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PLANT SPECIES DIVERSITY IN RELATION TO CARBON STOCKS AT JANGKOK WATERSHED, LOMBOK ISLAND

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ABSTRACT

Jangkok watershed has changed from a degrading forest to become a mosaic of land use systems. This research compared plant species diversity and C-stocks across land use systems. The research analysed the characteristics of six land use systems in a total of 18 plots i.e.Primary Forest (PF), Disturbed Forest (DF), Mahogany-Woodlot (MW), Candlenut-Agroforestry (CA), Multi strata Agroforestry (MA), and Simple-Agroforestry (SA).The species diversity level was measured using Shannon-Wiener index, while C-stocks were assessed according to the RaCSA method. Results showed that forest conversion to agricultural land uses reduced the number and density of tree species, average wood density and basal area. The PF represented the highest biodiversity index (3.46), while the other land uses were categorised as medium to low. The largest C-stock was found in PF and in MW, with the average of 550 Mgha^{-1}, while the lowest was in SA (70 Mgha^{-1}), with other land uses around 219 Mgha^{-1}.The quantity of C-stocks was not related to species diversity, but closely related to wood density (R^2=0.84), basal area of all sizes of tree (R^2=0.86), and the basal area of trees diameter >30 cm (R^2=0.71). Based on the number and species density, MA and CA resembled the characteristics of DF and PF.

Keywords: land use, plant species diversity, carbon stocks, primary forest, agroforestry

INTRODUCTION

Plant species diversity is an integral part of ecosystems (Thomson *et al*., 2011), and provides ecosystem services valuable for human life (Nasi *et al*., 2002). However, the importance of plant diversity in natural resource management and cultivation has not been closely taken into account by policy makers (Thomson *et al*., 2011).

The Jangkok watershed contains 60% of forest (11.453 ha). This forest area has a higher biodiversity level than other forest areas in the province of West Nusa Tenggara simply because the forest is in a good condition (Prayitno *et al.*, 2001). However, according to Tjakrawarsa *et al*., (2008), the flora and fauna in the forest areas of Lombok island keeps decreasing due to the land use change practices. Sousson *et al* (1995) and Chapin *et al* (2000) asserted the importance of maintaining plant diversity ecologically during this era of climate change is worth-doing in order to maintain the stability of macroclimate by means of the absorption and storage of carbon, maintain the balance in hydrological functions, maintain the soil quality by means of improvement of organic materials and soil nutrient, control erosion, and function as habitat for flora and fauna. Deforestation and forest degradation have caused the change in the composition, structure and function of plant diversity, which leads to the disruption in the ecosystem (Palmer *et al*., 2004; Hector *et al*., 2007; Spanos *et al*., 2007). As suggested by Loresu *et al*., 2001; Aerts *et al*., 2011, the challenge that may be faced in the near future is to maintain the environmental balance in order to keep up with the ever-changing dynamic of species diversity by not only relying on programmes aiming to protect but also being involved on those aiming to restore and rehabilitate.

As indicators of decreasing of species diversity level, a diversity index was used (Chapin *et al*., 2000; Sharman *et al*., 2012). Kessler *et al* (2005) reported a very high level of tree diversity

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in primary forest of Lore Lindu (Central Sulawesi), where 150 species of trees with the tree diameter >10 cm, and the highest basal area of 140 m^2 ha^{-1} were found. The abundance of tree species kept decreasing since the degradation due to land use change into agroforestry took place. Based on the research conducted in three villages in TN Lore Lindu, Kehlenbeck *et al* (2004) found 149 useful plant species from the following categories: fruits, vegetables, medicines and spices. The composition and plants density from those three villages were also found different from one another depending on the social and economic background of the owners and soil fertility.

The loss of plant diversity due to land use change varies depending on the form, the structure and the change of vegetation composition. The degradation of plant species diversity due to the forest land use change into other functions is associated with decrease of biomass and carbon stock (Chapin *et al*., 2000; Hairiah *et al*., 2006). However, the decrease of biodiversity index of species is not always followed by the decrease of carbon stock (Rahayu *et al*., 2012; Kendom *et al*., 2013), depending on the number of trees with high wood density. In general, trees with slow growth have high wood density and tend to store carbon longer (Hairiah *et al*., 2011). According to Michelsen (2008), the change in land use, biodiversity, and carbon stock tend to occur simultaneously. This research aimed to establish the degree of correlation between plant species diversity and carbon stocks in several land use systems in the forests at Jangkok watershed. The result of this research is expected to be useful for determining a suitable strategy for forest resource management.

