of environmental services in the form of clean water sources; fulfill household water needs and also provide additional income from collaboration with drinking water companies which utilizes springs in Hijau Makmur management area. The partnership with the parties in both Gapoktan enables to overcome the limitations of farmers towards achieving sustainable forests that can also provide livelihoods for their farmers. Qurniati et al. (2017) stated farmers have limitations in financial capital and technical assistance in agroforestry management, so a network with outside parties is required to improve the technical management of agroforestry.

The dominance of plant species and biodiversity in agroforestry land

Ecologically, the agroforestry system that farmers have developed can overcome land problems. The existence of a relatively complex form of land stratification can maintain the ecological function of the land. Spacing in agroforestry is generally irregular, and the number of trees varies, affecting the diversity index value of a plant community.

Agroforestry plant species that exist in a place can be influenced by several things, such as farmers' preferences in choosing plant species and the site's suitability. According to their preferences, farmers will add plant species to form a diverse plant composition on farmers' land. Each plant species has an Important Value Index (IVI), where this value describes the presence of a particular species compared to other species in an agroforestry area (Table 3).

Table 3. The highest IVI and the highest biodiversity index value in each plot

Plot	Gapoktan of Cempaka			Gapoktan of Hijau Makmur			Gapoktan of Mahardika			Gapoktan of Sinar Harapan		
	Scientific name	**IVI (%)**	**H'**	**Scientific name**	**IVI (%)**	**H'**	**Scientific name**	**IVI (%)**	**H'**	**Scientific name**	**IVI (%)**	**H'**
I	*Pithecellobium lobatum*	47.85	1.048	*Pithecellobium lobatum*	62.35	0.818	*Coffea arabica*	68.33	0.911	*Dalbergia latifolia*	93.55	0.650
	Parkia spesiosa	27.66		*Persea americana*	59.54		*Senna siamea*	45.49		*Coffea arabica*	91.42	
II	*Senna siamea*	64.51	0.932	*Dalbergia latifolia*	83.77	0.856	*Musa* sp.	109.86	0.788	*Mahoni*	93.43	0.597
	Pithecellobium lobatum	44.53		*Persea americana*	43.69		*Coffea arabica*	61.46		*Coffea arabica*	74.25	
III	*Senna siamea*	60.44	0.863	*Aleurites molucana*	69.89	0.876	*Coffea arabica*	117.37	0.472	*Coffea arabica*	79.99	0.686
	Coffea arabica	53.18		*Coffea arabica*	64.16		*Musa* sp.	103.5		*Aleurites molucana*	67.70	
IV	*Hevea brasiliensis*	189.20	0.490	*Pithecellobium lobatum*	65.67	0.820	*Coffea arabica*	59.07	0.915	*Dalbergia latifolia*	97.96	0.649
	Coffea arabica	41.06		*Durio zibethinus*	57.73		*Senna siamea*	47.12		*Coffea arabica*	80.69	
V	*Hevea brasiliensis*	101.69	0.829	*Coffea arabica*	50.77	0.886	*Coffea arabica*	72.78	0.756	*Aleurites molucana*	91.55	0.669
	Durio zibethinus	43.06		*Swietenia mahagoni*	50.45		*Musa* sp.	64.79		*Persea americana*	70.60	
VI	*Hevea brasiliensis*	179.75	0.658	*Coffea arabica*	64.73	0.912	*Mahoni*	85.52	0.669	*Dalbergia latifolia*	127.76	0.439
	Myristica fragrans	38.52		*Durio zibethinus*	55.83		*Coffea arabica*	78.73		*Coffea arabica*	127.56	
VII	*Hevea brasiliensis*	127.05	0.740	*Hevea brasiliensis*	80.74	0.74	*Coffea arabica*	77.62	0.869	*Coffea arabica*	84.13	0.740
	Durio zibethinus	55.96		*Pithecellobium lobatum*	68.02		*Durio zibethinus*	41.6		*Pithecellobium lobatum*	60.84	
VIII	*Hevea brasiliensis*	198.21	0.432	*Dalbergia latifolia*	74.89	0.807	*Coffea arabica*	51.87	0.882	*Coffea arabica*	109.18	0.550
	Pithecellobium lobatum	50.48		*Coffea arabica*	56.81		*Persea americana*	50.49		*Aleurites molucana*	94.10	
IX	*Hevea brasiliensis*	111.74	0.847	*Swietenia mahagoni*	68.75	0.935	*Coffea arabica*	69.87	0.919	*Coffea arabica*	87.85	0.748
	Durio zibethinus	53.70		*Coffea arabica*	54.34		*Dalbergia latifolia*	41.17		*Dalbergia latifolia*	57.23	

