Working Paper

Tree diversity and above-ground carbon stock estimation in various land use systems in Banjarnegara, Banyumas and Purbalingga, Central Java

Subekti Rahayu and Sidiq Pambudi

World Agroforestry Centre

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Abstract

The loss of biodiversity and biomass due to economic reasons has a high impact on the environmental services provided by landscapes as well as on landscape sustainability. Ideally, sustainable development can be achieved through increasing income while environmental conditions are well managed and even improved. There is a long history of plantations of resin, timber and perennial crops in Banjarnegara, Banyumas and Purbalingga districts. However, expansion of monocultures such as annual crops of vegetables has occurred at higher elevations designated as protected areas. Increasing the carbon stock and tree species diversity is an option to improve environmental conditions. In total, 75 plots (20 x 100 m) in 16 land use systems in Banyumas, Banjarnegara and Purbalingga were established to analyze the tree species composition and carbon stock content in each system. Low intensive management of complex agroforestry systems managed by smallholders contained a more diverse species range in all growth stages, but there were a more diverse range under medium-to-high intensive management by companies only in the seedling stage. Weeding activities direct impacted on naturally regenerating species in systems. Complex agroforest and slow-growing, timber-based agroforest contained 60% of the carbon stock in undisturbed forest and simple crop-based agroforest and fast-growing timber-based systems that in turn contained about 25% of the carbon stock of undisturbed forest.

Keywords:

carbon stock, Central Java, sustainable development, tree diversity

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1. Introduction

Banyumas, Banjarnegara and Purbalingga are located in the western part of Central Java Province. From the Serayu watershed perspective, Banjarnegara is located upstream, while Purbalingga and Banyumas are midstream. The hilly topography of northern Banjarnegara is currently dominated by horticultural systems, mostly for vegetables such as potato, cabbage and mushroom. Tea and pine plantations are other sources of land-based products in the area. Rice paddies and various compositions of agroforestry systems have spread out in the middle and southern parts of Banjarnegara, Banyumas and Purbalingga.

Monoculture potato plantations are potentially a source of emissions due to land use change from a higher carbon content, as well as losing environmental services due to the loss of tree diversity. Another source emission may be come from rice paddies due to inorganic fertilizer application and other unfriendly environmental practices.

Green Economy and Locally-Appropriate Mitigation Actions in Indonesia (GE-LAMA-I) is an initiative for building local government capacities in low emission development planning and developing locally and/or nationally appropriate mitigation actions. Baseline data for low emission development planning of the current and the past land cover condition, carbon stocks in various land use systems and tree biodiversity as environmental indicators are part of the input for planning development. The aims of the assessment undertaken were: (1) to inventory tree diversity across land use systems and (2) to estimate the carbon stock in various tree-based systems.