MATERIALS AND METHODS

Research Plots and Sites

This research was conducted in Jangkok watershed, Lombok island, in a study area defined by its geographical position of 116^{o}20'- 116^{o}31'E and 8^{o}43' - 8^{o}49'S, which comprises several villages such as Sesaot, Ranget and Buwun Sejati. The climate at the headwater of Jangkok watershed consists of four-month dry and eight-month wet climate. Based on the Schmidth Ferguson classification, such climatic characteristics are categorised in type C climate (Kurniawan *et al*., 2012). The annual average rainfall from 2005-2010 was 1392-1752 mm, or 1634 mm/year. According to Chave *et al* (2005), this area is categorised as a humid zone with its average rainfall of 1500-4000 mm/year. The soil texture in the area of the research is sandy with the average soil content of 63% in 0-30 cm in depth

The observation was conducted in 6 land use systems: (a) primary forest (PF), (b) disturbed forest (DF), (c) mahogany woodlot (MW), (d) candlenut agroforestry (CA), (e) multi strata agroforestry (MA), (f) simple agroforestry (SA).

Eighteen plots were selected to be involved in the measurement process with the following details: PF=2 plots, DF=3 plots, MW=2 plots, CA=4 plots, MA=5 plots, and SA=2 plots (Figure 1). Observations of tree species diversity and C stock used a plot size of 5 x 40 m^2, but were extended to 20 x 100 m^2 when trees with diameter (DBH) exceeding 30 cm were found (Hairiah *et al*., 2011).

Analysis on Plant Species Diversity

Tree species diversity observed in this research focused on trees with DBH ≥ 5 cm, measured at 1.3 m above the ground *(DBH= Diameter at Breast Height)*. The observation of plant species diversity relevant to carbon stock consisted of (Ludwiq *et al*., 1988; Prayitno *et al.,* 2001; Indriyanto, 2008): (a) species richness, (b) plant density, (c) wood density, (d) basal area, (e) species richness index, (f) species similarity between land uses, (g) importance value index, (h) biodiversity index, and (i) cluster and Biplot analysis. The species richness of plants represents the total number of species in the observed plots. The species density represents the number of the whole species in a measurement unit (ha). Relative density was the percentage of individuals in each species and the total number of individuals in all species. Wood density was put into four categories: (1) light wood (<0.6 g cm^{-3}); (2) medium wood (0.6 – 0,7^{5}g cm^{-3}); (3) heavy wood 0.75 – 0.9 ^{g} cm^{-3}); (4) very heavy wood (> 0.9 g cm^{-3}). The values of wood density were accessed in the publication of ICRAF on the following website: http://www. worldagroforestry.org/sea/Products/AFModels/treenwood/treenwood.htm

