Working Paper

Tree diversity and carbon stock in various land cover systems of Jayapura, Jayawijaya and Merauke Districts, Papua Province

Subekti Rahayu and Sidiq Pambudi

World Agroforestry Centre

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Abstract

Various ecosystems, huge area of swampy in Merauke, lowland forest in Jayapura and subalpine forest in Jayawijaya are found in Papua Province. During economic development, most of forest area in Papua is under threat due to source of agriculture land, timber plantation and infrastructure development. Forest conversion various purposes increase carbon emission and biodiversity lost. Developing mitigation action strategies as part of land use planning in Papua was done through considering balance between economic growth and sustainable forest function. Tree diversity and carbon stock is necessarily important to be assessed as input in land use planning. Amount of 64 plots of 20 x 100 m in 15 land use systems in Jayapura, Jayawijaya and Merauke were set up to observe tree species diversity and estimate carbon stock in each land use systems. Tree species richness in the natural ecosystems of Jayapura was higher than in Jayawijaya and Merauke due to biophysical conditions. The most important species in the man-mad ecosystems varied depending on the market conditions, with betel nut predominating in Jayapura while the most important was coffee in Jayawijaya and mixed fruits in Merauke. Natural ecosystems provide the best area for tree species conservation, in contrast to man-made ecosystems. Undisturbed dry land forest in Jayapura and Merauke contained the highest carbon stock compared to the other ecosystems, but pines forest and complex agroforest contained the highest carbon stock in Jayawijaya.

Keywords

Carbon stock, sustainable development, Papua, tree diversity

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1. Introduction

Papua has 25.8 million ha of forest which is equal to 83% of the province's total area. The most natural forest is in pristine condition which provides significant ecosystem services. Not only does this forest store a vast amount of carbon, therefore contributing to climate regulation, but also it serves as habitat for the extremely rich biodiversity. Many of the species are endemic flora and fauna owing to the diversity of the ecosystems. The topology of natural land cover terrain varies from lowland and montane rainforests, through freshwater swamp forests, mangroves, tropical savanna and grasslands to sub-alpine grasslands.

Greenhouse gases emission in Indonesia mostly is caused by forest conversion into other land uses (Harris et al 2012). The loss of forest cover has led to a loss of biodiversity that reduces the ecosystem services including carbon sequestration. Tree stands are the most affected component, caused by land use changes due to land clearing activity.

Planning in landscape management provides an important means of balancing social-economic needs with environmental sustainability as an action toward climate change mitigation. Therefore, assessment of the characteristics and potential existing land cover is needed in planning future development.

The effort to reduce emissions of CO_2 in the atmosphere is resulting in increased carbon sequestration. However, the level of carbon uptake by terrestrial ecosystems is dependent on three aspects: 1) vegetation (species composition, structure, and age of the vegetation), 2) conditions (variations in climate, soils, and natural disturbances such as forest fires) and 3) land management (Hairiah 2007). Of these three aspects, the most appropriate effort to reduce carbon in the air is through the management of vegetation, especially trees, as measuring carbon estimation through trees is relatively easy.

The value of the carbon stock of land cover is highly dependent on the presence of trees, as one component of the carbon pool, with specific information required on tree size, density and the characteristics of each species. While the sustainability of environmental services is not only characterized by the presence of trees alone, the existence of a certain tree species composition can have specific roles including supporting the sustainability of other species. In this study, we assessed the diversity of trees across land use systems and estimated the tree-based carbon stock.

The study location was spread over three districts in Northern Papua (Jayapura), Central Papua (Jayawijaya) and Southern Papua (Merauke) which have specific characteristics of the ecosystems from the central highlands to the dry lowlands and wetlands, different governance systems, a wide range of dynamics and drivers of land-use and land-use changes, and mixed capacity for low emissions development planning and implementation. The objectives of this study were: (1) to estimate the carbon stock in various land use systems as input data for land use planning for low emission development in the LUWES and LUMENS framework and (2) to assess tree diversity in various land use systems as the environmental services component in the LUMENS framework.

2. Methods

2.1 Study site

Tree diversity and carbon stock assessment was conducted in three districts of Papua Province, namely,: Jayapura, Jayawijaya and Merauke (Figure 1) The distribution of plot samples in the three districts covered various land use systems, with four types in Jayapura (undisturbed forest, sago forest, cacao agroforest and complex agroforest), five types in Jayawijaya (undisturbed forest, disturbed forest, pines forest, sengon agroforest and complex agroforest), 10 types in Merauke (Undisturbed dry land forest, disturbed dry land forest, undisturbed swamp forest, disturbed swamp forest, undisturbed mangrove forest, disturbed mangrove forest, shrub on dry land, shrub on swamp, complex agroforest , tree-based monoculture plantation).

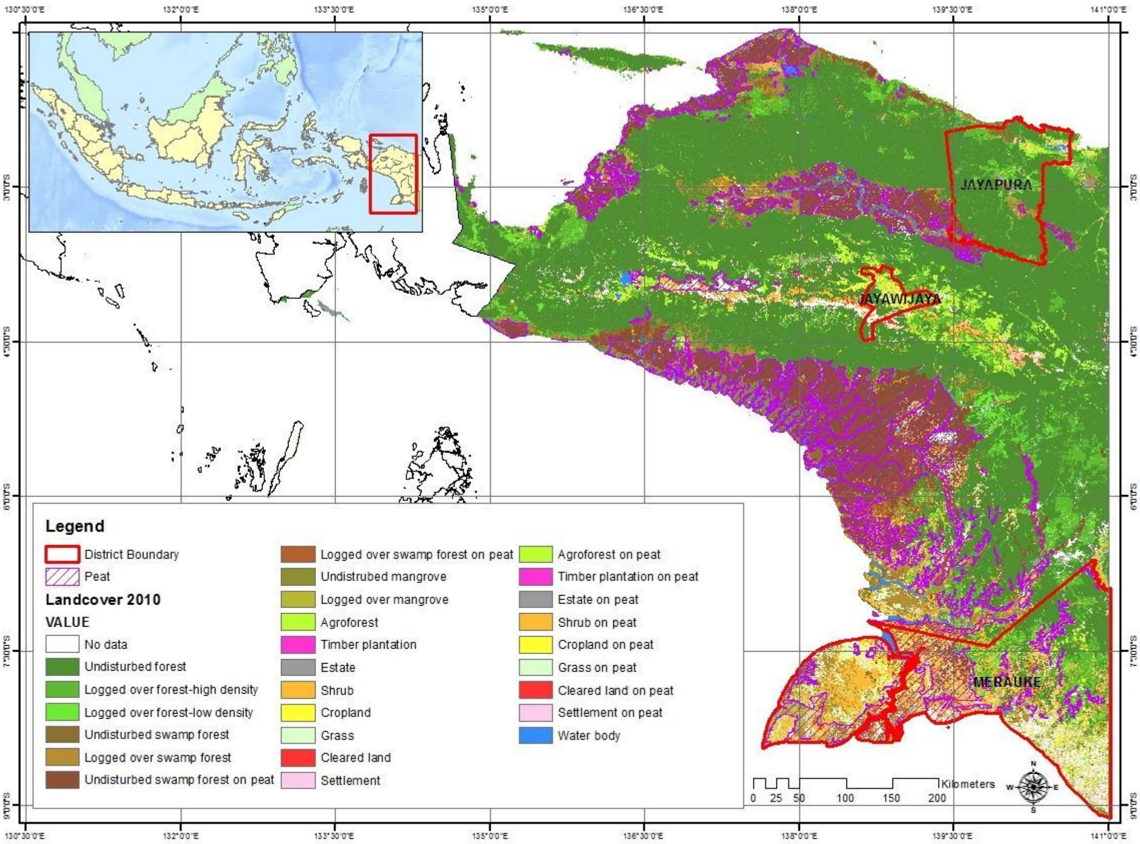

Figure 1. Study area

2.2 Sampling method

The sampling method for carbon stock assessment referred to the widespread method developed by Hairiah et al (2011); tree diversity assessment was also undertaken in the same plots as carbon stock determination with small modifications. Plots 2,000 m^2 in size (20 x 100 m) were placed in middle areas of observed land uses.

2.2.1 Tree diversity

Tree diversity sampling was done for four stages of tree growth, namely: seedling (woody plant less than 2 m height), sapling (woody plant less than 5 cm diameter at breast height/DBH, above 2 m height), pole (woody plant 5–10 cm DBH) and tree (woody plant above 10 cm DBH). Nested plots were set up in a 20 x 100 m plot to observe different stages of vegetative growth (Figure 2), with subplots (2 m x 2 m for seedling, 5 m x 5 m for sapling, 10 m x 10 m for pole and 20 m x 20 m for tree). All seedlings and saplings inside the respective subplots were identified through collecting leaf specimens and counting the individual number of each species. All poles and trees inside the respective subplots were measured for DBH and identified through their leaves, as well as flower and seed specimens if available.

