Aboveground biomass in tropical dry forest at Rote Ndao Regency, East Nusa Tenggara Province, Indonesia

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Abstract

Carbon stored in live biomass plays an important role for the global carbon cycle. Tropical dry forest is one of the terrestrial ecosystem which has the potential of carbon accumulation in the world. The main objective in this study is to estimate aboveground biomass storage in tropical dry forest at Rote Ndao Regency, East Nusa Tenggara, Indonesia. We examined species important value (IVI), basal area (BA), sequestered standing carbon stock or aboveground biomass (AGB) and relationship between BA to AGB for each species in dry forest of Daleholu station Rote Ndao Regency East Nusa Tenggara Province, Indonesia. The AGB estimated by non destructive method. Based on results of research, show that the AGB generally increased with increasing BA. The highest AGB was reached by Schleicera oleosa (0.724 kg/tree/ha), followed by *Tamarindus indica* (0.718 kg/tree/ha), *Vitex parviflora* (0.506 kg/tree/ha), *Dryobalanops aromatica* (0.449 kg/tree/ha), *Mangifera indica* (0.4 kg/tree/ha), *Ficus benyamina* (0.292 kg/tree/ha) and *Cordirchotoma torsi* (0.189 kg/tree/ha). In this study, information on quantification of AGB which include basic wood density are highly recommended for improved estimates accuracy when such information is available.

Keywords: Carbon stock, Species important value, basal area, aboveground biomass, non destructive method, wood density

Introduction

Accurate and precise measurements of forest ecosystem parameters such as biomass will be important for future forest management (Zeng, 2015). In addition to climate change, the development of a regional biomass energy industry and artificial forests means that the energy management problems will still exist, so highly accurate forest stand biomass models is of key importance (Temesgen, Affleck, Poudel, Gray, & Sessions, 2015). There are two methods to calculate forest biomass, one is direct method and the other is indirect method. Direct methods, also known as destructive methods, involves of felling trees to determine biomass (Salazar, Sanchez, Galindo, & Santa-Regina, 2010). Indirect means of estimation of stand biomass are based on allometric equations using measurable parameters. The use of circumference or girth at breast height alone (expressing the basal area) for above-ground biomass estimation is common to many studies that showed that diameter at breast height (DBH) is one of the universally used predictors, because it shows a high correlation with all tree biomass components and easy to obtain accurately (Zianis, 2008).

The current biomass equations mainly use biomass factor method, the outlier growth equation method and the volume source biomass method (Ostadhashemi, Rostami Shahraji, Roehle, & Mohammadi Limaei, 2014). Wood density (WD) and stand basal area (BA) have become more and more popular. For example, Gurdak et al. (2014) and Ribeiro et al. (2011) used a combination of DBH and H and WD, respectively, to establish a logarithmic and an exponential biomass model in combination with these indicators. Baker et al. (2004) used a fusion variable and established a logarithmic model to estimate the biomass of the Amazon forest. To study the structural relationships between form factor, WD and biomass in African savanna woodlands, Colgan, Swemmer, and Asner (2014) established a variable containing the D, H, WD and BA logarithmic combined biomass model.

In many cases, however, when the model was used to assess the biomass, the evaluation accuracy of large-scale or small-scale areas was not high, or there was uncertainty or restrictions (Jenkins, Chojnacky, Heath, & Birdsey, 2003). For instance, the definition of a forest stand is uncertain at large and small scales. So the selection of either scale leads to uncertainty when selecting a model (Malhi et al., 2006). In order to solve this problem, Zuo, Ren, Wang, Zhang, & Luo, (2014) used different biomass estimation parameters to analyze the biomass estimation model of fir forests. Gómez-García et al. (2014) used using D and H as the independent variables to determine a forest stand biomass model. And the relationship between the biomass and BA could be used to facilitate the estimation of biomass (Burrows, Hoffmann, Compton, Back, & Tait, 2000).

This paper is part of a larger research project to quantify the dynamics of ecosystem biomass and the carbon pools of East Nusa Tenggara tropical dry forest landscapes. Spesifically, the purpose of this research was to determine species important value (IVI) and BA, to estimate AGB, and determine relationship BA to AGB of each species in dry forest of Rote Ndao. The research focused only on most the most common native tree species in the study area, there are *Schleicera oleosa*, *Dryobalanops aromatic*, *Mangifera indica*, *Cordirchotoma torsi*, *Tamarindus indica*, *Ficus benyamina* and *Vitex parviflora*. These species are an important natural resources for the East Nusa Tenggara Province, it have been contributing significantly to ecosystem services for regional economic, culture, work and social welfare.

