

BUKTI-BUKTI PROSES REVIEW (KORESPONDENSI)

Judul	:	Development of Allometric Relationships for Estimate Above Ground Biomass of Trees in the Tropical Abandoned Land
Penulis	:	Karyati, Kusno Yuli Widiati, Karmini, dan Rachmad Mulyadi
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Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land
 KARYATI, KUSNO YULI WIDIATI, KARMINI, RACHMAD MULYADI

Round 1 Status
 Submission accepted.

Notifications

[biodiv] Editor Decision	2019-11-17 01:58 AM
[biodiv] Editor Decision	2019-11-17 02:04 AM

Notifications

[biodiv] Editor Decision	2019-11-17 01:58 AM
[biodiv] Editor Decision	2019-11-17 02:04 AM

Reviewer's Attachments

13279-1	.4546-Article Text-12164-1-4-20191001.doc	October 30, 2019
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Revisions

13705-1	Article Text, V-4546-Article Text-12164-1-4-20191001_KK3.doc	November 10, 2019	Article Text
13789-1	Article Text, 4546-Article Text-13707-1-18-KK.doc	November 12, 2019	Article Text

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Review Discussions

Name	From	Last Reply	Replies	Closed
Review	aseptiasari 2019-10-03 04:39 AM	karyati 2019-10-26 03:17 AM	2	<input type="checkbox"/>
▶ Feedback for reviewer's comments	karyati 2019-11-10 06:54 AM	-	0	<input type="checkbox"/>
Uncorrected Proof	editors 2019-11-10 10:30 AM	karyati 2019-11-15 05:31 PM	3	<input type="checkbox"/>
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 **Ahmad Dwi Setyawan** <smujo.id@gmail.com> Wed, Sep 11, 2019 at 3:17 PM
 To: Karyati Karyati

Karyati Karyati:


Thank you for submitting the manuscript, "D Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land: Development of allometric equations in abandoned land " to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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• **Smujo Editors** <smujo.id@gmail.com>
To: Karyati, Kusno Yuli Widiati, Karmini, Rachmad Mulyadi



Sun, Sep 15, 2019 at 7:50 AM ★

Karyati, Kusno Yuli Widiati, Karmini, Rachmad Mulyadi:

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Note:

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Unfortunately, this mss is too brief to be published in Biodiversitas journal. At least, you need to compose a 2500 words article from intro to conclusion (table and figure are excluded).

Kindly resubmit when it meets the requirements.

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Karyati Hanapi <karyati.hanapi@yahoo.com>

Fri, Oct 4, 2019 at 6:43 AM ★



Smujo Editors <smujo.id@gmail.com>

To: Karyati Karyati, Kusno Yuli Widiati, Karmini Karmini, Rachmad Mulyadi



Wed, Oct 30, 2019 at 12:05 PM



Karyati Karyati, Kusno Yuli Widiati, Karmini Karmini, Rachmad Mulyadi:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "D Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land: Development of allometric equations in abandoned land".

Our decision is: Revisions Required

Smujo Editors
editors@smujo.id

Reviewer V:

Based on the biomass data of 30 tree samples from destructive sampling, abovegroun biomass proportions were provided and biomass models were developed for different parts of trees in the tropical abandoned land, especially in Kalimantan, Indonesia. The topic of this manuscript is valuable, but some issues I concern are necessary to be revised for improving the MS.

1. What method was used in selecting sample trees both species and family? Please explain clearly
2. This model is for aboveground biomass, however, there is no flower and fruit parts. Why?
3. The model evaluation was only based on statistics for R square and P value, no including some statistics for errors, especially relative

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relationships for estimate above ground biomass of trees in the tropical abandoned land: Development of allometric equations in abandoned land".

Our decision is: Revisions Required

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Reviewer V:

Based on the biomass data of 30 tree samples from destructive sampling, abovegroun biomass proportions were provided and biomass models were developed for different parts of trees in the tropical abandoned land, especially in Kalimantan, Indonesia. The topic of this manuscript is valuable, but some issues I concern are necessary to be revised for improving the MS.

1. What method was used in selecting sample trees both species and family? Please explain clearly
2. This model is for aboveground biomass, however, there is no flower and fruit parts. Why?
3. The model evaluation was only based on statistics for R square and P value, no including some statistics for errors, especially relative errors. It is suggested to add some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al, 2017) for model evaluation. Due to limited samples (only 30 trees) in this study, cross validation was not conducted. In this case, MPE and others statistics are an important index for assessing the biomass models.
4. Please read and compare to Manuri et al. (2017) that it is related to effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region, including this reseach site.

Recommendation: Revisions Required



Karyati Hanapi <karyati.hanapi@yahoo.com>
To: Smujo Editors
Cc: Kusno Widiati, Karmini Kasiman, Rachmad Mulyadi

Wed, Oct 30, 2019 at 2:41 PM

Dear Managing Editor,

We will revised the manuscript as soon as possible.

Thank you very much.

Regards,

Karyati

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Karyati Hanapi <karyati.hanapi@yahoo.com>
To: Smujo Editors
Cc: karmini.kasiman@yahoo.com, Kusno Widiati, Rachmad Mulyadi, Karyati Kasiman

Sun, Nov 10, 2019 at 3:02 PM

Dear Managing Editor,

We would like to say thanks and appreciate for constructive suggestion from reviewer.

As attached below, our feedback for the reviewer's comments on our manuscript entitled "Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands"

No.	Page/ Line	Review	Feedback and revision
1	Page 5, line 207	What method was used in selecting sample trees both species and family?	Explanation had added → Thirty sample trees with DBH of > 15 cm were selected in the study site, with consideration of the species. These selected trees didnot considering individuals with damaged crowns or broken trunks. Almost 90% of the selected trees were categorized as the dominant species in terms of density and Importance Value Index (IVI) as observed in the current study, while few selected trees represented the rare species (Page 5, line 214-217).

2	Page 5, line 226	Is there no flower and fruit parts?	Explanation had added → The flower and fruit parts was not included in the observation, because very few sample trees that have flower and fruit during observation (Page 3, line 107-109)
3	Page 5, line 253	The model evaluation was only based on statistics for R^2 and P value, no including some statistics for errors, especially relative errors. It is suggested to add some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al., 2017) for model evaluation. Due to limited samples (only 30 trees) in this study, cross validation was not conducted. In this case, MPE and others statistics are an important index for assessing the biomass models.	Some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al., 2017) for model evaluation had added (Page 4, line 152-154; Page 7, Table 3)
4	Page 8, line 303	Please read and compare to Manuri <i>et al.</i> (2017) that it is related to effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region.	The comparison to Manuri et al. (2017) had added (Page 7, line 295; Page 8, line 313-316; Page 8, Tabel 4; Page 8, Figure 7)

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4	Page 8, line 303	Please read and compare to Manuri <i>et al.</i> (2017) that it is related to effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region.	The comparison to Manuri et al. (2017) had added (Page 7, line 295; Page 8, line 313-316; Page 8, Tabel 4; Page 8, Figure 7)
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Thank you very much.

Regards,
Karyati

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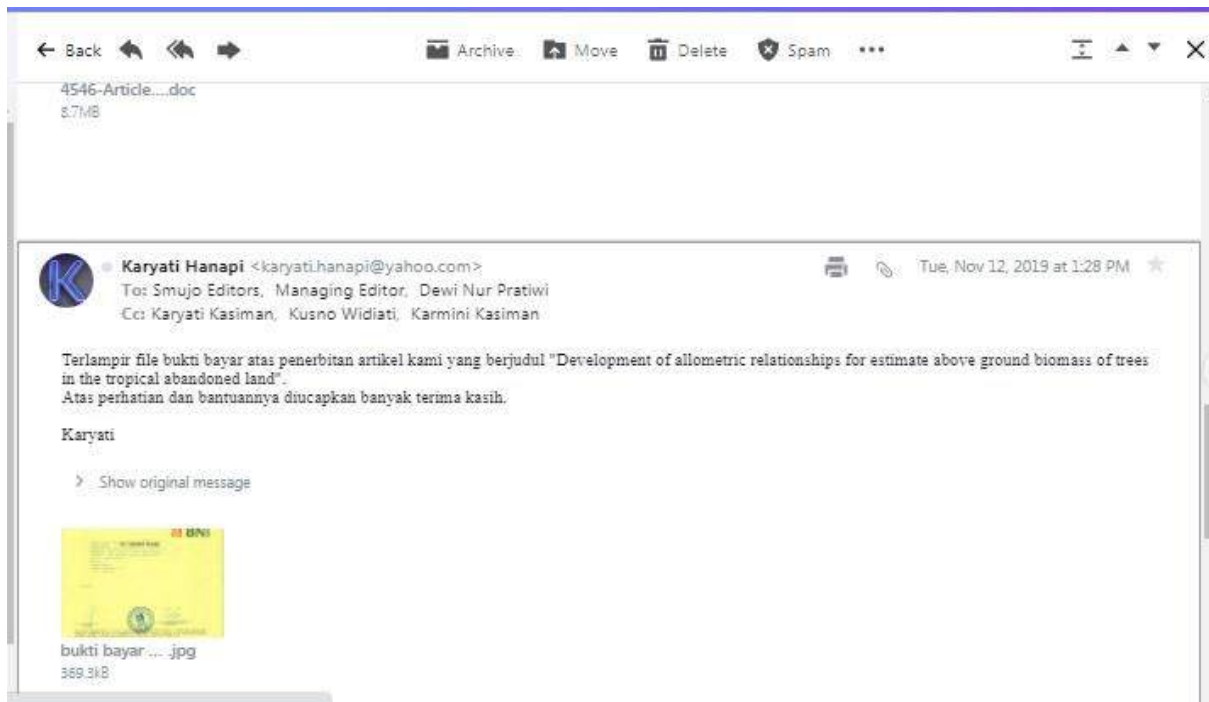
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K Karyati Hanapi <karyati.hanapi@yahoo.com> Tue, Nov 12, 2019 at 12:12 PM ★
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Managing Editor,

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Dear Managing Editor,

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Terima kasih.

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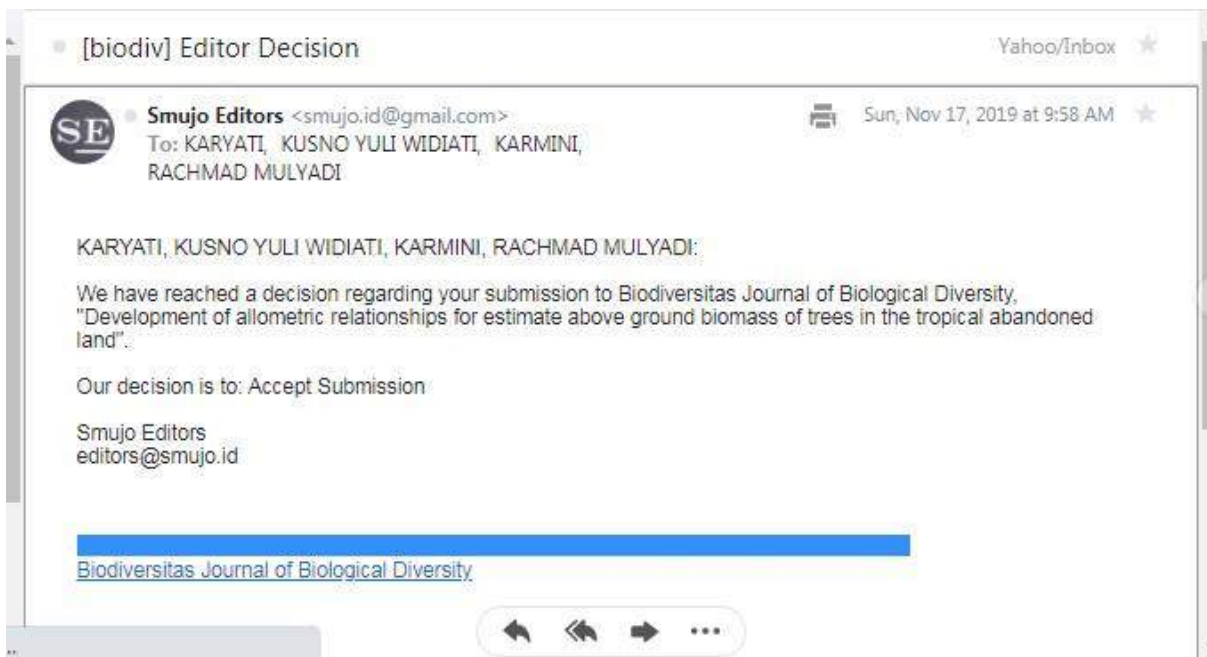
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Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land

Abstract. Karyati, Widiati KY, Karmini, Mulyadi R. 2019. *Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands. Biodiversitas* x: xx-xx. The abandoned lands have important role in the ecological fuction as well as carbon sequestration. The allometric equations to estimate above ground biomass in abandoned land are still limited available. This study objective was to develop allometric relationships between tree size variables (diameter at breast height (DBH) and tree height) and leaf, branch, trunk, and total above ground biomass (TAGB) in abandoned land in East Kalimantan, Indonesia. The correlation coefficients between stem DBH and tree height to leaf and branch indicating a relatively weak relationship. The moderately strong relationships were showed by DBH and tree height to trunk and TAGB. The specific allometric equation of above ground biomass for different land use and land type is needed to estimate the accurate TAGB in the site.

Key words: Abandoned land, allometric equation, biomass, destructive method

Running title: Development of allometric equations in abandoned land

INTRODUCTION

The National Land Affairs Agency identified 7.3 million hectares lands in Indonesia as abandoned lands in 2011 and about 4.8 million hectares was stated as abandoned lands. This area of abandoned lands increase from 2007 as much as 7.1 million hectares outside forest area (Nurlinda et al. 2014). The abandoned land area in East Kalimantan was about 3 million hectares. The abandoned lands provide habitat rotation to succession process in primary-secondary forest that will increase biodiversity (Chokkalingam et al. 2001). The plant composition, diversity, and growth during fallow periods after shifting cultivation was resulted from complex interaction between condition and factor before and after fallow periods, such as disturbance, land history, land management, tree and seed source composition from soil or surrounding forest, soil fertility, and climate factor (Awang Noor et al. 2008; Kendawang et al. 2007; Van Do et al. 2010).

Land use system on forest basis store CO₂ by carbon stock storage at their biomass (Gorte 2007; Roshetko et al. 2002). The carbon stock in old age stand could different compared to carbon stock in second growth stand that replace it, cause woody biomass in an area could not describe in nett ecosystem productivity (Janisch and Harmon 2002). Biomass dynamic in tropical forest play important role to evaluation of global carbon cycle and global climate change (Fearnside 1997; Seiler and Crutzen 1980). During the early succession process, amount of stand biomass increase fastly (Selaya et al. 2007). The carbon sequestration of forest area change constanly with vegetation growth, dead, and decomposition (Gorte 2007); species composition, age structur, and forest health (Harmon et al. 1990). Carbon stock at stand in the surface soil and standing tree mass could represented less than 1% to 60% from total carbon stock of forest ecosystem (Curtis 2008). Carbon stock of fertile soils is higher which could influence to carbon stock storage at vegetation biomass (Hairiah and Rahayu 2007).