The highest IVI in each different sample plot consists of MPTS (*Pithecellobium lobatum, Parkia spesiosa, Persea americana, Durio zibethinus, M. fragrans, Aleurites molucana*), crops (*H. brasiliensis, Coffea arabica, Musa* sp), and forest trees (*Dalbergia latifolia, Swietenia mahagoni, S. siamea*). The most important (dominant) species in the forests might be due to its mast fruiting, the synchronous production of fruits in the multi-years cycle at intervals of several years (Sofiah et al. 2018). The large IVI value indicates the degree of diversity of plants (Sofiah et al. 2018) and the ecological importance of species (Mbolo et al. 2016) in the community. Species with high IVI generally spread over the entire plot (Hidayat 2017). Rubber plants have the highest IVI value, especially in the Gapoktan Cempaka. It means that rubber is the dominant plant species among the existing plant species. Species with the highest IVI are species that can grow well at the place where they are planted or, in other words, it can be said, the plants have a good level of adaptation. In the Gapoktan of Cempaka, the average productive age of rubber is around ten years. In addition, it is recognized that the value of species dominancy also influences farmers' choices. In this case, farmers choose plant species with economic value and suitable for planting at a certain height.

In general, coffee has a high IVI in almost all farmers' fields. Most farmers at Batutegi grow coffee on their land, although it is not always dominant. Social and environmental factors influenced the reasons farmers grow coffee. People socially prefer to grow coffee because it is easy to maintain ad has high economic value. Ecologically, coffee plants are shade-tolerant plants, suitable for cultivation with agroforestry patterns. Shade trees in coffee farms are promoted for ecological sustainability and adaptation to climate change (Sebuliba et al. 2021). Coffee as a plantation crop combined with shade plants in MPTS and timber plantations in all sample plots. According to Sistla et al. (2016), the combination of plants carried out in this research location can be a fundamental component of biodiversity conservation and socio-ecological resilience.

The value of the species diversity index can determine the amount of plant dominance in a land. The more complex the plant species, the higher the H' index, improving the land's ecological function. The four Gapoktans have low diversity index values because the H' value is less than 2. Hidayat (2017) explains that a plant community's high and low diversity index depends on each species's number and species (species richness).

Hijau Makmur Gapoktan has fairly good forest conditions. So, apart from planting MPTS, many tree species such as *D. latifolia* (*sonokeling*) and *S. mahagoni* (*mahoni*) are well maintained. *Dalbergia latifolia* (*sonokeling*) and *S. mahagoni* (*mahoni*) trees are used as coffee shade trees, where shade trees are generally woody plants with trunk diameters >20 cm. The existence of a policy regarding the prohibition of cutting down trees on protected forest lands makes mahogany trees still exist and are native trees of the forest before being cultivated by farmers. The existence of trees, among others, can maintain hydrological functions. Many environmental services have increased people's income from springs, waterfalls, and water turbines. Landicho et al. (2021) explained a similar situation farmers believe that large trees provide a stable water supply in river systems and springs, so they are maintained and not cut by farmers. Meanwhile, Sinar Harapan Gapoktan has the lowest average species diversity (0.636) of all plots observed. The cropping pattern farmers of Sinar Harapan generally form simple agroforestry where the average number of plant species is less than five. It leads to a coffee monoculture system in some areas because farmers cultivate the same species. Optimization of land use by farmers is still lacking, and this caused only a small number of plant species to be planted, which can affect the structure of forest land.