Methodology

1. The study area

This study was conducted in the tropical dry forest at Daleholu station, Rote Ndao Regency, East Nusa Tenggara Province, Indonesia. Geographically, Rote Ndao Regency located at coordinates 10°25′ - 11°Southern Latitude, and 121°49′ - 123°26′ East West. Rainy season normally started from December to April. Average annual temperature is 27.6°C that distributed the range of 26.1°C to 29°C in the dry forest. The areas of research are presented in Figure 1.

Figure 1 Site map of Rote Ndao Regency

2. Study plot design and data collection

Each plot research sites had a square plot with 100 m x 100 m, respectively. The replications of plot in dry forest at Daleholu station were 2 plots, with 16 subplots for each plot. For each tree to be measured, the data collected were species name, height, and diameter at breast height (DBH) ≥ 20 cm (1.3 meters). The study focused on the species dominant in the research site, such as *Schleicera oleosa*, *Dryobalanops aromatic*, *Mangifera indica*, *Cordirchotoma torsi*, *Tamarindus indica*, *Ficus benyamina* and *Vitex parviflora*.

3. Methods of data analysis

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

Mentioned parameters in the above formula calculated the following formulas:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency (\%)} = \frac{\text{Number of individuals in which the species occured}}{\text{Total number of quadrats studied}} \text{ x } 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occured}}$$

$$\text{Relative density} = \frac{\text{Number of individual of the species}}{\text{Number of individual of all the species}} \text{ x } 100$$

$$\text{Relative frequency} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all the species}} \text{ x } 100$$

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all the species}} \text{ x } 100$$

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

$$BA = \frac{\pi \text{ x } r^2}{2}$$

Where ;

BA = basal area (m^2)

π = constant 3.142

r = radius

In this study used a undestructive method, which is determined by the following equation of Kristinawati, Adinugroho, and Imanuddin (2012).

$$AGB = V * WD * BEF$$

$$V = 0.25\pi * \left(\frac{Dbh}{100}\right)^2 * H * F$$

Where :

AGB = Aboveground biomass (kg);

V = Tree volume (m^3)

WD = Wood density (kg/m^3)

WD of *Schleicera oleosa* = 0.96 (Gan, Choo, & Lim, 1999)

WD of *Dryobalanops aromatic* = 0.695 (Gan *et al*., 1999)

WD of *Mangifera indica* = 0.55 (Gan *et al*., 1999)

WD of *Cordirchotoma torsi* = 0.456 (Gan *et al*., 1999)

WD of *Tamarindus indica* = 0.75 (Gan *et al*., 1999)

WD of *Ficus benyamina* = 0.65(Gan *et al*., 1999)

WD of *Fitex parviflora* = 0.94 (Orwa *et al*., 2009)

BEF = biomass expansion factor = 1.49 (Kristinawati et al., 2012)

Π = 3.14

Dbh = Diameter at breast height (cm)

H = Tree height (m)

F = Form factor = 0.6 (Kristinawati et al., 2012).

Biomass predictions for each model type were validated using the withheld validation data set, in terms of root mean square error (RMSE) between observed and predicted values. We calculated RMSE based on Powell *et al.* (2010) as follows where ($\hat{y}$i) was the predicted biomass, and (yi) the observed biomass:

$$RMSE = \sqrt{1/n\sum_{i=1}^{n}\left(\hat{y}_i - y_i\right)^2}$$

Results

1. Tree community characteristics

The most common tree species found in the study area ranked according to IVI are *Schleicera oleosa* (116.18 %), *Vitex parviflora* (53.94 %), *Dryobalanops aromatic* (53.587 %), *Mangifera indica* (42.27 %), *Ficus benyamina* (13.38 %), *Cordirchotoma torsi* (12.077 %), *Tamarindus indica* (8.547 %) (Table 1). Figure 2 shows the proportion of trees with small diameter (20 cm – 30 cm) were higher than trees with large diameter. In community of *Schleichera oleosa*, its dominated by the diameter class of diameter 20 cm – 30 cm with the amount of 88 trees.