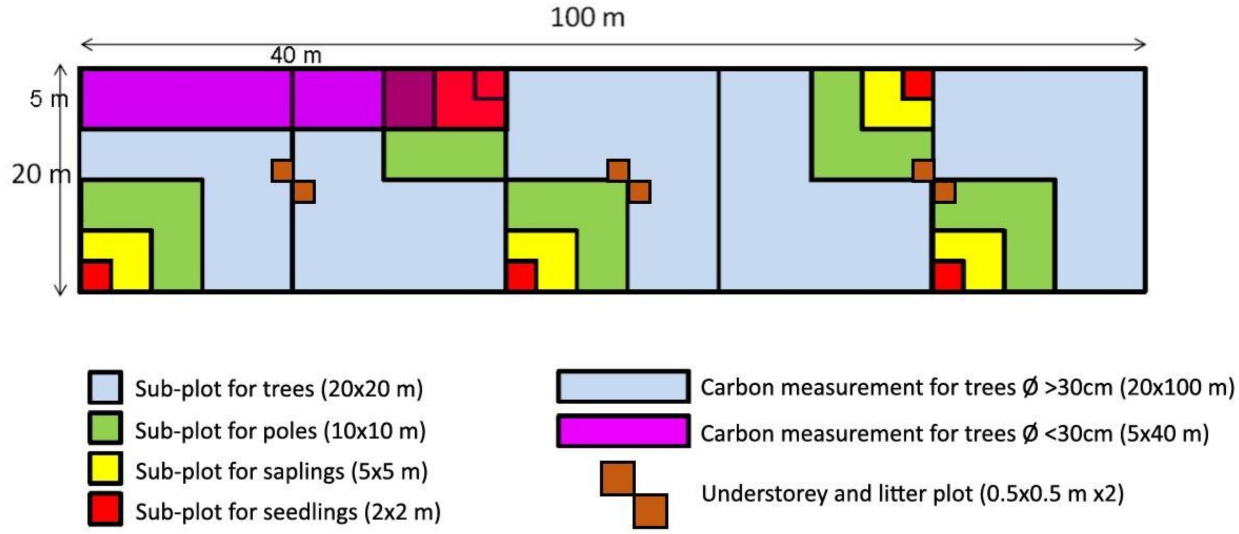

Figure 2. Plot design for tree diversity analysis

2.2.2 Aboveground carbon stock

Carbon stock assessment focused on the aboveground vegetation divided into four carbon pools: tree biomass, understorey, tree necromass and litter. A non-destructive method was applied to estimate tree biomass using allometric equations, while understorey and litter sampling used a destructive method by taking samples. Biomass estimation for large living and dead trees above 30 cm DBH was analyzed within the 2,000 m^2 plot, while the smaller living and dead trees (5–30 cm DBH) were analyzed in a 200 m^2 plot (5 m x 40 m). Understorey and litter sampling were conducted in a quadrant of (2 x 50 x 50 cm) placed randomly inside the 5 x 40 m plot. At least 3 replications were set up during the sampling. All understorey and litter within the quadrant were collected and weighed fresh and then reweighed after oven drying.

2.3 Data analysis

2.3.1 Tree diversity analysis

Species richness, Important value Index (IVI), Bray-Curtis dissimilarity and Shannon's diversity index were used to analyze tree diversity. Species richness is the number of different species represented in an ecological community, landscape or region (Cowell 2009). In this study, species richness represented the number of different species found in a certain land use system.

IVI expresses the dominance of species in the unit area based on their relative frequency, relative density and dominance (Curtis & McIntosh 1950):

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

a. Relative frequency

Relative frequency is the proportion of quadrats sampled in which the species is represented:

$$Frequency\ of\ species\ i = \frac{Number\ of\ quadrats\ with\ species\ i}{Total\ number\ of\ quadrat\ sampled}$$

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

b. Relative density

Relative density is the proportion of a species in relation to the total number of individuals of all species and is estimated by quantifying the number of individuals of a species per unit area:

$$Density\ of\ species\ i = \frac{Number\ of\ individual\ species\ i}{Area\ of\ quadrat\ sampled}$$

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

c. Relative dominance

The dominance of a species is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of the coverage of the rest of the species in the area:

$$Dominance\ (basal\ area\ of\ species\ i) = \frac{\pi * (Diameter\ of\ species\ i)^2}{4}$$

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

The similarity index is a comparison of the current vegetation components on an ecological site. A similarity index determines how closely the current plant community resembles either the potential natural community or some other reference community. The similarity index is expressed as a percentage of the reference community that is currently on the ecological site. The similarity index value varies between 0 and 1; 0 indicates very dissimilar and 1 indicates very similar.

Bray-Curtis dissimilarity (B) Index is used to quantify the compositional dissimilarity between two different sites, based on counts at each site. Bray-Curtis dissimilarity Index uses the individual number as the parameter in the calculation, so that both species and individual parameters affect the degree of similarity of 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 Index; 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 diversity index is a quantitative measurement that reflects how many different species there are on a site. 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 H' commonly varies between 0 and3.5, but 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 (< 1.5), medium (1.5–3.5) and high (> 3.5).

2.3.2 Tree biomass carbon stock analysis

The tree biomass carbon stock is generated from individual tree diameter (D) and wood density (□) using an allometric equation developed by Chave et al (2005) for humid/moist topical forest with precipitation between 1,500 and 4,000 mm/year:

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

For certain species such as coffee, cacao, oil palm, palm, banana and bamboo, we applied specific allometric equations developed by researchers previously (Table 1).

Table 1. Allometric equations for biomass estimation of specific species

Tree 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 of aboveground tree biomass, kg $tree^{-1}$; D = DBH, diameter at breast height, cm; H = tree height, m; ρ = wood density, g cm^{-3} (available from: http://db.worldagroforestry.org/wd).

The proportion used to convert biomass to carbon is 47% (Hairiah et al 2011).

3. Results

3.1 Land cover descriptions

3.1.1 Undisturbed dry land forest

Undisturbed dry land forest in the Jayapura plot samples ranged from low land mixed forest in Yepase (Figure 3) and Harapan village to the higher elevation of Waena village. In Jayawijaya, plot sampling occurred in Wosiala, Gotlan, Sagma II, Sekan and Wililimo villages; while in Merauke, sampling was in three villages of Yagebob, Ulilin, Muting and Eligobel.

Figure 3. Undisturbed forest of Yepase village

3.1.2 Disturbed dry land forest

Disturbed dry land forest plots for Jayawijaya were located in ten villages, they are: Berianggame, Isakusa, Fikha, Molima, Kewir, Napua, Sagma I, Pelima, Ukulik and Wukulik. In Merauke, they were located in four villages of Eligobel, Muting, Bupul and Sota.

3.1.3 Sago forest

Sago plot samples for Jayapura District were located in six villages of Folobo, Kehiran, Kenehulu, Kleublow, Loba and Wambena in areas of monoculture and mixed sago forest (Figure 4).

Figure 4. Mixed sago forest

3.1.4 Cacao agroforest

Cacao agroforest plots in Jayapura were located in Sere village. The old growth cacao system are mixed with betel nut and other fruit trees.

3.1.5 Complex agroforest

Complex agroforest in Jayapura commonly consists of betel nut and other fruits species, since betel nut is a valued product in Jayapura for traditional consumption. In Jayapura, complex agroforest plots were established in four villages of Wambena, Waibron, Dosai and Sabron Sari. In Jayawijaya, complex agroforest consists of coffee with sengon as a shade species and plots were established in two villages of Jagana and Kepima. In Merauke, complex agroforest consists of various fruit tree species and plots were set up in Muting, Nasai and Tanah Miring.

3.1.6 Pines forest

Pine forest is present in Jawajaya as part of mountain forest ecosystems that are dominated by *Casuarina papuana* and *Araucaria cunninghammii* (Figure 5).

Figure 5. Pine forest in Jayawijaya

3.1.7 Sengon plantation

Papua has a familiar clone of sengon that is resistant to rust disease. Large diameter, unlogged sengon trees can be found in Jayawijaya due to the low price of timber (Figure 6). Sengon plots were set up in Tulima.

Figure 6. Sengon plantation in Jayawijaya

3.1.8 Undisturbed swamp forest

Undisturbed swamp forest plots were set up in Merauke, located in Malind, Sota and Tanah Miring and were dominated by *Acacia crassicarpa, Melaleuca cajuputi* and *Melaleuca leucodendron* (Figure 7).

Figure 7. Undisturbed swamp forest in Sota

3.1.9 Disturbed swamp forest

Disturbed forest plots were located in Kurik, Sota, Tanah Miring and Merauke. various species were found in disturbed forest, with some plots dominated by *Melaleuca cajuputi* and *Melaleuca leucodendron.*

3.1.10 Undisturbed mangrove

Undisturbed mangrove plots were set up in Merauke and Semangga and contained various mangrove species (Figure 8).

Figure 8. Undisturbed mangrove in Merauke

3.1.11 Disturbed mangrove

Disturbed mangrove plots were set up in Malind, Semangga and Merauke. The species composition in disturbed mangrove is similar to undisturbed mangrove, but they have different population densities (Figure 9).

Figure 9. Disturbed mangrove in Merauke

3.1.12 Shrub on dry land

Shrubs commonly grow as natural regeneration from forest after disturbance from fire or logging activity. Late succession and pioneer species are found in shrub land cover (Figure 10). Shrub plot samples were set up in Sota, Tanah Miring and Jagebob.

Figure 10. Shrub on dry land

3.1.13 Shrub on swamp

Similar to shrub on dry land, there were late succession and pioneer species associated with the swamp ecosystem found in the plots located in Sota, Tanah Miring, Semangga and Kurik.

3.1.14 Monoculture tree-based

Tree-base monoculture systems in Merauke consist of cashew in Jagebob, rambutan in Ulilin and rubber in Muting.

3.2 Tree diversity analysis

3.2.1 Species richness

Species richness in the three districts of Papua as a measure of the different ecological condition of low dry land (Jayapura), highland (Jayawijaya) and low wet land (Merauke) was significantly different (Table 2). Undisturbed forest, representing natural ecosystems in Jayapura, contained the highest number of tree species compared to Jayawijaya and Merauke. Disturbing the forest ecosystems, in both Jayapura and Merauke did not have much effect on tree species richness, since the total species richness between undisturbed and disturbed forest was relatively similar. However, further analysis of similar species among different land cover types and among the vegetative growth stages is needed to quantify the level of disturbance and the regeneration process after disturbance.

Species richness of seedlings and saplings in undisturbed dry land forest in Jayapura was similar to the tree stage, but different for poles that were only about 50% of the tree stage. A low number of overlapping species among growth stages in the undisturbed dry land forest of Jayapura indicated high species diversity. In Jayawijaya and Merauke, species richness decreased with the vegetative growth stage and there were a large number of overlapping species among growth stages.