Contribution of agroforestry in climate change mitigation efforts

Agroforestry is a land-use option that can restore ecosystem services such as carbon sequestration (Goncalves et al. 2021; Udawatta and Jose 2011) and compensation for biodiversity loss (Pantera et al. 2021), which promotes synergy between adaptation and mitigation of climate change (Rijal 2019). Agroforestry systems can reduce the increase of CO_2 in the atmosphere through above-ground biomass, i.e., stems, branches, and leaves, and in below-ground biomass, i.e., roots, and in the soil (De Stefano and Jacobson 2018; Feliciano et al. 2018; Lorenz and Lal 2014; Mutuo et al. 2005; Oke et al. 2011; Rijal 2019). This carbon stock can generate from existing vegetation on land managed with an agroforestry pattern. According to Manaye et al. (2021), high-diversity vegetation absorbs more carbon than lower-diversity ecosystems. The process of carbon accumulation in plants is known as C sequestration, where C stored in biomass indicates the amount of CO_2 absorbed by plants. At the same time, emission is the process of releasing CO_2 into the atmosphere (Priyadarshini et al. 2019).

Based on the comparison of the average biomass and carbon stock, Hijau Makmur has the highest average of biomass and carbon stock with a value of 168.7 tons/ha and carbon 79.3 tons/ha. Most of the farmers in Hijau Makmur are coffee and pepper farmers (Figure 4). The development of pepper agroforestry can encourage increasing high crown plants (trees), which pepper plants need as a pathway. Pepper (*P. nigrum*) can be combined with coffee and or rubber (*H. brasiliensis*) by paying attention to the selection of suitable tree species that can be used not only as pepper stalks but also as shade for coffee (*C. arabica*). It makes the pepper cultivation system unique. The plants create trails sciophytic (shade-loving) vines on woody perennial support trees, making the agroforestry system look excellent - where cash crops are trailed on a broad spectrum of support trees (Kumar et al. 2021). Trees are the most significant component of above-ground biomass (Paudela et al. 2017). These species will provide a larger volume of plants, thereby increasing the value of biomass and carbon stocks. In addition, on forest land managed by farmers in Hijau Makmur, some trees range in age from 20-40 years.

Table 4. Comparison of biomass and carbon stocks in Hijau Makmur, Cempaka, Mahardika, and Sinar Harapan Gapoktans

Plot	Hijau Makmur			Mahardika			Cempaka			Sinar Harapan		
	H'	Biomass (ton/ha)	Carbon stocks (ton/ha)	H'	Biomass (ton/ha)	Carbon stocks (ton/ha)	H'	Biomass (ton/ha)	Carbon stocks (ton/ha)	H'	Biomass (ton/ha)	Carbon stocks (ton/ha)
I	0.818	394.3	185.3	0.911	107.6	50.5	0.911	116.3	54.7	0.911	217.2	102.1
II	0.856	138.1	64.9	0.788	135.3	63.6	0.788	98.8	46.4	0.788	194.3	91.3
III	0.876	130.3	61.2	0.472	67.1	31.5	0.472	89.1	41.9	0.472	191.8	90.1
IV	0.820	234.1	110.0	0.915	207.4	97.4	0.915	123.6	58.1	0.915	278.3	130.8
V	0.886	154.2	72.4	0.756	102.6	48.2	0.756	166.6	78.2	0.756	133.2	62.6
VI	0.912	140.2	65.9	0.669	90.1	42.3	0.669	194.6	91.5	0.669	89.1	41.8
VII	0.740	100.0	47.0	0.869	124.6	58.5	0.869	142.2	66.8	0.869	85.0	39.9
VIII	0.807	99.3	46.7	0.882	134.5	63.2	0.882	135.3	63.6	0.882	172.5	81.0
IX	0.935	128.3	60.3	0.919	146.6	68.9	0.919	117.6	55.3	0.919	133.5	62.7
Total	7.65	1519.0	714.0	7.181	1116.0	524.5	7.181	1216.9	556.5	7.181	1495.3	702.8
Average	0.85	168.7	79.3	0.798	124.0	58.22	0.798	135.2	61.8	0.798	166.1	78.1

