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Analysis of tree biomass, net sequestered carbon and bioenergy potency in dry forest ecosystem, Indonesia

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Abstract

This study examines the potential to tree component biomass, biomass for bioenergy product and sequester carbon of forest area. CO2FIX program was used to determine about these value. In order to know about these values, we used CO2FIX program. Thinning harvesting scenarios were analysed, involving the establishment of short rotation harvesting (each 10 years) and long rotation plantations (200 year). As a result, an overall tree biomass components (stem, foliage, branch and root) were respectively recorded as follow: 2.49 ton/ha±0.67, 0.14 ton/ha±0.03, 0.35 ton/ha±0.09 and 0.65 ton/ha±0.18. The potential of biomass for bioenergy product and sequester carbon was increase until the end of project simulation. The increase average biomass of bioenergy was 25.96 Mg/ha±13.46 and the average of net sequestered carbon increase about 16.6±35.9 MgCO2equiv/ha. Our analysis on this study for all research variables is highest at each 40 years period because at this age, the rate of increment in the biomass of the tree is maximized.

1. INTRODUCTION

Forests provide many important ecosystem services, including wildlife habitat, recreation, soil protection, clean air and water, and timber production. As we face unprecedented global challenges in the twenty-first century, forests are also increasingly recognized for other services, including the ability to store carbon and mitigate the impacts of climate change (Bonan 2008) and the potential to provide bioenergy from harvest residue (Malmsheimer et al. 2011). Today, wood energy supplies about 9 % of the worldwide demand for energy and is the single largest renewable energy source, equal to all other renewable sources combined. In addition, about 30 % of the world's population depends on wood for their primary source of energy. In the USA, wood was the sole source of human-harnessed energy until 1850 and remained the main source until coal became the primary source in the late nineteenth century (U.S. Energy information administration 2008).

Forest bioenergy has the potential to significantly reduce greenhouse gas (GHG) emissions compared with fossil fuel alternatives. However, interactions between biomass harvest and forest carbon and the resulting effect on the GHG mitigation performance of bioenergy systems are inadequately understood. The potential of forest-based bioenergy to reduce GHG emissions when displacing fossil-based energy must be balanced with forest carbon implications related to biomass harvest (Mckechnie et al. 2011). However, increasing harvest intensity to include biomass for bioenergy or other uses risks altering energy and nutrient cycles, soil quality, and other associated ecosystem services and attributes.

Wood has been an important source of energy and will continue to be for the foreseeable future. Large quantities of forest residues, including tops, limbs, cull sections, and non-merchantable round wood are potentially available for use in the production of energy, fuels, biochar, and other bioproducts, offsetting the use of fossil fuels and reducing greenhouse gas emissions (Jones et al. 2010). Forest restoration, bioenergy production, or rehabilitation treatments involve forest thinning that can produce 40–60 million dry metric tons of woody biomass per year (Desrochers et al. 1993) and potential supply of biomass from forests, stems, felling residues and bark is not expected to change significantly from 2010 to 2030, but the potential from wood industry residues will increase some 30% in the same period (Mantau et al. 2010).

Forest is an ecosystem that combines the interaction between biotic and abiotic factors. Ecologically, the formation of forest community forms gradually through the changing of the vegetation and habitat. Community of forest is a dynamic and always changing until it reaches an optimum stage. The growth of a tree species in a forest community is influenced by several factors including climatic, edaphic, physiological, and biotic factors. The changing in these factors can cause the effect on the vegetation structure and composition. Utilization of forests can be well managed if the information about the forest condition are available. The existence of the Kupang Regency, East Nusa Tenggara Province with high biodiversity information still limited. Hence, we need a study to in the Kupang Regency of the dry forest, analyze species the composition, and structure.

This paper considers different approaches to calculate carbon for bioenergy that use biomass from forests that are managed with long rotations to produce multiple forest products. The objectives of the study were: (i) to study the forest structure and composition in dry forest of East Nusa Tenggara, Indonesia; (ii) to provide baseline information on tree biomass component especially in stem, foliage, branch and root; (iii) to estimate the potential of biomass for bioenergy product and sequester carbon. In order to achieve these targets, we we have used the CO2FIX program and employing various thining harvesting scenario.