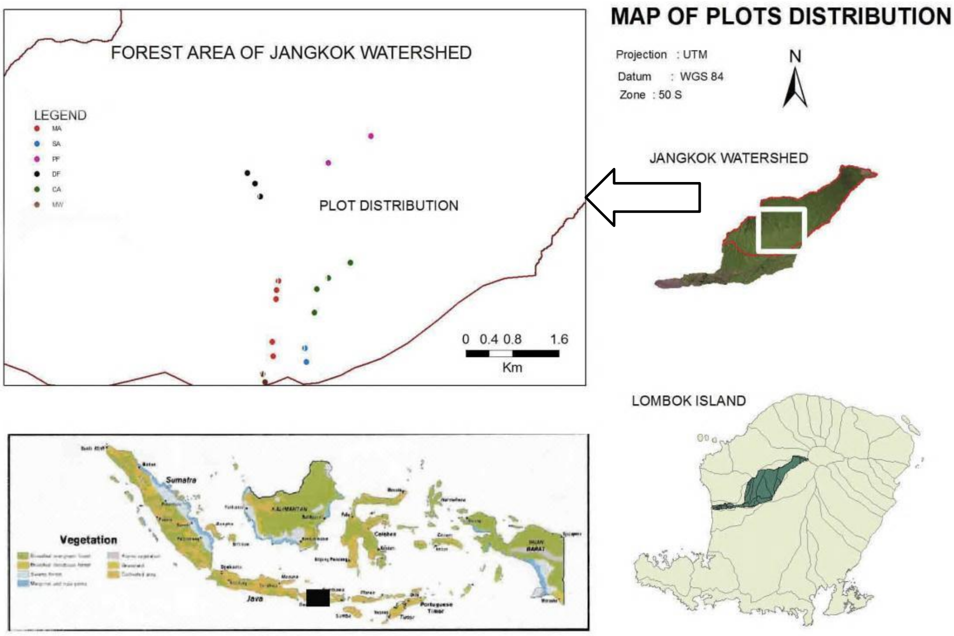

Figure 1. Site of plot distribution at Jangkok Watershed

The basal area describes the width of vegetation cover in an area where samples were taken in the following formula: BA (m^2) = Σπ $(D)^2/4$, where D is DBH. Importance Value Index represents the amount of Relative Density (RD) and Relative Dominance (RDs), so that the Importance Value Index is 0-200 %. Species Richness Index (SRI) represents the comparison of individual number of species in one community, where the smaller the SRI value, or the closer the value to 0, the lower value of species richness would be. Biodiversity index involves the following formula by Shannon-Wiener (H')

$$H' = -\sum_{i=0}^{n} \left(\frac{ni}{N}\right) Ln\left(\frac{ni}{N}\right)$$

Where :
ni = number of species
N = the total number of individuals of species

When H' < 1, the species diversity was low (unstable). When H'1–3, the diversity was average (fairly stable). When H' > 3, the species diversity was high (stable). Species Similarity Index (SI) describes the level of species abundance. When all species had the same level of species abundance, the SI would be at maximum level. However, species with different level would cause the SI to plummet to 0.

$$SI = \frac{H'}{Ln\ (S)}$$

Where:
H' = Shannon-Wiener Index
S = Species Richness.

Species similarity would be high when the value of SI ≥ 0.9; the species similarity would be average when 0.5<SI<0.9; and the species similarity would be low when SI ≤ 0.5.

Carbon Stock Analysis

The measurement of carbon stock in this research was based on Rapid Carbon Stock Appraisal (RaCSA) (Hairiah *et al*., 2011) which consists of tree and root biomass, understorey, necromass, litters, and soil. The biomass of trees in this research was analysed by using allometric equations developed by Chave *et al* (2005), while for the humid areas (with the rainfall ranging from 1500 – 4000 mm yr^{-1}) and other kinds of agroforestry trees, the allometric model was employed (Ketterings *et al*., 2001; Krisnawati *et al*., 2012).

Cluster Analysis

Cluster Analysis was employed in order to group the land use based on the similar characteristics of all variables (Tryfos, 1997; Rambamoorthi, 2013). The grouping was done by using similarity analysis according to Bray-Curtis Index on the analysis of seven variables: species and plant number, wood density (WD), basal area (BA), Shannon-Wiener Diversity Index, and Rate of Endemism (ROE) and carbon stock. Bray-Curtis index value ranged from 0-1. The closer it was to 1, the more obvious the similarity between object and variable. The analysis was followed by Biplot which was employed in order to find out the correlation clusters among the land use based on the seven variables. PAST Software was used in this analysis.

RESULTS AND DISCUSSION

Species Density, Wood Density and Basal Area

In eighteen plots observed, 68 tree species were found across the different land uses. Most of the species (87%) found were identified as native, while the rest was exotic (Barthlort, *et al*., 1999). The highest number of tree species (38 species) was found in PF, and the smallest number was in simple agroforestry SA (Table 1).

Table 1. Number of species, species density and number of trees

Land use system	Number of Species	Number of big trees ha^{-1}, (DBH>30cm)	Number of medium trees ha^{-1}, (DBH=5-30 cm)
1. PF	38	90	1486
2. DF	23	57	785
3. MW	6	160	420
4. CA	20	174	766
5. MA	18	75	1120
6. SA	4	20	720

Remarks: PF= Primary Forest, DF= Disturbed Forest, MW= Mahogany Woodlot, CA= Candlenut Agroforestry, MA= Multi strata Agroforestry System, SA = Simple Agroforestry System

Wood Density (WD) in various land uses ranged from 0.2 to 1.02 g cm^{-3}. The lowest density was found in Jatropha (*Jatropha curcas*), and the highest density was in Kusum trees (*Schleichera oleosa*). Based on the WD distribution, most of land use had been categorised as light (WD < 0.6 g cm^{-3}), and only the minority had very heavy wood (WD > 0.9 g cm^{-3}), while species of heavy density were not found in MW and SA (Figure 2).