Biomass is generally expressed in terms of dry weight and on occasion may be given in terms of ash free dry weight (Moore and Chapman 1986). The 'scaling' relationships, by which the ratios between different aspects of tree size change when small and large trees of the same species are compared generally known as 'allometric' relations (Hairiah et al. 2001). The previous studies had been developed allometric equations to estimate above ground biomass (AGB) in the secondary forests (Hashimoto et al. 2004; Kenzo et al. 2009a; Kenzo et al. 2009b; Ketterings et al. 2001; Kiyono and Hastaniah 2005; Nelson et al. 1999; Sierra et al. 2007; Karyati et al. 2019). However the allometric equations to estimate AGB in abandoned lands is still rare reported. The objective of this study was to develop allometric equations for estimation AGB in fallow lands. Information on the allometric relationships could predict biomass and carbon stock in lands after abandonment.

MATERIALS AND METHODS

Study site

The study was carried out in Salo Cella Village, Muara Badak Sub-district, Kutai Kartanegara Districts, East Kalimantan Province, Indonesia (Figure 1). This site was located in 0°17'18.7"S 117°18'08.2"E. Muara Badak Sub-district has 939.09 km² wide with population of 57,712 persons including 13 villages. Salo Cella Village is about 10 km from the capital of Sub-district. The capital of subdistrict was Muara Badak Ulu with 16 m height Above Mean Sea Level (AMSL). Muara Badak received average amount of 141 mm in rainfall and 11 raindays in 2017 (Statistics Kutai Kartanegara Regency 2018). Most of the population in this village were farmers' livelihoods. Muara Badak is administratively bordered with Marang Kayu Sub-district at north side, Anggana Sub-district Samarinda City at south side, Makassar Strait at east side, and Tenggarong Seberang Sub-district at west side. Muara Badak is one of oil and gas producer. This has also big potency in fishery and plantation sectors. The area was covered by lowland mixed dipterocarp forest.

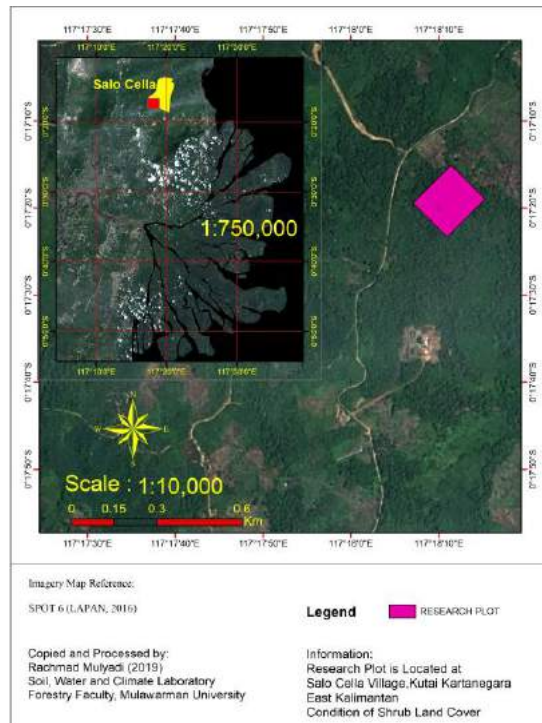


Figure 1. Map of study site in Salo Cella Village, Kutai Kartanegara Districts, East Kalimantan Province, Indonesia.

Data collection

Assessment on biomass in the field

Thirty sample trees were chosen in abandoned land. The sample trees were selected to obtain the representative species of land after abandonment. The selection of sample trees was based on consideration of the species and DBH. The standing DBH (1.3 m) of selected trees were measured using diameter tape. Measurement of the total height of the sample tree was completed once the tree had fallen. Felling sample trees were conducted by following the harvesting rules. The harvested trees were divided into several fractions which every tree fraction was 1 meter length. Then, parts of trees were separated into leaves and twigs (hereafter called leaves), branches, and main stems in the field as shown in Figure 2.

Dividing sample tree fractions was accomplished with the following criteria (Ministry of Forestry Indonesia, 2011):

- 1) Dividing sample tree fractions was done to separate parts of tree biomass including leaves, branches, and stem.
- 2) Dividing sample tree fraction to be weighed needs to consider the capacity of the available scales.

3) Especially for the stem fraction, the stem was divided into several sections (sub-fractions of the stem) taking into account the shape, uniformity, and weight of the pieces.

The fresh weight of all fractions were taken by the suitable scale in the field. The disk samples of trunk with 2-5 cm thick were collected as many as three disk sample if the harvested trees had less than 10 fractions and four disk samples if more than 10 fractions. Five branch samples of 20-30 cm in length and five leaf samples of 100-300 grams in weight were taken from each sample tree. Figure 3 illustrates tree components and the position of sub-sample being taken for AGB assessment. The wood density of each sample tree was conducted from the various literatures.

Analysis of dry-weight in the laboratory

Before oven-dried, all samples were air-dried in the laboratory to determine the moisture content. Then, samples of stem and branch fractions were dried in an oven at a temperature 105°C for 96 hours until reaching a constant weight. Samples of leaves were dried in an oven at temperature of 80°C for 48 hours until constant weight was reached. Weighing the samples of each fraction was performed using an analytical digital weighing scale after drying them in an oven.

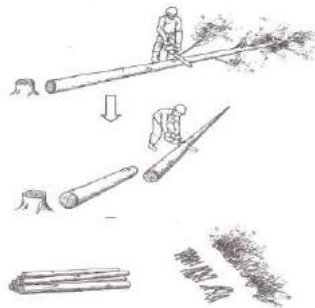


Figure 2. Dividing the trees (Source: Ministry of Forestry Indonesia, 2011).

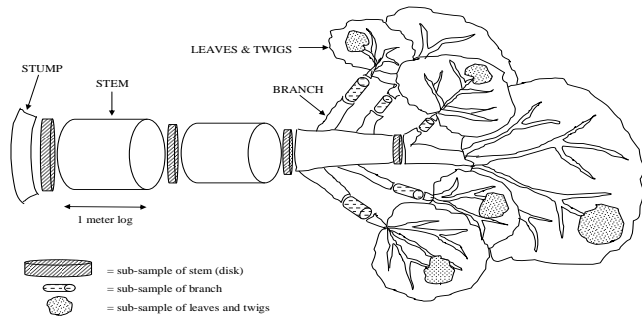


Figure 3. Illustration of tree components and the position of sub-sample being taken (Karyati 2013).

Data analysis

The total oven-dry weight of each seedling-sapling and tree part were determined using the following formula (Hairiah et al. 2001; Hairiah & Rahayu 2007; Ministry of Forestry Indonesia, 2011):

$$dw = (sdw \times fw) / sfw \tag{1}$$

where: dw = total dry weight (kg); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of the sample (g).

The five selected allometric equations of AGB were tested (Equations 2-6):

$$y = a + b x \tag{2}$$

$$y = ax^b \tag{3}$$

$$y = a + b (\ln x) \quad (4)$$

$$(\ln y) = a + b x \quad (5)$$

$$(\ln y) = a + b (\ln x) \quad (6)$$

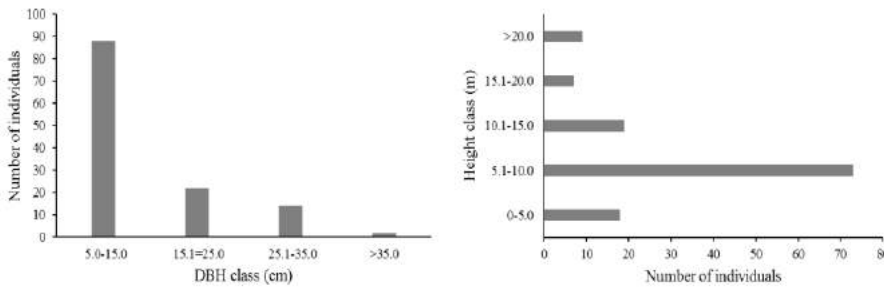
144 where: y = total dry weight or biomass of each plant part, such as trunk, branch, leaf, and total above ground biomass
 145 (TAGB) (kg); x = diameter at breast height (DBH, cm), total height (H, meter), and $(DBH^2 \times H)$ ($cm^2 m$); 'a' and 'b' =
 146 coefficients estimated by regression.

147 All regression analysis was carried out using SPSS version 18 for windows (SPSS Japan, Tokyo, Japan). The R^2 value
 148 was determined to evaluate precision among all tested allometric equations.

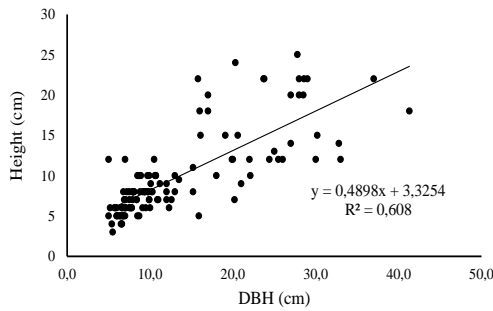
149 **RESULTS AND DISCUSSION**

150 **Selected samples of trees**

151 Thirty trees with DBH of ≥ 5 cm were harvested and measured to determine above ground parts in the study site as
 152 represent in Table 1. The DBH and height classes of selected sample trees for assessment AGB are illustrated in Figure 4.
 153 The DBH range was 5.0-17.4 cm and height was 5.0-12.5 m for selective sample trees. The relationship between DBH and
 154 total height of sample trees for assessment AGB in the study sites is presented in Figure 5. The illustration showed that an
 155 increase in DBH was followed by an increase in total height. The equations of this relationship was " $H=0.4898$
 156 $(DBH)+3.3254$ " ($n=30$; $R^2=0.608$). As stated 'H' is total height (m) and 'DBH' is diameter at breast height (cm).
 157



172 **Figure 4.** The distributions of (a) DBH classes and (b) height classes of sample trees to developed allometric equations.



189 **Figure 5.** The DBH and total height of sample trees to developed allometric equations.

191 **Tree variables**

192 Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters
 193 of destructive biomass are summarized in Table 1. The minimum and maximum weight of branches biomass, trunk biomass,
 194 and TAGB were 3.92-34.18 kg; 12.84-296.72 kg, and 34.28-308.98 respectively. The DBH of sample trees ranged 16.00-
 195 32.00 cm, with the height ranged 9.30-22.70 m. The wood densities of sample trees ranged 0.37-0.69 $g\ cm^{-3}$. The result
 196 showed that there were strong correlation ($P < 0.01$) among trunk biomass to DBH and tree height as well as TAGB and
 197 tree height. The correlation ($P < 0.05$) was showed by TAGB and DBH. The strong correlation ($P < 0.01$) was also showed
 198 between DBH and tree height. However, the leaf and branch biomass were not correlated with DBH and tree height

199 significantly ($P > 0.05$). In addition, the wood density was not also correlated to plant part biomass (leaf, branch, trunk, and
 200 TAGB) and tree dimensions (DBH and height).

201 **Table 1.** Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters of
 202 destructive biomass
 203
 204

	Pearson's correlation			Mean	Range
	DBH (cm)	H (m)	WD (g cm^{-3})		
Leaf biomass (kg)	-0.303 ^{ns}	-0.198 ^{ns}	0.262 ^{ns}	12.43	1.37 - 45.59
Branch biomass (kg)	0.205 ^{ns}	-0.072 ^{ns}	0.208 ^{ns}	16.99	3.92 - 34.18
Trunk biomass (kg)	0.527 ^{**}	0.768 ^{**}	0.027 ^{ns}	116.55	12.84 - 296.72
TAGB (kg)	0.494 [*]	0.710 ^{**}	0.098 ^{ns}	145.97	34.28 - 308.98
DBH (cm)	1	0.578 ^{**}	-0.357 ^{ns}	24.35	16.00 - 32.00
H (m)	0.578 ^{**}	1	-0.184 ^{ns}	14.54	9.30 - 22.70
WD (g cm^{-3})	-0.357 ^{ns}	-0.184 ^{ns}	1	0.53	0.37 - 0.69

205 Note: ^{ns} is not significant at the 0.05 level ($P > 0.05$); ^{*} and ^{**}Correlation are significant at the 0.05 and 0.01 level (2-tailed) respectively

206
 207 [There were 10 species of 10 genera of 9 families selected in study site.] Eight sample trees were *Pterospermum*
 208 *javanicum*-including (Malvaceae). There were 5 sample trees of *Glochidion obscurum* (Euphorbiaceae) and 4 sample trees
 209 of *Bridelia glauca* (Phyllanthaceae). Three sample trees were *Vatica javanica* (Dipterocarpaceae). The species of *Ficus*
 210 *septica* (Moraceae), *Trema orientalis* (Cannabaceae), *Archidendron jiringa* (Fabaceae), *Vernonia arborea* (Asteraceae)
 211 were selected for two sample trees respectively. One sample tree was *Heliciopsis artocarpoides* (Proteaceae) as well as
 212 *Artocarpus elasticus* (Moraceae). The range of dry weight was 1.37-45.59 kg for leaf, 3.92-34.18 kg for branch, 12.84-
 213 296.72 kg for trunk, and 34.28-308.98 kg for TAGB in this site (Table 2). The result showed that there are diverse
 214 variation among different species. The different tree species tends to has the different structure (growth, stratification, and
 215 crown cover) and physiognomy. The largest sample tree was *Artocarpus elasticus* with DBH of 32.60 cm. This species
 216 had the dry weight of leaf, branch, trunk, and TAGB were 14.15, 20.23, 183.51, and 217.89 kg respectively. On the other
 217 hand, the smallest selected tree was *Archidendron jiringa* with DBH of 16.00 cm. This species obtained 22.95 kg of leaf
 218 dry biomass, 9.27 kg of branch dry biomass, 24.09 kg of trunk dry biomass, and 56.30 kg of TAGB. *Pterospermum*
 219 *javanicum* with 22.70 m height was the tallest sample trees. This sample tree had the highest trunk dry biomass (296.72
 220 kg) and TAGB (308.98 kg). Contrarily, the other sample tree of *Pterospermum javanicum* had the lowest trunk dry biomass
 221 (12.84 kg) and TAGB (34.28 kg). The shortest sample tree with 9.30 m height was *Bridelia glauca*. The lowest leaf dry
 222 biomass (1.37 kg) and branch dry biomass (3.92 kg) were showed by *Vernonia arborea*. Meanwhile, the other sample tree
 223 of *Archidendron jiringa* had the highest leaf dry biomass (45.59 kg). The highest branch dry biomass (34.18 kg) was
 224 showed by *Glochidion obscurum*.