1.1. The study area

The study was carried out at the Mutis Timau Protected Forest Management Unit (Mutis Timau PFMU), which is covered on Kupang regency, Timor Tengah Selatan regency and Timor Tengah Utara regency (Lat. 90 20' 00" - 90 45' 10" South and long. 123.042'30" – 124.0 20' 00" E) in eastern Indonesia (Figure 1). Data for this study were collected from 4 dry forest study sites named Binafun, Bonmuti, Letkole and Oelbanu, each study site consisting in two 10.000 m² plots.

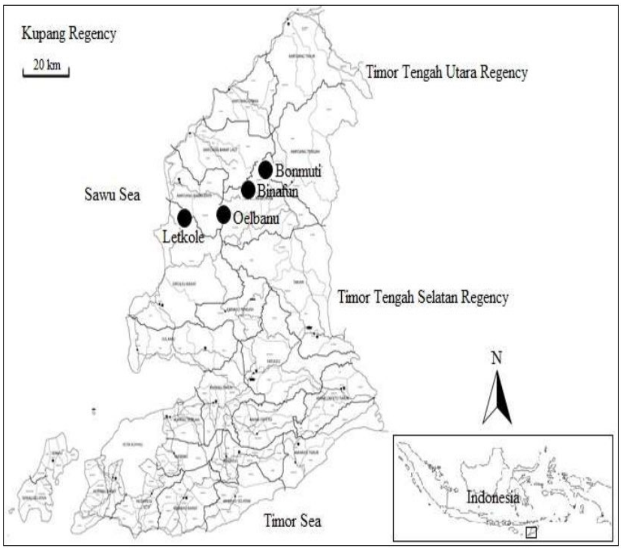

Figure 1: Location of research sites at Mutis Timau PFMU.

The research sites represent the dry forests of East Nusa Tenggara, Indonesia, and surrounding areas are the wettest areas on the island of Timor, the rain fell almost every month with the highest frequency of rainfall occurs during November to July, temperatures range between 14°C – 29°C, and in extreme conditions can decrease up to 9°C. High-speed winds occurred in November until March. About 71% area are hilly (15–30% slope) to mountainous (>30% slope). The high-intensity rainfall (2000–3000 mm/year) during the rainy season (Fisher et al., 1999).

2. MATERIALS AND METHODS

2.1. Plant census

A 8-ha permanent sampling plot was set up within the nature for the survey of the dry forest. A design of research plots is a permanent plot, with a plot size of 100 x 100m and was divided into 16 subplots with a size of 25 x 25 m (Figure 2). The data collection is based on the stands inventory by census in research plots. All individual trees ≥5 cm diameter at breast height (D) were tallied, tagged, and recorded by species name and D.

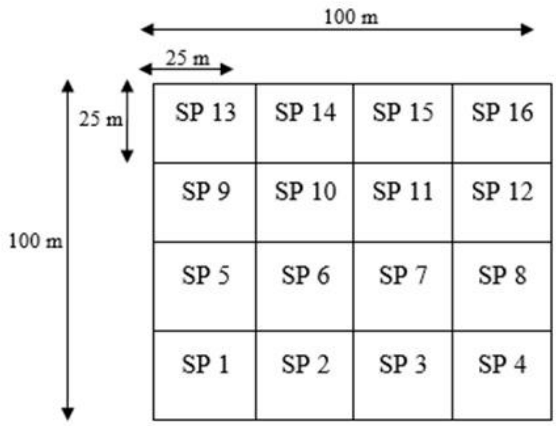

Figure 2: Design of sample plot.

2.2. Determination of importance value index (IVI)

According to Soerianegara and Indrawan (1988), species importance value index (IVI) for a species is a composite of three ecological parameters density, frequency and basal area, which measure different features and characteristics of a species in its habitat. Ecologically, density and frequency of a species measure the distribution of a species within the population while basal area measures the area occupied by the stems of trees. IVI was used for the assessment of the distribution of species abundance which is calculated in the following formula:

IVI = relative frequency+ relative density+ relative dominance

2.3. Determination of basal area and Shannon diversity index

Basal area per tree is the cross-sectional area of a tree at breast height. It can be calculated from diameter at breast height (Kusmana, 1997).

