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Diversity and Estimated Above Ground Biomass of Shade Trees in Some Coffee-based Agroforestries, Banyuwangi Regency

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ABSTRACT
This study was aimed to assess the diversity and estimate the above-ground biomass (AGB) of the shade tree in several coffee-based agroforestries in Banyuwangi, East Java. The data was collected from three villages, i.e. Gombengsari, Papring, and Kopendukuh. Vegetation analysis and biomass measurement were conducted by measuring the tree DBH (Diameter at Breast Height) in a square block plot 25 m x 25 m. The allometric formula was used to estimate the AGB, with wood density referred to ICRAF. The results were described descriptively. A total of 30 tree species were found as shade trees. Coconut (*Cocos nucifera*) has the highest important value index due to its high survival rate, easier maintenance and economic benefits. We found three types of shade trees: complex, simple, and single shade trees. The simple shade tree coffee-based agroforestry was mostly found in three villages. The highest species richness and the highest diversity of shade trees (1.93) was found in complex coffee-based agroforestry in Papring Village, followed by simple shade trees in Gombengsari (1.64), Papring (1.30), and Kopendukuh (1.13). The highest density and basal area were found in Gombengsari, which related to the highest AGB that measured in simple shade trees coffee-based agroforestry of Gombengsari for 47.110 ton.ha^{-1}. With a total AGB of 30.203 ton.ha^{-1}, Kopendukuh single shade tree coffee-based agroforestry has a higher AGB than complex shade trees coffee-based agroforestry in Papring (13.713 ton.ha^{-1}), due to the age of shade trees planted in the agroforestry lead to the higher rate of DBH.

Keywords: *Carbon stock estimation, Coffee-based agroforestry, Shade tree.*

1. INTRODUCTION

Agroforestry is an alternative natural resources management that considers both agricultural development and environment conservation efforts. Agroforestry becomes an intermediate intensity land-use, in which trees have a significant proportion of a landscape; the agroforestry affects the microclimate, energy and matter cycle, and biotic processes [1]. Cocoa and coffee agroforestry are examples with a high diversity of shade trees [2,3].

Coffee-based agroforestry is a common agricultural practice in Banyuwangi, as a traditional heritage from the previous generation. With specific local knowledge on plant use, coffee farmers chose the shade tree for the coffee plant. Besides economic or cultural merit, shade trees were also chosen due to their function as a better ecological service [4].

Coffee-based agroforestries in Banyuwangi Regency is varied in type of shade trees. The variation is expected to create a different ecological service. One of the parameters that show the ecological services of the shade tree is carbon stock within. The objective of this study was to assess the diversity and estimate the above-ground biomass (AGB) of shade trees in several coffee-based agroforestries in Banyuwangi Regency, East Java.

This study was expected to show a preliminary evaluation on the ecological services depicted from the vegetation structure and carbon stock within the coffee agroforestry. The results should lead the consideration to

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Figure 1. Site of Research (Source: Google Earth, 2021; = Sampling Site)

adopt a sustainable coffee agroforestry implementation by means of local government policy towards the coffee farmers.

2. MATERIAL AND METHODS

2.1. Sampling Site

Figure 2. A coffee-based agroforestry in Gombengsari

The data was collected in July-September 2021 from three villages in Banyuwangi Regency, East Java. The villages were Gombengsari, Papring, and Kopendukuh (Fig. 1). The coffee-based agroforestry (Fig. 2) was chosen randomly with 10 plots each village, totalled 30 plots. We used a square block plot 25 m x 25 m. We categorized the shade tree in three types, complex shade tree, simple shade tree [5] and single shade tree. Complex type consisted of more than five species of shade trees, while simple type consisted of less than five species of shade trees, and single type consisted only one species of shade tree.