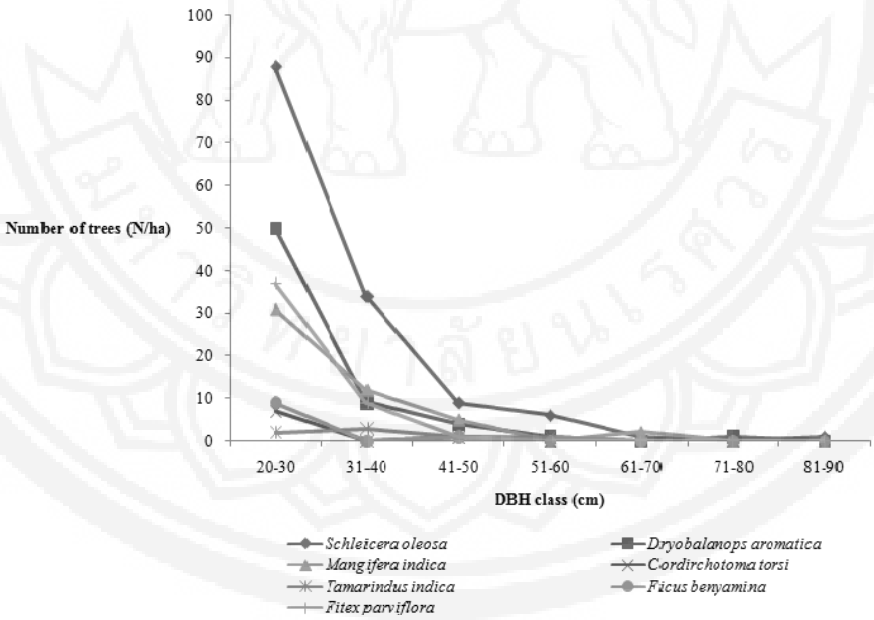

Figure 2 Number of trees by the diameter class

Tabel 1 Composition of trees at 16 research sub plot in Rote Ndao Regency, East Nusa Tenggara province, Indonesia

Local Name	Scientific Name	N[1]	D[2]	NSP[3]	BA[4]	RD[5]	RF[6]	RDo[7]	IVI[8]
Kesambi	*Schleicera oleosa*	139	1584	32	5.511	43.61	31.25	41.32	116.18
Kula	*Fitex parviflora*	47	656	32	2.285	18.06	18.75	17.13	53.94
Kapur	*Dryobalanops aromatica*	65	640	32	1.739	17.62	22.917	13.05	53.58
Mangga	*Mangifera indica*	50	400	32	2.501	11.01	12.5	18.76	42.27
Beringin	*Ficus benyamina*	10	128	32	0.482	3.52	6.25	3.61	13.38
Kinunak	*Cordirchotoma torsi*	8	128	32	0.586	3.52	4.167	4.39	12.07
Asam hutan	*Tamarindus indica*	7	96	32	0.233	2.64	4.167	1.74	8.54

[1]Number of sampled in total; [2]Data density; [3]Number of subplots; [4]Basal area (m²); [5]Relative density; [6]Relative frequency; [7]Relative dominance; [8]Important index value

2. Aboveground biomass in tropical dry forest

Table 2 shows the mean value of AGB varied by tree species. The highest amount of AGB was found in the *Schleicera oleosa* (0.724 kg/tree/ha), followed by *Tamarindus indica* (0.718 kg/tree/ha), *Fitex parviflora* (0.506 kg/tree/ha), *Dryobalanops aromatica* (0.449 kg/tree/ha), *Mangifera indica* (0.4 kg/tree/ha), *Ficus benyamina* (0.292 kg/tree/ha) and *Cordirchotoma torsi* (0.189 kg/tree/ha).

Table 2 Potential of dominant tree species in 16 subplots in Daleholu station, Rote Ndao regency, East Nusa Tenggara province, Indonesia

Species	Parameters				
	DBH (cm)[1]	H (m)[2]	V (m^3)[3]	AGB (kg/tree/ha)[4]	%[5]
Schleicera oleosa	20-81 (29.87)	7.28-14.95 (10.455)	0.12-3.18 (0.506)	0.16-4.55 (0.724)	22.086
Tamarindus indica	20-52 (36)	8.5-11.9 (9.773)	0.16-1.23 (0.643)	0.17-1.3 (0.718)	21.903
Vitex parviflora	20-49.3 (25.7)	7.7-14.05 (10.849)	0.16-1.48 (0.361)	0.22-2.06 (0.506)	15.436
Dryobalanops aromatica	20-74 (28.085)	6.4-15.6 (10.394)	0.12-2.53 (0.434)	0.12-2.61 (0.449)	13.697
Mangifera indica	20-68 (30.062)	7-14.04 (9.981)	0.13-2.7 (0.489)	0.11-2.21 (0.4)	12.202
Ficus benyamina	20-47 (26)	7.25-10.96 (9.31)	0.14-2.75 (0.302)	0.13-0.73 (0.292)	8.908
Cordirchotoma torsi	20-42 (23.8)	8.1-12.22 (10.27)	0.16-0.69 (0.279)	0.11-0.46 (0.189)	5.765