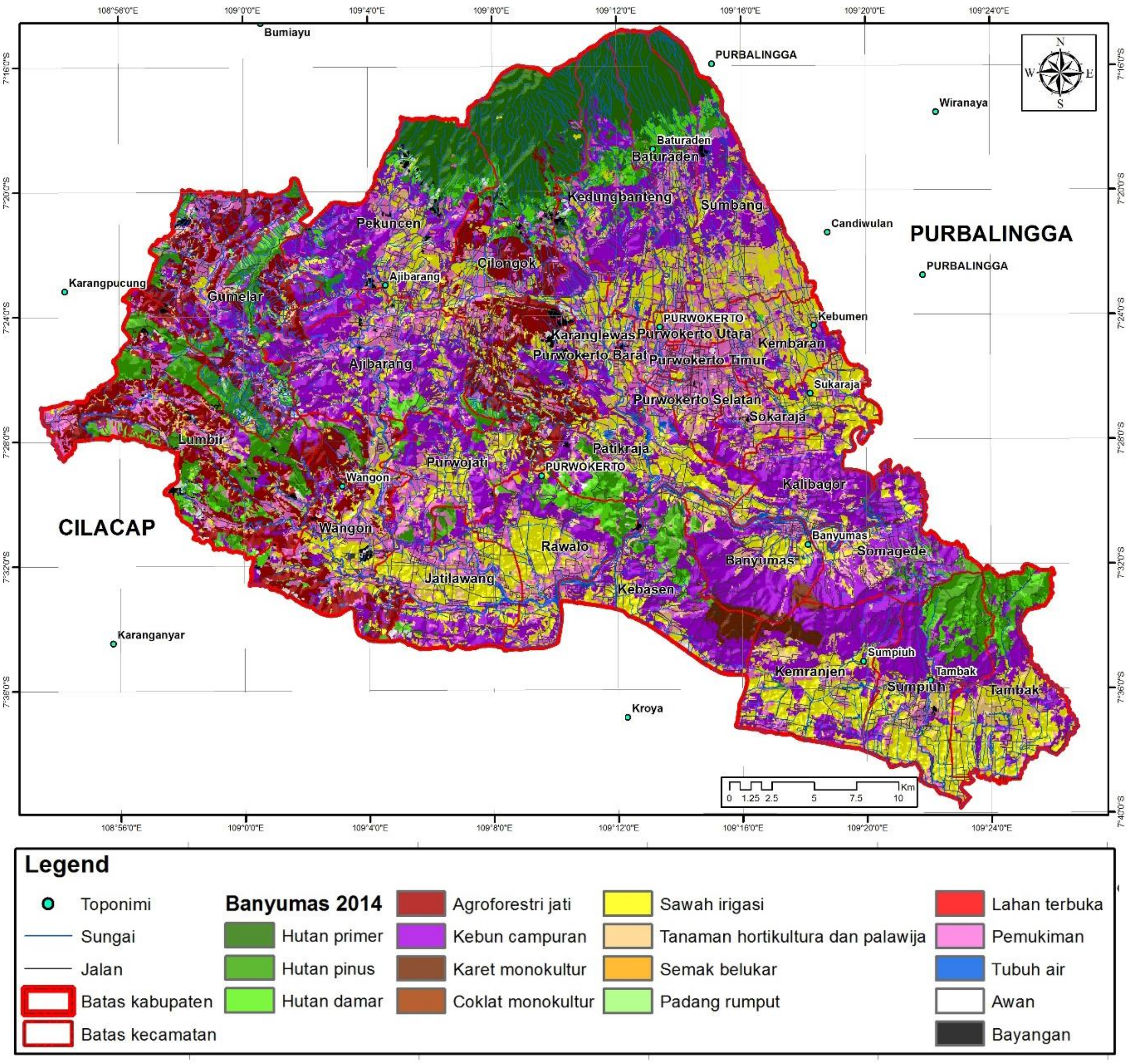
2. Methods

2.1 Study Site

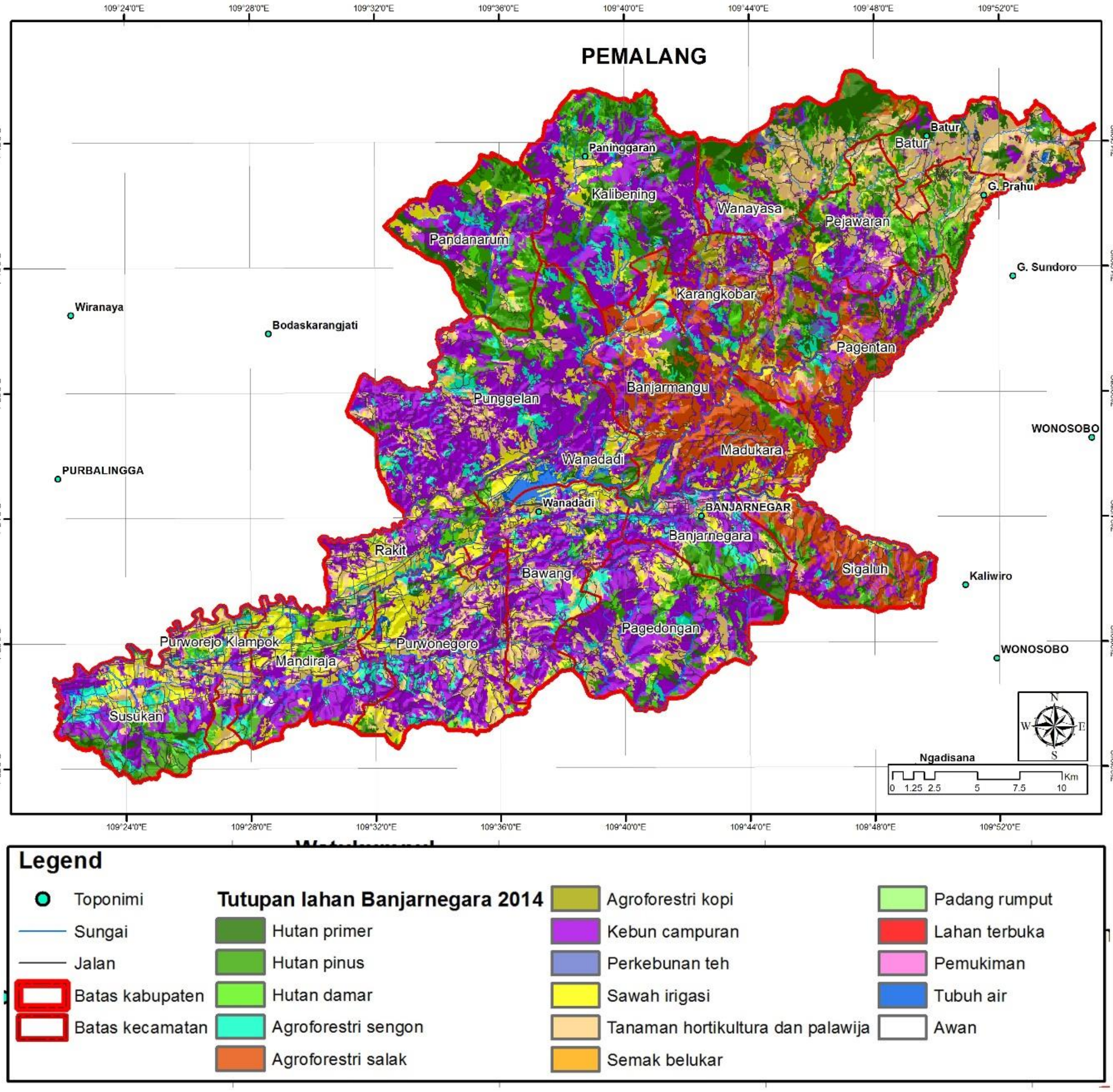
The assessment covered three districts of Banyumas, Banjarnegara and Purbalingga, Central Java (Figure 1). The assessment was conducted in three phases: 9-19 August 2015, 22 May-4 June 2016 and 24-28 August 2016.

Figure 1. Site study

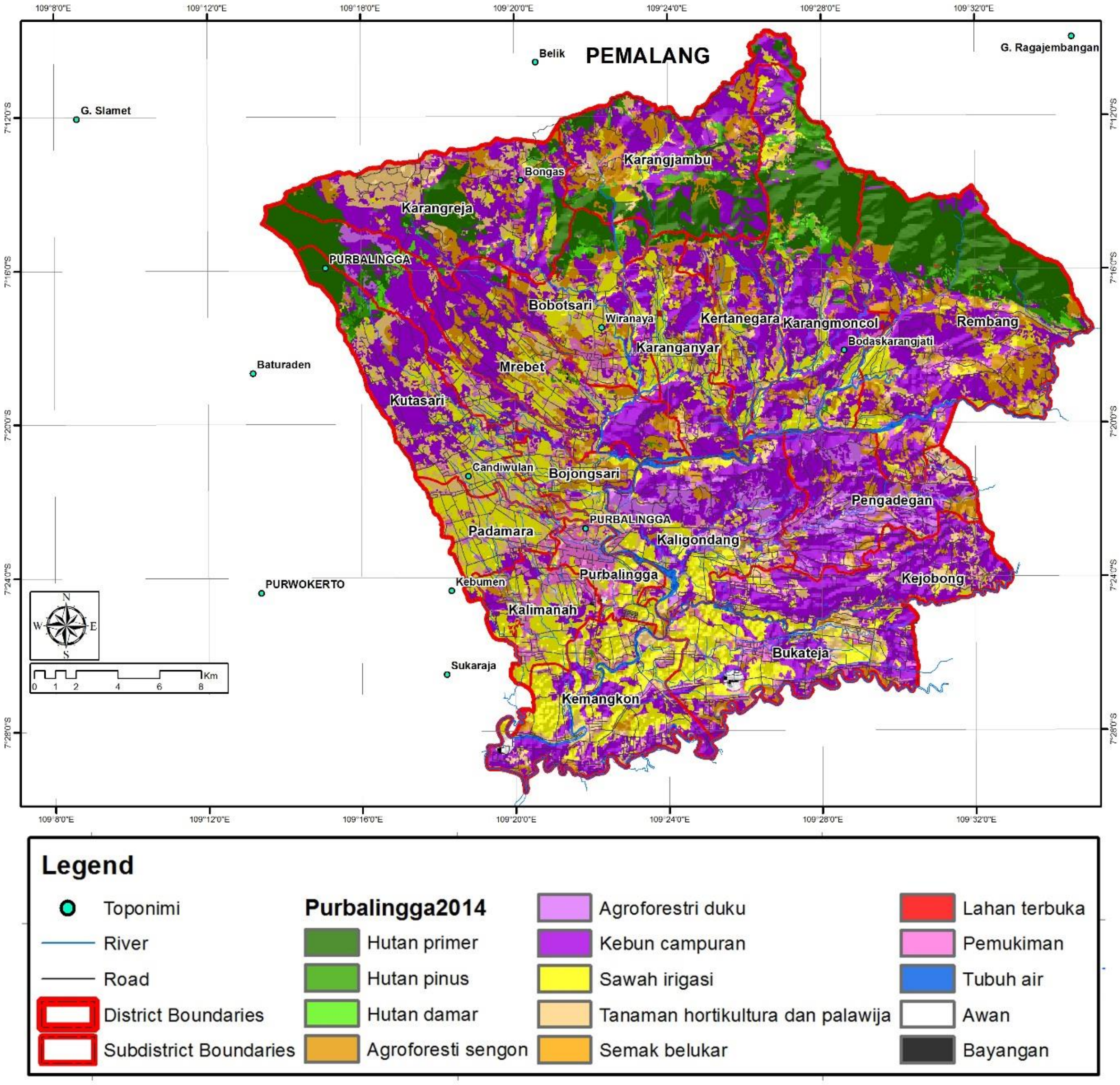
In total, 75 plots were set up in 16 selected land use systems available in the three districts (Figure 2), with 49 plots in Banyumas, 15 plots in Banjarnegara and 11 plots in Purbalingga (Table 1).