$BA= ¼\ \pi.D^2$

Where,

BA= basal area (m^2)

π = constant 3.142

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D = diameter at breast height of a tree (cm)
Species diversity were computed using Shannon's and Simpson's diversity indices (Magurran, 1987). The Shannon diversity index computed as:

$$H' = \sum_{i=1}^{s}\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right)$$

Where,
N = number species
ni = number of individuals in a species in sample quadrats

The diameter at breast height (D) of all trees in the sample plots was measured. Sample trees were selected with the D distributed across all D size classes, 10 species (<20 cm D) for tree height variable and 10 species (>20 cm D) for D variable. The height and D of trees was measured after felling. Harvested trees were dissected into their component parts (leaf, branch, stem, root). Subsamples of approximately 200-300 g for each component were taken for dry-weight determination in the laboratory. Dry weights to the nearest 0.1 g were obtained by drying the samples at 800°C until constant weight was achieved. The total biomass of the tree was obtained by summing the dry weights of the leaf, branch, stem, and root.

2.4. Analysis of tree biomass, potential of bioenergy product and net sequestered carbon

In the present study, we have used the CO2FIX program to analysis a tree biomass component (stem, foliage, branch and root), potential of bioenergy product and net sequestered carbon in bioenergy management. The CO2FIX stand level simulation model is a tool which quantifies the C stocks and fluxes in the forest biomass, the soil organic matter and the wood products chain. The model calculates the carbon balance with a time-step of one year. Basic input is stem volume growth and allocation pattern to the other tree compartments (foliage, branches and roots) (Schelhaas et al. 2004). The model is divided into three main modules: biomass, soil organic matter and products, and runs with time-steps of 1 year. The model produces output in tabular and graphic forms. It allows estimating the time evolution of total carbon sequestered at the stand level. The total carbon stored in the forest stand at any time (CTt) is considered to be CTt = Cbt + Cst + Cpt (t C/ha), where Cbt is the total carbon stored in living (above plus belowground) biomass at any time t, in metric tonnes per hectare (t C/ha); Cst , the carbon stored in soil organic matter (t C/ha), and Cpt is the carbon stored in wood products (t C/ha) (Masera et al. 2003).

The information on forest management practices for this study was synthesized from the literature. The dataset of management practices for model simulations consisted of product allocation for thinning harvesting and product line parameters. In this study, thinning harvesting is one of silviculture treatment scenarios that was applied every 10 years and timber harvesting in year 40, 80, 120, 160 and 200 because this is one of strategies for increasing carbon sequestration (Moore et al. 2012).

3. RESULT AND DISCUSSION

3.1. Importance Value Index (IVI) values

A total of 2097 tree individuals, representing 94 species, from 72 genera and 45 families, were identified within the 8.0 ha area survey. The species are found in complete growth stage (seedling, sapling, pole and tree) among the research sites are *Aglaia heptandra* (Letkole), *Alstonia villosa* (Binafun), *Casuarina junghuhniana* (Oelbanu), *Celtis wightii* (Bonmuti), *Ceriops tagal* (Binafun), *Dryobalanops aromatica* (Oelbanu), *Dysoxylum gaudichaudianum* (Binafun and Letkole), *Eucalyptus urophylla* (Bonmuti and Oelbanu), *Eugenia littorale* (Bonmuti), *Euodia macrophylla* (Bonmuti), *Ficus ampelos* (Letkole), *Ficus nervosa* (Binafun), *Ficus variegata* (Bonmuti), *Lagerstroemia sp* (Bonmuti), *Melaleuca cajuputi* (Letkole), *Phaleria laurifolia* (Binafun and Bonmuti), *Polyscias rumphiana* (Binafun), *Tarenna pubiflora* (Letkole), *Viburnum sp* (Binafun), *Wikstroemia androsaemifolia* (Letkole), *Zizyphus timoriensis* (Binafun and Bonmuti) and *Zizyphus timoriensis* that can be found at all the research sites.

The highest IVI value was that of *Elattostachys verrucosa* (88.88 %) followed by *Eucalyptus urophylla* (68.73 %) in Binafun and *Ceriops tagal* (113.88 %) followed by *Dryobalanops aromatica* in Oelbanu. Based on IVI values, *Eucalyptus urophylla* were found to be the most dominant species in the study area and *Elattostachys verrucosa* have potential to replace *Dryobalanops aromatica* as dominant species in Binafun and Bonmuti (Figure 3).