Parentheses indicate mean values; [1]Diameter at breast height (cm); [2]tree height (m); [3]tree volume (m^3); [4]Aboveground biomass (kg/tree/ha); [5]Percentage of AGB total (%)

The RMSE is the square root of the variance of the residuals. It indicates the absolute fit of the model to the data–how close the observed data points are to the model's predicted values. Figure 3 summarizes the overall performance of the models, *Cordirchotoma torsi* model had a lowest RMSE of 0.00014, followed by *Ficus benyamina* (0.00017), *Schleicera oleosa* (0.00027), *Mangifera indica* (0.00032), *Dryobalanops aromatic* (0.00033), *Tamarindus indica* (0.00036), and *Vitex parviflora* (0.00052). All values of RMSE in this research reflect the model's good ability to accurately predict the bioactivities, according to Veerasamy et al. (2011) for good predictive model the RMSE values should be low <0.3.

Generally, all species have similar tendency, which is they have positive and significant relationship between BA to AGB and this research was results equations of relationship between BA to AGB. It's very important, because the relationship between the BA to AGB could be used to facilitate the estimation of biomass (Burrows et al, 2000). The equations are: AGB = 0.3095ln(BA) - 0.1955, AGB = 0.2169ln(BA) - 0.1182, AGB = 0.6178ln(BA) - 0.6566, AGB = 0.6671ln(BA) - 0.5521, AGB= 0.997ln(BA) - 1.1202, AGB = 0.5518ln(BA) - 0.6288, AGB = 0.6701ln(BA) - 0.717 for *Ficus benyamina*, *Cordirchotoma torsi*, *Tamarindus indica*, *Vitex parviflora*, *Schleicera oleosa*, *Mangifera indica*, and *Dryobalanops aromatic*, *respectively* (Figure 4).