Disturbed dry land forests in Jayawijaya contained lower species richness than Merauke, with 51 species found in 11 plots. The species richness in the undisturbed and disturbed dry land forest of Merauke was higher than in swamp and mangrove. Complex agroforest in Jayapura had a similar species richness to Merauke, but was higher than for Jayawijaya.

Comparing the total species richness in each land cover system, species richness in Jayapura was in balance for all growth stages, at about 40% in undisturbed dry land forest, but 50% and 100% contributed by the tree stage for sago and cacao agroforest, respectively. In Jayawijaya, the contribution of species richness in each growth stage was higher than for Jayapura at about 60%, with Merauke the highest at 70%. There was a similar trend in the species richness composition for total species in complex agroforest in the three districts, although Jayawijaya did have lower species richness.

Table 2. Tree species richness in each land cover systems and each growth stage

District	Land cover	No. of plot	Seedling	Sapling	Pole	Tree	Total species
Jayapura	Undisturbed dry land forest	5	82	72	48	83	183
	Sago forest	3	9	9	6	15	26
	Cacao agroforest	2	-	-	4	22	22
	Complex agroforest	6	21	20	16	20	45
Jayawijaya	Undisturbed dry land forest	6	30	26	28	34	49
	Disturbed dry land forest	11	27	30	23	35	51
	Pine forest	1	3	6	5	4	10
	Sengon plantation	1	2	2	1	2	3
	Complex agroforest	2	8	7	7	12	18
Merauke	Undisturbed dry land forest	4	32	40	58	60	64
	Disturbed dry land forest	4	46	43	48	47	62
	Undisturbed swamp forest	3	28	35	28	23	38
	Disturbed swamp forest	4	29	29	34	27	41
	Undisturbed mangrove	3	17	16	14	16	18
	Disturbed mangrove	3	10	11	12	14	14
	Shrub on dry land	3	21	16	15	26	27
	Shrub on swamp	4	22	20	27	26	32
	Complex agroforest	3	17	29	16	18	45
	Tree-based monoculture plantatior	3	5	1	4	4	8

3.2.2 Dominant species

The Important Value Index (IVI) expresses the dominance of species in the sampled area. The species with the highest IVI were different among the types of land cover in the three districts of Jayapura, Jayawijaya and Merauke and among growth stages (Table 3). In this study, only the three highest IVI values have been recorded for each land cover for all growth stages of vegetation.

The dominant species differed in undisturbed dry land forest in each of Jayapura, Jayawijaya and Merauke. The species dominant in Jayapura and Merauke were typically low land mixed forest species, whereas Jayawijaya was dominated by mountainous species. Other natural ecosystems (such as disturbed forest in dry land, swamp and mangrove, as well as shrub in dry land and mangrove) were dominated by naturally growing species. However, the dominant species in the man-made ecosystems (such as cacao agroforest, complex agroforest and monoculture tree-based) were affected by human preference. Betel nut (*Areca catechu*) and cacao (*Theobroma cacao*) were the most dominant pole species in Jayapura, while coconut (*Cocos nucifera*) and matoa (*Pometia pinnata*) were the most dominant in the tree stage.

Ficus microcarpa was the second most dominant species after *Paraserianthes falcataria* in the tree stage in the coffee-based agroforest system in Jayawijaya indicating natural regeneration of the species due to low management. In sago forest, sago (*Metroxylon sago*) was the most dominant species in almost every vegetative growth stage, except for seedlings, as sago seedlings were in a clump included in the 5 x 5 m plot. *Macaranga hypoleuca*, a pioneer species, was the second most dominant in the sago forest.

Avicennia eucalyptifolia is mangrove species that is consistently included in the three most dominant species in all growth stages in undisturbed and disturbed mangrove in Merauke. Even though *Rhizophora* was the most dominant species in all growth stages in undisturbed mangrove, *Acacia eucaluptifolia* was the most dominant in disturbed mangrove. *Melaleuca leucadendra* was dominant species in undisturbed swamp forest in all growth stages and was the most dominant species in the pole and tree stages. Even in disturbed swamp forest, *Melaleuca leucadendra* was the most dominant in the tree stage. The dominance of *Acacia* increased in disturbed swamp forest in the sapling, seedling and tree stages compared to undisturbed swamp forest.

Table 3. Three highest IVI tree species in various land cover systems and growth stage vegetation

Land cover	Seedling	Sapling	Pole	Tree
		Jayapura		
Undisturbed dry land forest	*Syzygium naiadum* *Maranthes corymbosa* *Haplolobus floribundus*	*S. naiadum* *H. floribundus* *Ternstroemia merrilliana*	*Syzygium cf decipiens* *Canarium littorale* *Cryptocarya* sp.	*Syzygium decipiens* *Agathis sp.* *H. floribundus*
Sago forest	*Pometia pinnata* *Myristica subaculata* *Macaranga hypoleuca*	*Metroxylon sago* *M. hypoleuca* *Theobroma cacao*	*M. sago* *Areca catechu* *M. hypoleuca*	*M. sago* *M. hypoleuca* *A. catechu*
Cacao agroforest	-	-	*T. cacao* *A. catechu* *Nephelium lappaceum*	*A. catechu* *N. lappaceum* *T. cacao*

Land cover	Seedling	Sapling	Pole	Tree
Complex agroforest	*A. catechu* *Ficus* sp. *Hibiscus* sp.	*Sterculia ceramica* *P. pinnata* *A. cathechu*	*A. catechu* *T. cacao* *N. lappaceum*	*Cocos nucifera* *P. pinnata* *N. lappaceum*
Jayawijaya				
Undisturbed dry land forest	*Araucaria cunninghamii* *Ficus microcarpa* *Meliosma angulata*	*Glochidion* sp. *Mallotus* sp. *A. cunninghamii*	*F. microcarpa* *A. cuninghamii* *Glochidion* sp.	*Casuarina papuana* *Dacrydium novoguineensis* *A.cunninghamii*
Disturbed dry land forest	*F. microcarpa* *Mallotus* sp. *C. papuana*	*Mallotus* sp. *Glochidion* sp. *C. papuana*	*F. microcarpa* *C. papuana* *Glochidion* sp.	*C. papuana* *F. microcarpa* *Glochidion* sp.
Pine forest	*A. cunninghamii* *Glochidion* sp *Tarenna confusa*	*A. cunninghamii* *Linociera montana* *Glochidion* sp.	*A. cunninghamii* *Glochidion* sp. *Ilex densifolia*	*A. cunninghamii* *Arthrophyllum diversifolium* *Ilex densifolia*
Sengon plantation	*Coffea arabica* *Paraserianthes falcataria*	*C. arabica* *P. falcataria*	*P. falcataria*	*P. falcataria* *C. papuana*
Complex agroforest	*C. arabica* *P. falcataria* *M. angulata*	*C. arabica* *M. angulata* *P. falcataria*	*C. arabica* *Glochidion* sp. *M. angulata*	*P. falcataria* *F. microcarpa* *Glochidion* sp.
Merauke				
Undisturbed dry land forest	*Dipterocarpus cornutus* *Tabernaemontana pubescens* *Knema tomentella*	*D. cornutus* *T. pubescens* *Uncaria gambir*	*Eugenia* sp. *K. tomentella* *T. pubescens*	*D. cornutus* *Actiodaphne nitida* *Euodia elleryana*
Disturbed dry land forest	*Acacia leptocarpa* *Eucalyptus* sp. *Buchanania arborescens*	*Eucalyptus sp* *Eucalyptus pellita* *Acacia mangium*	*E. pellita* *Eucalyptus* sp. *Alstonia beatricis*	*Eucalyptus* sp. *E. pellita* *A. mangium*
Undisturbed swamp forest	*Melaleuca leucadendra* *Melaleuca cajuputi* *Syzygium cauliflorum*	*M. leucadendra* *M.cajuputi* *A. mangium*	*M. leucadendra* *E. pellita* *M. cajuputi*	*M. leucadendra* *E. pellita* *Eucalyptus* sp.
Disturbed swamp forest	*Ficus sp* *M.cajuputi* *E. pellita*	*M. cajuputi* *E. pellita* *A. leptocarpa*	*M. cajuputi* *E. pellita* *A. leptocarpa*	*M. leucadendra* *Acacia auriculiformis* *E. pellita*
Undisturbed mangrove	*Rhizophora apiculata* *Avicennia eucalyptifolia* *Bruguiera cylindrica*	*Rhizophora apiculata* *Sonneratia alba* *A. eucalyptifolia*	*R. apiculata* *Ceriops decandra* *A. eucalyptifolia*	*W. stilosa* *R. apiculata* *A. eucalyptifolia*
Disturbed mangrove	*B. cylindrica* *A. eucalyptifolia* *Hibiscus tiliaceus*	*A. eucalyptifolia* *B. cylindrica* *C. decandra*	*A.eucalyptifolia* *B.cylindica* *Xylocarpus moluccensis*	*A. eucalyptifolia* *A. officinalis* *B. cylindica*
Shrub on dry land	*E. pellita* *Melaleuca viridiflora* *Alstonia beatricis*	*E. pellita* *M. viridiflora* *A. mangium*	*E. pellita* *M. viridiflora* *A. mangium*	*E. pellita* *A. mangium* *M. cajuputi*
Shrub on swamp	*M. leucadendra* *M. cajuputi* *M. viridiflora*	*M. leucadendra* *M. cajuputi* *E. pellita*	*M. cajuputi* *M. leucadendra* *M. leucadendron*	*M. leucadendra* *M. cajuputi* *A.auriculiformis*
Complex agroforest	*N. lappaceum* *Syzigium aqueum* *Codiaeum variegatum*	*Aleurites moluccana* *M. sago* *Anacardium occidentale*	*Citrus aurantium* *Psidium guajava* *Mangifera sp.*	*C. nucifera* *Mangifera indica* *N. lappaceum*
Monoculture treebased	*Ficus septica* *Hevea brassiliensis* *N. lappaceum*	*F. septica*	*N. lappaceum* *A. occidentale* *H. brassiliensis*	*A. occidentale* *N. lappaceum* *H. brassiliensis*

3.2.3 Species similarity among land cover types

The species similarity among the land cover systems of Jayapura are low, except for the tree stage of cacao and complex agroforest that had the highest similarity, with a Bray-Curtis Index of 0.64 (Table 4). However, for both cacao and complex agroforest, there were no overlap species in the seedling and sapling stages. Domesticated fruits species, such as matoa (*Pometia pinnata*), rambutan (*Nephelium lappaceum*), mango (*Mangifera indica*) and betel nut (*Areca catechu*), were found in both complex and cacao agroforest.