3.2. Density, Basal Area and Shanon Index

The mean stand density was 353.62 individuals/ha. The highest stand density was observed in site 2 of Oelbanu (545 individuals/ha), whereas the lowest stand density was observed in site 1 of Oelbanu (166 individual/ha), and the other six plots showed moderate densities. The density of different tree species is along the study area. The basal area in all the study plots ranged from 5.78 m2/ha (site 2 of Bonmuti) to 27.79 m2/ha (site 1 of Binafun) and the mean basal area for the four plots was 19.97 m2/ha. Comparison of Shannon–Wiener indices (H') between the eight sites indicate a no significant different was found in tree species, except for site 1 of Oelbanu (1.5±0.029). Shannon index values for tree species diversity in this study ranged between 1.5±0.029 and 3.9±0.004. (Table 2), high value of Shannon index in this research relate to high tree species diversity and abundance in research sites and it was significantly influenced by forest structure and species composition (Huang et al. 2003).

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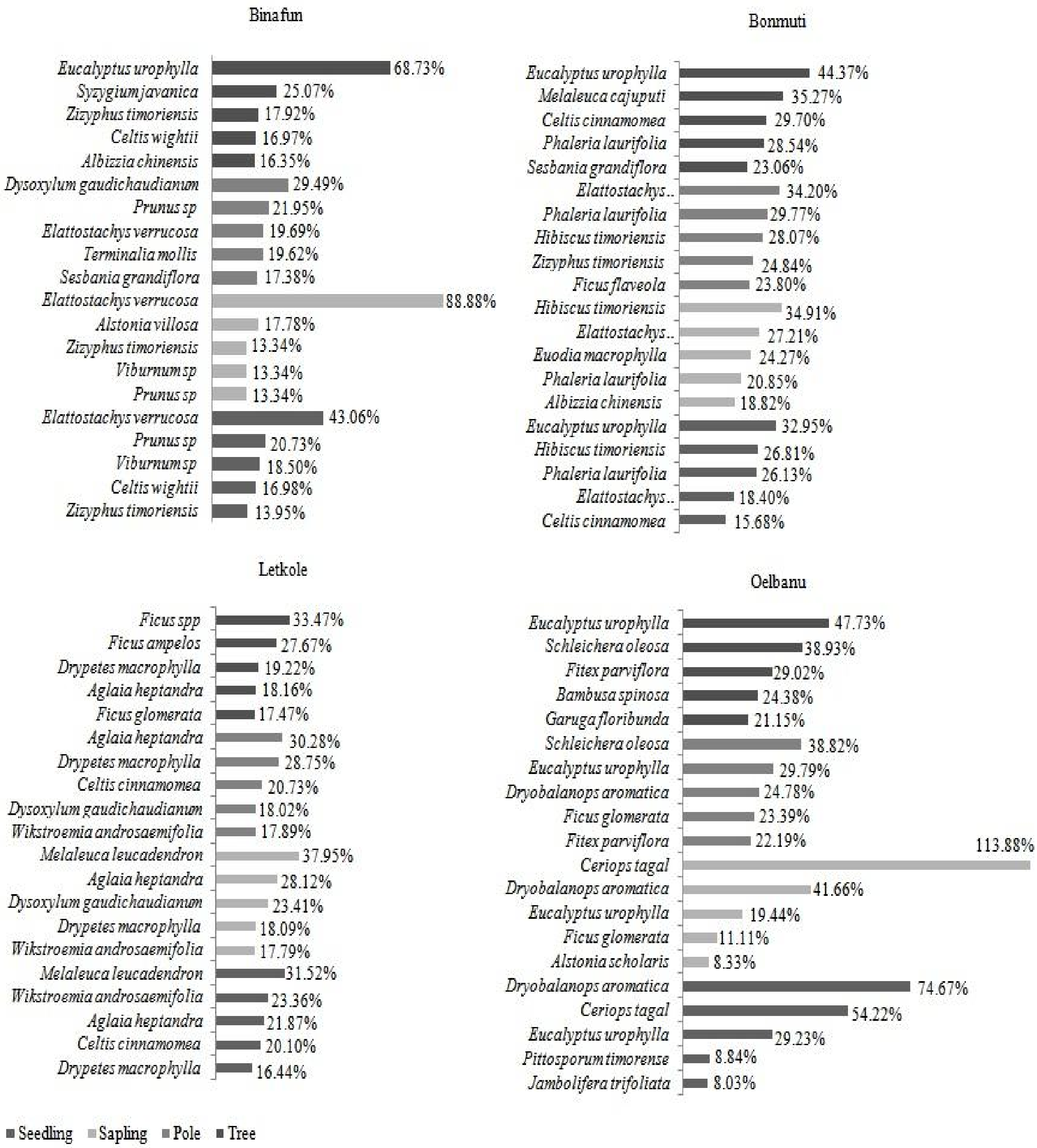

Figure 3: Five highest IVI for each research sites.