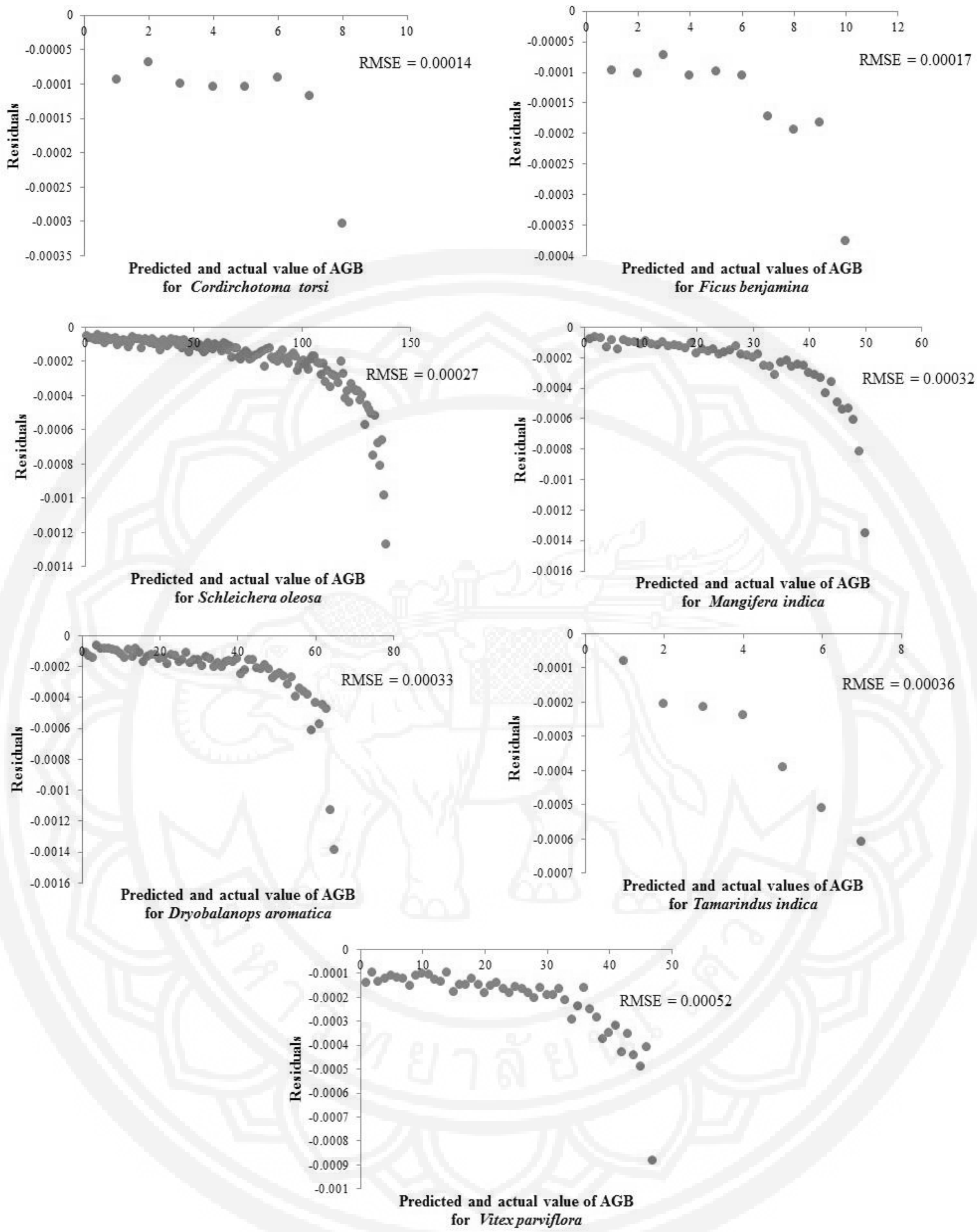

Figure 3 Value of the root mean square error (RMSE) for each species

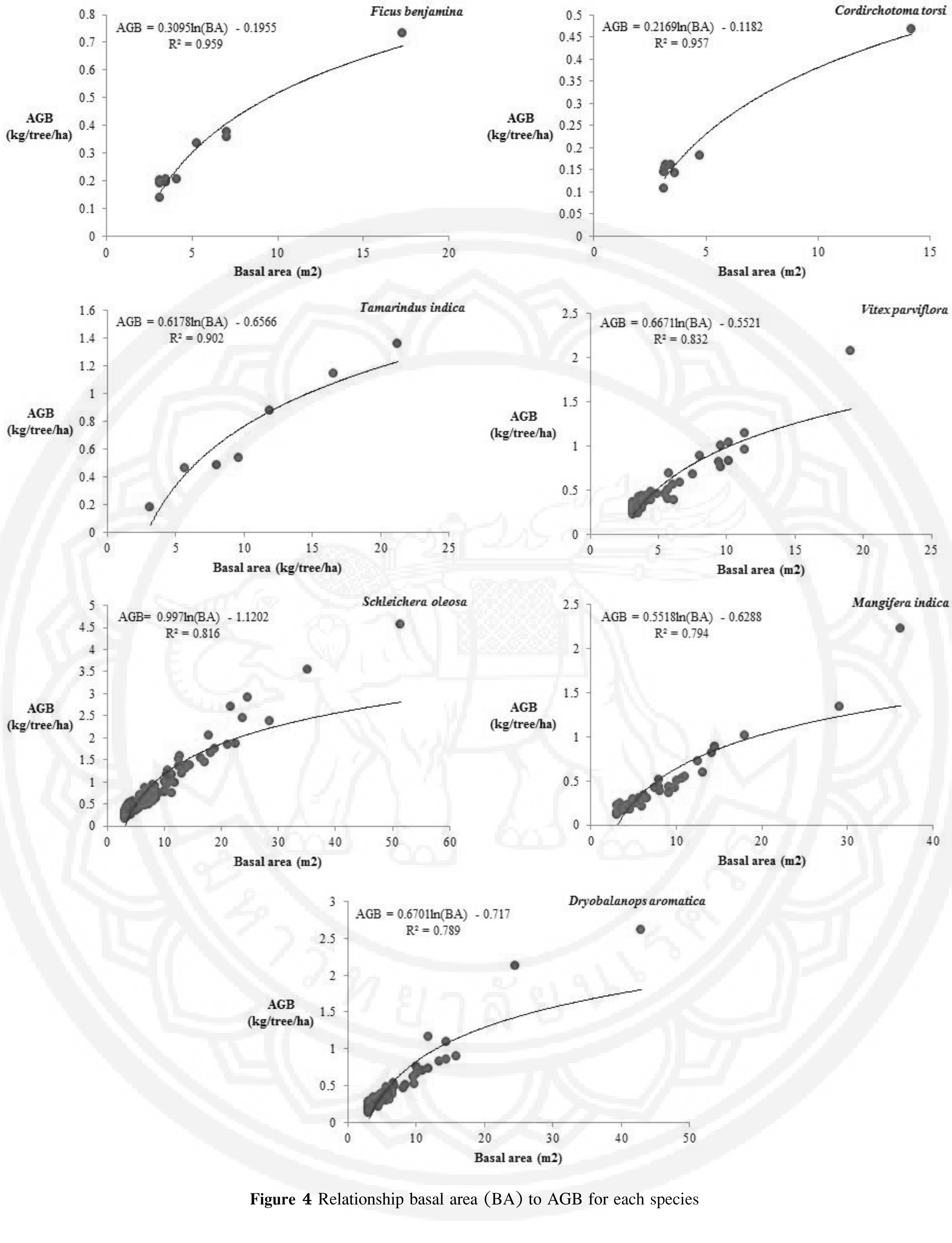

Figure 4 Relationship basal area (BA) to AGB for each species

Discussion

1. Community composition and tree structure

Floristic composition and community structure can be expressed as a wealth of forest, tropical forest floristic richness is closely related to environmental conditions such as climate, soil and light, where these factors form a climax stands (Mueller-Dombois & Ellenberg, 1974). Constituent vegetation composition of forest stands in the research include the number and dominance of species expressed in IVI. In this research, IVI high value for *Schleicera oleosa* (116.18 %), showed a high abundance of the species (Table 1). This can happen because *Schleicera oleosa* is one of species that can easy to growth, drought resistant and even resistant to the heat of the fire, leafy canopy and able to sprout throughout the year. *Schleicera oleosa* including plants that have a nature-tolerant plant. In the development of teak, *Schleicera oleosa* is the most ideal partner. Even in the literature stated that in general where there is growth of teak, there are *Schleicera oleosa* that can grow well (Suita, 2012).

The abundance of *Schleicera oleosa* and other trees (*Dryobalanops aromatic, Vitex parviflora and Mangifera indica*) that dominate in the research site raises concerns, because it may will greatly affect the growth of other species (*Cordirchotoma torsi, Tamarindus indica, Ficus benyamina*) because the canopy is very dense and shade, it may will inhibit growth and development for other plants, especially plants that do not require shade (intolerant).

According to Suhendang (1985), knowledge about the structure of forest stands are useful for determining the density of trees at different diameter classes, basal area and standing biomass. The structure of forest stands can also provide information on the population dynamics of a species or group of species from seedling, sapling, pole and tree (Istomo, 1994). In this study showed a high relationship between AGB and BA (Figure 4). BA, the sum of cross-sectional area measured at breast height (1.3 m) of all trees in a stand, expressed as m^2/ha, has frequently been used as a surrogate for biomass and carbon in tropical moist and dry forests (Brown, Gillespie, & Lugo, 1989). The BA is a good predictor for biomass and carbon since it integrates the effect of both the number and size of trees (Burrows et al., 2000). A correlation between these variables is to be expected since the BA and biomass are both related to the trunk diameter (Sarmiento, Pinillos, & Garay, 2005).