According to Mutuo et al. (2005), carbon stocks are influenced by differences in plant age. Biomass and carbon tend to increase with increasing plant age; the older the plant, the larger the diameter of the plant (Latifah et al. 2018). Diameter also affects carbon stock and tree density, species diversity, and tree base area (Urbano and Keeton 2017). The carbon stock value in the four Gapoktan studied at Batutegi KPHL is higher than the average carbon stock in Indonesia. According to Hairiah and Rahayu (2010), the carbon stock in coffee-based multi strata is higher agroforestry in several regions in Indonesia, which is 43 tons/ha on average.

Mahardika has the lowest average biomass and carbon stock values than other Gapoktan. The low average biomass and carbon stock in the Mahardika area is due to crops rather than woody plants. Woody plants (trees) have an essential role because large volumes of wood will increase the value of biomass so that carbon stocks will be larger. It is in line with Pontes et al. (2019) study that tree biomass in ecology depends on a combination of species, management practices, and site conditions. In addition, Siarudin et al. (2021) agree; that the variety of species in an agroforestry system consisting of various trees has a high potential for carbon storage.

The protected function in this area needs to maintain by considering the ecological impact caused by the composition of plants developed by farmers. Therefore, farmers' arrangement of plants must improve protected forests' function as a mandate to realize the preservation of natural resources and the environment for current and future generations as outlined in Government Regulation of the Republic of Indonesia No. 23 in 2021. Moreover, it is necessary to optimize growing space through species enrichment under existing land and plant conditions. Species enrichment needs to be carried out on the land with sufficient space to plant new species. So, there is no reason to cut the trees as an excuse to replace existing plants because the area of Batutegi KPHL is a protected forest where cutting trees is forbidden.

To conclude, the composition of plants in agroforestry patterns of Gapoktan of Cempaka, Hijau Makmur, Mahardika, and Sinar Harapan are varied, including agricultural crop, plantation, and forest trees, with the dominant crops being coffee (*Coffea arabica*), pepper (*Piper nigrum*), rubber (*Hevea brasiliensis*), and banana (*Musa* sp.). This composition increases the above-ground carbon stocks value greater than the average carbon stocks from agroforestry patterns in Indonesia. However, the value of biodiversity in Gapoktans is low. The number of trees (high canopy plants) needs to be increased, especially in Mahardika and Sinar Harapan. The collaboration with the government and private sector in Hijau Makmur and Cempaka has proven can encourage the increasing number of trees (woody perennial) and maintain the existing trees in the two Gapoktans.

Species enrichment for high canopy plants (woody perennial) is essential. Selection of plant species, setting the location or position of plants, spacing of plants, and plant maintenance, especially pruning of shade plants, are the keys to applying agroforestry patterns. The composition and number of plant species, which are different in each farmer's field, require various efforts. The selection of plant species requires more attention, particularly on land conditions and existing plant species, so their benefits can be more optimal. In addition, where it is not possible to add new trees on the land, it is necessary to carry out plant maintenance, especially pruning of high canopy plants on land where the main crop is coffee. So, the intensity of light received by coffee is under its need to increase coffee production. Therefore, it is important to provide counseling, assistance, and cooperation with parties that can be a stimulus for farmers to rehabilitate forest cover, especially in its protection function, by realizing complex agroforestry that can provide optimal benefits for the community environment.