225
 226 **Table 2.** All data sets for develop allometric equations in abandoned lands
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Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm^{-3})
1	Malvaceae	<i>Pterospermum javanicum</i>	31.85	18.10	5.68	32.61	249.73	288.01	0.53
2	Malvaceae	<i>Pterospermum javanicum</i>	20.06	17.10	9.31	9.39	119.09	137.80	0.53
3	Malvaceae	<i>Pterospermum javanicum</i>	28.98	22.70	3.86	8.39	296.72	308.98	0.53
4	Moraceae	<i>Ficus septica</i>	32.17	20.20	5.70	19.70	166.63	192.03	0.39
5	Moraceae	<i>Ficus septica</i>	28.03	15.60	1.92	10.47	93.98	106.38	0.39
6	Cannabaceae	<i>Trema orientalis</i>	26.75	14.16	7.37	22.89	86.11	116.36	0.44
7	Proteaceae	<i>Heliciopsis artocarpoides</i>	21.97	9.70	9.95	9.88	57.62	77.44	0.65
8	Phyllanthaceae	<i>Bridelia glauca</i>	28.66	13.90	6.78	12.37	80.76	99.91	0.50
9	Phyllanthaceae	<i>Bridelia glauca</i>	20.70	12.50	6.93	16.74	71.55	95.22	0.50
10	Cannabaceae	<i>Trema orientalis</i>	26.11	10.80	13.97	29.02	58.17	101.16	0.44
11	Malvaceae	<i>Pterospermum javanicum</i>	29.62	16.00	8.76	10.12	77.63	96.52	0.53
12	Malvaceae	<i>Pterospermum javanicum</i>	16.88	10.60	6.88	14.56	12.84	34.28	0.53
13	Phyllanthaceae	<i>Bridelia glauca</i>	26.75	15.80	12.89	33.00	89.17	135.07	0.50
14	Euphorbiaceae	<i>Glochidion obscurum</i>	26.00	15.30	10.65	8.34	114.02	133.01	0.67
15	Euphorbiaceae	<i>Glochidion obscurum</i>	20.40	13.70	11.88	9.24	89.41	110.53	0.67
16	Fabaceae	<i>Archidendron jiringa</i>	16.00	10.36	22.95	9.27	24.09	56.30	0.42
17	Dipterocarpaceae	<i>Vatica javanica</i>	19.95	13.00	38.71	32.40	43.01	114.11	0.69
18	Euphorbiaceae	<i>Glochidion obscurum</i>	19.70	14.65	8.64	14.25	78.32	101.21	0.67
19	Fabaceae	<i>Archidendron jiringa</i>	24.60	16.00	45.59	22.73	160.89	229.21	0.42
20	Dipterocarpaceae	<i>Vatica javanica</i>	20.70	12.00	39.17	16.92	129.92	186.01	0.69
21	Euphorbiaceae	<i>Glochidion obscurum</i>	20.39	9.50	20.97	34.18	104.42	159.57	0.67
22	Dipterocarpaceae	<i>Vatica javanica</i>	28.60	13.90	7.66	29.95	184.53	222.14	0.69
23	Euphorbiaceae	<i>Glochidion obscurum</i>	21.50	10.90	11.24	21.63	142.13	175.00	0.67

Commented [SV1]: What method was used in selecting sample trees both species and family?

Commented [SV2]: Is there no flower and fruit parts?

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
24	Moraceae	<i>Artocarpus elasticus</i>	32.60	20.70	14.15	20.23	183.51	217.89	0.46
25	Asteraceae	<i>Vernonia arborea</i>	23.30	9.82	1.37	3.92	52.70	57.99	0.37
26	Asteraceae	<i>Vernonia arborea</i>	29.40	13.50	3.79	9.83	121.02	134.64	0.37
27	Phyllanthaceae	<i>Bridelia glauca</i>	21.50	9.30	14.28	17.31	67.24	98.83	0.50
28	Malvaceae	<i>Pterospermum javanicum</i>	20.29	16.10	4.04	3.94	163.39	171.38	0.53
29	Malvaceae	<i>Pterospermum javanicum</i>	20.36	18.50	6.66	8.55	189.90	205.12	0.53
30	Malvaceae	<i>Pterospermum javanicum</i>	26.60	21.70	11.19	17.72	187.95	216.85	0.53
Average			24.35	14.54	12.43	16.99	116.55	145.96	0.53
Minimum			16.00	9.30	1.37	3.92	12.84	34.28	0.37
Maximum			32.60	22.70	45.59	34.18	296.72	308.98	0.69
Standard deviation			4.66	3.75	10.93	9.13	65.59	66.98	0.11

Note: DBH=diameter at breast height; H=total height; TAGB=total above ground biomass; WD=wood density.

The allometric equations for Above Ground Biomass (AGB) of trees

The results of regression analyses for predicting plant part biomass of subject trees from diameter at breast height (DBH) and total height (H) using data all studied individuals are shown in Table 3. The relationships between DBH, (DBH²×H), and height of trees as independent variables were not significant to related leaf and branch dry biomass (*P* value > 0.05) as well as DBH to trunk dry biomass. This means that the DBH, (DBH²×H), height of trees were not a good predictor to leaf and branch dry biomass based on the goodness of fit. Similarly DBH was not also good predictor to trunk dry biomass. The correlations between (DBH²×H) and height of trees to trunk dry biomass and TAGB showed moderately strong relationships as well as DBH to TAGB (*P* value < 0.001).

The selected allometric equations to estimate above ground biomass of trees were dominated by log-linear model ($\ln y = a + b \ln x$) and linear model ($y = a + bx$). These equations were fitting model to relate dependent variables (leaf, branch, trunk, and AGB) and independent variables (DBH, (DBH²×H), and H) for tree stage. From all tested regression, there are only four equations with relatively high R² (>0.400). These equations are “ $\ln(\text{trunk dry biomass}) = 0.837 \times \ln(\text{DBH}^2 \times \text{H}) - 29.45$ ” (R²=0.500), “ $\ln(\text{trunk dry biomass}) = 1.812 \times \ln(\text{H}) - 0.217$ ” (R²=0.461), “ $\ln(\text{AGB}) = 0.576 \times \ln(\text{DBH}^2 \times \text{H}) - 0.301$ ” (R²=0.431), and “ $\ln(\text{AGB}) = 1.331 \times \ln(\text{H}) - 1.350$ ” (R²=0.455). However, the result showed there are very weak relationships between leaves and branches dry biomass of trees and plant dimensions in the abandoned land. The trunk dry biomass and AGB in the tropical secondary forests of different ages (5, 10 and 20 years after abandonment) showed strong correlations (adjusted R²= 0.59-0.95) with diameter at breast height (DBH) and height. The leaf and branch dry biomass had weak correlations with height (adjusted R²=0.36-0.50) (Karyati et al. 2019). The mixed-species allometric equations showed AGB correlates significantly with diameter at stump height (R²=0.78; *P*<0.01) and tree height (R²=0.41, *P*<0.05) (Mokria et al. 2018). Generally, the developed allometric equations showed relatively low R² (<0.60). This may caused by the high variation sample trees. The variation sample trees lead the variation on wood density, structure, and physiognomy. Parlucha (2017) stated that comparing growth performance for different level of species type (native or exotic) is not conclusive since the growth of trees varies. It is happen from specific species character level and matching with the existing site condition. The regression between the trunk biomass and TAGB and the product of square DBH and height (cm² m) and the natural logarithm of height was illustrated in Figure 6.

Table 3. The allometric equations for predicting plant part biomass of subject trees in the study site

Dependent variable (y)	Independent variable (x)	Equation	<i>P</i> value	R ²
Leaf dry biomass (kg)	DBH (cm)	$\ln(y) = 0.054 \times (x) - 3.524$	>0.05	0.099
	(DBH ² ×H) (cm ² m)	$\ln(y) = 0.4132 \times \ln(x) - 5.932$	>0.05	0.086
	H (m)	$(y) = 0.001 \times (x) - 17.614$	>0.05	0.074
Branch dry biomass (kg)	DBH (cm)	$\ln(y) = 0.695 \times \ln(x) + 0.4687$	>0.05	0.060
	(DBH ² ×H) (cm ² m)	$\ln(y) = 0.001 \times (x) + 2.5228$	>0.05	0.023
	H (m)	$(y) = 0.001 \times (x) + 15.097$	>0.05	0.014
Trunk dry biomass (kg)	DBH (cm)	$\ln(y) = 1.910 \times \ln(x) - 1.501$	>0.05	0.347
	(DBH ² ×H) (cm ² m)	$\ln(y) = 0.837 \times \ln(x) - 2.945$	<0.001	0.500
	H (m)	$\ln(y) = 1.812 \times \ln(x) - 0.217$	<0.001	0.461
Above ground biomass (kg)	DBH (cm)	$\ln(y) = 1.277 \times \ln(x) + 0.808$	<0.001	0.283
	(DBH ² ×H) (cm ² m)	$\ln(y) = 0.576 \times \ln(x) - 0.301$	<0.001	0.431
	H (m)	$\ln(y) = 1.331 \times \ln(x) - 1.350$	<0.001	0.455

Note: *P* values of the regression analysis are shown, R² denotes multiple coefficient of determination.

Commented [SV3]: The model evaluation was only based on statistics for R² and *P* value, no including some statistics for errors, especially relative errors. It is suggested to add some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al, 2017) for model evaluation. Due to limited samples (only 30 trees) in this study, cross validation was not conducted. In this case, MPE and others statistics are an important index for assessing the biomass models.

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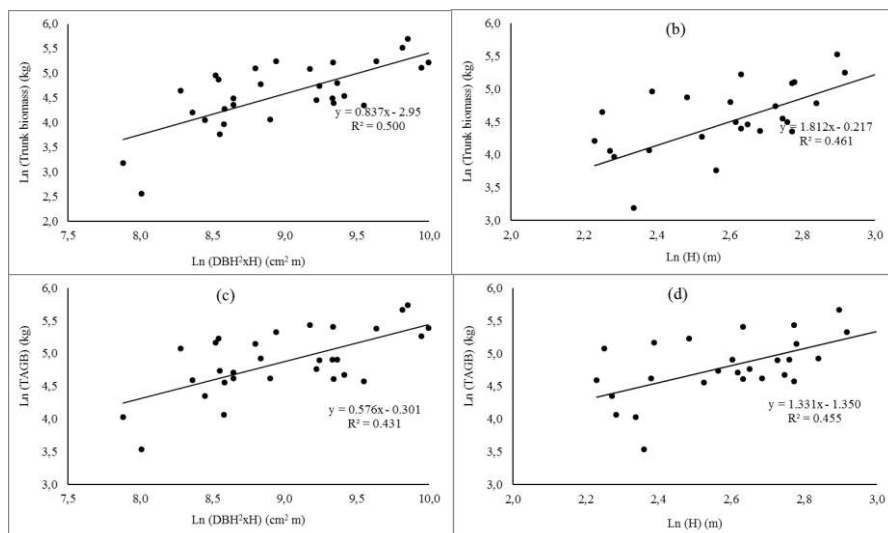


Figure 6. Regression between the trunk biomass (kg) and the product of square DBH and height (cm² m) (a) and the natural logarithm of height (m) (b); Regression between total above ground biomass (TAGB) (kg) and the product of square DBH and height (cm² m) (c) and the natural logarithm of height (m) (d).

Comparison among various allometric equations

The estimation of AGB using the developed allometric equation in this study was lower than using the previous developed equations as presented in Table 3. The AGB estimation of 33.31 Mg ha⁻¹ was lower than 115.90, 91.65, 85.60, 76.31, 68.08, 63.99, 60.32 Mg ha⁻¹ of AGB calculated using the formulas of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown (1997), Basuki et al. (2009), Kiyono and Hastaniah (2008), and Nelson et al. (1999) respectively. The value resulted by the developed allometric equation was similar than those using other previous reported equations, i.e., 38.86 Mg ha⁻¹ (Kenzo et al. 2009a), 39.31 Mg ha⁻¹ (Hashimoto et al. 2004), 49.05 Mg ha⁻¹ (Sierra et al. (2007), 49.63 Mg ha⁻¹ (Kettering et al. 2001), 50.31Mg ha⁻¹ (Karyati et al. 2019), and 5.94 Mg ha⁻¹ (Kenzo et al. 2009b). The comparison between AGB and DBH estimated by previously reported relationships was illustrated in Figure 7.

The calculation using equations of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown (1997), Basuki et al. (2009), and Kiyono and Hastaniah (2008) resulted the overestimation than the developed allometric equation. This might be caused the low wood density (0.37-0.69) of trees in the study site, because tree species observed in the abandoned land was dominated by pioneer species. The allometric equations for pioneer species may differ significantly caused usually these species has the low wood (Hashimoto et al. 2004). The wood densities of trees were 0.40-0.79 for Brown's equation, 0.32-0.86 for Basuki et al.'s equation, and 0.67 for Kiyono and Hastaniah's equation. The similar values of AGB were estimated by using equations of Kenzo et al. (2009a) with wood density of 0.35, Kettering et al. (2001) with wood density of 0.35 to 0.91, Karyati et al. (2019) with wood density of 0.24-0.44, and Kenzo et al. (2009b) with wood density of 0.35. Kenzo et al. (2009a), Hashimoto et al. (2004), and Karyati et al. (2019) developed allometric equation for mixed species in tropical forest of Kalimantan, while Kettering et al. (2001) developed allometric for mixed secondary forest in Sumatra. Sierra et al. (2007) reported allometric equation for tropical forest in Colombia. The similar tree species in abandoned land of study site and the mixed secondary forest caused the similar estimation of AGB by using the developed equations.

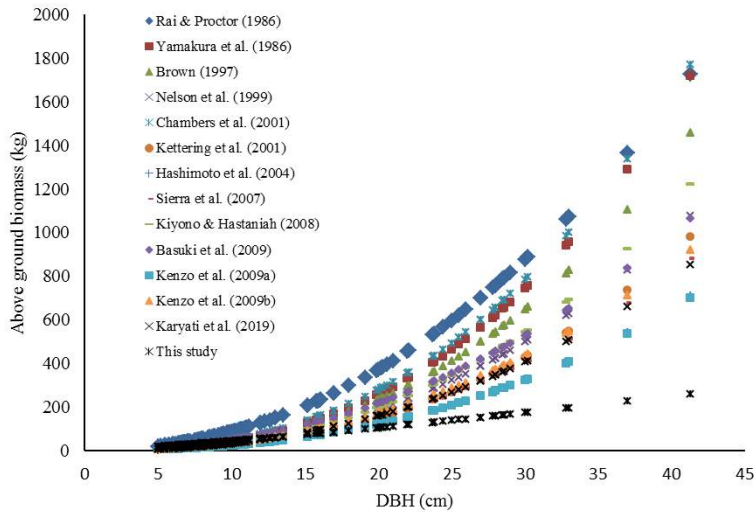
The using appropriate allometric equations to estimate AGB is needed, because it will give accurate estimation on AGB in the study site. When specific allometric equation for different land use and land coverage was developed, the users will choose suitable alternative equations.