a. Banyumas districts



b. Banjarnegara districts



c. Purbalingga districts

Figure 2. Land use systems in three districts of Banyumas (a), Banjarnegara (b) and Purbalingga (c)

Table 1. Number of plots in various land use systems in Banyumas, Banjarnegara and Purbalingga

District	Land use system	Number of plots
Banjarnegara	Sengon agroforest	2
	Sengon monoculture	2
	Coffee agroforest	1
	Complex agroforest	2
	Pines plantation	3
	Shrub	1
	Snakefruit agroforest	2
	Tea plantation	2
Banyumas	Acacia plantation	3
	Agathis plantation	5

District	Land use system	Number of plots
	Sengon agroforest	4
	Sengon monoculture	3
	Cacao agroforest	3
	Complex agroforest	3
	Pines plantation	3
	Rubber monoculture	11
	Shrub	1
	Teak agroforest	7
	Teak monoculture	6
Purbalingga	Agathis plantation	1
	Sengon agroforest	1
	Sengon monoculture	1
	Coffee agroforest	2
	Duku agroforest	3
	Undisturbed forest	3

2.2 Sampling Methods

The same plot was used for tree diversity sampling and the carbon stock inventory. A modified plot size was used (5 x 20 x 20 m) with nested smaller plots (Figure 3) used to sample tree diversity. Carbon stock estimation use the method described in Hairiah et al. (2011). A 2000 m^2 plot (20 x 100 m) was placed in the targeted land cover (Figure 4).

2.2.1 Tree diversity

Four stages of vegetation growth were considered: seedlings (<2 m height), saplings (≥2 m height, < 5 cm stem diameter), poles (5–10 cm diameter) and trees (>10 cm diameter), with nested sampling of plots (2 m x 2 m for seedlings, 5 m x 5 m for saplings, 10 m x 10 m for poles and 20 x 20 m for trees).

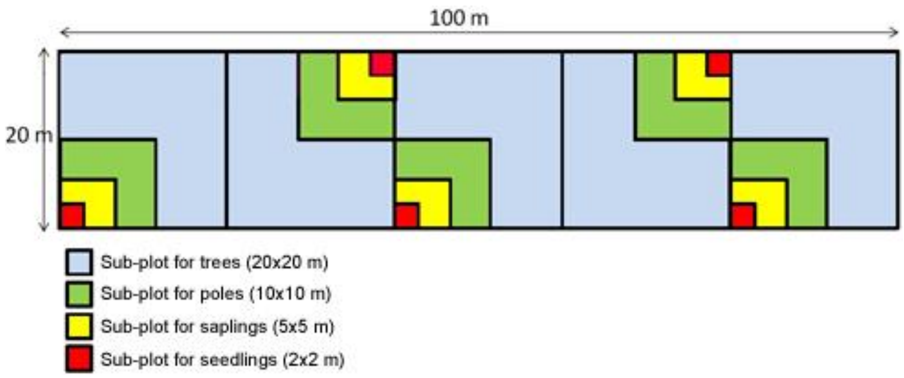


Figure 3. Plot design for tree diversity analysis

All seedlings and saplings included in the plot samples were enumerated and each species was identified. All stem diameters of poles and trees in the plot samples were measured at breast height (1.3 meters above-ground surface; DBH) and identified. Leaf specimens of all species were collected and identified in the Herbarium Bogoriense, at Cibinong, Indonesia.

2.2.2 Above-ground Carbon Stock

Four carbon pools were included in the assessment: tree biomass, understorey, tree necromass and litter. Biomass estimation for large living and dead trees above 30 cm DBH were determined in the 20 x 100 m plot, while the smaller living and dead trees 5-30 cm DBH were measured in the 40 x 5 m plot (Figure 4). The decomposition factor for dead trees was estimated based on visual inspection.

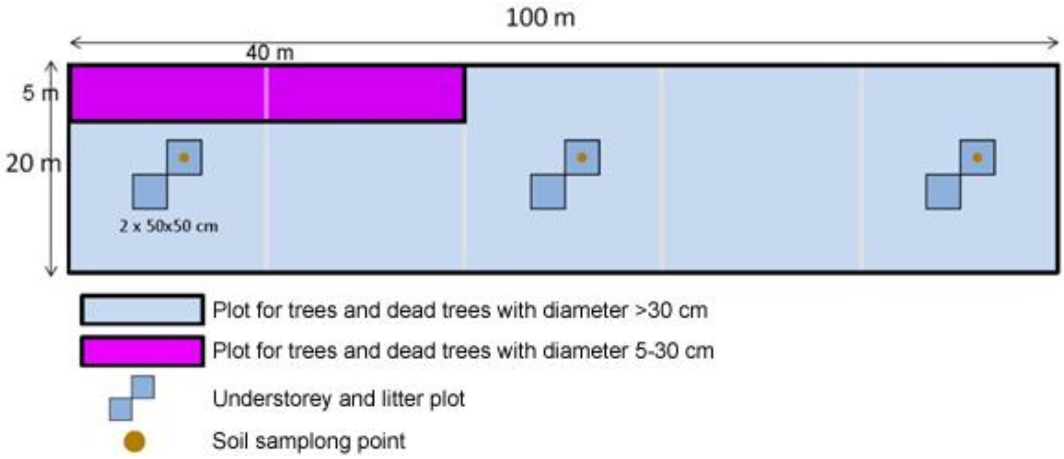


Figure 4. Plot design for carbon stock estimation analysis

Understorey and litter sampling were conducted in a set of quadrants (2 x 0.5 x 0.5 m) placed randomly inside the 20 x 100 m plot, with a minimum of three replications in each plot. The fresh and dry weights of the understorey and litter samples were used in this analysis.