Table 2: The value of density, basal area and Shannon index

Parameter	Binafun		Bonmuti		Letkole		Oelbanu	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Species richness	23	31	14	21	51	49	7	27
Density (ind/ha)	352	219	273	225	515	534	166	545
Basal area (m^2/ha)	27.79	27.27	18.81	5.78	18.27	24	18.49	19.37
Shannon–Wiener index (H')	3.3±0.008	3.2±0.006	3.24±0.009	3.28±0.009	3.8±0.005	3.9±0.004	1.5±0.029	3.07±0.01

Knowing species diversity is a useful tool in plant ecology and forestry to compare the composition of different species. Tree species diversity in tropical forests differ greatly from location to location mainly due to variation in biogeography, habitat, and disturbance (Padalia et al. 2004). Density and frequency distributions of trees contribute to the structure of forests. Most of the species had low frequency suggesting that most of them would be expected in typical species abundance distribution (Yam and Tripathi, 2016) and tree species diversity that influences the forests are climate, stand structure, species composition, and geomorphology. Forest stand structure is a key element in understanding forest ecosystems and also an important element of stand biodiversity (Ozcelik, 2004).

The averages of diameter at breast height (D) and tree height (H) for each tree sample species and detailed results of tree components biomass are shown in Table 3. The values of measured mean D reported in this study for *Terminalia mollis* at D > 20cm are lower compared to others tree sample and were higher for individuals with greater mean H (144.500±55.905) at D<20cm. In the present study, *Pipturus argenteus* was found as large with 22.225±7.539 of the mean D, it was represented in 11.500 cm-31.500 cm D ranges and the highest H range represent in 152.813±57.849 of all the tree samples.

The results showed that the mean biomass per components for leaf, branch, stem, root, total biomass and tree biomass with D<20cm was 0.033 ton/ha, 0.067 ton/ha, 0.289 ton/ha, 0.049 ton/ha, 0.441 ton/ha and 0.039 ton/ha respectively. The mean biomass per tree species was highest for *Vitex parviflora* presenting in 0.082 ton/ha and 0.162 ton/ha in both leaf and branch components. The highest biomass of stem and root found was 0.403 ton/ha and 0.089 ton/ha for *Terminalia mollis* and *Garuga floribunda*, respectively. The mean total biomass of tree sample at D > 20cm (0.441 ton/ha) represented more than a ten time of tree sample at D < 20cm (0.039 ton/ha).

For all species, the mean of the tree biomass was 0.124 ton/ha, 0.095 ton/ha, 0.267 ton/ha and 0.133 ton/ha for tree height class at 50 cm-100 cm, 100 cm – 150 cm, 150 cm – 200 cm and 200 cm – 250 cm, respectively. The proportion of the biomass varied between the tree components and between species. Between tree components the proportion of tree biomass was 20.031% for tree height class at 50 cm-100 cm; 15. 361 % for tree height class at 100 cm-150 cm; 43.148 % for tree height class at 150 cm-200 cm and 21.457 % for tree height class at 200 cm-250 cm. *Alstonia scholaris* had the highest mean tree biomass (0.255 ton/ha and 0.750 ton/ha) at 100 cm-150 cm and 150 cm – 200 cm tree height class compared with others tree species. Same pattern for *Alstonia villosa* (0.247 ton/ha) and *Garuga floribunda* (0.331 ton/ha) at 50 cm – 100 cm and 200 cm – 250 cm tree height class (Figure 3).

We found that biomass by D class (10 cm- 15cm, 15 cm -20cm, 20cm-25, 25cm- 30cm and 30cm-35cm) differed among the sample tree species. D class of 10 cm-15cm (24.868%), 25cm-30cm (23.860%) and 30cm-35cm (20.345%) contributed predominantly to tree biomass accumulation, whereas D class of 15 cm -20cm (11.261%), 20cm-25 (19.664%) were responsible for a small proportion of the total tree biomass. *Terminalia mollis* (4.979 ton/ha), *Vitex parviflora* (2.662 ton/ha), *Vitex parviflora* (3.470 ton/ha), *Tamarindus indica* (4.090 ton/ha) and *Alstonia villosa* (2.539 ton/ha) had the highest biomass in each D class (Figure 4).