303 **Table 4.** Estimation of AGB using various reported relationships for trees in the study site

No.	Equation	Author	Estimate of AGB (Mg ha ⁻¹)
1	$\ln(\text{AGB})=2.12 \times \ln(\text{DBH})-0.435$	Rai and Proctor (1986)	115.90
2	$\ln(\text{AGB})=2.62 \times \ln(\text{DBH})-2.30$	Yamakura et al. (1986)	85.60
3	$\ln(\text{AGB})=2.53 \times \ln(\text{DBH})-2.13$	Brown (1997)	76.31
4	$\ln(\text{AGB})=2.413 \times \ln(\text{DBH})-1.997$	Nelson et al. (1999)	60.32
5	$\ln(\text{AGB})=2.55 \times \ln(\text{DBH})-2.010$	Chambers et al. (2001)	91.65
6	$\ln(\text{AGB})=2.59 \times \ln(\text{DBH})-2.75$	Kettering et al. (2001)	49.63
7	$\ln(\text{AGB})=2.44 \times \ln(\text{DBH})-2.51$	Hashimoto et al. (2004)	39.31
8	$\ln(\text{AGB})=2.422 \times \ln(\text{DBH})-2.232$	Sierra et al. (2007)	49.05
9	$\text{AGB}=0.1008 \times \text{DBH}^{2.5264}$	Kiyono and Hastaniah (2008)	63.99
10	$\ln(\text{AGB})=2.196 \times \ln(\text{DBH})-1.201$	Basuki et al. (2009)	68.08
11	$\text{AGB}=0.0829 \times \text{DBH}^{2.43}$	Kenzo et al. (2009a)	38.86
12	$\text{AGB}=0.1525 \times \text{DBH}^{2.34}$	Kenzo et al. (2009b)	53.94
13	$\ln(\text{AGB})=2.3207 \times \ln(\text{DBH})-1.89$	Karyati et al. (2019)	50.31
14	$(\text{AGB})=12.683 \times (\text{DBH}^2 \times \text{H})-38.403$	This study	33.31

Commented [SV4]: Please read and compare to Manuri *et al.* (2017) that it is related to effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region

304 Note: AGB = above ground biomass ; DBH = diameter at breast height.



319 Figure 7. Comparison among various allometric relationships between above ground biomass (AGB) and diameter at breast height (DBH) in the study site

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Dear Managing Editor,

We would like to say thanks and appreciate for constructive suggestion from reviewer.

As attached below, our feedback for the reviewer's comments on our manuscript entitled "Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands"

No.	Page/ Line	Review	Feedback and revision
1	Page 5, line 207	What method was used in selecting sample trees both species and family?	Explanation had added → Thirty sample trees with DBH of > 15 cm were selected in the study site, with consideration of the species. These selected trees didnot considering individuals with damaged crowns or broken trunks. Almost 90% of the selected trees were categorized as the dominant species in terms of density and Importance Value Index (IVI) as observed in the current study, while few selected trees represented the rare species (Page 5, line 214-217).
2	Page 5, line 226	Is there no flower and fruit parts?	Explanation had added → The flower and fruit parts was not included in the observation, because very few sample trees that have flower and fruit during observation (Page 3, line 107-109)
3	Page 5, line 255	The model evaluation was only based on statistics for R^2 and P value, no including some statistics for errors, especially relative errors. It is suggested to add some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al, 2017) for model evaluation. Due to limited samples (only 30 trees) in this study, cross validation was not conducted. In this case, MPE and others statistics are an important index for assessing the biomass models.	Some assessment indices such as mean relative error (MRE), mean absolute relative error (MARE) (Manuri et al., 2017), total relative error (TRE) and mean prediction error (MPE) (Zeng et al, 2017) for model evaluation had added (Page 4, line 152-154; Page 7, Table 3)
4	Page 8, line 303	Please read and compare to Manuri <i>et al.</i> (2017) that it is related to effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region.	The comparison to Manuri et al. (2017) had added (Page 7, line 295; Page 8, line 313-316; Page 8, Tabel 4; Page 8, Figure 7)

Samarinda, 10 November 2019



Karyati

Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land

Abstract. Karyati, Widiati KY, Karmini, Mulyadi R. 2019. *Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands. Biodiversitas x: xx-xx.* The abandoned lands have important role in the ecological fuction as well as carbon sequestration. The allometric equations to estimate above ground biomass in abandoned land are still limited available. This study objective was to develop allometric relationships between tree size variables (diameter at breast height (DBH) and tree height) and leaf, branch, trunk, and total above ground biomass (TAGB) in abandoned land in East Kalimantan, Indonesia. The correlation coefficients between stem DBH and tree height to leaf and branch indicating a relatively weak relationship. The moderately strong relationships were showed by DBH and tree height to trunk and TAGB. The specific allometric equation of above ground biomass for different land use and land type is needed to estimate the accurate TAGB in the site.

Key words: Abandoned land, allometric equation, biomass, destructive method

Running title: Development of allometric equations in abandoned land

INTRODUCTION

The National Land Affairs Agency identified 7.3 million hectares lands in Indonesia as abandoned lands in 2011 and about 4.8 million hectares was stated as abandoned lands. This area of abandoned lands increase from 2007 as much as 7.1 million hectares outside forest area (Nurlinda et al. 2014). The abandoned land area in East Kalimantan was about 3 million hectares. The abandoned lands provide habitat rotation to succession process in primary-secondary forest that will increase biodiversity (Chokkalingam et al. 2001). The plant composition, diversity, and growth during fallow periods after shifting cultivation was resulted from complex interaction between condition and factor before and after fallow periods, such as disturbance, land history, land management, tree and seed source composition from soil or surrounding forest, soil fertility, and climate factor (Awang Noor et al. 2008; Kendawang et al. 2007; Van Do et al. 2010).

Land use system on forest basis store CO₂ by carbon stock storage at their biomasss (Gorte 2007; Roshetko et al. 2002). The carbon stock in old age stand could different compared to carbon stock in second growth stand that replace it, cause woody biomass in an area could not describe in nett ecosystem productivity (Janisch and Harmon 2002). Biomass dynamic in tropical forest play important role to evaluation of global carbon cycle and global climate change (Fearnside 1997; Seiler and Crutzen 1980). During the early succession process, amount of stand biomass increase fastly (Selaya et al. 2007). The carbon sequestration of forest area change constanly with vegetation growth, dead, and decomposition (Gorte 2007); species composition, age structur, and forest health (Harmon et al. 1990). Carbon stock at stand in the surface soil and standing tree mass could represented less than 1% to 60% from total carbon stock of forest ecosystem (Curtis 2008). Carbon stock of fertile soils is higher which could influence to carbon stock storage at vegetation biomass (Hairiah and Rahayu 2007).

Biomass is generally expressed in terms of dry weight and on occasion may be given in terms of ash free dry weight (Moore and Chapman 1986). The 'scaling' relationships, by which the ratios between different aspects of tree size change when small and large trees of the same species are compared generally known as 'allometric' relations (Hairiah et al. 2001). The previous studies had been developed allometric equations to estimate above ground biomass (AGB) in the secondary forests (Hashimoto et al. 2004; Kenzo et al. 2009a; Kenzo et al. 2009b; Ketterings et al. 2001; Kiyono and Hastaniah 2005; Nelson et al. 1999; Sierra et al. 2007; Karyati et al. 2019). However the allometric equations to estimate AGB in abandoned lands is still rare reported. The objective of this study was to develop allometric equations for estimation AGB in fallow lands. Information on the allometric relationships could predict biomass and carbon stock in lands after abandonment.

49 **Study site**

50 The study was carried out in Salo Cella Village, Muara Badak Sub-district, Kutai Kartanegara Districts, East
 51 Kalimantan Province, Indonesia (Figure 1). This site was located in 0°17'18.7"S 117°18'08.2"E. Muara Badak Sub-district
 52 has 939.09 km² wide with population of 57,712 persons including 13 villages. Salo Cella Village is about 10 km from the
 53 capital of Sub-district. The capital of subdistrict was Muara Badak Ulu with 16 m height Above Mean Sea Level (AMSL).
 54 Muara Badak received average amount of 141 mm in rainfall and 11 raindays in 2017 (Statistics Kutai Kartanegara
 55 Regency 2018). Most of the population in this village were farmers' livelihoods. Muara Badak is administratively bordered
 56 with Marang Kayu Sub-district at north side, Anggana Sub-district Samarinda City at south side, Makassar Strait at east
 57 side, and Tenggarong Seberang Sub-district at west side. Muara Badak is one of oil and gas producer. This has also big
 58 potency in fishery and plantation sectors. The area was covered by lowland mixed dipterocarp forest.

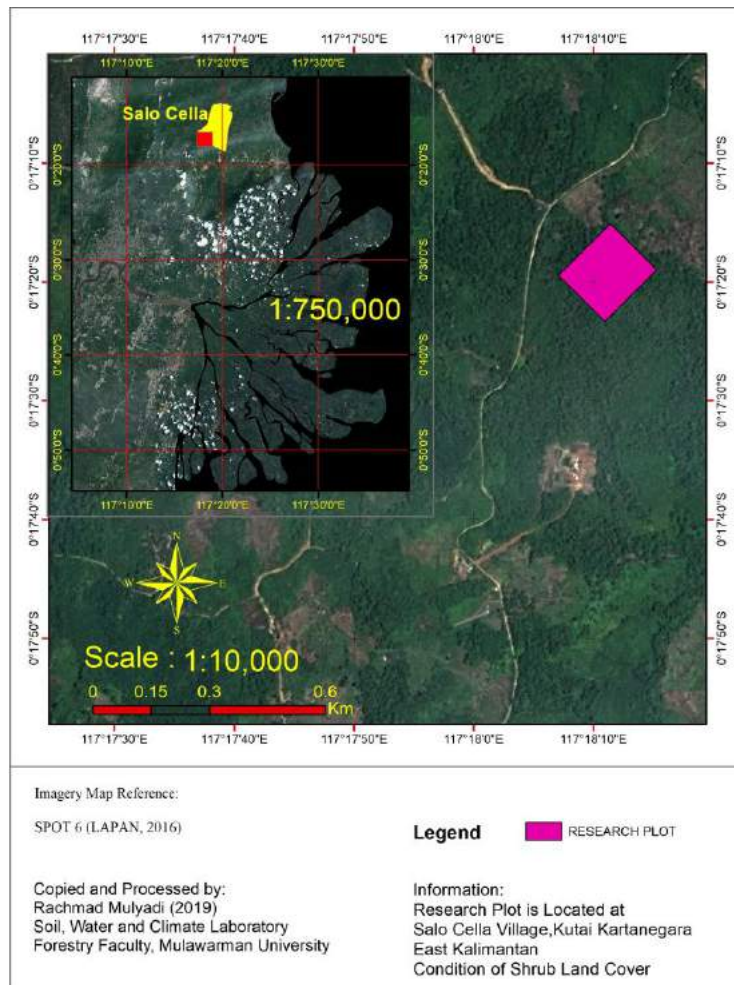


Figure 1. Map of study site in Salo Cella Village, Kutai Kartanegara Districts, East Kalimantan Province, Indonesia.

96 **Data collection**97 *Assessment on biomass in the field*

98 Thirty sample trees were chosen in abandoned land. The sample trees were selected to obtain the representative species
 99 of land after abandonment. The selection of sample trees was based on consideration of the species and DBH. The
 100 standing DBH (1.3 m) of selected trees were measured using diameter tape. Measurement of the total height of the sample
 101 tree was completed once the tree had fallen. Felling sample trees were conducted by following the harvesting rules. The
 102 harvested trees were divided into several fractions which every tree fraction was 1 meter length. Then, parts of trees were
 103 separated into leaves and twigs (hereafter called leaves), branches, and main stems in the field as shown in Figure 2.

104 Dividing sample tree fractions was accomplished with the following criteria (Ministry of Forestry Indonesia, 2011):

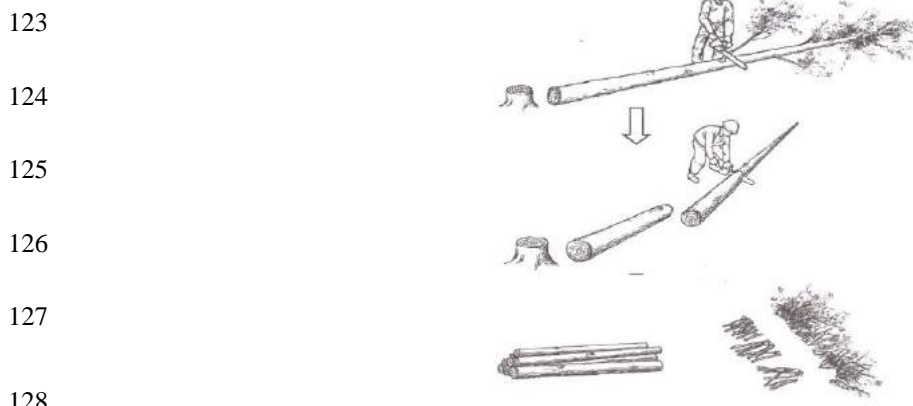
- 105 1) Dividing sample tree fractions was done to separate parts of tree biomass including leaves, branches, and stem. The
 106 flower and fruit parts was not included in the observation, because very few sample trees that have flower and fruit
 107 during observation.

- 108 2) Dividing sample tree fraction to be weighed needs to consider the capacity of the available scales.
 109 3) Especially for the stem fraction, the stem was divided into several sections (sub-fractions of the stem) taking into
 110 account the shape, uniformity, and weight of the pieces.