2. Relationship between tree structure and aboveground biomass

Biomass is an essential aspect of studies of carbon cycle (Ketterings, Coe, van Noordwijk, & Palm, 2001). Plant biomass can be considered a diagnostic indicator for desertification assessment, and determine the health of rangeland for grazing capacity (Zhang & Chen, 2007). Plant biomass is an important factor in the study of functional plant biology and growth analysis, and is the basis for the calculation of net primary production and growth rate (Tackenberg, 2007). Figure 4 presents relationship equations for *Ficus benyamina, Cordirchotoma torsi, Tamarindus indica, Vitex parviflora, Schleicera oleosa, Mangifera indica, and Dryobalanops aromatic*. AGB generally increased with increasing BA. Most relationship equations are developed for specific sites, and cannot be assumed to apply to other locations. Despite this lack of generality, there is some justification for producing a generalized equation that is applicable to many sites. For example, biomass equations developed from different locations in the northeast U.S. and found that in most cases regressions for a given species give similar estimates (Tritton & Hornbeck, 1982). In addition, biomass equations for red maple in Great Lake States do not differ significantly by stand age and site index, and that a single predictive model is statistically valid for a wide range of conditions (Crow, 1983). However, that generalized equations work best for estimates of aboveground biomass or total biomass, but are less satisfactory for estimates of variables such as foliage biomass or crown volume that vary widely with stand conditions (Grigal & Kernik, 1984).

Data on AGB in the different species showed that the highest amount of carbon was stored in the biomass of *Schleichera oleosa*. Because tree sizes at *Schleichera oleosa* were quite large when compared to others species so calculated AGB are the highest in this species. It does not mean that others species not important, because the mainly groups of small tree sizes will grow to bigger size in the near future. They will have greater potential for future sequestration if the forests are under appropriate management without human disturbance. Huston and Marland (2003) showed that carbon sequestration depended not only on rates of productivity but also on the size of the tree. Tree with large diameter sequester more carbon compared to small diameter.