The mean of tree components biomass (tree/ha) was 0.032 ± 0.015 (range 0.009–0.071) for leaf biomass (Fig. 4), 0.067 ± 0.033 (range 0.026–0.149) for branch biomass, 0.288 ± 0.079 (range 0.142–0.444) for stem biomass, 0.048±0.022 (range 0.02-0.104) for root biomass and 0.441±0.151 (range 0.201-0.775) for total biomass. The values of tree biomass for each components varied depending on the diameter at breast height (D). Generally, tree components biomass increased with D for all species. Totally, tree species biomass had high coefficient of determination (leaf biomass=0.877, branch biomass=0.877, stem biomass=0.943, root biomass=0.897 and total biomass=0.938).

In the present study stems (66%) of all tree species contained more biomass than the leaf, branch and root components, and the value of tree biomass with <20cm (0.039±0.014) almost similar to leaf biomass (0.033±0.016). Henry et al., (2011) reported similar pattern, they found percentage stem biomass (69%) to be higher than for branch (27%) and leaf (4%). However, Geldenhuys et al., (2008) reported that more than 50% of the timber in woodlands is branch biomass and Chamshama et al., (2004) found a significantly higher percentage biomass for branches than stems among species in the Miombo woodland stands. The distribution of biomass among different tree components might be related to the site conditions where the trees are growing. In dense forests with strong competition for light and space, the trees tend to develop smaller branches and foliage biomass than in open forest types (Segura and Kanninen, 2005).

3.3. Analysis of tree biomass, potential of bioenergy product and net sequestered carbon by forest management

The potential of tree biomass components (stem, foliage, branch and root) were presented in Figure 4 and showed the similar pattern of components tree biomass. The tree biomass components tended to increase with simulating time. The increase of tree biomass was significant in stem, foliage, branch and root ($p<0.05$). Based on the results, all tree components had a biomass maximum at each 40 years, with the maximum at stem, foliage, branch and root, were accounted 2.49 ton/ha±0.67, 0.14 ton/ha±0.03, 0.35 ton/ha±0.09 and 0.65 ton/ha±0.18, respectively

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Table 3: Characteristic and biomass values of tree sample

No	Species	DBH<20cm			DBH>20cm			
		Mean H	SD H	Biomass	Biomass			
					Leaf	Branch	Stem	Root
1	*Alstonia scholaris*	150.625	34.15	0.071±0.024	0.027±0.008	0.071±0.013	0.399±0.077	0.035±0.005
2	*Broussonetia papyrifera*	147.813	41.189	0.061±0.002	0.024±0.008	0.064±0.015	0.364±0.074	0.031±0.006
3	*Euodia macrophylla*	145.625	35.538	0.052±0.022	0.020±0.004	0.050±0.018	0.339±0.063	0.027±0.005
4	*Ficus glomerata*	141.5	44.706	0.037±0.020	0.014±0.003	0.036±0.009	0.283±0.045	0.023±0.005
5	*Pipturus argenteus*	152.813	57.849	0.021±0.014	0.010±0.002	0.024±0.007	0.229±0.064	0.018±0.005
6	*Oroxylum indicum*	136.563	56.737	0.015±0.008	0.008±0.001	0.022±0.017	0.225±0.072	0.016±0.004
7	*Hibiscus tiliaceus*	140.625	54.768	0.013±0.010	0.008±0.003	0.020±0.011	0.186±0.068	0.014±0.004
8	*Macaranga tanarius*	135	56.774	0.012±0.013	0.008±0.003	0.023±0.021	0.159±0.083	0.015±0.006
9	*Eucalyptus urophylla*	144.688	57.979	0.019±0.013	0.011±0.004	0.032±0.027	0.192±0.060	0.030±0.010
10	*Nauclea orientalis*	139.75	60.263	0.030±0.009	0.019±0.008	0.039±0.018	0.230±0.060	0.063±0.032