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REFERENCES

Asmi MT, Qurniati R, Haryono D. 2014. Komposisi tanaman agroforestri dan kontribusinya terhadap pendapatan rumah tangga di Desa Pesawaran Indah Kabupaten Pesawaran Lampung. Jurnal Sylva Lestari 1 (1): 55-64. DOI: 10.23960/jsl1155-64. [Indonesian]

Austin KG, Schwantes A, Gu Y, Kasibhatla PS. 2019. What causes deforestation in Indonesia? Environ Res Lett 14 (2): 1-9. DOI: 10.1088/1748-9326/aaf6db.

Bhandari RP, Joshi R, Paudel D. 2021. Agroforestry practices for climate change adaptation and its contribution to farmers' income. J Nat Resour 4 (3): 42-51. DOI: 10.33002/nr2581.6853.040305.

Borek R. 2015. Agroforestry systems in Poland a preliminary identification. Pap Glob Change 22: 37-51. DOI: 10.1515/igbp-2015-0014.

Budiastuti MTS. 2020. Agroforestry as climate change mitigation. Nusantara Sci Technol Proc 23-29. DOI: 10.11594/NSTP.2020.0603.

De Stefano A, Jacobson MG. 2018. Soil carbon sequestration in agroforestry systems: a meta-analysis. Agrofor Syst 92 (2): 285-299. DOI: 10.1007/S10457-017-0147-9.

Evizal R, Sugiatno, Prasmatiwi FE, Nurmayasari I. 2016. Shade tree species diversity and coffee productivity in Sumberjaya, West Lampung, Indonesia. Biodiversitas 17 (1): 234-240. DOI: 10.13057/biodiv/d170134.

Evizal R, Tohari, Prijambada ID, Widada J. 2012. Peranan pohon pelindung dalam menentukan produktivitas kopi. Jurnal Agrotropika 17 (1): 19-23. DOI: 10.23960/ja.v17i1.4276. [Indonesian]

Feliciano D, Ledo A, Hillier J, Nayak DR. 2018. Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions? Agric Ecosyst Environ 254: 117-129. DOI: 10.1016/J.AGEE.2017.11.032.

Goncalves N, Andrade D, Batista A, Cullen L, Souza A, Gomes H, Uezu A. 2021. Potential economic impact of carbon sequestration in coffee agroforestry systems. Agrofor Syst 95 (2): 419-430. DOI: 10.1007/S10457-020-00569-4.

Hairiah K, Rahayu S. 2010. Mitigasi perubahan iklim: agroforestri kopi untuk mempertahankan cadangan karbon lanskap. Prosiding Simposium Kopi. [Indonesian]

Hairiah K, Sonya D, Agus F, Velarde S, Ekadinata A, Rahayu S, van Noordwijk M. 2011. Measuring Carbon Stocks Accross Land Use Systems. World Agroforestry Centre, ICRAF South-east Asia and University of Brawijaya (UB) World Agroforestry Centre (ICRAF), SEA Regional Offi, Bogor, Indonesia.

Hidayat M. 2017. Analisis vegetasi dan keanekaragaman tumbuhan di kawasan manifestasi Geotermal Ie Suum Kecamatan Mesjid Raya Kabupaten Aceh Besar. BIOTIK: Jurnal Ilmiah Biologi Teknologi dan Kependidikan 5 (2): 114-124. DOI: 10.22373/BIOTIK.V5I2.3019. [Indonesian]

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories - A primer, prepared by the National Greenhouse Gas Inventories Programme. In: Eggleston HS, Miwa K, Srivastava N, Tanabe K (eds) IGES, Japan.

Kumar BM, Sasikumar B, Kunhamu TK. 2021. Agroecological aspects of black pepper (*Piper nigrum* L.) cultivation in kerala: A review. Agrivita J Agric Sci 43 (3): 648-664. DOI: 10.17503/agrivita.v43i3.3005.

Landicho LD, Theresa M, Ocampo NP, Cabahug RED, Abadillos MG, Cosico RSONA, Castillo AKA, Armie MA, Ramirez JP, Laruan KA. 2021. Local knowledge and practices towards ecological restoration of a selected landscape in Atok, Benguet, Philippines. Biodiversitas 22 (7): 2785-2794. DOI: 10.13057/biodiv/d220728.