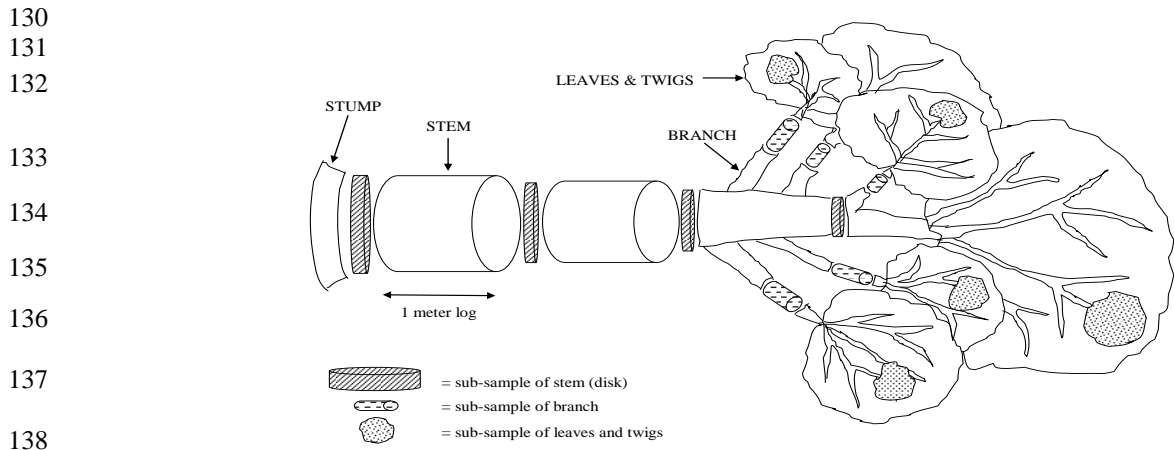
111 The fresh weight of all fractions were taken by the suitable scale in the field. The disk samples of trunk with 2-5 cm
 112 thick were were collected as many as three disk sample if the harvested trees had less than 10 fractions and four disk
 113 samples if more than 10 fractions. Five branch samples of 20-30 cm in length and five leaf samples of 100-300 grams in
 114 weight were taken from each sample tree. Figure 3 illustrates tree components and the position of sub-sample being taken for AGB
 115 assessment. The wood density of each sample tree was conducted from the various literatures.
 116

117 *Analysis of dry-weight in the laboratory*

118 Before oven-dried, all samples were air-dried in the laboratory to determine the moisture content. Then, samples of
 119 stem and branch fractions were dried in an oven at a temperature 105°C for 96 hours until reaching a constant weight.
 120 Samples of leaves were dried in an oven at temperature of 80°C for 48 hours until constant weight was reached. Weighing
 121 the samples of each fraction was performed using an analytical digital weighing scale after drying them in an oven.
 122



129 **Figure 2.** Dividing the trees (Source: Ministry of Forestry Indonesia, 2011).



139 **Figure 3.** Illustration of tree components and the position of sub-sample being taken (Karyati 2013).

140 **Data analysis**

141 The total oven-dry weight of each tree part were determined using the following formula (Hairiah et al. 2001; Hairiah
 142 & Rahayu 2007; Ministry of Forestry Indonesia, 2011):

$$dw = (sdw \times fw) / sfw \tag{1}$$

143 where: dw = total dry weight (kg); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of
 144 the sample (g).

145 The five selected allometric equations of AGB were tested (Equations 2-6):

$$y = a + b x \tag{2}$$

$$y = ax^b \quad (3)$$

$$y = a + b (\ln x) \quad (4)$$

$$(\ln y) = a + b x \quad (5)$$

$$(\ln y) = a + b (\ln x) \quad (6)$$

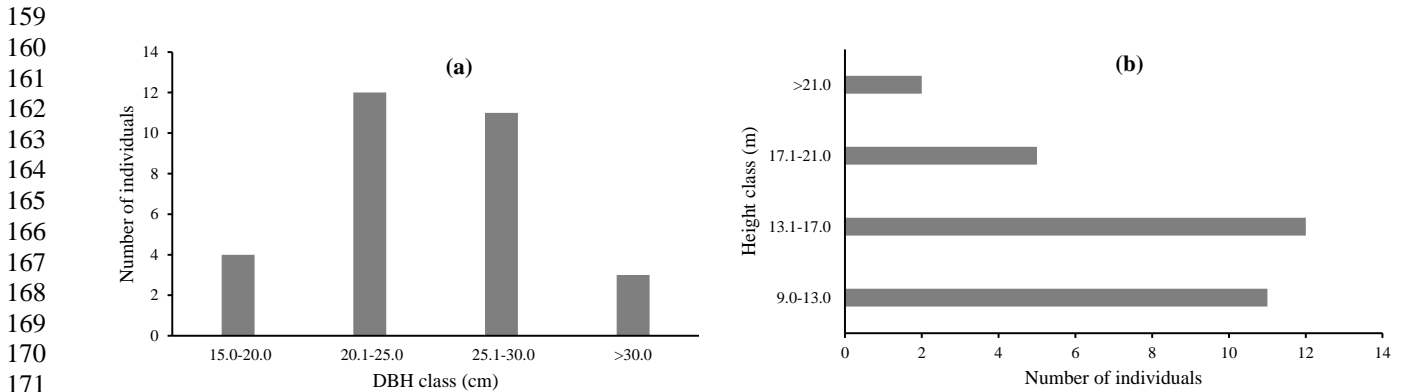
146 where: y = total dry weight or biomass of each plant part, such as trunk, branch, leaf, and total above ground biomass
 147 (TAGB) (kg); x = diameter at breast height (DBH, cm), total height (H, meter), and $(DBH^2 \times H)$ ($cm^2 m$); 'a' and 'b' =
 148 coefficients estimated by regression.

149 All regression analysis was carried out using SPSS version 18 for windows (SPSS Japan, Tokyo, Japan). The R^2 value
 150 was determined to evaluate precision among all tested allometric equations.

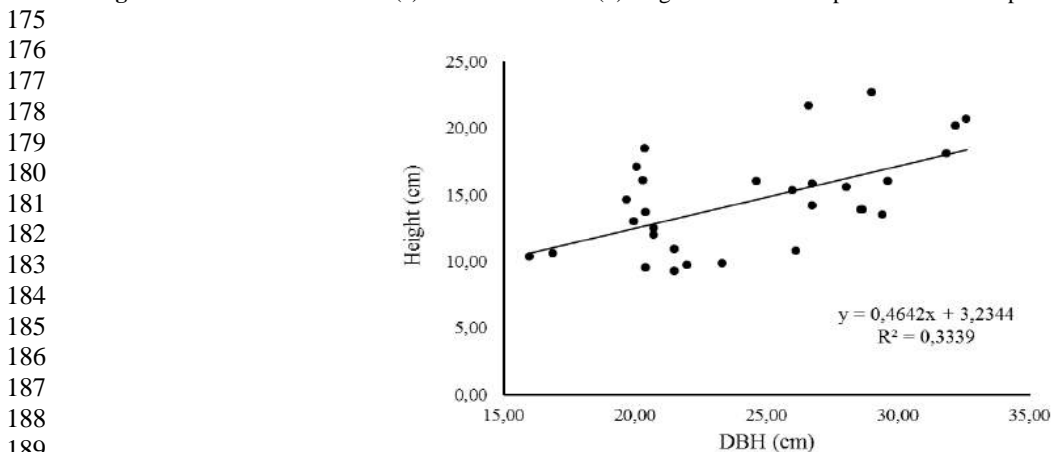
151 RESULTS AND DISCUSSION

152 Selected samples of trees

153 Thirty trees with DBH of ≥ 15 cm were harvested and measured to determine above ground parts in the study site as
 154 represent in Table 1. The DBH and height classes of selected sample trees for assessment AGB are illustrated in Figure 4.
 155 The DBH range was 16.0-32.6 cm and height was 9.3-22.7 m for selective sample trees. The relationship between DBH
 156 and total height of sample trees for assessment AGB in the study site is presented in Figure 5. The illustration showed that
 157 an increase in DBH was followed by an increase in total height. The equations of this relationship was " $H=0.4642$
 158 $(DBH)+3.2344$ " ($n=30$; $R^2=0.3339$). As stated 'H' is total height (m) and 'DBH' is diameter at breast height (cm).



171 **Figure 4.** The distributions of (a) DBH classes and (b) height classes of sample trees to developed allometric equations.



172 **Figure 5.** The DBH and total height of sample trees to developed allometric equations.

173 Tree variables

174 Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters
 175 of destructive biomass are summarized in Table 1. The minimum and maxiu weight of branches biomass, trunk biomass,
 176 and TAGB were 3.92-34.18 kg; 12.84-296.72 kg, and 34.28-308.98 respectively. The DBH of sample trees ranged 16.00-
 177 32.00 cm,with the the height ranged 9.30-22.70 m. The wood densites of sample trees ranged 0.37-0.69 $g\ cm^{-3}$. The result
 178 showed that there were strong correlation ($P < 0.01$) among trunk biomass to DBH and tree height as well as TAGB and
 179 tree height. The correlation ($P < 0.05$) was showed by TAGB and DBH. The strong correlation ($P < 0.01$) was also showed

200 between DBH and tree height. However, the leaf and branch biomass were not correlated with DBH and tree height
 201 significantly ($P>0.05$). In addition, the wood density was not also correlated to plant part biomass (leaf, branch, trunk, and
 202 TAGB) and tree dimensions (DBH and height).

203
 204 **Table 1.** Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters of
 205 destructive biomass
 206

	Pearson's correlation			Mean	Range
	DBH (cm)	H (m)	WD (g cm ⁻³)		
Leaf biomass (kg)	-0.303 ^{ns}	-0.198 ^{ns}	0.262 ^{ns}	12.43	1.37 - 45.59
Branch biomass (kg)	0.205 ^{ns}	-0.072 ^{ns}	0.208 ^{ns}	16.99	3.92 - 34.18
Trunk biomass (kg)	0.527 ^{**}	0.768 ^{**}	0.027 ^{ns}	116.55	12.84 - 296.72
TAGB (kg)	0.494 [*]	0.710 ^{**}	0.098 ^{ns}	145.97	34.28 - 308.98
DBH (cm)	1	0.578 ^{**}	-0.357 ^{ns}	24.35	16.00 - 32.00
H (m)	0.578 ^{**}	1	-0.184 ^{ns}	14.54	9.30 - 22.70
WD (g cm ⁻³)	-0.357 ^{ns}	-0.184 ^{ns}	1	0.53	0.37 - 0.69

207 Note: ^{ns} is not significant at the 0.05 level ($P>0.05$) ; ^{*} and ^{**}Correlation are significant at the 0.05 and 0.01 level (2-tailed) respectively
 208

209 Thirty sample trees with DBH of > 15 cm were selected in the study site, with consideration of the species. These
 210 selected trees didnot considering individuals with damaged crowns or broken trunks. Almost 90% of the selected trees
 211 were categorized as the dominant species in terms of density and Importance Value Index (IVI) as observed in the
 212 preminilary study, while few selected trees represented the rare species. There were 10 species of 10 genera of 9 families
 213 selected in study site. Eight sample trees were *Pterospermum javanicum*-including (Malvaceae). There were 5 sample trees
 214 of *Glochidion obscurum* (Euphorbiaceae) and 4 sample trees of *Bridelia glauca* (Phyllanthaceae). Three sample trees were
 215 *Vatica javanica* (Dipterocarpaceae). The species of *Ficus septica* (Moraceae), *Trema orientalis* (Cannabaceae),
 216 *Archidendron jiringa* (Fabaceae), *Vernonia arborea* (Asteraceae) were selected for two sample trees respectively. One
 217 sampe tree was *Heliciopsis artocarpoides* (Proteaceae) as well as *Artocarpus elasticus* (Moraceae). The range of dry
 218 weight was 1.37-45.59 kg for leaf, 3.92-34.18 kg for branch, 12.84-296.72 kg for trunk, and 34.28-308.98 kg for TAGB in
 219 this site (Table 2). The result showed that there are diverse variation among different species. The different tree species
 220 tends to has the different structure (growth, stratification, and crown cover) and physiognomy. The largest sample tree was
 221 *Artocarpus elasticus* with DBH of 32.60 cm. This species had the dry weight of leaf, branch, trunk, and TAGB were
 222 14.15, 20.23, 183.51, and 217.89 kg respectively. On the other hand, the smallest selected tree was *Archidendron jiringa*
 223 with DBH of 16.00 cm. This species obtained 22.95 kg of leaf dry biomass, 9.27 kg of branch dry biomass, 24.09 kg of
 224 trunk dry biomass, and 56.30 kg of TAGB. *Pterospermum javanicum* with 22.70 m height was the tallest sample trees.
 225 This sample tree had the highest trunk dry biomass (296.72 kg) and TAGB (308.98 kg). Contraslly, the other sample tree of
 226 *Pterospermum javanicum* had the lowest trunk dry biomass (12.84 kg) and TAGB (34.28 kg). The shortest sampe tree with
 227 9.30 m height was *Bridelia glauca*. The lowest leaf dry biomass (1.37 kg) and branch dry biomass (3.92 kg) were showed
 228 by *Vernonia arborea*. Meanwhile, the other sample tree of *Archidendron jiringa* had the highest leaf dry biomass (45.59
 229 kg). The highest branch dry biomass (34.18 kg) was showed by *Glochidion obscurum*.
 230

231 **Table 2.** All data sets for develop allometric equations in abandoned lands
 232

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
1	Malvaceae	<i>Pterospermum javanicum</i>	31.85	18.10	5.68	32.61	249.73	288.01	0.53
2	Malvaceae	<i>Pterospermum javanicum</i>	20.06	17.10	9.31	9.39	119.09	137.80	0.53
3	Malvaceae	<i>Pterospermum javanicum</i>	28.98	22.70	3.86	8.39	296.72	308.98	0.53
4	Moraceae	<i>Ficus septica</i>	32.17	20.20	5.70	19.70	166.63	192.03	0.39
5	Moraceae	<i>Ficus septica</i>	28.03	15.60	1.92	10.47	93.98	106.38	0.39
6	Cannabaceae	<i>Trema orientalis</i>	26.75	14.16	7.37	22.89	86.11	116.36	0.44
7	Proteaceae	<i>Heliciopsis artocarpoides</i>	21.97	9.70	9.95	9.88	57.62	77.44	0.65
8	Phyllanthaceae	<i>Bridelia glauca</i>	28.66	13.90	6.78	12.37	80.76	99.91	0.50
9	Phyllanthaceae	<i>Bridelia glauca</i>	20.70	12.50	6.93	16.74	71.55	95.22	0.50
10	Cannabaceae	<i>Trema orientalis</i>	26.11	10.80	13.97	29.02	58.17	101.16	0.44
11	Malvaceae	<i>Pterospermum javanicum</i>	29.62	16.00	8.76	10.12	77.63	96.52	0.53
12	Malvaceae	<i>Pterospermum javanicum</i>	16.88	10.60	6.88	14.56	12.84	34.28	0.53
13	Phyllanthaceae	<i>Bridelia glauca</i>	26.75	15.80	12.89	33.00	89.17	135.07	0.50
14	Euphorbiaceae	<i>Glochidion obscurum</i>	26.00	15.30	10.65	8.34	114.02	133.01	0.67
15	Euphorbiaceae	<i>Glochidion obscurum</i>	20.40	13.70	11.88	9.24	89.41	110.53	0.67
16	Fabaceae	<i>Archidendron jiringa</i>	16.00	10.36	22.95	9.27	24.09	56.30	0.42
17	Dipterocarpaceae	<i>Vatica javanica</i>	19.95	13.00	38.71	32.40	43.01	114.11	0.69
18	Euphorbiaceae	<i>Glochidion obscurum</i>	19.70	14.65	8.64	14.25	78.32	101.21	0.67

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
19	Fabaceae	<i>Archidendron jiringa</i>	24.60	16.00	45.59	22.73	160.89	229.21	0.42
20	Dipterocarpaceae	<i>Vatica javanica</i>	20.70	12.00	39.17	16.92	129.92	186.01	0.69
21	Euphorbiaceae	<i>Glochidion obscurum</i>	20.39	9.50	20.97	34.18	104.42	159.57	0.67
22	Dipterocarpaceae	<i>Vatica javanica</i>	28.60	13.90	7.66	29.95	184.53	222.14	0.69
23	Euphorbiaceae	<i>Glochidion obscurum</i>	21.50	10.90	11.24	21.63	142.13	175.00	0.67
24	Moraceae	<i>Artocarpus elasticus</i>	32.60	20.70	14.15	20.23	183.51	217.89	0.46
25	Asteraceae	<i>Vernonia arborea</i>	23.30	9.82	1.37	3.92	52.70	57.99	0.37
26	Asteraceae	<i>Vernonia arborea</i>	29.40	13.50	3.79	9.83	121.02	134.64	0.37
27	Phyllanthaceae	<i>Bridelia glauca</i>	21.50	9.30	14.28	17.31	67.24	98.83	0.50
28	Malvaceae	<i>Pterospermum javanicum</i>	20.29	16.10	4.04	3.94	163.39	171.38	0.53
29	Malvaceae	<i>Pterospermum javanicum</i>	20.36	18.50	6.66	8.55	189.90	205.12	0.53
30	Malvaceae	<i>Pterospermum javanicum</i>	26.60	21.70	11.19	17.72	187.95	216.85	0.53
Average			24.35	14.54	12.43	16.99	116.55	145.96	0.53
Minimum			16.00	9.30	1.37	3.92	12.84	34.28	0.37
Maximum			32.60	22.70	45.59	34.18	296.72	308.98	0.69
Standard deviation			4.66	3.75	10.93	9.13	65.59	66.98	0.11

Note: DBH=diameter at breast height; H=total height; TAGB=total above ground biomass; WD=wood density.