Generally, species similarity among land cover systems (both natural and man-made ecosystems) in Jayawijaya was relatively low. Species similarity between undisturbed and disturbed forest in Jayawijaya was at the medium level for all growth stages. Similar results is occur between complex agroforest and sengon plantation for the seedling, sapling and tree stages (Table 5). No overlap species were found between sengon plantation and pine forest at the seedling, pole and tree stages.

Table 4. Matrix of species similarity among land cover systems and growth stages in Jayapura

Growth stage	Land cover system	Land cover system			
		Undisturbed dry land forest	Complex agroforest	Sago forest	Undisturbed dry land forest
Seedling	Undisturbed dry land forest	1	0.01	0	0.03
	Sago forest		1	0	0.17
	Cacao agroforest			1	0
	Complex agroforest				1
Sapling	Undisturbed dry land forest	1	0	0	0.04
	Sago forest		1	0	0.07
	Cacao agroforest			1	0
	Complex agroforest				1
Pole	Undisturbed dry land forest	1	0.01	0	0
	Sago forest		1	0.09	0.06
	Cacao agroforest			1	0.15
	Complex agroforest				1
Tree	Undisturbed dry land forest	1	0.01	0.01	0.02
	Sago forest		1	0.07	0.13
	Cacao agroforest			1	0.64
	Complex agroforest				1

Table 5. Matrix of species similarity among land cover systems and growth stages in Jayawijaya

Growth stage	Land cover systems	Land cover systems				
		Undisturbed dry land forest	Disturbed dry land forest	Pine forest	Sengon plantation	Complex agroforest
Seedling	Undisturbed dry land forest	1	0.48	0.05	0.11	0.15
	Disturbed dry land forest		1	0.05	0.09	0.14
	Pine forest			1	0	0.02
	Sengon plantation				1	0.46
	Complex agroforest					1
Sapling	Undisturbed dry land forest	1	0.47	0.04	0.16	0.14
	Disturbed dry land forest		1	0.03	0.06	0.08
	Pine forest			1	0.01	0.05
	Sengon plantation				1	0.6
	Complex agroforest					1

Growth stage	Land cover systems	Land cover systems				
		Undisturbed dry land forest	Disturbed dry land forest	Pine forest	Sengon plantation	Complex agroforest
Pole	Undisturbed dry land forest	1	0.49	0.1	0.08	0.03
	Disturbed dry land forest		1	0.05	0.06	0.02
	Pine forest			1	0	0.03
	Sengon plantation				1	0
	Complex agroforest					1
Tree	Undisturbed dry land forest	1	0.51	0.16	0.01	0.12
	Disturbed dry land forest		1	0.12	0.02	0.13
	Pine forest			1	0	0
	Sengon plantation				1	0.45
	Complex agroforest					1

Mostly, species similarity among land use systems in Merauke was low for all growth stages with Bray-Curtis Similarity Index values below 0.20 (Table 6). There was medium similarity between undisturbed and disturbed mangrove for all growth stages. Shrub on swamp and disturbed dry land forest to undisturbed and disturbed swamp forest had medium to high species similarity for the sapling, pole and tree stages, but the index tended to be low for the seedling stage.

Table 6. Matrix of species similarity among land cover systems and growth stages in Merauke

Growth stage	Land cover system	Land cover system									
		UDLF	DDLF	USF	DSF	UM	DM	SDL	SSW	CAF	TBM
Seedling	Undisturbed dry land forest (UDLF)	1	0.2	0.06	0.04	0	0	0.08	0.03	0.01	0
	Disturbed dry land forest (DDLF)		1	0.18	0.15	0	0	0.11	0.13	0.04	0
	Undisturbed swamp forest (USF)			1	0	0	0.46	0.14	0.18	0	0
	Disturbed swamp forest (DSF)				1	0	0	0.18	0.21	0.02	0.01
	Undisturbed mangrove (UM)					1	0.19	0	0	0	0
	Disturbed mangrove (DM)						1	0	0	0	0
	Shrub on dry land (SDL							1	0.14	0.01	0
	Shrub on swamp (SSW)								1	0.01	0
	Complex agroforest (CAF)									1	0.04
	Tree-based monoculture (TBM)										1
Sapling	Undisturbed dry land forest (UDLF)	1	0.25	0.05	0.02	0	0	0.09	0.01	0.03	0
	Disturbed dry land forest (DDLF)		1	0.21	0.24	0	0	0.32	0.13	0.06	0
	Undisturbed swamp forest (USF)			1	0.27	0	0	0.15	0.52	0.03	0
	Disturbed swamp forest (DSF)				1	0	0	0.25	0.3	0.05	0
	Undisturbed mangrove (UM)					1	0.22	0	0	0	0
	Disturbed mangrove (DM)						1	0	0	0	0
	Shrub on dry land (SDL							1	0.17	0.04	0

Growth stage	Land cover system	Land cover system									
		UDLF	DDLF	USF	DSF	UM	DM	SDL	SSW	CAF	TBM
	Shrub on swamp (SSW)								1	0.12	0
	Complex agroforest (CAF)									1	0
	Tree-based monoculture (TBM)										1
Pole	Undisturbed dry land forest (UDLF)	1	0.22	0.08	0.06	0	0	0.13	0.04	0	0
	Disturbed dry land forest (DDLF)		1	0.31	0.3	0	0	0.46	0.2	0	0.01
	Undisturbed swamp forest (USF)			1	0.38	0	0	0.3	0.37	0.02	0
	Disturbed swamp forest (DSF)				1	0	0	0.28	0.35	0.01	0
	Undisturbed mangrove (UM)					1	0.38	0	0	0	0
	Disturbed mangrove (DM)						1	0	0	0	0
	Shrub on dry land (SDL							1	0.23	0.01	0
	Shrub on swamp (SSW)								1	0.01	0
	Complex agroforest (CAF)									1	0.07
	Tree-based monoculture (TBM)										1
Tree	Undisturbed dry land forest (UDLF)	1	0.23	0.11	0.1	0	0	0.18	0.04	0	0
	Disturbed dry land forest (DDLF)		1	0.37	0.25	0	0	0.38	0.13	0.03	0.01
	Undisturbed swamp forest (USF)			1	0.43	0	0	0.41	0.3	0.06	0
	Disturbed swamp forest (DSF)				1	0	0	0.26	0.6	0.03	0
	Undisturbed mangrove (UM)					1	0.48	0	0.01	0.01	0
	Disturbed mangrove (DM)						1	0	0	0	0
	Shrub on dry land (SDL							1	0.21	0	0
	Shrub on swamp (SSW)								1	0.05	0.01
	Complex agroforest (CAF)									1	0.06
	Tree-based monoculture (TBM)										1

3.2.4 Species similarity among growth stages

Species similarity among growth stages for certain land cover types varied depending on the management and human intervention during species regeneration (Table 7).

Table 7. Species similarity among growth stages in land cover types for Jayapura, Jayawijaya and Merauke

District	Land cover system	Growth stage	Growth stage			
			Seedling	Sapling	Pole	Tree
Jayapura	Undisturbed dry land forest	Seedling	1	0.26	0.16	0.19
		Sapling		1	0.32	0.22
		Pole			1	0.29
		Tree				1
	Sago forest	Seedling	1	0.15	0.04	0.07
		Sapling		1	0.25	0.38
		Pole			1	0.56

District	Land cover system	Growth stage	Growth stage			
			Seedling	Sapling	Pole	Tree
		Tree				1
	Cacao agroforest	Seedling	1	0.00	0.00	0.00
		Sapling		1	0.00	0.00
		Pole			1	0.25
		Tree				1
	Complex agroforest	Seedling	1	0.18	0.06	0.08
		Sapling		1	0.09	0.12
		Pole			1	0.55
		Tree				1
Jayawijaya	Undisturbed dry land forest	Seedling	1	0.46	0.22	0.26
		Sapling		1	0.4	0.41
		Pole			1	0.32
		Tree				1
	Disturbed dry land forest	Seedling	1	0.62	0.35	0.50
		Sapling		1	0.38	0.39
		Pole			1	0.4
		Tree				1
	Pines forest	Seedling	1	0.29	0.19	0.33
		Sapling		1	0.47	0.08
		Pole			1	0.07
		Tree				
	Sengon plantation	Seedling	1	0.27	0.05	0.16
		Sapling		1	0.28	0.52
		Pole			1	0.44
		Tree				1
	Complex agroforest	Seedling	1	015	0.11	0.05
		Sapling		1	0.8	0.08
		Pole			1	0.04
		Tree				1
Merauke	Undisturbed dry land forest	Seedling	1	0.44	0.31	0.32
		Sapling		1	0.55	0.52
		Pole			1	0.71
		Tree				1
	Disturbed dry land forest	Seedling	1	0.52	0.46	0.4
		Sapling		1	0.67	0.54
		Pole			1	0.67
		Tree				1
	Undisturbed swamp forest	Seedling	1	0.43	0.33	0.32
		Sapling		1	0.49	0.39
		Pole			1	0.7
		Tree				1
	Disturbed swamp forest	Seedling	1	0.62	0.48	0.33
		Sapling		1	0.45	0.3
		Pole			1	0.49
		Tree				1
	Undisturbed mangrove	Seedling	1	0.60	0.34	0.33

District	Land cover system	Growth stage	Growth stage			
			Seedling	Sapling	Pole	Tree
		Sapling		1	0.52	0.5
		Pole			1	0.67
		Tree				1
	Disturbed mangrove	Seedling	1	0.77	0.55	0.46
		Sapling		1	0.46	0.39
		Pole			1	0.74
		Tree				1
	Shrub on dry land	Seedling	1	0.53	0.26	0.27
		Sapling		1	0.51	0.42
		Pole			1	0.67
		Tree				1
	Shrub on swamp	Seedling	1	0.62	0.61	0.47
		Sapling		1	0.69	0.64
		Pole			1	0.67
		Tree				1
	Complex agroforest	Seedling	1	0.33	0.18	0.21
		Sapling		1	0.14	0.19
		Pole			1	0.27
		Tree				1
	Tree-based monoculture	Seedling	1	0.35	0.03	0.02
		Sapling		1	0.00	0.00
		Pole			1	0.49
		Tree				1

Species similarity among growth stages in natural ecosystems are tend to higher than in man-made ecosystems. High similarity in natural ecosystems mostly occurred between seedlings to saplings and poles to trees. Similarity for those categories in Merauke was high, reaching above 60%. However, species similarity values between seedlings to poles, seedlings to trees, saplings to poles and saplings to trees were within the range 26–69% in the natural ecosystems of Merauke and within the range 16–32% in Jayapura, whereas in Jayawijaya the similarity between saplings to poles was around 40%.