Latifah S, Muhdi, Purwoko A, Tanjung E. 2018. Estimation of aboveground tree biomass Toona sureni and Coffea arabica in agroforestry system of Simalungun, North Sumatra, Indonesia. Biodiversitas 19 (2): 670-675. DOI: 10.13057/biodiv/d190239.

Lestari NDWI, Suprayogo D, Rachmansyah A. 2019. Local biodiversity conservation in Sigi, Central Sulawesi, Indonesia: analysis of the effect of elevation, land accessibility, and farmers' income and perception on vegetation diversity in agroforestry systems. Biodiversitas 20 (1): 283-291. DOI: 10.13057/biodiv/d200132.

Lorenz K, Lal R. 2014. Soil organic carbon sequestration in agroforestry systems. A review. Agron Sustain Dev 34 (2): 443-454. DOI: 10.1007/S13593-014-0212-Y.

Manaye A, Tesfamariam B, Tesfaye M, Worku A, Gufi Y. 2021. Tree diversity and carbon stocks in agroforestry systems in northern Ethiopia. Carbon Balance Manag 16 (1): 1-10. DOI: 10.1186/S13021-021-00174-7/TABLES/7.

Mbolo MMA, Zekeng JC, Mala WA, Fobane JL, Chimi CD, Tangboulou Ngavounsia, Nyako CM, Menyene LFE, Tamanjong YV. 2016. The role of cocoa agroforestry systems in conserving forest tree diversity in the Central region of Cameroon. Agrofor Syst 90 (4): 577-590. DOI: 10.1007/s10457-016-9945-8.

Molla B. 2019. The role of agroforestery on house hold income of rural communities the ase Soddo Zuria Woreda; South Ehiopia. Glob J Hum-Soc Sci Res 19 (3): 38-48.

Mutuo PK, Cadisch G, Albrecht A, Palm CA, Verchot L. 2005. Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. Nutr Cycl Agroecosyst 71 (1): 43-54. DOI: 10.1007/S10705-004-5285-6.

Nawansih O, Evizal R, Qurniati R, Rosanti N, Djuardi AUP, Fadhallah EG. 2020. Impact study of good agricultural practices (GAP) and agroforestry training programs of coffee farmers in Lampung. Bandar Lampung, Indonesia. [Indonesian]

Notaro M, Gary C, Deheuvels O. 2020. Plant diversity and density in cocoa-based agroforestry systems: how farmers' income is affected in the Dominican Republic. Agrofor Syst 94 (3): 1071-1084. DOI: 10.1007/s10457-019-00472-7.

Oke D, Olatiilu A. 2011. Carbon storage in agroecosystems: a case study of the cocoa based agroforestry in Ogbese Forest Reserve, Ekiti State, Nigeria. J Environ Prot 2 (8): 1069-1075. DOI: 10.4236/JEP.2011.28123.

Pantera, Mosquera-Losada MR, Herzog F, den Herder M. 2021. Agroforestry and the environment. Agrofor Syst 95 (5): 767-774. DOI: 10.1007/s10457-021-00640-8.

Parikesit, Withaningsih S, Rozi F. 2021. Socio-ecological dimensions of agroforestry called kebun campuran in tropical karst ecosystem of West Java, Indonesia. Biodiversitas 22 (1): 122-131. DOI: 10.13057/biodiv/d220117.

Paudela D, Tiwaria KR, Bajracharyab RM, Rautb N, Sitaulac BK. 2017. Agroforestry system: an opportunity for carbon sequestration and climate change adaptation in the Mid-Hills of Nepal. Octa J Environ Res 5 (1): 22-31.