The allometric equations for Above Ground Biomass (AGB) of trees

The results of regression analyses for predicting plant part biomass of subject trees from diameter at breast height (DBH) and total height (H) using data all studied individuals are shown in Table 3. The relationships between DBH, (DBH²×H), and height of trees as independent variables were not significant to related leaf and branch dry biomass (*P* value > 0.05) as well as DBH to trunk dry biomass. This means that the DBH, (DBH²×H), height of trees were not a good predictor to leaf and branch dry biomass based on the goodness of fit. Similarly DBH was not also good predictor to trunk dry biomass. The correlations between (DBH²×H) and height of trees to trunk dry biomass and TAGB showed moderately strong relationships as well as DBH to TAGB (*P* value < 0.001).

The selected allometric equations to estimate above ground biomass of trees were dominated by log-linear model ($y=a+b \ln x$) and linear model ($y=a+bx$). These equations were fitting model to relate dependent variables (leaf, branch, trunk, and AGB) and independent variables (DBH, (DBH²×H), and H) for tree stage. From all tested regression, there are only four equations with relatively high *R*² (>0.400). These equations are “ln (trunk dry biomass) = 0.837 × ln (DBH²×H) – 29.45” (*R*²=0.500), “ln (trunk dry biomass) = 1.812 × ln (H) – 0.217” (*R*²=0.461), “ln (AGB) = 0.576 × ln (DBH²×H) – 0.301” (*R*²=0.431), and “ln (AGB) = 1.331 × ln (H) – 1.350” (*R*²=0.455). However, the result showed there are very weak relationships between leaves and branches dry biomass of trees and plant dimensions in the abandoned land. The trunk dry biomass and AGB in the tropical secondary forests of different ages (5, 10 and 20 years after abandonment) showed strong correlations (adjusted *R*²= 0.59-0.95) with diameter at breast height (DBH) and height. The leaf and branch dry biomass had weak correlations with height (adjusted *R*²=0.36-0.50) (Karyati et al. 2019). The mixed-species allometric equations showed AGB correlates significantly with diameter at stump height (*R*²=0.78; *P*<0.01) and tree height (*R*²=0.41, *P*<0.05) (Mokria et al. 2018). Generally, the developed allometric equations showed relatively low *R*² (<0.60). This may caused by the high variation sample trees. The variation sample trees lead the variation on wood density, structure, and physiognomy. Parlucha (2017) stated that comparing growth performance for different level of species type (native or exotic) is not conclusive since the growth of trees varies. It is happen from specific species character level and matching with the existing site condition. The regression between the trunk biomass and TAGB and the product of square DBH and height (cm² m) and the natural logarithm of height was illustrated in Figure 6.

Table 3. The allometric equations for predicting plant part biomass of subject trees in the study site

Dependent variable (y)	Independent variable (x)	Equation	<i>P</i> value	<i>R</i> ²	MRE	MARE
Leaf dry biomass (kg)	DBH (cm)	$\ln (y) = 0.054 \times (x) - 3.524$	>0.05	0.099		
	(DBH ² ×H) (cm ² m)	$\ln (y) = 0.4132 \times \ln (x) - 5.932$	>0.05	0.086		
	H (m)	$(y) = 0.001 \times (x) - 17.614$	>0.05	0.074		
Branch dry biomass (kg)	DBH (cm)	$\ln (y) = 0.695 \times \ln (x) + 0.4687$	>0.05	0.060		
	(DBH ² ×H) (cm ² m)	$\ln (y) = 0.001 \times (x) + 2.5228$	>0.05	0.023		
	H (m)	$(y) = 0.001 \times (x) + 15.097$	>0.05	0.014		
Trunk dry biomass (kg)	DBH (cm)	$\ln (y) = 1.910 \times \ln (x) - 1.501$	>0.05	0.347		
	(DBH ² ×H) (cm ² m)	$\ln (y) = 0.837 \times \ln (x) - 2.945$	<0.001	0.500		
	H (m)	$\ln (y) = 1.812 \times \ln (x) - 0.217$	<0.001	0.461		
Above ground biomass (kg)	DBH (cm)	$\ln (y) = 1.277 \times \ln (x) + 0.808$	<0.001	0.283		
	(DBH ² ×H) (cm ² m)	$\ln (y) = 0.576 \times \ln (x) - 0.301$	<0.001	0.431		
	H (m)	$\ln (y) = 1.331 \times \ln (x) - 1.350$	<0.001	0.455		

Note: *P* values of the regression analysis are shown, *R*² denotes multiple coefficient of determination.

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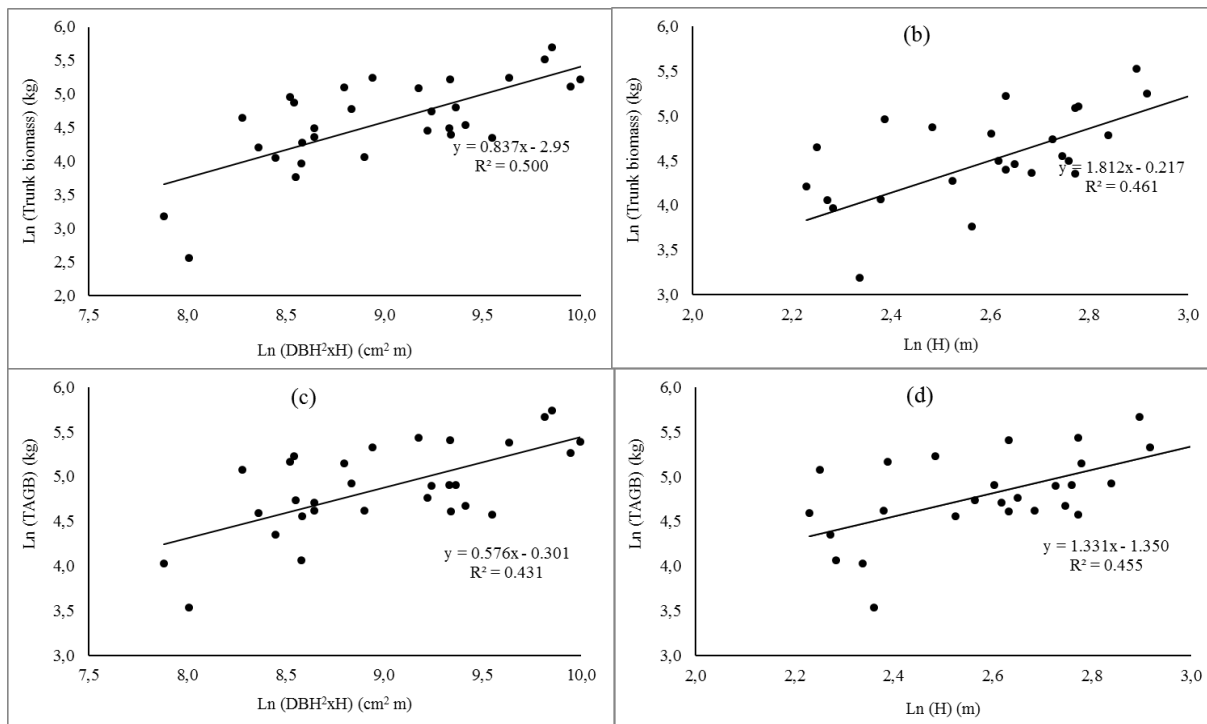
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274 Figure 6. Regression between the trunk biomass (kg) and the product of square DBH and height (cm² m) (a) and the
 275 natural logarithm of height (m) (b); Regression between total above ground biomass (TAGB) (kg) and the product of
 276 square DBH and height (cm² m) (c) and the natural logarithm of height (m) (d).

277 **Comparison among various allometric equations**

278 The estimation of AGB using the developed allometric equation in this study was lower than using the previous
 279 developed equations as presented in Table 3. The AGB estimation of 33.31 Mg ha⁻¹ was lower than 115.90, 91.65, 85.60,
 280 76.31, 68.08, 63.99, 60.32 Mg ha⁻¹ of AGB calculated using the formulas of Rai and Proctor (1986), Chambers et al.
 281 (2001), Yamakura et al. (1986), Brown (1997), Basuki et al. (2009), Kiyono and Hastaniah (2008), and Nelson et al.
 282 (1999) respectively. The value resulted by the developed allometric equation was similar than those using other previous
 283 reported equations, i.e., 38.86 Mg ha⁻¹ (Kenzo et al. 2009a), 39.31 Mg ha⁻¹ (Hashimoto et al. 2004), 49.05 Mg ha⁻¹ (Sierra
 284 et al. (2007), 49.63 Mg ha⁻¹ (Kettering et al. 2001), 50.31Mg ha⁻¹ (Karyati et al. 2019), and 5.94 Mg ha⁻¹ (Kenzo et al.
 285 2009b). The comparison between AGB and DBH estimated by previously reported relationships was illustrated in Figure
 286 7.

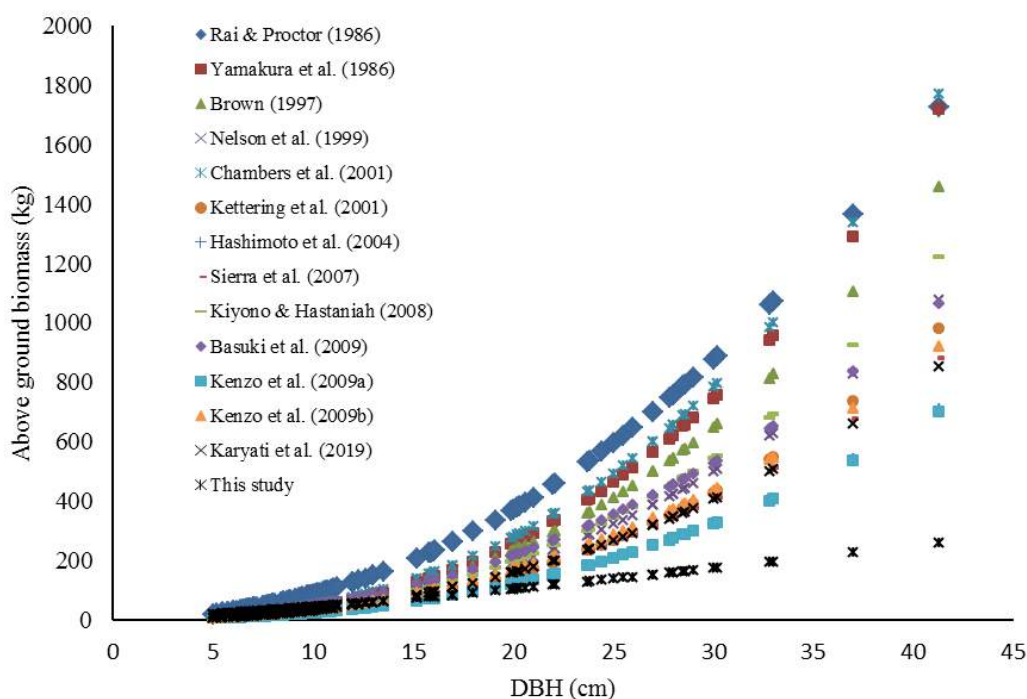
287 The calculation using equations of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown
 288 (1997), Basuki et al. (2009), and Kiyono and Hastaniah (2008) resulted the overestimation than the developed allometric
 289 equation. This might be caused the low wood density (0.37-0.69) of trees in the study site, because tree species observed in
 290 the abandoned land was dominated by pioneer species. The allometric equations for pioneer species may differ
 291 significantly caused usually these species has the low wood (Hashimoto et al. 2004). The wood densities of trees were
 292 0.40-0.79 for Brown's equation, 0.32-0.86 for Basuki et al.'s equation, and 0.67 for Kiyono and Hastaniah's equation. The
 293 similar values of AGB were estimated by using equations of Kenzo et al. (2009a) with wood density of 0.35, Kettering et al.
 294 (2001) with wood density of 0.35 to 0.91, Karyati et al. (2019) with wood density of 0.24-0.44, and Kenzo et al.
 295 (2009b) with wood density of 0.35. Kenzo et al. (2009a), Hashimoto et al. (2004), and Karyati et al. (2019) developed
 296 allometric equation for mixed species in tropical forest of Kalimantan, while Kettering et al. (2001) developed allometric
 297 for mixed secondary forest in Sumatra. Sierra et al. (2007) reported allometric equation for tropical forest in Colombia.
 298 The similar tree species in abandoned land of study site and the mixed secondary forest caused the similar estimation of
 299 AGB by using the developed equations.