A specific semi destructive sampling method was developed to estimate snakefruit (salak) biomass. Three salak leaves selected using three length criteria (short, medium and long relative to all leaves in the plot) were taken from each salak clump in the 20 x 100 m plot. The weights of fresh and dry leaves, stalks and fronds were used to estimate the dry matter percentage of leaves. The total leaf weight in the plot was determined using multiplication factors.

2.3 Data Analysis

2.3.1 Tree Diversity Analysis

Species richness, important value index (IVI), similarity index using the Bray-Curtis dissimilarity index and the Shannon-Wiener diversity index were used for the tree diversity analysis. Species richness is the number of different species represented in an ecological community, landscape or region (Colwell, 2009). IVI expresses the dominance of species per unit area based on the relative frequency, relative density and relative dominance (Curtis & McIntosh 1950):

$$IVI = Relative\ Frequency + Relative\ Density + Relative\ Dominance$$

a. Relative frequency: $Frequency\ of\ species\ i = \frac{Number\ of\ quadrats\ species\ i}{Total\ number\ of\ quadrat\ sampled}$

$$Relative\ Frequency = \frac{Frequency\ of\ species\ i}{Total\ Frequency}$$

b. Relative density: $Density\ of\ species\ i = \frac{Number\ of\ species\ i}{Area\ of\ quadrat\ sampled}$

$$Relative\ Density = \frac{Density\ of\ species\ i}{Total\ density}$$

c. Relative dominance: $Dominance\ (Basal\ area\ of\ species\ i) = \frac{\pi * (Diameter\ of\ species\ i)^2}{4}$

$$Relative\ Dominance = \frac{Basal\ area\ of\ species\ i}{Total\ basal\ area}$$

Bray-Curtis dissimilarity (B) is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site. Bray-Curtis dissimilarity uses individual numbers as a parameter in the calculation, so that it involves both species and individual parameters affecting the degree of similarity between two compared sites.

$$Bray\text{–}\ Curtis\ similarity\ (1 - B) = 1 - \frac{\sum_{i=1}^{S} |(n_{1i} - n_{2i})|}{\sum_{i=1}^{S} (n_{1i} + n_{2i})}$$

where:

B = Bray-Curtis dissimilarity
S = total species number in land use 1 and land use 2
n_1 = number of individual species i in land use 1
n_2 = number of individual species i in land use 2
The Shannon-Wiener diversity index (H') is a popular index used in ecological studies. It represents the species heterogeneity of a site and incorporates species richness and evenness. The value of the Shannon-Wiener index commonly varies between 0 and 3.5 and rarely surpasses 4.5.

$$H' = -\sum pi\ (ln\ pi)$$

where, pi = proportion of individual number of each species to total species i

The value of H' represents species heterogeneity and is classified into: low (H' <1.5), medium (1.5-3.5) and high (H'>3.5).

2.3.2 Carbon Stock Analysis

The above-ground tree biomass of general species was calculated using the allometric equation developed by Chave et al. (2005) for humid/moist topical forest stands with precipitation between 1500mm and 4000mm/year:

$$Above - Ground\ Biomass_{.est}(kg) = \rho * esp(-1.499 + 2.148\ ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)$$

However, for specific species, we used allometric equations developed by various researchers compiled in Hairiah et al. (2011) (Table 2).

Table 2. Allometric equations for biomass estimation of specific species

Species	Allometric Equation	Source
Coffee regularly pruned	(AGB)est = 0.281 $D^{2.06}$	Arifin, 2001
Cacao	(AGB)est = 0.1208 $D^{1.98}$	Yuliasmara, 2008
Oil palm	(AGB)est = 0.0976 H + 0.0706	ICRAF, 2009
Palm	(AGB)est = exp{-2.134 + 2.530 x ln(D)}	Brown, 1997
Palm	(AGB)est = 4.5 + 7.7 x H	Frangi and Lugo, 1985
Bamboo	(AGB)est = 0.131 $D^{2.28}$	Priyadarsini, 2000
Banana	(AGB)est = 0.030 $D^{2.13}$	Arifin, 2001

Note: (AGB)est = estimation above-ground tree biomass, kg/tree; D = DBH, diameter at breast height, cm; H = tree height, m; ρ = Wood density, gcm^{-3} (available from: http://db.worldagroforestry.org/wd).

3. Results

3.1 Sampled Plot Descriptions

3.1.1 Undisturbed forest

Undisturbed forest is a typical natural land use composed of native species with a dense canopy and highly diverse species and basal areas (Figure 5). Three plots of undisturbed forest were sampled around Slamet Mountain at -7.22897 and 109.24315°, -7.22953° and 109.24301°, -7.22779° and 109.24554°. The sampled plots conditions consisted of mountain forest zone in steeply sloping terrain at 1993-2152 meters above sea level (asl).

Figure 5. Undisturbed forest on Slamet Mountain in Purbalingga, Central Java

3.1.2 Agathis plantation

Agathis (*Agathis* loranthifolia) plantation was established by PT. Perhutani, as a state plantation operated in Java Island in the Forest Management Unit (FMU) Banyumas Timur (Figure 6). The status of the forest is limited production forest covering 17,552.8 ha including Baturaden Botanical Garden. Besides *Agathis loranthifolia*, some blocks of puspa (*Schima wallichii*), pine (*Pinus merkusii*), rasamala (*Altingia excelsa*), mahoni (*Switenia macrophylla*), kaliandra (*Callyandra calothyrsus*) have been established in the area (Budiana & Sukarsa, 2012). Six plots of agathis forest were established in Banyumas and Purbalingga at -7.30786° and 109.22122°, -7.30701° and 109.22675°, -7.22573° and 109.31161°, -7.1823° and 109.1405. However, two plots of agathist forest co-ordinate were not recorded. Plots were set up in various ages of plantation from old (60 years), through medium (30 years) to the youngest (10 years). Planting spacing was 5 x 5 m in the agathis planting at 772-993 meters asl.

Figure 6. Agathis plantation in Baturaden Botanical Garden

3.1.3 Pine plantation

Monoculture plantation of pine (*Pinus merkusii*) was established by PT. Perhutani in FMU Banyumas Timur (Figure 7). Six plots of pines plantation were established in Banyumas and Banjarnegara at -7.429119 and 108.96798°, -7.42936° and 108.95044°, -7.51592° and 109.20394°, -7.1728° and 109.3641°, -7.1434° and 109.3802°, -7.1427° and 109.3851°. The status of the forest is limited production forest covering 28,897.46 ha. The planting spacing was 8-10 meters. Sampled plots were established various ages of planting from the oldest (40 years) through medium (20 years) to the youngest (10 years) at locations 51-1049 meters asl.