The values of basal areas (BA) of a land represent the density level and DBH of available trees. The results of the analysis show that the highest value of BA was found in MW cover (62 m^2 ha^{-1}), followed by primary forest (50 m^2 ha^{-1}), and simple agroforestry system (6 m^2 ha^{-1}) for the lowest (Figure 3A).

In order to evaluate the composition of types and density of the trees, further analysis was carried out on relative and cumulative BA to BA maximum ($BA_{cumul.}/BA_{max}$), where it was revealed that PF and MA had more trees of various size for the BA and of several categories for the WD (Figure 3B).

Important Value Index (IVI) and Diversity Index (DI)

Every land use had species with the highest IVI different from each other. In PF, the highest IVI was found in *bangsal* (*Enghelhartia spicata*), followed by DF in *Pahung* (*Sauraria leprosa*), MW in mahogany (*Swietenia macrophylla*), CA in candlenuts (*Aleurites moluccana*) and MA and SA in banana (*Musa paradisiaca*) (Table 2).

Species density determines the IVI, while its contribution relies on the value of basal area. In PF, species Sentulmulon, Kepundung and Bajur had the highest species density, while the species density was also found in Sentul and Kelokos in DF, and durian in MA; however, the IVI of these species was not the highest.

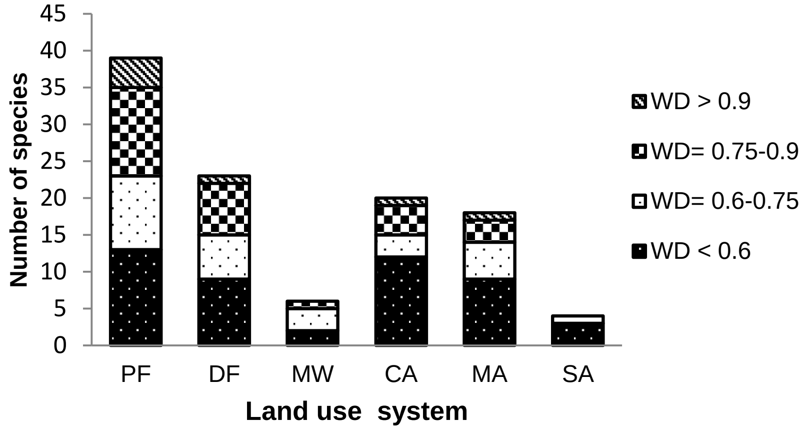

Figure 2. The number of species based on characteristic of their wood density (WD, gcm^{-3}). (PF: Primary Forest, DF: Disturbed Forest , MW: Mahogany Woodlot, CA: Candlenut Agroforestry, MA: Multistrata Agroforestry, SA: Simple Agroforestry)

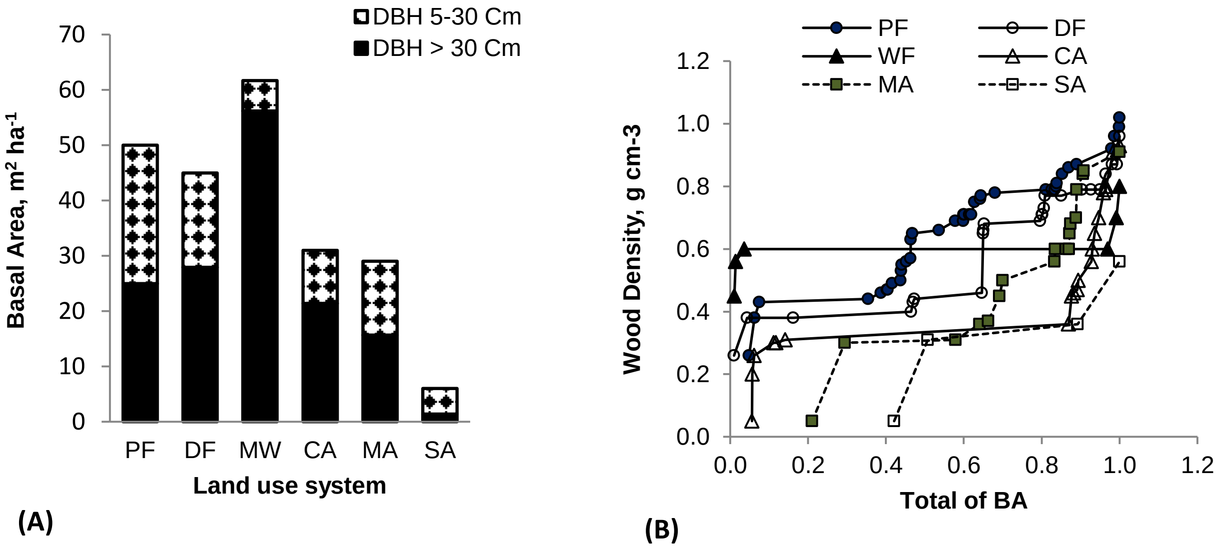

Figure 3. Basal Area (BA) based on DBH (A) and the correlation between WD and cumulative BA (B) (PF=Primary Forest, DF=Disturbed Forest, CA=Candlenut Agroforestry, MW=Mahogany Woodlot, MA=Multi strata Agroforestry System)