2.2. Vegetation Analysis and AGB Estimation

Vegetation analysis and biomass measurement were conducted in each square block plot. The diversity index (H') of Shannon-Wienner is shown in Equation 1, where p_i is proportion of individuals of i-th species in a whole community, n is individuals of given species, and N is total number of individuals in the community. Important Value Index (IVI) is shown in Equation 2, where *RD* is relative density, *RF* is relative frequency, and *RD* is relative dominance. Tree density, basal area, relative frequencies and species richness were used to describe the vegetation structure. The shade tree that we included are the trees with DBH > 20 cm. The measurement of the tree's DBH is done by the method of Hairiah and Rahayu [6]. The allometric formula of Chave *et al.* [7] was used to estimate the Above Ground Biomass (AGB) is shown in Equation (3), where ρ is wood density (g.cm^{-3}), and *DBH* is Diameter at Breast Height (cm), with wood density referred to the ICRAF wood density database (http://db.worldagroforestry.org/wd). The results were described descriptively.

$$\mathbf{H'} = -\Sigma[(p_i) \times \ln (p_i)]$$
$$\boldsymbol{p_i} = n / \mathrm{N} \quad (1)$$

$$\mathbf{IVI} = \mathrm{RD} + \mathrm{RF} + \mathrm{RD} \quad (2)$$

$$\mathbf{AGB} = \rho * \exp((-1{,}499 + 2{,}14811 \ln(DBH) + 0{,}207 \ln(DBH)^2) - 0{,}0281 \ln(DBH))^3) \quad (3)$$

3. RESULTS AND DISCUSSION

3.1. Composition of Shade Tree

Shade trees species found in the coffee-based agroforestry were totalled 30 species. The simple shade tree types was found mostly in three villages. Shade tree species that found in all type of coffee-agroforestry in all three villages were coconut (*Cocos nucifera*). It is supported by the highest important value index (Supplementary 1), which was occupied by coconut (*C. nucifera*) in each agroforestry type in all villages. Local farmers and agroforestry owners (Personal Communication, 2021) choose coconut in their garden due to its high tolerance [8] and easier maintenance, besides its economic benefit [9]. Besides coffee agroforestry, coconut was also dominantly used as shade trees in cocoa agroforestry [10].

Avocado (*Persea americana*), mahogany (*Switenia macrophylla*), and durian (*Durio zibethinus*) were found in all simple and complex type of shade trees coffee

Table 1. Vegetation Structure of Shade Tree

Plot	Species Richness	Density (Indiv.ha^{-1})	Basal Area (m^2.Ha^{-1})	Shade Tree Type
Papring 5	8	11	0.81	Complex
Papring 8	7	9	0.63	Complex
Gombengsari 6	5	14	0.92	Simple
Papring 4	5	8	0.76	Simple
Kopendukuh 7	5	8	0.42	Simple
Papring 1	5	6	0.40	Simple
Gombengsari 5	4	9	0.63	Simple
Gombengsari 1	4	9	0.53	Simple
Papring 9	4	7	0.46	Simple
Gombengsari 3	4	7	0.44	Simple
Gombengsari 2	4	5	0.39	Simple
Gombengsari 7	3	13	1.03	Simple
Papring 3	3	8	0.60	Simple
Papring 10	3	7	0.50	Simple
Papring 2	3	7	0.42	Simple
Gombengsari 8	3	7	0.55	Simple
Gombengsari 4	3	6	0.42	Simple
Kopendukuh 1	3	6	0.46	Simple
Kopendukuh 2	3	6	0.46	Simple
Papring 6	3	5	0.31	Simple
Gombengsari 9	2	6	0.45	Simple
Kopendukuh 5	2	6	0.58	Simple
Kopendukuh 6	2	6	0.57	Simple
Kopendukuh 9	2	6	0.48	Simple
Kopendukuh 8	2	6	0.33	Simple
Gombengsari 10	2	6	0.35	Simple
Papring 7	2	3	0.17	Simple
Kopendukuh 3	1	10	0.83	Single
Kopendukuh 4	1	8	0.78	Single
Kopendukuh 10	1	8	0.78	Single

agroforestry. Avocado and durian as shade trees for coffee-based agroforestry were also found in Bondowoso, along with clove (*Syzigium aromaticum*) and several seasonal plants [11]. In Krisik, Malang, avocado and Durian also found in the coffee agroforestry along with *Albizia falcataria, Parkia speciosa* (petai) and *Pithecellobium jiringa* (jengkol) [12].