Figure 7. Pine plantation in Banyumas

3.1.4 Complex agroforest

Complex agroforest consists of various utilized commodities on a piece of land and is a very common land use system in the area (Figure 8). The timber product of sengon (*Paraserianthes falcataria*) is a popular commodity in the districts in combination with some fruit trees, bamboo and other species. There is a complex age structure and sizing, with species occurring in a random pattern. Five plots of complex agroforest were established in Banyumas and Banjarnegara at -7.44095° and 109.14123°, -7.47594° and 109.20743°, -7.45207° and 109.51150°, -7.416663° and 109.045575°, -7.480814° and 109.385196° between 60-134 meters asl.

Figure 8. Complex agroforest timber and fruit species based in Banyumas

3.1.5 Sengon agroforest

Sengon agroforest is a land use type dominated by sengon (*Paraserianthes falcataria*) combined with other tree species (Figure 9). The timber of sengon is very popular in the area and commands a good price. Various plants integrated in the sengon plantation include cassava, coffee and sometimes fruits or another timber species. Seven plots of sengon agroforest were established in Banyumas, Purbalingga and Banjarnegara at -7.53672° and 109.34338°, -7.36187° and 109.27467°, -7.422331° and 108.961959°, -7.526845° and 109.315533°, -7.394268° and 109.614771°, -7.351522° and 109.588221°, -7.356141° and 109.523319 at 25-297 meters asl.

Figure 9. Sengon agroforest in Banyumas

3.1.6 Sengon monoculture

Sengon monoculture is intensively managed. Weeding is undertaken periodically in the younger stands (2 m x 2 m spacing) and in the older stands (4x4 meters spacing) (Figure 10). Thinning occurs while the plants are actively growing to provide a better growing environment. Six plots of sengon monoculture were established in Banyumas, Purbalingga and Banjarnegara in young plantations (2-3 years) and medium-aged stands (5-6 years) at -7.38998° and 109.27628°, -7.42057° and 109.78452°, -

7.413945° and 109.200795°, -7.442676° and 109.243119°, -7.353818° and 109.546658°, -7.388377° and 109.375064° at 50-490 meters asl.

Figure 10. Sengon monoculture

3.1.7 Teak agroforest

Teak agroforest is land use type dominated by teak combined with other species such as fruit trees, coconut, coffee, melinjo (*Gnetum gnemon*) and some other timber species such as sengon, mahogany and acacia. Low intensive management is applied by smallholder farmers (Figure 11). Seven plots of teak agroforest were established in Banyumas at -7.49941° and 109.21614°, -7.48853° and 109.20917°, -7.52279° and 109.33704°, -7.49157° and 109.23717°, -7.518518° and 109.345560°, -7.517039° and 109.336745°, -7.515001° and 109.266278 at 34-68 meters asl.

Figure 11. Teak agroforest

3.1.8 Teak monoculture

Teak monoculture is a land use type managed intensively with teak (*Tectona grandis*) as the main commodity (Figure 12). Teak plantations, in both monoculture and agroforest systems are spread out in Banyumas. Some monoculture plantations were established by PT. Perhutani in FMU Banyumas Timur. Six plots of teak monoculture were established in medium-aged teak plantation (10-18 years) with one older plot (above 20 years). Commonly, teak was planted at spacings of 2.5 x 2.5 meters up to 5 x 5 meters. The plots were located at -7.430796° and 109.064089°, -7.540850° and 109.064371°,

-7.504979° and 109.068124°, -7.564140° and 109.272755°, -7.515379° and 109.268947°, -7.514448° and 109.271073° at 40-194 meters asl.

Figure 12. Medium-aged teak monoculture plantation

3.1.9 Coffee agroforest

Coffee agroforest integrated with sengon as shading tree was found in Purbalingga (Figure 13) and Banjarnegara. Robusta coffee was cultivated in the lowlands of Purbalingga at around 200 m asl at a spacing of 1.5 x1.5 meters. However, arabica coffee was found at higher elevation (1100 m asl) in Banjarnegara. Three plots of coffee agroforest were established at -7.28873° and 109.82946°, -7.36067° and 109.50253°, -7.34534° and 109.50581°.

Figure 13. Coffee agroforest in Purbalingga, using sengon as shade trees

3.1.10 Cacao agroforest

Cacao agroforest was only found in Banyumas where it had been established by PT. Rumpun Sari Antan IV. Coconut, teak and cassava were integrated in the cacao agroforest system (Figure 14). Three plots of 24-year-old cacao agroforest were established in Darmakradenan, Ajibarang at -7.420196° and 109.024948°, -7.421193° and 109.025020°, -7.420525° and 109.025901° at 150 meters asl.

Figure 14. Cacao agroforest

3.1.11 Duku agroforest

Duku agroforest is a complex system dominated by duku (*Lansium domesticum*) (Figure 15) in Kalikajar, Kaligondang, Purbalingga. This system was established as protected area for the duku germplasm as it was considered to represent good fruit quality (RPJMD Purbalingga 2010-2015). Coconut, sengon and rambutan are integrated in the duku system. Three plots of duku agroforest were established at -7.36633° and 109.38403°, -7.37973° and 109.38595°, -7.36504° and 109.38203° at 73-198 meters asl.

Figure 15. Duku agroforest

3.1.12 Snake fruit agroforest

Snake fruit (salak) is cultivated in intensively managed areas using organic farming under various species such as damar, mahogany, aren, jackfruit, coconut, sengon, avocado and petai (Figure 16) and was commonly found in Banjarnegara. Snake fruit plants are planted at spacings of 2.5 x 2.5 meters or 1.5 x 1.5 meters under the tree canopy. Two plots of snake fruit agroforest were established at -7.34694° and 109.68428°, -7.401241° and 109.775271° at 365-423 meters asl.

Figure 16. Snake fruit agroforest

3.1.13 Rubber monoculture

The rubber monoculture in Banyumas (2,051.25 ha) was established by PT. Perkebunan Nusantara IX Unit Kerja Kebun Krumput (Figure 17). The plantation is located in two administrative districts, Banyumas (1,202.88 ha) in Krumput and Tumiyang division and in Cilacap (848.37 ha) which includes Kubangkangkung division. In Banyumas, rubber plantation hasbeen established in hilly areas at 50-400 meters asl in Latosol and Regosol soil types. Rubber trees planted from 1996 to 2011 are spaced at 3 x 6 meters. Eleven plots of rubber monoculture aged 1-19 years were established in Banyumas: -7.57378° and 109.27650°, -7.57319° and 109.26584°, -7.55660° and 109.26309°, -7.57046° and 109.28422°,-7.571732° and 109.265285°, -7.569380° and 109.262794°, -7.563276° and 109.271867°, -7.563411° and 109.283512°, -7.563307° and 109.279549°, -7.564955° and 109.278140°, -7.564683° and 109.279861°.