In general conclusion from this research, each size class had a different carbon stock. Almost small up to medium sizes of trees had a greater potential for AGB than big trees due to the forest type because the growth rate will slowly in bigger trees.

Conclusions

Aboveground biomass can be varied by community composition and tree population structure. In the tropical dry forest of Rote Ndao Regency, East Nusa Tenggara, Indonesia shows the highest amount of aboveground biomass found in *Schleichera oleosa* (0.724 kg/tree/ha), which has the highest potential of carbon sequestration following by *Tamarindus indica* (0.718 kg/tree/ha), *Vitex parviflora* (0.506 kg/tree/ha), *Dryobalanops aromatica* (0.449 kg/tree/ha), *Mangifera indica* (0.4 kg/tree/ha), *Ficus benyamina* (0.292 kg/tree/ha) and *Cordirchotoma torsi* (0.189 kg/tree/ha) respectively. Tree sizes in dy forest at 20 cm - 30 cm has trend of carbon sequestration potential more than other size classes, this evidence indicates smaller trees are not the highest carbon sequestration potential but they are relevant in terms of their future potential to grow up.

Based on this research, we recommend, because AGB estimation is a complex process, we should make use of already available resources such as wood density for each tree species and forest inventory databases. Making combination of different datasets for model development and model verification will offer opportunities to improve AGB estimation and focus should also be made on belowground biomass estimation to accurately estimate the full dry forest contribution to carbon sequestration.

References

Baker, T. R., Phillips, O. L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., & Lewis, S. L. (2004). Variation in wood density determines spatial patterns inAmazonian forest biomass. *Global Change Biology*, *10*(5), 545-562.

Brown, S., Gillespie, A. J., & Lugo, A. E. (1989). Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest science*, *35*(4), 881-902.

Burrows, W. H., Hoffmann, M. B., Compton, J. F., Back, P. V., & Tait, L. J. (2000). Allometric relationships and community biomass estimates for some dominant eucalypts in Central Queensland woodlands. *Australian Journal of Botany*, *48*(6), 707-714.

Colgan, M. S., Swemmer, T., & Asner, G. P. (2014). Structural relationships between form factor, wood density, and biomass in African savanna woodlands. *Trees*, *28*(1), 91-102.

Crow, T. R. (1983). Comparing biomass regressions by site and stand age for red maple. *Canadian Journal of Forest Research*, *13*(2), 283-288.

Gan, K.S., Choo, T., & Lim, S.C. (1999). Timber notes - medium hardwoods I (Kapur, Kasai, Kelat, Keledang, Kempas). Timber Technology Bulletin No. 11. Timber Technology Centre (TTC), Kuala Lumpur: Forest Research Institute Malaysia.

Gómez-García, E., Crecente-Campo, F., Tobin, B., Hawkins, M., Nieuwenhuis, M., & Diéguez-Aranda, U. (2013). A dynamic volume and biomass growth model system for even-aged downy birch stands in south-western Europe. *Forestry*, *87*(1), 165-176.

Grigal, D. F., & Kernik, L. K. (1984). Generality of black spruce biomass estimation equations. *Canadian Journal of Forest Research*, *14*(3), 468-470.

Gurdak, D. J., Aragão, L. E., Rozas-Dávila, A., Huasco, W. H., Cabrera, K. G., Doughty, C. E., ... & Malhi, Y. (2014). Assessing above-ground woody debris dynamics along a gradient of elevation in Amazonian cloud forests in Peru: balancing above-ground inputs and respiration outputs. *Plant Ecology & Diversity*, *7*(1-2), 143-160.

Huston, M. A., & Marland, G. (2003). Carbon management and biodiversity. *Journal of environmental Management*, *67*(1), 77-86.

Istomo. (1994). *The relationship between composition, structure and ramin* (*Gonystylus bancanus* Miq. Kurz) *Diversity to properties of peat soil* (the cases in PT. Perhutani III Kalimantan Selatan). (PhD. Thesis). Bogor Agricultural University, Bogor, Indonesia. (In Indonesia).

Jenkins, J. C., Chojnacky, D. C., Heath, L. S., & Birdsey, R. A. (2003). National-scale biomass estimators for United States tree species. *Forest Science*, *49*(1), 12-35.

Ketterings, Q. M., Coe, R., van Noordwijk, M., & Palm, C. A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and management*, *146*(1), 199-209.