While Jati (*Tectona grandis*), Nangka (*Artocarpus heterophyllus*), and Waru Gunung (*Hibiscus macrophyllus*) have not been found in Kopendukuh Village, Petai (*Parkia speciosa*) and Rambutan (*Nephelium lappaceum*) were not found in Papring Village. Langsat (*Lansium domesticum*), Santen (*Lannea coromandelica*), Trembesi (*Samanea saman*), Jengkol (*Archidendron pauciflorum*), and Lamtoro (*Leucaena leucocephala*) were found in simple shade trees coffee agroforestry in Gombengsari Village. Meanwhile, Sukun (*Artocarpus altilis*), Mangir (*Ganophyllum falcatum*), Laben (*Vitex pubescens*), Jabon (*Neolamarckia cadamba*), Sengon (*Albizia chinensis*), Segawe Mikro (*Adenanthera microsperma*), Kecrutan (*Spathodea campanula*), Mangga Golek (*Mangifera indica*) were found in simple shade trees coffee agroforestry in Papring Village.

The highest species richness was found in the complex shade tree type of Papring Village. However, the highest density and basal area showed in the simple shade tree of Gombengsari 6, for 14 individual per ha and 0.92 $m^2.ha^{-1}$, followed by Gombengsari 7 for 13 individual.ha^{-1} and 1.03 $m^2.ha^{-1}$ (Table 1).

Papring Village was the only one that has the complex shade tree coffee agroforestry (Table 1). The shade trees within it were Wongso (*Cananga* sp.), Mangga Kuweni (*Mangifera odorata*), Sosoan (*Litsea glutinosa*), Sukun (*Artocarpus altilis*), and Mangga Golek (*Mangifera indica*). Sengon (*Albizia chinensis*) that found in both Papring and Kopendukuh simple shade tree coffee agorofrestry, was not found in Gombengsari Village. In addition, Manggis (*Garcinia mangostana*) and Wuru (*Hibiscus tiliaceus*) were specifically found in Kopendukuh simple shade tree coffee agroforestry.

Shade trees species that was chosen by the farmers to be planted in their coffee agroforestry were for economic and daily use. Fruit tree, timber and fodder plant were the commonly shade trees used by coffee-based agroforestry farmers [11,12].

3.2. Characteristic of Shade Tree in Coffee-based Agroforestries

In Table 2, the highest diversity of shade trees found in complex coffee-based agroforestry in Papring Village, followed by simple shade trees in Gombengsari, Papring and Kopendukuh. A total of 47.110 ton.ha^{-1} above ground mass was found in simple shade trees coffee-based agroforestry of Gombengsari Village as the highest AGB. It is related to the highest density and basal area in Gombengsari. Although Kopendukuh single shade tree coffee-based agroforestry has no diversity of shade trees, the total AGB (15.246 ton.ha^{-1}) was higher than complex shade trees coffee-based agroforestry in Papring Village (13.713 ton.ha^{-1}). It was because shade trees in single shade tree Kopendukuh had a higher rate of DBH than shade trees in complex shade trees in Papring. We assumed it has to do with the age of shade trees planted in their agroforestry. Shade trees in Papring was about 5-7 years old while shade trees in Kopendukuh was more than 8 years old (Personal Communication, 2021).

Table 2. Characteristics of Shade Trees Coffee-based Agroforestry

Type of Shade Trees	Number of plots	Diversity Index (H')	Shade Tree AGB (Ton.ha^{-1})
Gombengsari			
Complex	-	-	-
Simple	10	1.64	47.110
Single	-	-	-
Papring			
Complex	2	1.93	13.713
Simple	8	1.30	31.005
Single	-	-	-
Kopendukuh			
Complex	-	-	-
Simple	7	1.13	30.203
Single	3	0.00	15.246

Complex coffee agroforestry will occur with a larger shade tree and the increased diversity, with function in carbon sequestration. The age of coffee and shade trees increases the carbon stocks, with the assumption that a greater number of shade trees grow along with the age of coffee plants [13]. However, our study has the limitation that some of timber shade trees that have been harvested, replaced by new plants, like in Papring Village. Thus, the age of coffee agroforestry cannot be used as the parameter in determine its characteristic related to the carbon stock, but the age of shade trees and wood density were.