Figure 17. Rubber monoculture plantation aged 11 years

3.1.14 Acacia monoculture

Acacia monoculture plantation (Figure 18) was found in Banyumas having been established by PT. Perhutani in Banyumas Timur. Plant spacings of 2 x 3 meters and 5 x 5 meters were applied by the company. Three plots of 10-year-old acacia monoculture were established at 100 meters asl, however only one co-ordinate location that recorded (-7.3016° and 109.0624°).

Figure 18. Acacia monoculture plantation aged 10 years

3.1.15 Tea plantation

The tea plantation identified (612 ha) is intensively managed by PT. Pagilaran Unit Produksi Jatilawang (Figure 19), Banjarnegara. The plantation is located in hilly areas at 740-1600 m asl and on slopes of 1-35^{o}. The tea plants were spaced at 1.5 x 1.5 meters. Beside the plantation own by PT. Pagilaran, local farmers also cultivate tea on a small scale at a denser (0.5 x 0.5 m) spacing integrated with sengon trees. Two plots of tea plantation were established with co-ordinate location at -7.264490° and 109.714620°, -7.207345° and 109.760306°.

Figure 19. Tea plantation

3.1.16 Shrub

Shrub land is a non-tree-based land use system consisting of non-arboreal or small tree vegetation, usually less than 5-6 meters high. Sometimes abandoned land that has been occupied by pioneer vegetation is categorized as shrub land (Figure 20). Two plots of shrub land were established with co-ordinate location at -7.42033° and 109.19402°, -7.210085° and 109.762581°. The sampled plots were located at different elevation in Banjarnegara is at 1394 m asl and in Banyumas at 81 m asl, respectively.

Figure 20. Shrub land

3.2 Tree Diversity and Composition

3.2.1 Species Richness and Diversity

Agroforestry types in Banyumas, Banjarnegara and Purbalingga had different characteristic regarding species richness and tree diversity (Table 3). The low intensive management of complex agroforest and duku agroforest contained the most diverse tree species that tended to be constant among growth stages. There was a relative increase from seedlings to trees in the complex agroforest. Undisturbed forest, located in mountainous areas, contained fewer tree species than the complex agroforest, duku agroforest and snake-fruit agroforest that were mostly managed by smallholder farmers.

The tree species diversity in the timber-based systems, for both agroforest and monoculture (teak and sengon) decreased dramatically from the seedling to the tree stage, due to weeding activity.

The perennial crop-based systems of cacao and coffee had very different tree species richness and diversity. The cacao agroforest managed by the private company was less divers than the coffee agroforest managed by smallholder farmers. In coffee agroforest, the tree species diversity tended to increase from the seedling to the tree stage, but the opposite occurred in cacao agroforest. Farmers usually planted other utilized species or did selected weeding for utilized species in the coffee agroforest, but the private company managed the cacao agroforest intensively, only focusing on cacao and shade-tree species.

The monoculture systems and plantations managed by companies (both state-owned and private) such as pine, agathis and tea, had low tree species richness and diversity. Tree diversity dramatically decreased from the seedling to the tree stage.

Table 3. Species richness and diversity index for various land use systems

Land use	Number of plots	Species richness	Shannon-Wiener diversity index (H')				
			Seedling	Sapling	Pole	Tree	All growth stage
Undisturbed forest	3	12	0	1.53	1.17	1.73	1.88
Agathis plantation	6	15	1.52	1.64	0	0.16	0.58
Pines plantation	6	17	1.71	0.80	0.64	0.15	0.47
Acacia plantation	3	5	0.63	0.68	0.48	0.88	1.16
Duku agroforest	3	27	1.71	2.06	2.04	1.71	2.06
Complex agroforest	5	53	2.43	2.40	2.57	2.68	2.92
Teak agroforest	7	36	2.49	2.03	1.29	1.24	0.18
Teak monoculture	6	15	0.19	0	0	0	0.03
Rubber monoculture	11	4	1.41	1.29	0.29	0.15	1.64
Sengon agroforest	7	26	1.51	1.36	0.57	0.33	0.65
Sengon monoculture	6	8	1.39	0.15	0.03	0.15	0.18
Cacao agroforest	3	8	0.68	0	0	0.35	0.39
Coffee agroforest	3	14	0.51	0.94	0.94	0.75	1.40
Snakefruit agroforest	2	14	0.33	0.50	1.52	1.94	2.03
Tea plantation	2	2	0	0	0	0	0.37
Shrub	2	4	0.69	0	0	0	1.04

3.2.2 Species Dominance

The most three dominant species in the agroforestry systems in Banyumas, Banjarnegara and Purbalingga varied in the seedling, sapling, pole and tree stages (Table 4) depending on the system and management applied. A pioneer species (*Ficus septica*) was very common and was one of the most dominant seedling species in many land use systems. Mahogany (*Swietenia macrophylla*) was a common species in the seedling and sapling stages in complex systems such as complex agroforest, duku agroforest and teak agroforest. In the seedling stage, it was possible for many species to regenerate in various systems depending on the availability of seed dispersal agents and the sampling distance from the seed sources. However, management applied in the systems affected the surviving species in the higher growth stages. Intensive management may have resulted in some seedling species being lost due to weeding activities, but selective weeding may have allowed some seedling species to develop to later stages. In the coffee and cacao-based agroforest, we found that the main commodity was the dominant species in all growth stages. No seedlings were found in the tea plantation due to high density which provided no chance for most species to germinate under such a dense canopy. Intensive weeding applied in the tea plantation (usually herbicide) would have killed all competing seedling species.