Table 2. Five species listed from the highest IVI

Land Use	Five species with the highest IVI			
	Scientific name	**Other name (English)**	**Local name (Indonesia)**	**IVI, 0-200 %**
PF	*Engelhardtia spicata*	Thitswelve	Kukrup	32.2
	Villebrunea rubescens	Watchsell	Nangsi	17.8
	Alphonsea javanica Scheff	Maluwitam	Kelicung	13.3
	Saurauia leprosa	Pahung	Pranajeewa	10
	Aglaia macrocarpa	Birajang	Sentul	9.2
DF	*Sauraria leprosa*	Pahung	Pranajeewa	44.8
	Ficus sp	Banyan	Beringin	28.7
	Knema cinerea	Kumpang	Jelema	26.6
	Laportea stimulans	Jetatang	Jelateng	14
	Laportea decumana	Salad	Jelateng	13.3
MW	*Swietenia macrophylla*	Mahogany	Mahoni	154.1
	Coffea canefora var robusta	Coffee	Kopi	14.8
	Theobroma cacao	Cocoa	Kakao, Coklat	13.7
	Artocarpus integra	Jackfruit	Nangka	9.2
	Durio zibethinus	Durian	Durian	3.8
CA	*Aleurites moluccana*	Candlenut	Kemiri	97.9
	Musa paradisiaca	Banana	Pisang	19.5
	Durio zibethinus	Durian	Durian	15.9
	Nephelium lappaceum	Rambotan	Rambutan	7
	Toona sureni	Suren	Suren	1.7
MA	*Musa paradisiaca*	Banana	Pisang	55.7
	Theobroma cacao	Cocoa	Kakao	19.6
	Coffea canefora var robusta	Coffee	Kopi	16.9
	Lansium domesticum	Langsat	Langsat	8.7
	Nephelium lappaceum	Rambotan	Rambutan	16.2
SA	*Musa paradisiaca*	Banana	Pisang	82.1
	Aleurites moluccana	Candlenut	Kemiri	60.8
	Artocarpus integra	Jackfruit	Nangka	28.7
	Erytrina sp.	Dadap	Dadap	28.4

Remarks: PM= Primary Forest, DF= Disturbed Forest, MW=Mahogany Woodlot, CA= Candlenut Agroforestry, MA=Multistrata Agroforestry System, SA=Simple Agroforestry System

Table 3. Analysis on species diversity index in several land uses

Land Use	Richness Index		Diversity Index		Similarity Index	
	Value	Criterion	Value	Criterion	Value	Criterion
PF	1.06	High	3.46	High	0.93	High
DF	0.93	Medium	2.51	Medium	0.77	Medium
MW	0.26	Low	1.41	Medium	0.79	Medium
CA	0.67	Medium	2.46	Medium	0.82	Medium
MA	0.53	Medium	1.97	Medium	0.68	Medium
SA	0.14	Low	0.49	Low	0.35	Low

Remarks: PF=Primary Forest, DF=Disturbed Forest, MW=Mahogany Woodlot, CA=Candlenut Agroforestry, MA=Multistrata Agroforestry System, SA=Simple Agroforestry System

The diversity index analysed consisted of richness index, diversity and similarity index. PF had met the criteria of high values in those three categories (Table 3). The research by Prayitno *et al.* (2001) in forest areas of Mount Rinjani on dense forest cover showed the similar results, where the diversity index obtained ranged from 3.20 – 3.60. However, those values are smaller than the species diversity of PF in Kalimantan (6.4) (Brearly *et al*., 2004). Those three aforementioned indices were in medium categories for CA and MA, low for SA, and varied for MW.