In the man-made ecosystems, the result show different trend among the districts. In complex agroforestry in Jayapura, the highest similarity occurred between the pole and tree stages followed by seedlings and sapling stages. The trend was similar for the monoculture tree-based land cover system in Merauke. On the contrary, in complex agroforest in Merauke and Jayawijaya, the highest similarity is occurred between seedlings to saplings. Poles and trees are the only growth stage that has similarity species in the cacao agroforest of Jayapura. In the monoculture tree-based system of Merauke, there was no similar of species between saplings to poles and trees.

3.2.5 Tree diversity index

The diversity index shows the degree of diversity in each land cover. Based on the results, natural land cover had a diversity index ranging from 1.46 to 3.92, depending on the forest type and the severity of disturbance. Man-made land cover had a wider range, with diversity index values ranging between 0.11 and 3.19. The highest diversity index was found in undisturbed dry land forest at the sapling level, while the lowest were found in sengon monoculture in Jayapura for the pole stage and in monoculture fruit tree-based for the sapling stage (Table 8).

Table 8. Shannon-Wiener diversity in each land covers systems and each growth stage

District	Land cover	No. of plots	Seedling	Sapling	Pole	Tree
Jayapura	Undisturbed dry land forest	5	3.11	3.92	3.51	3.82
	Sago forest	3	2.02	1.69	0.48	0.61
	Cacao agroforest	2	-	-	0.85	1.76
	Complex agroforest	6	2.93	2.91	0.73	2.09
Jayawijaya	Undisturbed dry land forest	6	2.20	2.87	2.02	2.68
	Disturbed dry land forest	11	2.52	2.63	2.54	2.49
	Pine forest	1	0.64	1.63	1.47	0.11
	Sengon plantation	1	0.68	0.67	0	0.17
	Complex agroforest	2	0.35	0.94	0.49	1.47
Merauke	Undisturbed dry land forest	4	3.03	3.36	3.60	3.74
	Disturbed dry land forest	4	3.64	3.33	3.27	3.30
	Undisturbed swamp forest	3	2.33	2.78	1.76	2.76
	Disturbed swamp forest	4	2.93	2.72	2.78	2.38
	Undisturbed mangrove	3	2.36	2.37	1.46	2.40
	Disturbed mangrove	3	1.51	1.94	1.47	2.21
	Shrub on dry land	3	2.30	1.96	2.15	2.44
	Shrub on swamp	4	1.76	2.13	2.10	2.19
	Complex agroforest	3	2.56	3.19	2.42	2.52
	Tree-based monoculture	3	1.42	0	0.68	1.07

3.3 Carbon stock in various land cover systems

3.3.1 Tree biomass carbon stock

Aboveground carbon stock in this analysis was calculated only for tree biomass. The aboveground carbon stock varied among the land covers systems of Jayapura, Jayawijaya and Merauke. Variation in the carbon stock also occurred among plot samples (Table 9). The highest aboveground carbon stock was found in complex agroforest in Jayawijaya followed by pine forest consisting of *Casuarina papuana* and *Araucaria cunninghammii*. The highest variation among plot samples occurred in disturbed dry land forest in Jayawijaya, reaching almost 80% for the average of 9 plot samples. Undisturbed dry land forest in the three districts of Papua Province contained similar aboveground carbon stock, in the range 120–135 Mg ha^{-1}.

Table 9. Plot level aboveground carbon stock in Jayapura, Jayawijaya and Merauke

District	Land cover	Number of plots	Carbon stock (Mg ha^{-1})	Standard deviation
Jayapura	Undisturbed dry land forest	5	134.5	53.3
	Sago forest	6	28.2	26.1
	Cacao agroforest	2	62.4	29.7
	Complex agroforest	5	50.5	29.9
Jayawijaya	Undisturbed dry land forest	6	131.7	39.7
	Disturbed dry land forest	9	108.9	79.2
	Pines forest	1	177.0	-
	Sengon plantation	1	57.7	-
	Complex agroforest	2	207.3	36.2
Merauke	Undisturbed dry land forest	4	121.7	25.6
	Disturbed dry land forest	4	80.3	30.0
	Undisturbed swamp forest	3	61.7	15.5
	Disturbed swamp forest	4	64.1	21.0
	Undisturbed mangrove	3	100.2	58.5
	Disturbed mangrove	3	74.4	29.9
	Shrub on dry land	3	70.0	5.9
	Shrub on swamp	4	75.9	27.1
	Complex agroforest	3	26.9	9.7
	Tree-based monoculture	3	44.5	27.6

3.3.2 Tree biomass composition

Tree biomass carbon stock in certain land cover types was affected by the wood density, tree density and tree diameter. Average values of the wood density and tree density varied among land cover systems (Table 10).

The average wood density in the natural ecosystems in Jayapura, Jayawijaya and Merauke could be categorized from very low to medium, except for mangrove. Trees 10–30 cm DBH were dominant in almost all land cover types, except in sago forest where the DBH of trees was higher. In Jayapura and Jayawijaya, 30% of the tree biomass carbon stock was generated from trees 5–30 cm in DBH and

70% from trees > 30 cm DBH, but in Merauke the contribution of 5–30 cm and > 30 cm DBH was 60% and 40%, respectively, except for the monoculture tree-based system where 95% was generated from trees with 5–30 cm DBH. This last result clearly indicated that the monoculture tree-based systems in Merauke (rubber, cashew and rambutan) had been developed in the last two decades.

Table 10. Average wood density and tree density by diameter class in various land cover systems in Jayapura, Jayawijaya and Merauke

District	Land cover	Average Wood density (g cm^{-1})	Tree density per unit sample			Carbon stock (Mg ha^{-1})		Total Carbon (Mg ha^{-1})
			5-10 cm	10-30 cm	>30 cm	5-30 cm	>30 cm	
Jayapura	Undisturbed dry land forest	0.58	22	54	20	23.4	111.2	**134.6**
	Sago forest	0.26	19	5.3	9	12.4	15.9	**28.2**
	Cacao agroforest	0.53	20	129	10	19.5	42.9	**62.4**
	Complex agroforest	0.46	22	30	8	11.3	39.2	**50.5**
Jayawijaya	Undisturbed dry land forest	0.62	25	83	20	33.1	98.5	**131.7**
	Disturbed dry land forest	0.63	25	60	14	25.9	83	**108.9**
	Pines forest	0.47	22	287	26	103.7	73.3	**177**
	Sengon plantation	0.42	41	106	36	13.7	44	**57.7**
	Complex agroforest	0.53	60	73	42	30.71	176.5	**207.2**
Merauke	Undisturbed dry land forest	0.65	105	120	12	67.1	54.6	**121.7**
	Disturbed dry land forest	0.65	98	70	7	47.9	32.4	**80.3**
	Undisturbed swamp forest	0.67	64	51	12	35.5	26.2	**61.7**
	Disturbed swamp forest	0.7	98	70	7	34.5	29.5	**64.1**
	Undisturbed mangrove	0.79	69	75	7	55.6	44.5	**100.2**
	Disturbed mangrove	0.72	78	85	6	56.1	18.3	**74.4**
	Shrub on dry land	0.66	69	88	7	42	28	**70**
	Shrub on swamp	0.66	107	64	5	59	16.8	**75.9**
	Complex agroforest	0.6	16	16	6	8.7	18.2	**26.9**
	Tree-based monoculture	0.62	46	129	2	42.1	2.5	**44.5**

4 Discussion

4.1 Tree diversity

Generally, undisturbed dry land forest in the three districts of Jayapura, Jayawijaya and Merauke contained higher tree species richness than other natural ecosystems; Jayapura had the leading tree species richness followed by Merauke and Jayawijaya. The ecological condition of the sampling area was the main factor in tree species richness differentiation. The dry land forest of Jayawijaya is located at higher elevation (above 1,500 m asl) and is much affected by lower montane forest vegetation; while in Merauke, it is much affected by lowland monsoon evergreen forest that is dominated by *Acacia* and *Melaleuca*. Species richness in lower montane forest is commonly lower than in lowland forest. In Gunung Gede, West Java at 1,600 m asl, 104 species per hectare have been reported (Kartawinata 2010), whereas in Jayawijaya, the number of species was about 50% lower.

The higher species composition among growth stages in Jayawijaya and Merauke than in Jayapura indicates a higher species overlap, but lower total species richness. The number of overlap species among growth stages in mangrove was high (in the range 70–100%) due to the low diversity of mangrove species compared to other natural ecosystems. Mangrove species richness in Merauke (18 species in the undisturbed area and 14 species in the disturbed area) was higher than in undisturbed mangrove forest of Raja Ampat, where 10 species of true mangrove were reported (Prawiroatmodjo & Kartawinata 2014). The lower species richness in man-made ecosystems of complex agroforest in Jayawijaya compared to Jayapura and Merauke may have occurred due to the availability of domesticated commercial species that were integrated in the systems and also influenced by local community culture that favored the cultivation of sweet potato as the main food.