Kristinawati, H., Adinugroho, W.C., & Imanuddin, R. (2012). *Monograf: Model-model alometric for tree biomass estimation in land use type of Indonesia forest ecosystem*. Bogor, Indonesia: The Centre of Research and Development for Conservation and Rehabilitation, Forest Research and Development Agency. Ministry of *Forestry*. (In Indonesia).

Malhi, Y., Wood, D., Baker, T. R., Wright, J., Phillips, O. L., Cochrane, T., ... & Higuchi, N. (2006). The regional variation of aboveground live biomass in old-growth Amazonian forests. *Global Change Biology*, *12*(7), 1107-1138.

Mueller-Dombois, D., & Ellenberg, H., (1974). *Aims and method of vegetation*. New York: Wiley International Ed. John Wiley & Sons.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., Anthony, S. (2009). *Agroforestree database: a tree reference and selection guide version 4.0.* Kenya: World Agroforestry Centre.

Ostadhashemi, R., Rostami Shahraji, T., Roehle, H., & Mohammadi Limaei, S. (2014). Estimation of biomass and carbon storage of tree plantations in northern Iran. *Journal of forest science*, *60*(9), 363-371.

Powell, S. L., Cohen, W. B., Healey, S. P., Kennedy, R. E., Moisen, G. G., Pierce, K. B., & Ohmann, J. L. (2010). Quantification of live aboveground forest biomass dynamics with Landsat time-series and field inventory data: A comparison of empirical modeling approaches. *Remote Sensing of Environment*, *114*(5), 1053-1068.

Ribeiro, S. C., Fehrmann, L., Soares, C. P. B., Jacovine, L. A. G., Kleinn, C., & de Oliveira Gaspar, R. (2011). Above-and belowground biomass in a Brazilian Cerrado. *Forest Ecology and Management*, *262*(3), 491-499.

Salazar, S., Sanchez, L. E., Galindo, P., & Santa-Regina, I. (2010). Above-ground tree biomass equations and nutrient pools for a paraclimax chestnut stand and for a climax oak stand in the Sierra de Francia Mountains, Salamanca, Spain. *Scientific Research and Essays*, *5*(11), 1294-1301.

Sarmiento, G., Pinillos, M., & Garay, I. (2005). Biomass variability in tropical American lowland rainforests. *Ecotropicos*, *18*(1), 1-20.

Soerianegara, I., & Indrawan, A., (1988). *Forest ecology.* Faculty of Forestry, Bogor Agricultural University, Bogor, Indonesia. (In Indonesia)

Suhendang, E., (1985). *The study of tree species structure model in low land rain forest at Bengkunat, Lampung Province*. (PhD. Thesis). Bogor Agricultural University, Bogor, Indonesia. (In Indonesia).

Suita, L., (2012). Kesambi (*Schleichera oleosa* MERR.). Forest Tree Seed Technology Research and Development Center. Forest Research and Development Agency. Ministry of Forestry. (In Indonesia).

Tackenberg, O. (2007). A new method for non-destructive measurement of biomass, growth rates, vertical biomass distribution and dry matter content based on digital image analysis. *Annals of botany*, *99*(4), 777-783.

Temesgen, H., Affleck, D., Poudel, K., Gray, A., & Sessions, J. (2015). A review of the challenges and opportunities in estimating above ground forest biomass using tree-level models. *Scandinavian Journal of Forest Research*, *30*(4), 326-335.

Tritton, L. M., & Hornbeck, J. W. (1982). *Biomass equations for major tree species of the Northeast*. Broomall : USDA Forest Service.

Veerasamy, R., Rajak, H., Jain, A., Sivadasan, S., Varghese, C. P., & Agrawal, R. K. (2011). Validation of QSAR models-strategies and importance. *International Journal of Drug Design & Discovery*, *2*(3), 511-519.

Zeng, W. S. (2015). Integrated individual tree biomass simultaneous equations for two larch species in northeastern and northern China. *Scandinavian journal of forest research*, *30*(7), 594-604.

Zhang, J. T., & Chen, T. (2007). Effects of mixed Hippophae rhamnoides on community and soil in planted forests in the Eastern Loess Plateau, China. *ecological engineering*, *31*(2), 115-121.

Zianis, D. (2008). Predicting mean aboveground forest biomass and its associated variance. *Forest Ecology and Management*, *256*(6), 1400-1407.

Zuo, S. Z., Ren, Y., Wang, X. K., Zhang, X. Q., & Luo, Y. J. (2014). Biomass estimation factors and their determinants of Cunninghamia lanceolata forests in China. *Scientia Silvae Sinicae*, *50*(11), 1-12.