The Change of Species Diversity

The diversity measurement does not mainly measure the number of species, but more importantly, it looks at the species distribution in one landscape in a particular period of time (Swift *et al*., 2004). However, the change in the number of species is an important indicator used to value the dynamic and quality of environment integrally (Hector *et al*., 2007). The land use change in Jangkok watershed gradually reduced species diversity, their density, and the average of wood density (WD) (Figure 4).

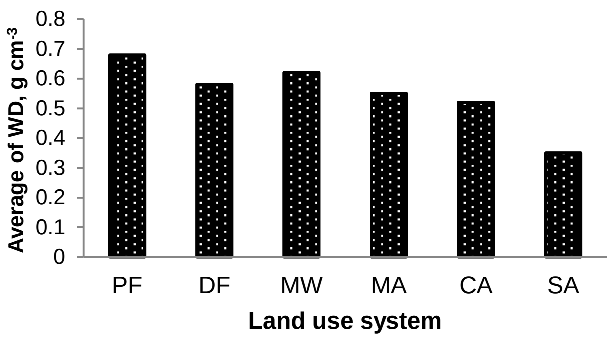

Figure 4. The average of wood density (WD) of various land use systems (PF=Primary Forest, DF= Disturbed Forest, MW= Mahogany Woodlot, CA=Candlenut Agroforestry, MA=Multi strata Agroforestry System, SA=Simple Agroforestry System

There were 24 species in PF which were not found any more in DF, and 70% of the lost species had the WD > 0.6 g cm^{-3}. This could be caused by the following factors: (1) the illegal logging on high quality woods in PF and DF, (2) cultivating and enrichment programme in plant such as in mahogany and candlenut which cause the growth of other species to decrease, (3) the development of agroforestry system causing farmers to put the plants that give them more profit in priority over others (Muktar, 2011).

Carbon Stock

Tree biomass is the main component (approximately 63%) of carbon stock, followed by soil organic matter, root biomass, understorey, surface litter and necromass (Table 4). . For PF and MW, the proportion of carbon stock in tree biomass and soil organic matters was 83% and 15%, respectively. Conversely, for SA, the proportion of carbon stock in soil organic matter and biomass was 78% and 17%, respectively. The other components of carbon stock such as understorey, litter and necromass only contributed 3-4% of the total carbon stock. The research conducted in Nunukan regency, East Kalimantan (Lusiana *et al*., 2005) and Sumberjaya, Lampung (van Noordwijk *et al*., 2002) revealed that there was a similar result where the carbon of tree biomass contributed as much as 90% of total carbon stock, and 8-10% came from necromass, understorey and litter.

The carbon stock above ground in PF in DAS Jangkok was larger than the average carbon stock in natural forests in Indonesia ranging from 161-300 Mg ha^{-1} (Murdiyarso *et al*., 2008) while in natural forest in Nunukan(Central Kalimantan) was 230 Mg ha^{-1} (Lusiana *et al*., 2005). This number, however, was lower than that of East Casteel watershed, Papua in the average of 400 Mg ha^{-1} (Kendom *et al*., 2013). The amount of carbon in DF was also higher than that of the natural forests in East Java which was about 253 Mg ha^{-1} (Sari *et al*., 2013).

Table 4. Amount of carbon stocks from five components

Land Use System (LUS)	Amount of C stock, Mg ha^{-1}						Total C-stock Mg ha^{-1}
	Tree Biomass	Root	Under storey	Surface Litter	Necromass	Soil 0-30 cm	
1. PF	375	93	2.40	5.80	0.70	77.6	554
2. DF	178	44	1.90	4.20	0.80	75.4	304
3. MW	389	97	6.40	4.50	0.90	61.3	559
4. CA	118	29	2.10	2.40	1.80	69.9	223
5. MA	95.1	23	0.50	2.00	0.30	66.8	188
6. SA	10.9	2	1.50	1.80	0.10	53.6	70

Remarks: PF=Primary Forest, DF=Disturbed Forest, MW=Mahogany Woodlot, CA=Candlenut Agroforestry, MA=Multistrata Agroforestry System, SA=Simple Agroforestry System

Correlation of Wood Density and Basal Area to Carbon Stock

Wood density, basal area of all trees (DBH=5-30 cm), and basal area of big trees (DBH>30cm) are the main factors affecting the carbon stock (Figure 5A, 5B, 5C), while the tree density did not affect the level of carbon stock (Figure 5D).

This fact caused uncertainty in estimating the carbon stock based on analysis of satellite imagery which relies only on canopy cover of vegetation (Leaf Area Index). Therefore, carbon calculation at landscape level based on spacial analysis must be accompanied by an measurement of the basal area and identification wood density of trees.