300 The using appropriate allometric equations to estimate AGB is needed, because it will give accurate estimation on
 301 AGB in the study site. When specific allometric equation for different land use and land coverage was developed, the users
 302 will choose suitable alternative equations.
 303
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308 **Table 4.** Estimation of AGB using various reported relationships for trees in the study site

No.	Equation	Author	Estimate of AGB (Mg ha ⁻¹)
1	$\ln(\text{AGB})=2.12 \times \ln(\text{DBH})-0.435$	Rai and Proctor (1986)	115.90
2	$\ln(\text{AGB})=2.62 \times \ln(\text{DBH})-2.30$	Yamakura et al. (1986)	85.60
3	$\ln(\text{AGB})=2.53 \times \ln(\text{DBH})-2.13$	Brown (1997)	76.31
4	$\ln(\text{AGB})=2.413 \times \ln(\text{DBH})-1.997$	Nelson et al. (1999)	60.32
5	$\ln(\text{AGB})=2.55 \times \ln(\text{DBH})-2.010$	Chambers et al. (2001)	91.65
6	$\ln(\text{AGB})=2.59 \times \ln(\text{DBH})-2.75$	Kettering et al. (2001)	49.63
7	$\ln(\text{AGB})=2.44 \times \ln(\text{DBH})-2.51$	Hashimoto et al. (2004)	39.31
8	$\ln(\text{AGB})=2.422 \times \ln(\text{DBH})-2.232$	Sierra et al. (2007)	49.05
9	$\text{AGB}=0.1008 \times \text{DBH}^{2.5264}$	Kiyono and Hastaniah (2008)	63.99
10	$\ln(\text{AGB})=2.196 \times \ln(\text{DBH})-1.201$	Basuki et al. (2009)	68.08
11	$\text{AGB}=0.0829 \times \text{DBH}^{2.43}$	Kenzo et al. (2009a)	38.86
12	$\text{AGB}=0.1525 \times \text{DBH}^{2.34}$	Kenzo et al. (2009b)	53.94
13	$\ln(\text{AGB})=2.3207 \times \ln(\text{DBH})-1.89$	Karyati et al. (2019)	50.31
14	$(\text{AGB}) = 12.683 \times (\text{DBH}^2 \times \text{H}) - 38.403$	This study	33.31

309 Note: AGB = above ground biomass ; DBH = diameter at breast height.



324
 325
 326
 327
 328 Figure 7. Comparison among various allometric relationships between above ground biomass (AGB) and diameter at breast height
 329 (DBH) in the study site

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- 387

Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land

Abstract. Karyati, Widiati KY, Karmini, Mulyadi R. 2019. *Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands. Biodiversitas x: xx-xx.* The abandoned lands have important role in the ecological fuction as well as carbon sequestration. The allometric equations to estimate above ground biomass in abandoned land are still limited available. This study objective was to develop allometric relationships between tree size variables (diameter at breast height (DBH) and tree height) and leaf, branch, trunk, and total above ground biomass (TAGB) in abandoned land in East Kalimantan, Indonesia. The correlation coefficients between stem DBH and tree height to leaf and branch indicating a relatively weak relationship. The moderately strong relationships were showed by DBH and tree height to trunk and TAGB. The specific allometric equation of above ground biomass for different land use and land type is needed to estimate the accurate TAGB in the site.

Key words: Abandoned land, allometric equation, biomass, destructive method

Running title: Development of allometric equations in abandoned land

INTRODUCTION

The National Land Affairs Agency identified 7.3 million hectares lands in Indonesia as abandoned lands in 2011 and about 4.8 million hectares was stated as abandoned lands. This area of abandoned lands increase from 2007 as much as 7.1 million hectares outside forest area (Nurlinda et al. 2014). The abandoned land area in East Kalimantan was about 3 million hectares. The abandoned lands provide habitat rotation to succession process in primary-secondary forest that will increase biodiversity (Chokkalingam et al. 2001). The plant composition, diversity, and growth during fallow periods after shifting cultivation was resulted from complex interaction between condition and factor before and after fallow periods, such as disturbance, land history, land management, tree and seed source composition from soil or surrounding forest, soil fertility, and climate factor (Awang Noor et al. 2008; Kendawang et al. 2007; Van Do et al. 2010).

Land use system on forest basis store CO₂ by carbon stock storage at their biomass (Gorte 2007; Roshetko et al. 2002). The carbon stock in old age stand could different compared to carbon stock in second growth stand that replace it, cause woody biomass in an area could not describe in nett ecosystem productivity (Janisch and Harmon 2002). Biomass dynamic in tropical forest play important role to evaluation of global carbon cycle and global climate change (Fearnside 1997; Seiler and Crutzen 1980). During the early succession process, amount of stand biomass increase fastly (Selaya et al. 2007). The carbon sequestration of forest area change constanly with vegetation growth, dead, and decomposition (Gorte 2007); species composition, age structur, and forest health (Harmon et al. 1990). Carbon stock at stand in the surface soil and standing tree mass could represented less than 1% to 60% from total carbon stock of forest ecosystem (Curtis 2008). Carbon stock of fertile soils is higher which could influence to carbon stock storage at vegetation biomass (Hairiah and Rahayu 2007).

Biomass is generally expressed in terms of dry weight and on occasion may be given in terms of ash free dry weight (Moore and Chapman 1986). The 'scaling' relationships, by which the ratios between different aspects of tree size change when small and large trees of the same species are compared generally known as 'allometric' relations (Hairiah et al. 2001). The previous studies had been developed allometric equations to estimate above ground biomass (AGB) in the secondary forests (Hashimoto et al. 2004; Kenzo et al. 2009a; Kenzo et al. 2009b; Ketterings et al. 2001; Kiyono and Hastaniah 2005; Nelson et al. 1999; Sierra et al. 2007; Karyati et al. 2019). However the allometric equations to estimate AGB in abandoned lands is still rare reported. The objective of this study was to develop allometric equations for estimation AGB in fallow lands. Information on the allometric relationships could predict biomass and carbon stock in lands after abandonment.

49 Study site

50 The study was carried out in Salo Cella Village, Muara Badak Sub-district, Kutai Kartanegara Districts, East
 51 Kalimantan Province, Indonesia (Figure 1). This site was located in 0°17'18.7"S 117°18'08.2"E. The study site was
 52 abandoned land after selective cutting about 20 years ago. Muara Badak Sub-district has 939.09 km² wide with population
 53 of 57,712 persons including 13 villages. Salo Cella Village is about 10 km from the capital of Sub-district. The capital of
 54 subdistrict was Muara Badak Ulu with 16 m height Above Mean Sea Level (AMSL). Muara Badak received average
 55 amount of 141 mm in rainfall and 11 raindays in 2017 (Statistics Kutai Kartanegara Regency 2018). Most of the
 56 population in this village were farmers' livelihoods. Muara Badak is administratively bordered with Marang Kayu Sub-
 57 district at north side, Anggana Sub-district Samarinda City at south side, Makassar Strait at east side, and Tenggarong
 58 Seberang Sub-district at west side. Muara Badak is one of oil and gas producer. This has also big potency in fishery and
 59 plantation sectors. The area was covered by lowland mixed dipterocarp forest.

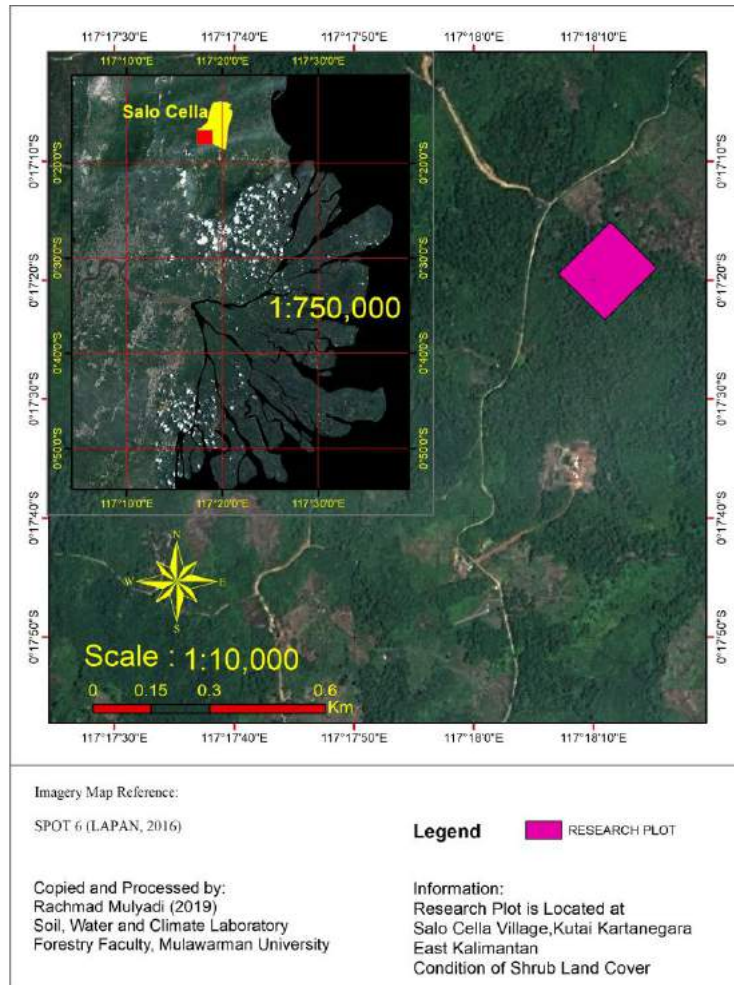


Figure 1. Map of study site in Salo Cella Village, Kutai Kartanegara Districts, East Kalimantan Province, Indonesia.

97 Data collection

98 Assessment on biomass in the field

99 Thirty sample trees were chosen in abandoned land. The sample trees were selected to obtain the representative species
 100 of land after abandonment. The selection of sample trees was based on consideration of the species and DBH. The
 101 standing DBH (1.3 m) of selected trees were measured using diameter tape. Measurement of the total height of the sample
 102 tree was completed once the tree had fallen. Felling sample trees were conducted by following the harvesting rules. The
 103 harvested trees were divided into several fractions which every tree fraction was 1 meter length. Then, parts of trees were
 104 separated into leaves and twigs (hereafter called leaves), branches, and main stems in the field as shown in Figure 2.

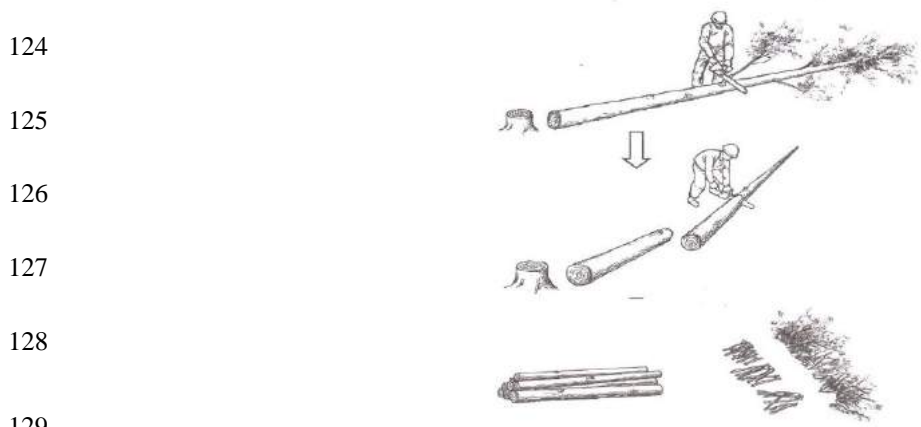
105 Dividing sample tree fractions was accomplished with the following criteria (Ministry of Forestry Indonesia, 2011):

- 106 1) Dividing sample tree fractions was done to separate parts of tree biomass including leaves, branches, and stem. The
 107 flower and fruit parts was not included in the observation, because very few sample trees that have flower and fruit
 108 during observation.
 109 2) Dividing sample tree fraction to be weighed needs to consider the capacity of the available scales.
 110 3) Especially for the stem fraction, the stem was divided into several sections (sub-fractions of the stem) taking into
 111 account the shape, uniformity, and weight of the pieces.

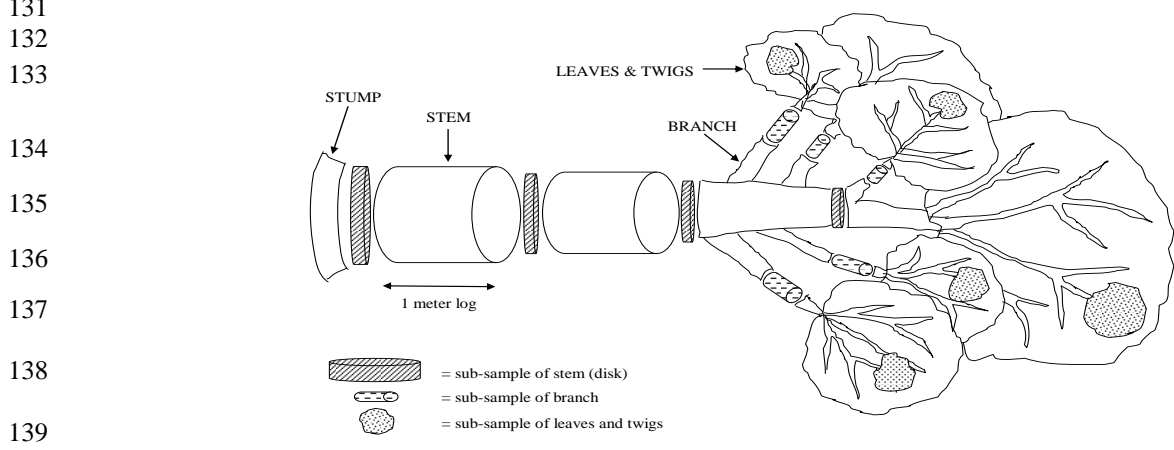
112 The fresh weight of all fractions were taken by the suitable scale in the field. The disk samples of trunk with 2-5 cm
 113 thick were were collected as many as three disk sample if the harvested trees had less than 10 fractions and four disk
 114 samples if more than 10 fractions. Five branch samples of 20-30 cm in length and five leaf samples of 100-300 grams in
 115 weight were taken from each sample tree. Figure 3 illustrates tree components and the position of sub-sample being taken for AGB
 116 assessment. The wood density of each sample tree was conducted from the various literatures.
 117

118 *Analysis of dry-weight in the laboratory*

119 Before oven-dried, all samples were air-dried in the laboratory to determine the moisture content. Then, samples of
 120 stem and branch fractions were dried in an oven at a temperature 105°C for 96 hours until reaching a constant weight.
 121 Samples of leaves were dried in an oven at temperature of 80°C for 48 hours until constant weight was reached. Weighing
 122 the samples of each fraction was performed using an analytical digital weighing scale after drying them in an oven.
 123



130 **Figure 2.** Dividing the trees (Source: Ministry of Forestry Indonesia, 2011).



140 **Figure 3.** Illustration of tree components and the position of sub-sample being taken (Karyati 2013).