H=Tree height (cm), DBH=tree diameter (cm), SD= standard deviation

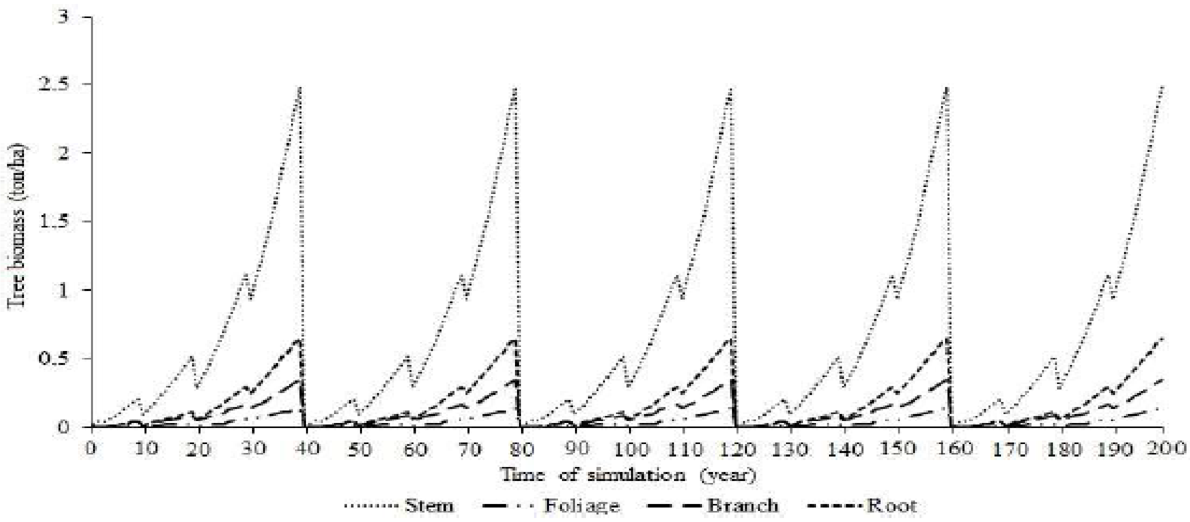

Figure 4: Tree biomass dynamics for each tree components in 200 years time simulated.

In the present study, all tree biomass type increased rapidly during the simulation time of 30-40 year, 70-80 year, 110-120 year, 150-160 year and 190-200 year. This value increased from 0.94 ton/ha to 2.49 ton/ha, 0.05 ton/ha to 0.14 ton/ha, 0.14 ton/ha to 0.35 ton/ha and 0.25 ton/ha to 0.65 ton/ha for stem, foliage, branch and root, respectively. This may result from silviculture treatment (thining harvesting scenario). However, on each simulated time of 0-10 year, 40-50 year, 80-90 year, 120-130 year and 160-170 year, the tree biomass of all components had the lowest biomass accumulation that comprised approximately ranging from 0.36 % (stem), 0.57 % (foliage), 0.47 % (branch) and 0.28 % (root) of the total biomass in this study, due to high thinning harvesting volume (Figure 5).

In Figure 5, we present the averages of biomass values and compare the percentage of each biomass component of total biomass. The biomass values and percentage of tree biomass component was varied widely from component to component. The silviculture treatments effect was statistically relevant and contribute to the total variation of the biomass tree components ($p<0.05$). The average values for each component showed differences: 0.69 Mg/ha±0.67 (68%), 0.04 Mg/ha ±0.03 (4%), 0.10 Mg/ha ±0.09 (10%) and 0.18 Mg/ha ±0.18 (18%) in stem, foliage, branch and root, respectively. The value of biomass stock for bioenergy product in this study was increased until the end of simulation period. The annual increases have varied considerably from 10 year to 10 year (statistically, it was a significant difference), ranging from as little as 3.03 Mg/ha to as much as 522.25 Mg/ha per 10 year. The increase average carbon stock of bioenergy was 25.96 Mg/ha±13.46.

The potential of net sequestered carbon from the atmosphere were presented in Figure 6. The pattern of this variable always reaches highest value in one year before silviculture treatments applied and drastically decreased when silviculture treatments (thining harvesting) applied. This indicated an opposite relationship between thining harvesting and net sequestered carbon in bioenergy product. Generally, the average of net sequestered carbon increase about 16.6±35.9 MgCO2equiv/ha (Figure 6). The highest net sequestered carbon was found in the end of project simulation (519.41 MgCO2equiv/ha).

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Generally, harvesting residues can be distinguished into stumps, shortcut of stems and branches. In Indonesia, on average of short-cut of stems, branches accounted for about 78% to 80% of the total residues. And with the stumps in natural production forest ranged from 8.0% to 37.1%, with an average of 20.1% of the total residues, while in industrial forest plantation they ranged from 22.0% to 22.4%, with an average of 22.2% of the total residues. This implies that for every 1 m3 produced log in natural production forest and industrial forest plantation there would be 0.351 m3 and 0.153 m3 harvest residues available, respectively for biomass energy. Based on productions of sawnwood, plywood, veneer sheets, chipwood and assuming the same wood specific gravity and heating value, estimates of potential bioenergy from wood processing residues for the year 2013 was about 3.60 million tons or 65.55 Petajoule (PJ) (Simangunsonga et al. 2017).