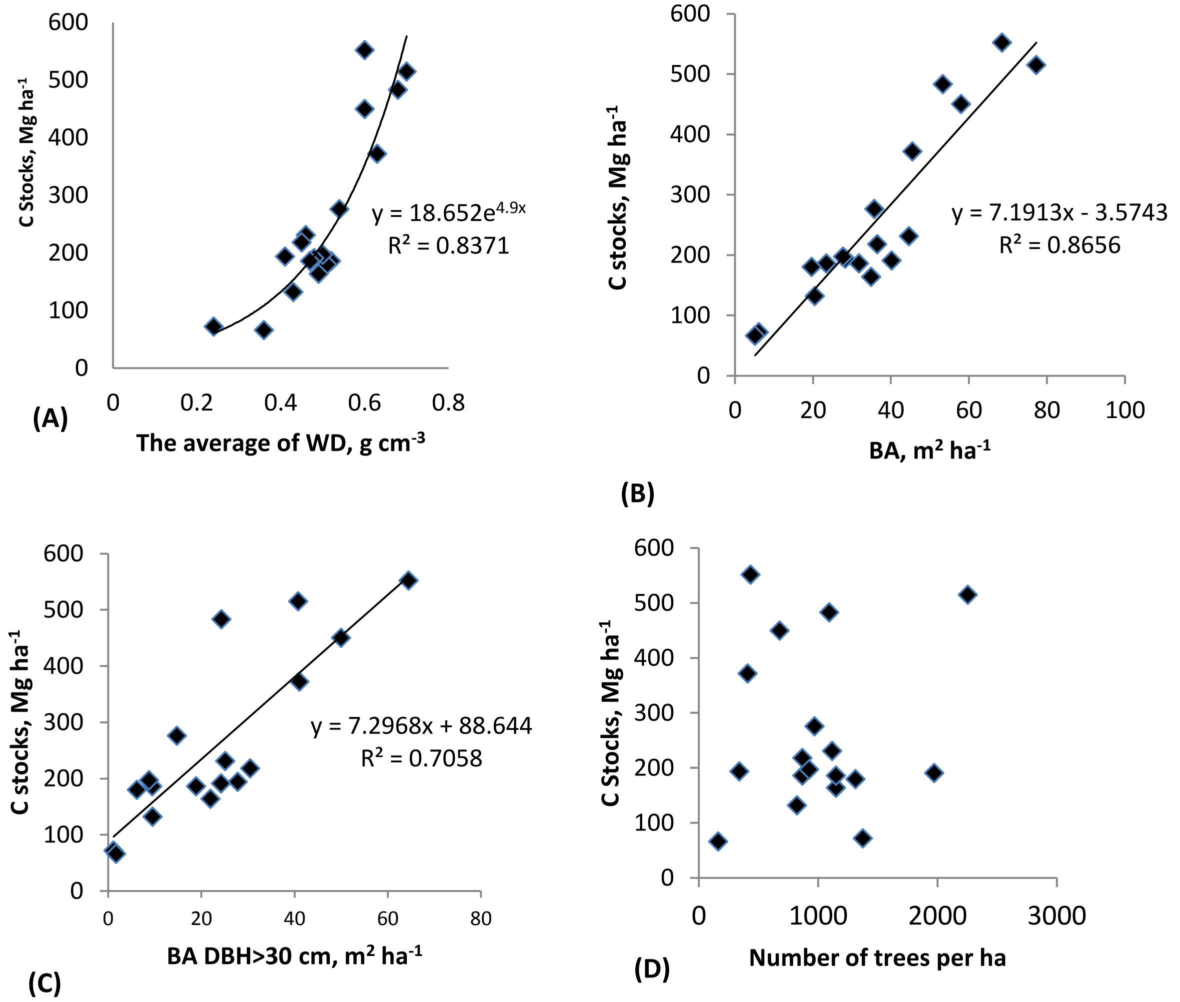

Figure 5. Correlation between plot characteristics and carbon stock (A), correlation between basal area and carbon stock (B), correlation of basal area and DBH> 30 cm to carbon stock (C), and correlation between number of trees and carbon stock (D) in several kinds of land use of 18 measured plots.