Table 4. Three most dominant species in various land use systems

Land use system	Vegetation growth stage			
	Seedling	Sapling	Pole	Tree
Undisturbed forest[1]	*Lithocarpus spicatus*	*L. spicatus* *Debregeasia longifolia* *Macropanax dispermus*	*L.spicatus* *Macropanax dispermus* *Schefflera fastigiata*	*M.dispermus* *Engelhardia spicata* *Astronia spectabilis*
Agathis plantation	*Calliandra calothyrsus* *Agathis loranthifolia* *Coffea canephora*	*Agathis loranthifolia* *Castanopsis argentea* *Xanthophyllum vitellinum*	-	*A. loranthifolia* *Schima wallichii* *Eucalyptus urophylla*
Pines plantation	*Ficus septica* *Calliandra calothyrsus* *C. canephora*	*F. septica* *Gnetum gnemon* *Hibiscus tiliaceus*	*Pinus merkusii* *Citrus aurantifolia* *S. wallichii*	*P. merkusii* *S. wallichii* *Senna siamea*
Acacia[2] plantation	*Pterocarpus indicus* *Acacia auriculiformis*	*P. indicus* *A. auriculiformis*	*A. auriculiformis* *Tectona grandis*	*A. auriculiformis* *Acacia mangium* *T. grandis*
Duku agroforest	*F. septica* *Lansium domesticum* *Vitex pinnata*	*L. domesticum* *Peronema canescens* *Swietenia macrophylla*	*L. domesticum* *Albizia chinensis* *Durio zibethinus*	*L. domesticum* *Cocos nucifera* *A. chinensis*
Complex agroforest	*S. macrophylla* *Buchanania sessilifolia* *Dalbergia latifolia*	*S. macrophylla* *Hibiscus tiliaceus* *Nephelium lappaceum*	*S. macrophylla* *Theobroma cacao* *A. chinensis*	*A. chinensis* *C. nucifera* *S. macrophylla*
Teak agroforest	*S. macrophylla* *F. septica* *C. canephora*	*T. grandis* *S.macrophylla* *C. canephora*	*T. grandis* *A. chinensis* *A. auriculiformis*	*T. grandis* *C. nucifera* *A. chinensis*
Teak Monoculture	*T. grandis* *C. siamea* *S. macrophylla*	*T. grandis* *C. siamea* *Leucaena leucocephala*	*T. grandis* *A. auriculiformis* *Cassia siamea*	*T. grandis* *C. nucifera* *A. auriculiformis*
Rubber monoculture	*Hevea brasiliensis* *N. lappaceum* *F. septica*	*H. brasiliensis* *C. canephora* *Gliricidia sepium*	*H. brasiliensis*	*H. brasiliensis*
Sengon agroforest	*C. canephora* *F. septica* *P. falcataria*	*C. canephora* *G. sepium* *P. falcataria*	*P. falcataria* *C. canephora* *T. grandis*	*P. falcataria* *T. grandis* *C. nucifera*
Sengon monoculture	*P. falcataria* *F. septica* *S. macrophylla*	*P. falcataria* *S. macrophylla*	*P. falcataria* *S. macrophylla*	*P. falcataria* *C. nucifera* *Anthocephalus cadamba*
Cacao agroforest[3]	*F. septica* *Theobroma cacao*	*T. cacao*	*T. cacao*	*T. cacao* *C. nucifera* *T. grandis*
Coffee agroforest	*C. canephora* *Camellia sinensis* *Coffea arabica*	*C. canephora* *C. arabica* *P. falcataria*	*P. falcataria* *C. canephora* *Artocarpus heterophyllus*	*P. falcataria* *Artocarpus heterophyllus* *Archidendron fagifolium*
Snakefruit agroforest	*C. canephora* *F. septica*	-	*C. canephora* *L. leucocephala* *P. falcataria*	*L. leucocephala* *A. heterophyllus* *C. nucifera*
Tea plantation[4]	-	*Camellia sinensis*	*Camellia sinensis*	*Paraserianthes falcataria*
Shrub[5]	*Psidium guajava* *Eucalyptus urophylla*	-	*Acacia mangium*	*A. mangium*

[1] In the undisturbed forest there are only found single species at seedling
[2] In the acacia plantation there are only found two species at seedling to pole
[3] In the cacao agroforest there are only found two species at seedling, even single species at sapling and pole
[4] In the tea plantation are only found single species at sapling to tree
[5] In the shrub there only two species found at seedling and single species at pole and tree

3.2.3 Similarity Index Comparisons

A similarity index determines how closely the current vegetation community resembles either the potential natural community or some other reference community. The similarity index values among the land use systems in the three districts of Banyumas, Banjarnegara and Purbalingga varied depending on the land use and growth stage comparison (Table 5). Species composition in undisturbed forest plots located at a higher elevation and categorized as mountainous forest were completely different to other land use systems. Beside the undisturbed forest, tea and acacia plantation also has a specific species composition which was completely different to the other land use systems in the area in all growth stages.

Generally, shared species occurred among agroforestry systems, but the numbers of shared species decreased in the higher level growth stages. Teak and complex agroforest had the highest number of shared species compared to the other agroforest systems indicting that the teak and complex agroforests in the area can accommodate more species to regenerate. In contrast, the monoculture systems of rubber, sengon and teak had shared species in the seedling stage, but only a few in the higher level growth stages. Weeding activities only allow tree species to regenerate but not necessarily to further develop.

Table 5. Similarity matrix of seedling, sapling, pole and tree species among land uses systems

Land use system	AcP	AgP	SAF	SM	CcA	CoA	DAF	CmA	PP	UF	RM	SH	SF	TP	TAF	TM
Seedling																
Acacia plantation (AcP)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05
Agathis plantation (AgP)			0.22	0.00	0.00	0.20	0.00	0.07	0.30	0.00	0.00	0.00	0.27	0.00	0.13	0.00
Sengon agroforest (SAF)				0.34	0.19	0.46	0.11	0.17	0.22	0.00	0.02	0.00	0.59	0.00	0.33	0.09
Sengon monoculture (SM)					0.44	0.00	0.23	0.09	0.20	0.00	0.02	0.00	0.10	0.00	0.13	0.07
Cacao agroforest (CcA)						0.00	0.20	0.02	0.22	0.00	0.02	0.00	0.12	0.00	0.09	0.04
Coffee agroforest (CoA)							0.00	0.09	0.13	0.00	0.00	0.00	0.43	0.00	0.21	0.00
Duku agroforest (DAF)								0.10	0.32	0.00	0.02	0.04	0.05	0.00	0.22	0.08
Complex agroforest (CmA)									0.07	0.00	0.04	0.00	0.13	0.00	0.37	0.13
Pines plantation (PP)										0.00	0.02	0.00	0.20	0.00	0.23	0.03
Undisturbed forest (UF)											0.00	0.00	0.00	0.00	0.00	0.00
Rubber monoculture (RM)												0.02	0.02	0.00	0.05	0.03
Shrub (SH)													0.00	0.00	0.16	0.10
Snakefruit agroforest (SF)														0.00	0.21	0.04
Tea plantation (TP)															0.00	0.00
Teak agroforest (TAF)																0.27
Teak monoculture (TM)																
Sapling																
Acacia plantation (AcP)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03
Agathis plantation (AgP)			0.04	0.00	0.00	0.01	0.04	0.02	0.00	0.00	0.00	0.00	0.13	0.00	0.04	0.00
Sengon agroforest (SAF)				0.08	0.00	0.23	0.21	0.17	0.08	0.00	0.00	0.00	0.21	0.00	0.28	0.07
Sengon monoculture (SM)					0.00	0.10	0.13	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Cacao agroforest (CcA)						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coffee agroforest (CoA)							0.06	0.06	0.00	0.00	0.00	0.00	0.05	0.00	0.07	0.00
Duku agroforest (DAF)								0.27	0.09	0.00	0.00	0.00	0.10	0.00	0.23	0.04
Complex agroforest (CmA)									0.07	0.00	0.00	0.00	0.10	0.00	0.32	0.11