Pontes DMF, Engel VL, Parrotta JA. 2019. Forest structure, wood standing stock, and tree biomass in different restoration systems in the Brazilian Atlantic Forest. Forests 10(7):588. DOI: 10.3390/f10070588

Priyadarshini R, Hamzah A, Widjajani BW. 2019. Carbon stock estimates due to land cover changes at Sumber Brantas Sub-Watershed, East Java. Caraka Tani: J Sustain Agric 34 (1): 1-12. DOI: 10.20961/carakatani.v34i1.27124.

Qurniati R, Febryano IG, Zulfiani D. 2017. How trust influence social capital to support collective action in agroforestry development? Biodiversitas 18 (3): 1201-1206. DOI: 10.13057/biodiv/d1844.

Rahman SA, Jacobsen JB, Healey JR, Roshetko JM, Sunderland T. 2017. Finding alternatives to swidden agriculture: does agroforestry improve livelihood options and reduce pressure on existing forest? Agrofor Syst 91 (1): 185-199. DOI: 10.1007/s10457-016-9912-4.

Rai SM. 2013. Short Communication: Global warming-Problem with environmental and economic impacts. Nusantara Biosci 5 (2): 102-105. DOI: 10.13057/nusbiosci/n050207.

Rijal S. 2019. Agroforestry system: approaches for climate change mitigation and adaptation. Big Data in Agriculture (BDA) 1 (2): 23-25. DOI: 10.26480/bda.02.2019.23.25.

Sebuliba E, Majaliwa JGM, Isubikalu P, Turyahabwe N, Eilu G, Ekwamu A. 2021. Characteristics of shade trees used under Arabica coffee agroforestry systems in Mount Elgon Region, Eastern Uganda. Agrofor Syst 96 (1): 1-13. DOI: 10.1007/S10457-021-00688-6.

Siarudin M, Rahman SA, Artati Y, Indrajaya Y, Narulita S, Ardha MJ, Larjavaara M. 2021. Carbon sequestration potential of agroforestry systems in degraded landscapes in West Java, Indonesia. Forest 12 (6): 1-13. DOI: 10.3390/f12060714.

Sistla SA, Roddy AB, Williams NE, Kramer DB. 2016. Agroforestry practices promote biodiversity and natural resource diversity in Atlantic. PloS one 11 (9): 1-20. DOI: 10.1371/journal.pone.0162529.
Sofiah S, Metusala D, Trimanto, Nurfadilah S. 2018. Flora diversity, composition and ecology in Besiq Bermai tropical forest of Damai District, East Kalimantan. Biotropia 25 (2): 85-94. DOI: 10.11598/btb.2018.25.2.724.
Udawatta RP, Jose S. 2011. Carbon sequestration potential of agroforestry practices in Temperate North America. Springer, Dordrecht. DOI: 10.1007/978-94-007-1630-8_2.
Urbano AR, Keeton WS. 2017. Carbon dynamics and structural development in recovering secondary forests of the northeastern U.S. For Ecol Manag 392: 21-35. DOI: 10.1016/J.FORECO.2017.02.037.
Wagner S, Rigal C, Liebig T, Mremi R, Hemp A, Jones M, Price E, Preziosi R. 2019. Ecosystem services and importance of common tree species in coffee-agroforestry systems: local knowledge of small-scale farmers at Mt. Kilimanjaro, Tanzania. Forests 10 (11): 1-16. DOI: 10.3390/f10110963.
Wanderi W, Qurniati R, Kaskoyo H. 2019. Kontribusi tanaman agroforestri terhadap pendapatan dan kesejahteraan petani. Jurnal Sylva Lestari 7 (1): 118-127. DOI: 10.23960/jsl17118-127.
Wijayanto N. 2011. Species identification and selection to develop agroforestry at Lake Toba Catchment Area (LTCA) Biodiversitas 12 (1): 52-58. DOI: 10.13057/biodiv/d120110.
Zomer RJ, Neufeldt H, Xu J, Ahrends A, Bossio D, Trabucco A, Van Noordwijk M, Wang M. 2016. Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets. Sci Rep 6 (1): 1-12. DOI: 10.1038/srep29987.

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