Based on the results, there is any strong relationship between silviculture treatment (thining harvesting) and biomass of tree components, biomass for bioenergy production and net sequestered carbon in bioenergy management. Thinning harvesting is used to improve timber production (to obtain larger diameter and higher quality timber), but only a few data are available on how it influences tree biomass. In this study, average analysis showed that biomass stock increased by the result of the long-term thinning. The effects of thinning on biomass carbon accumulation have varied between studies (Dong, 2001), due to differences in thinning intensity and the length of time after thinning practice was carried out (Tian, 2012).

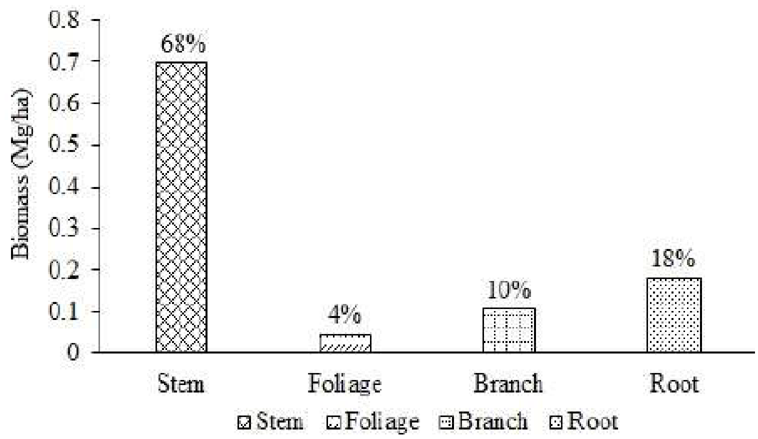

Figure 5: The averages of biomass values and percentage of tree biomass component.

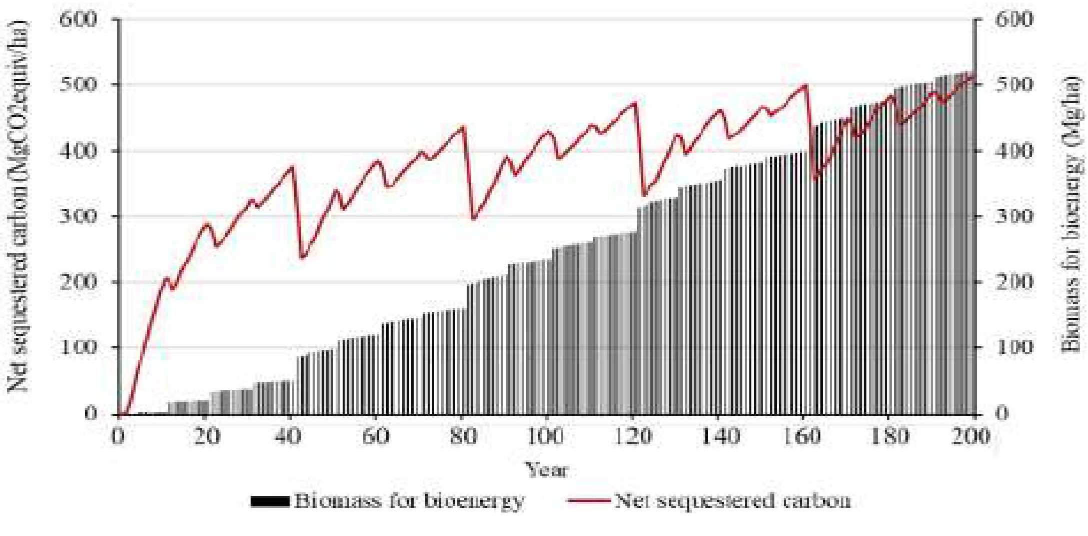

Figure 6: The potential of biomass and net sequestered carbon for 200-year simulation period.

4. CONCLUSION

Our findings support the suggestion that long-term thinning of forest in this study can improve tree biomass, biomass for bioenergy product and potential of net sequestered carbon. The most relevant findings of this study are that average increases the net sequestered carbon in 200-year rotation plantations by 16.6±35.9 MgCO2equiv/ha. The implications of the results are that tree species in this study actually enhance carbon sequestration, are carbon sinks and store more carbon. The findings endorse the significance of thining harvesting to increase carbon sinks and this role will broaden in the future.

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