Coffee-based agroforestry in Gombengsari, Papring, and Kopendukuh Villages has complex, simple, and single shade tree types. With a total of 30 shade tree species that found in the coffee-based agroforestry, the highest species richness was found in Papring, while the highest density and basal area were found in Gombengsari. The highest diversity of shade trees was found in complex coffee-based agroforestry in Papring Village. Meanwhile, the highest AGB found in simple shade trees coffee-based agroforestry of Gombengsari Village for 47.110 ton.ha^{-1}. Further study on the wood density and age of trees in coffee-based agroforestry is needed considering that the bigger DBH of trees yields the greater AGB.

AUTHORS' CONTRIBUTIONS

First author contributes in writing the paper. The second, the third, and fourth authors contribute in supervising and supporting the writing concept.

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Supplementary 1. Shade Tree Species of Coffee-based Agroforestry

No.	Local Name (Taxa)	Coffee-based Agroforestry				
		Gombengsari	Papring		Kopendukuh	
		Simple	Complex	Simple	Simple	Single
1	Kelapa (*Cocos nucifera*)	155.02	92.67	166.14	185.52	300.00
2	Jati (*Tectona grandis*)	26.88	42.60	13.67	-	-
3	Petai (*Parkia speciosa*)	19.22	-	-	18.60	-
4	*Gmelina* sp.	18.59	-	-	-	-
5	Alpukat (*Persea americana*)	15.21	11.30	-	7.39	-
6	Mahoni (*Swietenia macrophylla*)	13.25	17.82	30.74	40.10	-
7	Buru (*Machilus rimota*)	8.83	-	-	-	-
8	Durian (*Durio zibethinus*)	7.15	12.91	-	8.65	-
9	Nangka (*Artocarpus heterophyllus*)	6.62	12.59	11.28	-	-
10	Rambutan (*Nephelium lappaceum*)	5.12	-	-	7.97	-
11	Langsat (*Lansium domesticum*)	4.64	-	-	-	-
12	Waru gunung (*Hibiscus macrophyllus*)	4.61	12.23	5.75	-	-
13	Santen (*Lannea coromandelica*)	3.87	-	-	-	-
14	Trembesi (*Samanea saman*)	3.78	-	-	-	-
15	Jengkol (*Archidendron pauciflorum*)	3.74	-	-	-	-
16	Lamtoro (*Leucaena leucocephala*)	3.46	-	-	-	-
17	Wongso (*Cananga sp.*)	-	22.28	-	-	-
18	Mangga Kuweni (*Mangifera odorata*)	-	18.87	-	-	-
19	Sosoan (*Litsea glutinosa*)	-	11.34	-	-	-
20	Sukun (*Artocarpus altilis*)	-	14.61	6.21	-	-
21	Mangir (*Ganophyllum falcatum*)	-	-	5.32	-	-
22	Laben (*Vitex pubescens*)	-	-	5.84	-	-
23	Jabon (*Neolamarckia cadamba*)	-	-	6.12	-	-
24	Sengon (*Albizia chinensis*)	-	-	24.04	7.37	-
25	Segawe Mikro (*Adenanthera microsperma*)	-	-	7.58	-	-
26	Kecrutan (*Spathodea campanula*)	-	-	6.12	-	-
27	Mangga Golek (*Mangifera indica*)	-	13.39	11.19	-	-
28	Mangga (*Mangifera indica*)	-	17.37	-	-	-
29	Manggis (*Garcinia mangostana*)	-	-	-	14.86	-
30	Wuru (*Hibiscus tiliaceus*)	-	-	-	9.55	-