Land use system	AcP	AgP	SAF	SM	CcA	CoA	DAF	CmA	PP	UF	RM	SH	SF	TP	TAF	TM
Pines plantation (PP)										0.00	0.00	0.00	0.00	0.00	0.19	0.00
Undisturbed forest (UF)											0.00	0.00	0.00	0.00	0.00	0.00
Rubber monoculture (RM)												0.00	0.00	0.00	0.00	0.00
Shrub (SH)													0.00	0.00	0.00	0.00
Snakefruit agroforest (SF)														0.00	0.16	0.00
Tea plantation (TP)															0.00	0.00
Teak agroforest (TAF)																0.31
Teak monoculture (TM)																
Pole																
Acacia plantation (AcP)		0.00	0.04	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.16
Agathis plantation (AgP)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sengon agroforest (SAF)				0.67	0.00	0.49	0.09	0.13	0.00	0.00	0.00	0.00	0.07	0.00	0.14	0.03
Sengon monoculture (SM)					0.00	0.28	0.03	0.05	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.00
Cacao agroforest (CcA)						0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coffee agroforest (CoA)							0.09	0.10	0.00	0.00	0.00	0.00	0.14	0.00	0.12	0.00
Duku agroforest (DAF)								0.16	0.00	0.00	0.00	0.00	0.21	0.00	0.11	0.00
Complex agroforest (CmA)									0.00	0.00	0.00	0.00	0.09	0.00	0.17	0.04
Pines plantation (PP)										0.00	0.00	0.00	0.00	0.00	0.00	0.00
Undisturbed forest (UF)											0.00	0.00	0.00	0.00	0.00	0.00
Rubber monoculture (RM)												0.00	0.00	0.00	0.00	0.00
Shrub (SH)													0.00	0.00	0.02	0.00
Snakefruit agroforest (SF)														0.00	0.04	0.00
Tea plantation (TP)															0.00	0.00
Teak agroforest (TAF)																0.72
Teak monoculture (TM)																
Tree																
Acacia plantation (AcP)		0.00	0.02	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.06	0.04
Agathis plantation (AgP)			0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Land use system	AcP	AgP	SAF	SM	CcA	CoA	DAF	CmA	PP	UF	RM	SH	SF	TP	TAF	TM
Sengon agroforest (SAF)				0.86	0.03	0.26	0.08	0.27	0.00	0.00	0.00	0.00	0.03	0.08	0.09	0.03
Sengon monoculture (SM)					0.01	0.22	0.05	0.20	0.00	0.00	0.00	0.00	0.02	0.07	0.05	0.01
Cacao agroforest (CcA)						0.01	0.06	0.06	0.00	0.00	0.00	0.01	0.04	0.01	0.04	0.02
Coffee agroforest (CoA)							0.17	0.32	0.00	0.00	0.00	0.00	0.12	0.39	0.11	0.00
Duku agroforest (DAF)								0.24	0.00	0.00	0.00	0.00	0.11	0.16	0.15	0.02
Complex agroforest (CmA)									0.00	0.00	0.00	0.00	0.07	0.10	0.28	0.06
Pines plantation (PP)										0.00	0.00	0.00	0.00	0.00	0.00	0.00
Undisturbed forest (UF)											0.00	0.00	0.00	0.00	0.00	0.00
Rubber monoculture (RM)												0.00	0.00	0.00	0.00	0.00
Shrub (SH)													0.00	0.00	0.00	0.00
Snakefruit agroforest (SF)														0.04	0.09	0.02
Tea plantation (TP)															0.08	0.00
Teak agroforest (TAF)																0.75
Teak monoculture (TM)																

3.3 Above-ground Carbon Stock

Slow-growing, timber-based agroforest, complex agroforest and duku agroforest as germplasm conservation areas contained about 60% of the carbon stock in the undisturbed forest, but twice as much as the fast-growing, timber-based systems of acacia and sengon (Table 6).

Table 6. Above-ground carbon stock of various land use systems

Land use system	Number of plots	Above-ground carbon stock (Mg ha^{-1})						
		Tree	Necromass	Understorey	Litter	Frond	Stalk	Total
Undisturbed forest	1	162.7	7.3	3.9	8.5	-	-	182.4
Agathis plantation	6	110.1	0.6	2.3	4.5	-	-	117.5
Pines plantation	6	80.9	0.1	0.7	1.0	-	-	82.8
Acacia plantation	3	48.0	0	0	0	-	-	48.0
Duku agroforest	3	84.0	0	0.2	1.1	-	-	85.3
Complex agroforest	5	77.6	0.4	0.2	1.6	-	-	79.8
Teak agroforest	7	69.8	0.1	0.5	0.6	-	-	71.0
Teak monoculture	6	60.5	0	0.5	0.8	-	-	61.7
Rubber monoculture	9	49.6	0.1	0.5	0.5	-	-	50.7
Sengon agroforest	7	43.1	0	0.5	0.7	-	-	44.4
Sengon monoculture	6	39.6	0.1	1.6	0.5	-	-	41.8
Cacao agroforest	3	33.8	0.5	1.7	2.4	-	-	38.3
Coffee agroforest	3	24.3	0.1	0.4	1.2	-	-	26.0
Snakefruit agroforest	2	6.6	0	0.2	0.6	10.03	1.28	18.7
Tea plantation	2	17.7	0.1	1.2	1.1	-	-	20.1
Shrub	2	2.5	0	3.3	0.1	-	-	5.9

Conclusions

Higher tree species richness and diversity were found in the complex systems of the complex agroforest, duku agroforest and teak agroforest which were low intensively managed. High species richness and tree diversity under medium and intensive management such as for timber plantations and crop-based agroforestry managed by companies (both state-owned and private) only occurred in the seedling stage. Weeding activity had a high impact resulting in tree species being lost from systems. Wild pioneer species were commonly found as a dominant species in any land use system in the seedling stage. No tree species common among land use systems were found in undisturbed forest, acacia and teak monoculture plantation. Complex systems and slow-growing, timber-based systems contained greater carbon stock than fast-growing, timber-based and crop-based systems.

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