Betel nut (*Areca catechu*) was a dominant species in the complex agroforest of Jayapura for all growth stages. In addition, betel nut was one of the top-three species in sago forest and cacao agroforest. Demand for betel nut for traditional consumption is high in Jayapura and the good price for betel nut (Rp. 50.000–100.000 per small plastic bag) has resulted in the local community being interested in either keeping or planting betel nut seedlings on their land (Kobepa 2016).

Araucaria cunninghammii was one of the top-three dominant species in all growth stages in the undisturbed forest of Jayawijaya. Isolated *A. cunninghammii* trees indicated that the area has been the site for ceremonial events. *Casuarina papuana* was the dominant species in the disturbed forest for all growth stages. The existence of this anthropogenic species indicates earlier settlement. The local community grows this species for building materials, firewood and fencing of their sweet potato crops (Purwanto 2003). *Ficus* and *Glochidion* were also in the top-three dominant species, indicating that forest disturbance dates back more than 20 years (Purwanto 2003). *Paraserianthes falcataria* was commonly found in the complex agroforest forest; nowadays this species is used as shading for new coffee systems.

The undisturbed dry land forest of Merauke was dominated by low land forest species such as *Dipterocarpus cornutus* in the seedling, sapling and tree stages and by *Eugenia* sp. in the pole stage, though *D. cornutus* was not in the top-three species. Changes in the dominance of species in certain ecosystems can indicate disturbance has occurred. In natural ecosystems, there is no single dominant species, with often hundred species sharing an area (Leigh 2004). The diversity in dominant species in all growth stages represents the complex interactions among species in natural ecosystems. In contrast, in disturbed forest, some species tend to dominate the area.

Gambir was commonly found in Merauke beside gaharu, kayu putih (*Melaleuca* sp.), merbau (*Instia bijuga*), rahai (*Acacia* sp.), mahosi and lawang (Wattimena 2013). The bark of gambir is extracted by the local community as a forest product used for cosmetics purposes. Extracting bark from individual poles and trees may decrease the gambir population in these stages. The dominance of fruits and other domesticated commercial species in the man-made ecosystems (complex agroforest and monoculture tree-based) was influenced by migrant communities from the government transmigration program over the last 20 years (Fitri 2015).

Dominance is an indicator of species composition in a habitat (Lohbeck et al 2014). The dominance of a species refers to its relative importance in its habitat (Chase et al 2003), which determine the degree of influence of the species in a habitat. The dominance of a certain species provides major ecosystem services, but it doesn’t mean that other species have minor roles in ecosystem services.

Man-made ecosystems that focus on commercial species for economic purposes can have a high impact and result in the ecosystem having low similarity with the species in natural ecosystems. Only a selected few natural species were found in man-made ecosystems. Tree biodiversity in Papua is threatened by the unwise expansion of paddy rice for food security, particularly in Jayapura and Merauke, as well as by the monoculture tree-based systems of industrial forest estates. In ecosystems, trees play important roles in providing habitat to other biodiversity, both animals and other plants, even microorganisms. On the other hand, animals such as birds and bats also play important roles in the ecosystems as pollinators and in seed dispersal and pest control. Trees in the ecosystems provide services supporting biodiversity, even for human wellbeing. The more complex the biodiversity composition in a certain area indicates a more stable ecosystem.

Similarity in species among growth stages in natural ecosystems was higher than in man-made ecosystems. This indicates that species in natural ecosystems are more sustainable. Management activities in the man-made ecosystems create gaps in the growth stages of the vegetation. People tend to keep the poles and trees of certain species, but plant seedlings of different species to enrich the land for economic purposes. Non-economic species are sometimes removed during weeding. Natural species actually can survive in man-made ecosystems, as long as their seed dispersal agents still exist. The probability of a species surviving increases when the ecosystems directly adjacent are natural. Low variation in the diversity index among growth stages was found in natural land cover due to the high number of species and low evenness, as there is no single species dominant and the regeneration process is continuous. With man-made land cover, the diversity index in the growth stage was relatively high. Dominance of certain species in a certain stage occurred due to planting activity with a similar age of seedlings.

4.2 Tree biomass carbon stock

Tree biomass carbon stock in the undisturbed dry land forests of Jayapura, Jayawijaya and Merauke was relatively low (about 130 Mg ha^{-1}) compared to Sumatra and Kalimantan where values of more than 200 Mg ha^{-1} have been reported (van Noordwijk et al 2002; Rahayu et al 2005). Normally Indonesian forests have been estimated to contain carbon stocks ranging from 161 to 300 Mg ha^{-1} (Murdiyarso et al 1995), but according to Lasco (2002) the carbon stock of Southeast Asian forests varied between 40 and 250 Mg ha^{-1}. The average wood density of species was relatively low at 0.58 g cm^{-3} (Jayapura), 0.62 g cm^{-3} (Jayawijaya) and 0.65 g cm^{-3} (Merauke) compared to low land forest in Kalimantan (about 0.72 g cm^{-3}) and this results in a lower total carbon stock (Rahayu et al 2005; Rahayu et al 2016).

Both the undisturbed and disturbed swamp forest of Merauke contained low carbon stock (about 60 Mg ha^{-1}) compared to a previous survey, where 200 Mg ha^{-1} in undisturbed swamp and 92 Mg ha^{-1} in disturbed swamp were reported (Rahayu & Harja 2012). The tree density in each plot may have affected the total tree biomass and hence the carbon stock. However, more samples plots are needed to represent the large area of swamp forest in Merauke. Additional plot samples will affect the average carbon stock estimates in certain areas due to plot variation in tree density and species composition. However, the shrub on swamp area was 100% higher than that in a previous study (Rahayu & Harja 2012), due to the different age of shrubs regenerating in the plots and misclassification of either disturbed swamp forest or shrub on swamp.

In this study, the tree biomass carbon stock in the undisturbed mangrove of Merauke was similar to a previous survey with values in the range 100–120 Mg ha^{-1}, but was 100% higher for disturbed mangrove (Rahayu & Harja 2012). The distribution of plot samples in various disturbance levels affected the estimation of tree biomass carbon stock, since the level of disturbance influences the tree density. variation in the tree biomass carbon stock in the complex agroforest system of Jayapura, Jayawijaya and Merauke was influenced by the species composition in the systems. Cacao and other fruits were dominant species in Jayapura, in contrast to mixed fruits in Merauke and coffee with sengon as a shading tree in Jayawijaya. The high population of large sengon trees (> 30 cm DBH) contributed to the high carbon stock. The monoculture tree-based system in Merauke was categorized as having low carbon stock. The availability of established old systems for sampling in Merauke was a constraint. Additional plot samples covering the full range for young to old plantation is needed for further analysis. The carbon stock composition based on tree size indicates the regeneration period. If the contribution to tree biomass carbon stock in bigger trees (> 30 cm DBH) is higher, then the system has been established for a long time. In contrast, if there are many smaller trees (5–30 cm DBH), then the system is relatively young.

5. Conclusions

Tree species richness in the natural ecosystems of Jayapura was higher than in Jayawijaya and Merauke due to biophysical conditions. The most important species in the man-mad ecosystems varied depending on the market conditions, with betel nut predominating in Jayapura while the most important was coffee in Jayawijaya and mixed fruits in Merauke. Natural ecosystems provide the best area for tree species conservation, in contrast to man-made ecosystems. Undisturbed dry land forest in Jayapura and Merauke contained the highest carbon stock compared to the other ecosystems, but pines forest and complex agroforest contained the highest carbon stock in Jayawijaya.

6. Suggestion

For further analysis, additional sampling plots are needed to reduce bias.

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Table Appendix 1. Tree species in each land cover type in Jayapura District

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
1	*Actinodaphne akoensis*	v			
2	*Adenanthera* sp.	v			
3	*Agathis borneensis*	v			
4	*Agathis* sp.	v			
5	*Agathis* sp.1	v			
6	*Aglaia* sp.1	v	v		
7	*Aglaia* sp.2	v			
8	*Aglaia* sp.3	v			
9	*Aglaia* sp.4	v			
10	*Agrostistachys* sp.	v			
11	*Alphitonia macrocarpa*			v	
12	*Alseodaphne laevis*	v			
13	*Alseodaphne umbelliflora*	v			
14	*Alstonia* sp.		v		
15	*Anisoptera thurifera*	v			
16	*Annona muricata*			v	v
17	*Anthocephalus chinensis*	v			
18	*Aporosa* sp.1	v	v		v
19	*Aporosa* sp.2	v			
20	*Areca catechu*		v	v	v
21	*Arecaceae*	v			
22	*Artocarpus altilis*	v	v		v
23	*Artocarpus* sp.		v	v	v
24	*Averrhoa carambola*			v	
25	*Bambusa* sp.		v		
26	*Barringtonia lauterbachii*	v			
27	*Breynia cernua*	v			
28	*Bruguiera sexangula*	v			
29	*Burckella* sp.	v			
30	*Calophyllum soulattri*	v			v
31	*Calophyllum* sp.2	v			
32	*Canarium denticulatum*				v
33	*Canarium littorale*	v			
34	*Canarium maluense*	v			
35	*Canarium* sp.	v			
36	*Canarium sylvestre*	v			
37	*Carica papaya*				v