Cluster Analysis

The result obtained from cluster analysis on species diversity by Bray-Curtis was ≥ 0.8, where the land uses in Jangkok watershed were divided into 4 clusters: 1=CA, MA, 2=PF and DF, 3=MW and 4=SA. PF and DF were in the same cluster as they were characterised by similar value of richness index, Shannon-Wiener Index, Rate of Endemism (ROE), and wood density, where they showed high value. Meanwhile, with their medium values, MA and CA had similarity in almost all variables. MW was in separated cluster which was characterised by high values of basal area and carbon stock, while SA was characterised with low value in all variables, especially in ROE (Figure 6A).

Biplot analysis underlines that carbon stock value is not closely correlated to species diversity. High carbon stock does not always provide high diversity index, as shown in MW. The cultivation of either MA or CA was close to that of DF and PF, which indicates that MA, CA were possibly similar to DF and PF especially in the number of species, diversity index and richness index. Different result was shown in cluster analysis according to plant community structure (Figure 6B), where there seemed to be no grouping in several kinds of land use, which indicates that species and species structure of each land use had undergone some significant changes, so that different land use brought different characters.

CONCLUSION

Land use change has led to changes in plant species diversity, the number and density of the species, the average of wood density and basal area of trees. Number of species in the PF (38 species) decreased to 42-84% due to the land use conversion. Mostly (70%), the decrease was triggered by the decreasing tree species whose wood density was > 0.6 g cm^{-3}. The highest diversity index was found in PF (3.46), and the lowest in SA (0.49), while in other land uses in a range of 1.41 to 2.51. Land use changes also led to the change in carbon stocks. The highest carbon stock was found in MW and PF (around 550 Mg ha^{-1}), followed by the average amount of carbon stock in DF (304 Mg ha^{-1}), CA (223 Mg ha^{-1}), MA (188 Mg ha^{-1}), while the lowest carbon stock was in SA (70 Mg ha^{-1}). Plant density was not closely correlated to carbon stock. In fact, basal area of trees and wood density were the two factors that affect the level of carbon stock, in which the increase of the basal area and wood density was followed by the increase of carbon stock. The diversity index and species richness of MA and CA were slightly similar to those of DF and PF which indicates the success of agroforestry practices.

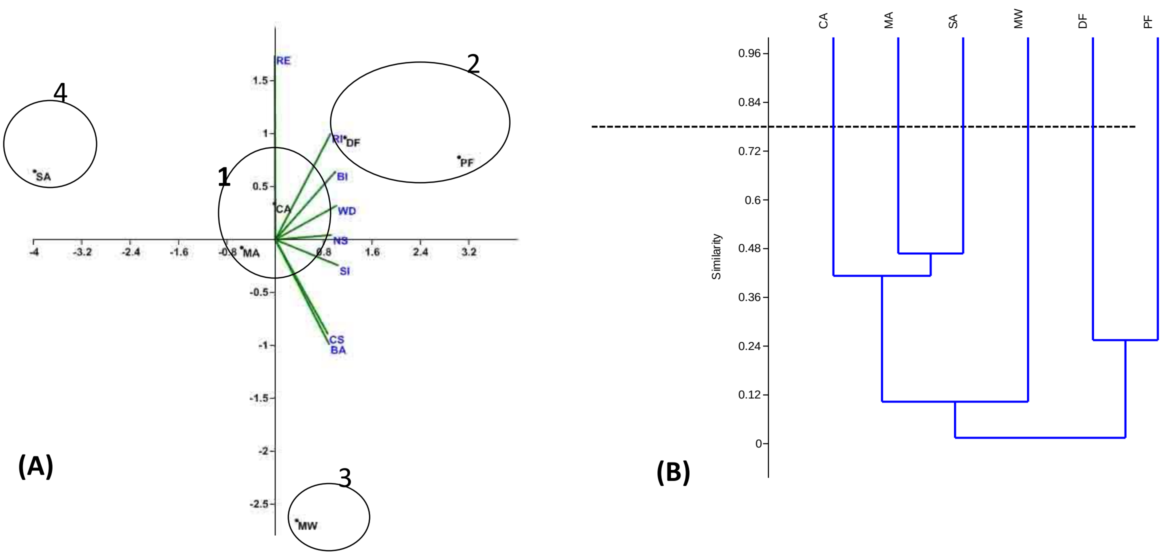

Figure 6. Cluster and Biplot analysis according to species diversity. (A) cluster analysis according to species structure (B) (RI=Richness Index, BI= Biodiversity Index, SI=Similarity Index, WD=Wood Density, NS=Number of Species, ROE=Rate of Endemism, BA=Basal Area, CS=Carbon Stocks

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