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
38	*Casuarina junghuhniana*	v			
39	*Cerbera* sp.1	v	v		
40	*Champereia manillana*	v			
41	*Chionanthus* sp.1	v			
42	*Chionanthus* sp.2	v			
43	*Cinnamomum* sp.	v			
44	*Cocos nucifera*		v	v	v
45	*Coffea* sp.				v
46	*Cryptocarya* sp.1	v			
47	*Cyathocalyx cauliflorus*	v			
48	*Cynometra* sp.				v
49	*Diospyros lolin*	v			
50	*Dipterocarpus validus*	v			
51	*Durio* sp.			v	v
52	*Dysoxylum arborescens*	v			
53	*Dysoxylum* sp.1	v			
54	*Elaeocarpus* cf. *sepikanus*	v			
55	*Elaeocarpus* sp.	v			
56	*Elattostachys* sp.	v			
57	*Endiandra* cf. *rubescens*	v			
58	*Erythroxylum ecarinatum*	v			
59	*Eugenia* sp.			v	v
60	*Evodia* sp.	v			
61	*Fagraea racemosa*	v			
62	*Fagraea* sp.	v			
63	*Ficus glandulifera*			v	
64	*Ficus montana*				v
65	*Ficus* sp.1	v			
66	*Ficus* sp.2				v
67	*Ficus* sp.3				v
68	*Ficus* sp.4	v			
69	*Ficus tinctoria*	v			
70	*Ficus vasculosa*	v			
71	*Garcinia* cf. *riedeliana*	v			
72	*Garcinia parvifolia*	v			
73	*Garcinia* sp.	v			
74	*Gironniera nervosa*	v			
75	*Gironniera subaequalis*	v			
76	*Gliricidia sepium*			v	v

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
77	*Glochidion* cf. *arborescens*	v			
78	*Gmelina arborea*		v	v	
79	*Gnetum gnemon*	v			v
80	*Gomphandra australiana*	v			
81	*Gonystylus*	v			
82	*Guioa membranifolia*	v			
83	*Guioa pteropoda*	v			
84	*Gymnacranthera paniculata*	v			
85	*Haplolobus* cf. *floribundus*	v			
86	*Haplolobus floribundus*	v			
87	*Haplolobus floribundus* ssp. floribundus	v			
88	*Haplolobus pachypodus*	v			
89	*Haplolobus* sp.	v			
90	*Haplolobus* sp.1	v			
91	*Haplolobus* sp.2	v			
92	*Hibiscus* sp.				v
93	*Homalium foetidum*		v		
94	*Hopea* sp.1	v			
95	*Horsfieldia lancifolia*	v			
96	*Inocarpus fagiferus*	v	v		v
97	*Ioides* sp.	v			
98	*Ixora* cf. *amboinica*	v			
99	*Ixora* sp.	v			
100	*Koilodepas* sp.	v			
101	*Lansium domesticum*		v		v
102	*Lasianthus* sp.	v			
103	*Leucaena leucocephala*				v
104	*Litsea mappacea*	v			
105	*Macaranga hypoleuca*		v		
106	*Macaranga inermis*	v			
107	*Macaranga* sp.				v
108	*Mangifera* sp.			v	v
109	*Manihot* sp.				v
110	*Maranthes corymbosa*	v		v	
111	*Metroxylon sagu*		v		
112	*Mischocarpus sundaicus*	v			
113	*Morinda citrifolia*				v
114	*Musa* sp.		v		v

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
115	*Myristica subalulata*		v		
116	*Nephelium lappaceum*		v	v	v
117	*Nephelium* sp.			v	
118	*Oncosperma tigillarium*		v		
119	*Pandanus* sp.	v			
120	*Paratocarpus venenosa*	v			
121	*Parinari* sp.	v			
122	*Parkia speciosa*		v		v
123	*Phyllanthus* cf. *niruri*				v
124	*Pimelodendron amboinicum*	v			
125	*Planchonella* cf. *firma*	v	v		
126	*Planchonella firma*	v			
127	*Planchonella* sp.1	v			
128	*Planchonia papuana*			v	
129	*Plectronia horrida*	v			
130	*Pleomele angustifolia*	v			
131	*Pometia pinnata*	v	v	v	v
132	*Psychotria* sp.1	v			
133	*Psychotria* sp.2	v			
134	*Psychotria* sp.1	v			
135	*Quisqualis indica*	v			
136	*Rhodamnia cinerea*	v			
137	*Salacia* sp.1	v			
138	*Sloetia elongata*	v			
139	*Smilax* sp.1	v			
140	*Smilax* sp.2	v			
141	*Stemonurus monticola*	v			
142	*Sterculia ceramica*		v		v
143	*Sterculia* cf. *macrophylla*	v			
144	*Syzygium anomalum*	v			
145	*Syzygium aqueum*			v	
146	*Syzygium* cf. *decipiens*	v			
147	*Syzygium fibrosum*	v			
148	*Syzygium malaccense*				v
149	*Syzygium naiadum*	v			
150	*Syzygium* sp.1	v			v
151	*Syzygium* sp.2	v			v
152	*Syzygium* sp.3	v			
153	*Syzygium* sp.5	v			

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
154	*Teijsmaniodendron*	v			
155	*Terminalia kaernbachii*	v			
156	*Ternstroemia merrilliana*	v			
157	*Theobroma cacao*		v	v	v
158	Unidentified_1	v			
159	Unidentified_10	v			
160	Unidentified_11	v			
161	Unidentified_12	v			
162	Unidentified_13	v			
163	Unidentified_14	v			
164	Unidentified_16	v			
165	Unidentified_17	v			
166	Unidentified_18	v			
167	Unidentified_19	v			
168	Unidentified_2	v			
169	Unidentified_20	v			
170	Unidentified_21	v			
171	Unidentified_22	v			
172	Unidentified_23	v			
173	Unidentified_24	v			
174	Unidentified_25	v			
175	Unidentified_26	v			
176	Unidentified_27	v			
177	Unidentified_28				v
178	Unidentified_29	v			
179	Unidentified_30	v			
180	Unidentified_31	v			
181	Unidentified_32	v			
182	Unidentified_33	v			
183	Unidentified_34	v			
184	Unidentified_35		v		
185	Unidentified_36				v
186	Unidentified_37	v			
187	Unidentified_38	v			
188	Unidentified_39		v		
189	Unidentified_4	v			
190	Unidentified_40	v			
191	Unidentified_41	v			
192	Unidentified_42	v			

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
193	Unidentified_43	v			
194	Unidentified_44	v			
195	Unidentified_45	v			
196	Unidentified_46	v			
197	Unidentified_47	v			
198	Unidentified_48	v			
199	Unidentified_49	v			
200	Unidentified_5	v			
201	Unidentified_50	v			
202	Unidentified_51	v			
203	Unidentified_52	v			
204	Unidentified_53	v			
205	Unidentified_54	v			
206	Unidentified_55	v			
207	Unidentified_56	v			
208	Unidentified_57	v			
209	Unidentified_58	v			
210	Unidentified_59				v
211	Unidentified_6	v			
212	Unidentified_60	v			
213	Unidentified_61	v			
214	Unidentified_62	v			
215	Unidentified_63				v
216	Unidentified_65				v
217	Unidentified_66				v
218	Unidentified_67	v			
219	Unidentified_68	v			
220	Unidentified_69	v			
221	Unidentified_7	v			
222	Unidentified_70	v			
223	Unidentified_71	v			
224	Unidentified_72	v			
225	Unidentified_73	v			
226	Unidentified_74	v			
227	Unidentified_76	v			
228	Unidentified_77	v			
229	Unidentified_78	v			
230	Unidentified_79	v			
231	Unidentified_8	v			

No.	Tree Species	Land cover			
		Undisturbed dry land forest	Sagoo	Cacao agroforest	Complex agroforest
232	Unidentified_80				v
233	Unidentified_81	v			
234	Unidentified_9	v			
235	Unidentified_a			v	
236	Unidentified_saweng			v	
237	Unidentified_SR3			v	
238	*Villebrunea rubescens*				v
239	*Voacanga grandifolia*				v
	Number of species	183	26	22	45

Table Appendix 2. Tree species in each land cover type in Jayawijaya District

No	Tree Species	Land Cover				
		Undisturbed dry land forest	Disturbed dry land forest	Pine forest	Sengon plantation	Complex Agroforest
1	*Adinandra* sp.	v	v			
2	*Aphanomyrtus* sp.	v				
3	*Araucaria cunninghamii*	v	v	v		v
4	*Arthrophyllum diversifolium*		v	v		
5	*Artocarpus altilis*	v				
6	*Bambusa*		v			
7	*Bischofia papuana*	v	v			v
8	*Buddleja asiatica*	v	v			
9	*Callicarpa* sp.	v				
10	*Casuarina papuana*	v	v		v	v
11	*Chionanthus* sp.	v	v	v		
12	*Coffea arabica*	v	v		v	v
13	*Coffea* sp.	v	v			
14	*Commersonia* sp.	v				
15	*Cynometra* sp.		v			
16	*Cyphomandra betacea*					v
17	*Cyrtandra* sp.	v	v			
18	*Dacrydium novaguineensis*	v	v			
19	*Dodonaea viscosa*	v	v			
20	*Elaeocarpus obtusa*		v			
21	*Erythrina lithosperma*		v			
22	*Eugenia paucipunctata*	v	v			
23	*Fagraea elliptica*	v	v			
24	*Fagraea* sp.		v			
25	*Ficus glomerata*	v				
26	*Ficus microcarpa*	v	v			v
27	*Ficus quercifolia*	v	v			
28	*Firmania* sp.	v				
29	*Glochidion* sp.	v	v	v		v
30	*Glochidion* sp.1	v	v			v
31	*Glochidion* sp.2	v	v			v
32	*Glochidion* sp.3	v	v	v		
33	*Grevillea papuana*		v			
34	*Haeckeria* sp.		v			
35	*Heckeria peltata*		v			
36	*Heckeria* sp.	v				
37	*Homalanthus* sp		v			

No	Tree Species	Land Cover				
		Undisturbed dry land forest	Disturbed dry land forest	Pine forest	Sengon plantation	Complex Agroforest
38	*Ilex densifolia*		v	v		
39	*Lansium domesticum*	v	v	v		
40	*Linociera montana*	v	v	v		v
41	*Lithocarpus rufovillosus*	v	v			
42	*Litsea* sp.	v	v			
43	*Mallotus* sp.	v	v			v
44	*Melastoma malabthricum*		v			
45	*Meliosma angulata*	v	v			v
46	*Meliosma* sp.		v			
47	*Musa* sp.	v	v			
48	*Mussaenda frondosa*	v				
49	*Nothofagus recurva*	v				
50	*Paraserianthes falcataria*	v	v	v	v	v
51	*Paraserianthes minahassae*					v
52	*Payena leerii*		v			
53	*Persea americana*					v
54	*Plectronia horrida*	v				
55	*Saurauia* sp.	v	v			
56	*Schefflera rigida*	v	v			
57	*Solanum torvum*	v				
58	*Sycopsis dunnii*	v				
59	*Tarenna confusa*	v	v	v		
60	*Timonius* sp.	v	v			
61	*Trimenia papuana*		v			
62	Unidentified 82		v			
63	Unidentified 83		v			
64	Unidentified_42	v	v			
65	Unidentified_44	v	v			
66	Unidentified_46	v				
67	Unidentified_48					v
68	Unidentified_79		v			
69	Unidentified_8	v				
70	Unidentified_92					v
71	Unidentified_93					v
72	*Vaccinium wisselianum*	v				
73	*Ziziphus jujuba*	v				
	Number of species	**49**	**51**	**10**	**3**	**18**

Table Appendix 3. Tree species in each land cover type in Merauke District

No.	Tree species	Land cover									
		UDLF	DDLF	USF	DSF	UM	DM	SDL	SSW	CAF	TBM
1	*Acacia acutifolium*			v							
2	*Acacia auriculiformis*		v	v	v			v	v	v	
3	*Acacia crassicarpa*			v					v		
4	*Acacia decurrens*		v		v			v			
5	*Acacia leptocarpa*		v	v	v				v		
6	*Acacia mangium*	v	v	v	v			v	v		
7	*Actinodaphne nitida*	v	v								
8	*Adenanthera microsperma*		v								
9	*Adina* sp.	v	v								
10	*Aegialitis annulata*					v					
11	*Aegiceras corniculatum*					v					
12	*Aglaia argentea*	v	v								
13	*Aglaia cucullata*	v	v	v	v						
14	*Aglaia* sp.									v	
15	*Aleurites moluccana*		v						v	v	v
16	*Alphitonia incana*		v	v	v				v		
17	*Alstonia actynophylla*			v	v			v	v		
18	*Alstonia cf beatricis*	v	v	v	v			v	v	v	
19	*Alstonia scholaris*	v	v								
20	*Anacardium occidentale*									v	v
21	*Anisoptera polyandra*	v									
22	*Anthocephalus chinensis*	v									
23	*Artocarpus fretessii*									v	
24	*Artocarpus heterophylla*									v	
25	*Artocarpus integra*									v	
26	*Artocarpus* sp.									v	
27	*Asteromyrtus symphyocarpa*		v	v	v				v		
28	*Astronia spectabilis*		v								
29	*Avicennia eucalyptifolia*					v	v				
30	*Avicennia officinalis*					v	v				
31	*Baccaurea* sp.	v									
32	*Banksia dentata*				v			v			
33	*Barringtonia acutangula*									v	
34	*Bruguiera cylindrica*					v	v				

35	*Bruguiera gymnorrhiza*					v	v			
36	*Buchanania arborescens*	v	v	v	v			v		
37	*Callistemon* sp.			v				v		
38	*Calophyllum euryphyllum*	v	v					v		
39	*Calophyllum euryphyllum*	v								
40	*Calophyllum neoebudicum*		v							
41	*Calophyllum savanarum*		v							
42	*Calophyllum soulattri*	v						v		
43	*Calophyllum vexans*	v								
44	*Canarium australianum*	v								
45	*Cassia alata*				v				v	v
46	*Ceiba pentandra*									v
47	*Ceriops decandra*					v	v			
48	*Chionanthus macrocarpa*			v						
49	*Chionanthus macrocarpus*		v							
50	*Citrus aurantium*									v
51	*Citrus nobilis*									v
52	*Cocos nucifera*									v
53	*Codiaeum variegatum*									v
54	*Cryptocarya densiflora*	v								
55	*Cryptocarya palmerensis*		v							
56	*Cryptocarya* sp.	v	v							
57	*Decaspermum fruticosum*		v	v	v				v	
58	*Decaspermum* sp.		v							
59	*Dillenia alata*			v	v					
60	*Dillenia papuana*			v	v			v	v	
61	*Dipterocarpus cornutus*	v	v							
62	*Dracontomelon edule*	v								
63	*Durio* sp.									v
64	*Durio zibethinus*									v
65	*Elaeocarpus arnhemicus*	v						v		

66	*Elaeocarpus* cf. *sepikanus*	v	v								
67	*Elaeocarpus sphaericus*	v									
68	*Erithryna* sp.			v					v	v	
69	*Eucalyptus pellita*	v	v	v	v			v	v	v	
70	*Eucalyptus* sp.	v	v	v				v			
71	*Eugenia* sp.	v	v					v		v	
72	*Eugenia* sp.1		v	v							
73	*Eugenia suringariana*		v								
74	*Euodia elleryana*	v	v	v				v			
75	*Excoecaria agallocha*					v	v				
76	*Fagraea racemosa*	v	v							v	
77	*Ficus* sp.2									v	
78	*Ficus septica*										v
79	*Ficus* sp.	v	v		v						
80	*Ficus* sp.1								v		
81	*Flindersia laevicarpa*	v									
82	*Flindersia pimenteliana*	v									
83	*Garcinia dulcis*	v		v				v			
84	*Garcinia latissima*	v			v			v			
85	*Gliricidia sepium*									v	
86	*Glochidion* sp.		v		v				v	v	v
87	*Gnetum gnemon*	v	v								
88	*Gonocaryum pyriforme*	v	v							v	
89	*Grevillea papuana*				v						
90	*Guettarda speciosa*		v								
91	*Heritiera littoralis*					v	v				
92	*Hevea brasiliensis*										v
93	*Hibiscus tiliaceus*					v	v				
94	*Homalium foetidum*	v									
95	*Jagera pseudorhus*				v				v		
96	*Jatropha curcas*								v	v	
97	*Knema tomentella*	v	v								
98	*Lansium domesticum*									v	
99	*Leucaena glauca*			v						v	
100	*Leucaena leucocephala*	v									
101	*Leucosyke* sp.			v							
102	*Linociera lanceolata*	v									
103	*Lithocarpus rufovillosus*	v									

104	*Litsea ledermannii*	v									
105	*Litsea* sp		v								
106	*Litsea* sp.4		v								
107	*Litsea* sp1	v									
108	*Litsea* sp3		v								
109	*Litsea tuberculata*	v									
110	*Lumnitzera littoralis*					v					
111	*Lumnitzera racemosa*					v	v				
112	*Macaranga* sp.	v	v								
113	*Macaranga* sp1	v									
114	*Macaranga tanarius*	v							v		
115	*Mallotus* sp		v								
116	*Mangifera indica*									v	
117	*Mangifera* sp.									v	
118	*Melaleuca cajuputi*		v	v	v			v	v	v	
119	*Melaleuca leucadendra*		v	v	v			v	v		
120	*Melaleuca leucadendron*			v					v		
121	*Melaleuca* sp.			v							
122	*Melaleuca viridiflora*							v	v		
123	*Melastoma malabathricum*		v		v					v	
124	*Meliosma angulata*				v						
125	*Metrosideros petiolata*	v	v	v	v				v		
126	*Metroxylon sagu*									v	
127	*Mimusops elengi*				v				v		
128	*Morinda citrifolia*				v				v	v	
129	*Myristica fatua*	v									
130	*Myristica kajewski*		v								
131	*Nauclea orientalis*			v	v				v	v	v
132	*Nephelium lappaceum*									v	v
133	*Palaquium amboinense*	v	v								
134	*Parkia speciosa*									v	
135	*Pimeliodendron amboinicum*	v									
136	*Pithecellobium*									v	
137	*Planchonia careya*				v			v			
138	*Pleomele angustifolia*	v		v							
139	*Podocarpus blumei*	v									
140	*Polyalthia glauca*	v									

141	*Pongamia pinnata*					v					
142	*Premna corymbosa*						v				
143	*Psidium guajava*									v	
144	*Psychotria nesophila*				v						
145	*Rhizophora apiculata*					v	v				
146	*Rhizophora stylosa*					v	v				
147	*Rhodamnia cinerea*		v	v	v			v			
148	*Semecarpus decipiens*	v									
149	*Sonneratia acida*						v				
150	*Sonneratia alba*					v					
151	*Sterculia parkinsonii*	v	v								
152	*Sterculia quadrifida*				v						
153	*Sterculia* sp.							v			
154	*Syzygium aqueum*			v						v	
155	*Syzygium cauliflorum*	v	v	v	v						
156	*Syzygium fibrosum*				v				v		
157	*Syzygium* sp.2	v	v	v	v				v		
158	*Syzygium* sp.		v	v				v	v		
159	*Syzygium* sp.1				v						
160	*Tabernaemontana pubescens*	v	v	v	v						v
161	*Terminalia catappa*					v			v	v	
162	*Timonius timon*								v	v	
163	*Trema orientalis*	v									
164	*Uncaria gambir*	v	v								
165	*Vatica papuana*	v	v								
166	*Voacanga grandifolia*		v								
167	*Xanthostemon brassii*		v	v	v			v			
168	*Xanthostemon crenulatus*				v			v			
169	*Xylocarpus moluccensis*					v	v				
	Number of species	**64**	**62**	**38**	**41**	**18**	**14**	**27**	**32**	**45**	**8**

Notes: UDLF = Undisturbed dry land forest; DDLF = disturbed dry land forest; USF = undisturbed swamp forest; DSF = disturbed swamp forest; UM = undisturbed mangrove; DM = Disturbed mangrove; SDL = shrub on dry land; SSW = shrub on swamp; CAF = complex agroforest; TBM = Tree-based monoculture

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