141 **Data analysis**

142 The total oven-dry weight of each tree part were determined using the following formula (Hairiah et al. 2001; Hairiah
 143 & Rahayu 2007; Ministry of Forestry Indonesia, 2011):

$$dw = (sdw \times fw) / sfw \tag{1}$$

144 where: dw = total dry weight (kg); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of
 145 the sample (g).

146 The five selected allometric equations of AGB were tested (Equations 2-6):

$$y = a + b x \quad (2)$$

$$y = ax^b \quad (3)$$

$$y = a + b (\ln x) \quad (4)$$

$$(\ln y) = a + b x \quad (5)$$

$$(\ln y) = a + b (\ln x) \quad (6)$$

147 where: y = total dry weight or biomass of each plant part, such as trunk, branch, leaf, and total above ground biomass
 148 (TAGB) (kg); x = diameter at breast height (DBH, cm), total height (H, meter), and (DBH²×H) (cm² m); ‘a’ and ‘b’ =
 149 coefficients estimated by regression.

150 All regression analysis was carried out using SPSS version 18 for windows (SPSS Japan, Tokyo, Japan). The R² value
 151 and P value were determined to evaluate precision among all tested allometric equations. The indices of relative errors
 152 such as mean prediction error (MPE), total relative error (TRE), mean relative error (MRE), and mean relative absolute
 153 error (MRAE) were also assessed for model evaluation.

154 RESULTS AND DISCUSSION

155 Selected samples of trees

156 Thirty trees with DBH of ≥ 15 cm were harvested and measured to determine above ground parts in the study site as
 157 represent in Table 1. The DBH and height classes of selected sample trees for assessment AGB are illustrated in Figure 4.
 158 The DBH range was 16.0-32.6 cm and height was 9.3-22.7 m for selective sample trees. The relationship between DBH
 159 and total height of sample trees for assessment AGB in the study site is presented in Figure 5. The illustration showed that
 160 an increase in DBH was followed by an increase in total height. The equations of this relationship was “H=0.4642
 161 (DBH)+3.2344” (n=30; R²=0.3339). As stated ‘H’ is total height (m) and ‘DBH’ is diameter at breast height (cm).
 162

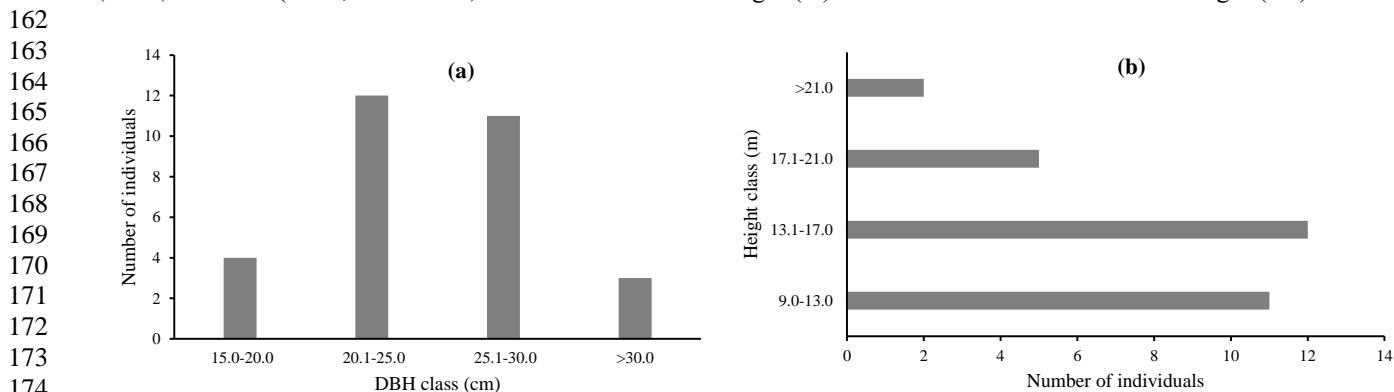


Figure 4. The distributions of (a) DBH classes and (b) height classes of sample trees to developed allometric equations.

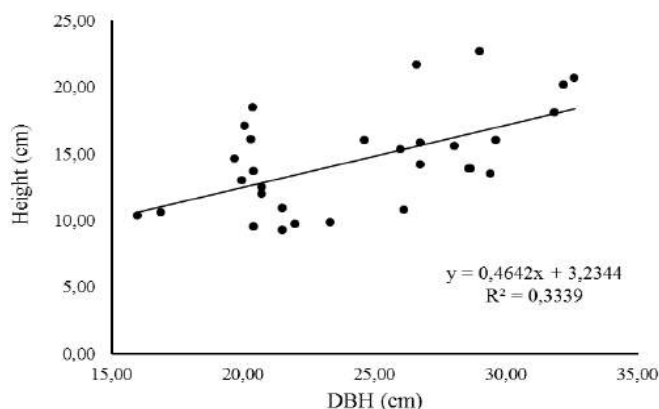


Figure 5. The DBH and total height of sample trees to developed allometric equations.

Tree variables

Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters of destructive biomass are summarized in Table 1. The minimum and maximum weight of branches biomass, trunk biomass, and TAGB were 3.92-34.18 kg; 12.84-296.72 kg, and 34.28-308.98 respectively. The DBH of sample trees ranged 16.00-32.00 cm, with the height ranged 9.30-22.70 m. The wood densities of sample trees ranged 0.37-0.69 g cm⁻³. The result showed that there were strong correlation ($P < 0.01$) among trunk biomass to DBH and tree height as well as TAGB and tree height. The correlation ($P < 0.05$) was showed by TAGB and DBH. The strong correlation ($P < 0.01$) was also showed between DBH and tree height. However, the leaf and branch biomass were not correlated with DBH and tree height significantly ($P > 0.05$). In addition, the wood density was not also correlated to plant part biomass (leaf, branch, trunk, and TAGB) and tree dimensions (DBH and height).

Table 1. Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters of destructive biomass

	Pearson's correlation			Mean	Range
	DBH (cm)	H (m)	WD (g cm ⁻³)		
Leaf biomass (kg)	-0.303 ^{ns}	-0.198 ^{ns}	0.262 ^{ns}	12.43	1.37 - 45.59
Branch biomass (kg)	0.205 ^{ns}	-0.072 ^{ns}	0.208 ^{ns}	16.99	3.92 - 34.18
Trunk biomass (kg)	0.527 ^{**}	0.768 ^{**}	0.027 ^{ns}	116.55	12.84 - 296.72
TAGB (kg)	0.494 [*]	0.710 ^{**}	0.098 ^{ns}	145.97	34.28 - 308.98
DBH (cm)	1	0.578 ^{**}	-0.357 ^{ns}	24.35	16.00 - 32.00
H (m)	0.578 ^{**}	1	-0.184 ^{ns}	14.54	9.30 - 22.70
WD (g cm ⁻³)	-0.357 ^{ns}	-0.184 ^{ns}	1	0.53	0.37 - 0.69

Note: ^{ns} is not significant at the 0.05 level ($P > 0.05$); ^{*} and ^{**} Correlation are significant at the 0.05 and 0.01 level (2-tailed) respectively

Thirty sample trees with DBH of > 15 cm were selected in the study site, with consideration of the species. These selected trees did not considering individuals with damaged crowns or broken trunks. Almost 90% of the selected trees were categorized as the dominant species in terms of density and Importance Value Index (IVI) as observed in the current study, while few selected trees represented the rare species. There were 10 species of 10 genera of 9 families selected in study site. Eight sample trees were *Pterospermum javanicum*—including (Malvaceae). There were 5 sample trees of *Glochidion obscurum* (Euphorbiaceae) and 4 sample trees of *Bridelia glauca* (Phyllanthaceae). Three sample trees were *Vatica javanica* (Dipterocarpaceae). The species of *Ficus septica* (Moraceae), *Trema orientalis* (Cannabaceae), *Archidendron jiringa* (Fabaceae), *Vernonia arborea* (Asteraceae) were selected for two sample trees respectively. One sample tree was *Heliciopsis artocarpoides* (Proteaceae) as well as *Artocarpus elasticus* (Moraceae). The range of dry weight was 1.37-45.59 kg for leaf, 3.92-34.18 kg for branch, 12.84-296.72 kg for trunk, and 34.28-308.98 kg for TAGB in this site (Table 2). The result showed that there are diverse variation among different species. The different tree species tends to has the different structure (growth, stratification, and crown cover) and physiognomy. The largest sample tree was *Artocarpus elasticus* with DBH of 32.60 cm. This species had the dry weight of leaf, branch, trunk, and TAGB were 14.15, 20.23, 183.51, and 217.89 kg respectively. On the other hand, the smallest selected tree was *Archidendron jiringa* with DBH of 16.00 cm. This species obtained 22.95 kg of leaf dry biomass, 9.27 kg of branch dry biomass, 24.09 kg of trunk dry biomass, and 56.30 kg of TAGB. *Pterospermum javanicum* with 22.70 m height was the tallest sample trees. This sample tree had the highest trunk dry biomass (296.72 kg) and TAGB (308.98 kg). Contrarily, the other sample tree of *Pterospermum javanicum* had the lowest trunk dry biomass (12.84 kg) and TAGB (34.28 kg). The shortest sample tree with 9.30 m height was *Bridelia glauca*. The lowest leaf dry biomass (1.37 kg) and branch dry biomass (3.92 kg) were showed by *Vernonia arborea*. Meanwhile, the other sample tree of *Archidendron jiringa* had the highest leaf dry biomass (45.59 kg). The highest branch dry biomass (34.18 kg) was showed by *Glochidion obscurum*.

Table 2. All data sets for develop allometric equations in abandoned lands

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
1	Malvaceae	<i>Pterospermum javanicum</i>	31.85	18.10	5.68	32.61	249.73	288.01	0.53
2	Malvaceae	<i>Pterospermum javanicum</i>	20.06	17.10	9.31	9.39	119.09	137.80	0.53
3	Malvaceae	<i>Pterospermum javanicum</i>	28.98	22.70	3.86	8.39	296.72	308.98	0.53
4	Moraceae	<i>Ficus septica</i>	32.17	20.20	5.70	19.70	166.63	192.03	0.39
5	Moraceae	<i>Ficus septica</i>	28.03	15.60	1.92	10.47	93.98	106.38	0.39
6	Cannabaceae	<i>Trema orientalis</i>	26.75	14.16	7.37	22.89	86.11	116.36	0.44
7	Proteaceae	<i>Heliciopsis artocarpoides</i>	21.97	9.70	9.95	9.88	57.62	77.44	0.65
8	Phyllanthaceae	<i>Bridelia glauca</i>	28.66	13.90	6.78	12.37	80.76	99.91	0.50
9	Phyllanthaceae	<i>Bridelia glauca</i>	20.70	12.50	6.93	16.74	71.55	95.22	0.50
10	Cannabaceae	<i>Trema orientalis</i>	26.11	10.80	13.97	29.02	58.17	101.16	0.44
11	Malvaceae	<i>Pterospermum javanicum</i>	29.62	16.00	8.76	10.12	77.63	96.52	0.53
12	Malvaceae	<i>Pterospermum javanicum</i>	16.88	10.60	6.88	14.56	12.84	34.28	0.53

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
13	Phyllanthaceae	<i>Bridelia glauca</i>	26.75	15.80	12.89	33.00	89.17	135.07	0.50
14	Euphorbiaceae	<i>Glochidion obscurum</i>	26.00	15.30	10.65	8.34	114.02	133.01	0.67
15	Euphorbiaceae	<i>Glochidion obscurum</i>	20.40	13.70	11.88	9.24	89.41	110.53	0.67
16	Fabaceae	<i>Archidendron jiringa</i>	16.00	10.36	22.95	9.27	24.09	56.30	0.42
17	Dipterocarpaceae	<i>Vatica javanica</i>	19.95	13.00	38.71	32.40	43.01	114.11	0.69
18	Euphorbiaceae	<i>Glochidion obscurum</i>	19.70	14.65	8.64	14.25	78.32	101.21	0.67
19	Fabaceae	<i>Archidendron jiringa</i>	24.60	16.00	45.59	22.73	160.89	229.21	0.42
20	Dipterocarpaceae	<i>Vatica javanica</i>	20.70	12.00	39.17	16.92	129.92	186.01	0.69
21	Euphorbiaceae	<i>Glochidion obscurum</i>	20.39	9.50	20.97	34.18	104.42	159.57	0.67
22	Dipterocarpaceae	<i>Vatica javanica</i>	28.60	13.90	7.66	29.95	184.53	222.14	0.69
23	Euphorbiaceae	<i>Glochidion obscurum</i>	21.50	10.90	11.24	21.63	142.13	175.00	0.67
24	Moraceae	<i>Artocarpus elasticus</i>	32.60	20.70	14.15	20.23	183.51	217.89	0.46
25	Asteraceae	<i>Vernonia arborea</i>	23.30	9.82	1.37	3.92	52.70	57.99	0.37
26	Asteraceae	<i>Vernonia arborea</i>	29.40	13.50	3.79	9.83	121.02	134.64	0.37
27	Phyllanthaceae	<i>Bridelia glauca</i>	21.50	9.30	14.28	17.31	67.24	98.83	0.50
28	Malvaceae	<i>Pterospermum javanicum</i>	20.29	16.10	4.04	3.94	163.39	171.38	0.53
29	Malvaceae	<i>Pterospermum javanicum</i>	20.36	18.50	6.66	8.55	189.90	205.12	0.53
30	Malvaceae	<i>Pterospermum javanicum</i>	26.60	21.70	11.19	17.72	187.95	216.85	0.53
Average			24.35	14.54	12.43	16.99	116.55	145.96	0.53
Minimum			16.00	9.30	1.37	3.92	12.84	34.28	0.37
Maximum			32.60	22.70	45.59	34.18	296.72	308.98	0.69
Standard deviation			4.66	3.75	10.93	9.13	65.59	66.98	0.11

Note: DBH=diameter at breast height; H=total height; TAGB=total above ground biomass; WD=wood density.

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237 The allometric equations for Above Ground Biomass (AGB) of trees

238 The results of regression analyses for predicting plant part biomass of subject trees from diameter at breast height
239 (DBH) and total height (H) using data all studied individuals are shown in Table 3. The relationships between DBH,
240 (DBH²×H), and height of trees as independent variables were not significant to related leaf and branch dry biomass (*P*
241 value > 0.05) as well as DBH to trunk dry biomass. This means that the DBH, (DBH²×H), height of trees were not a good
242 predictor to leaf and branch dry biomass based on the goodness of fit. Similarly DBH was not also good predictor to trunk
243 dry biomass. The correlations between (DBH²×H) and height of trees to trunk dry biomass and TAGB showed moderately
244 strong relationships as well as DBH to TAGB (*P* value < 0.001).

245 The selected allometric equations to estimate above ground biomass of trees were dominated by log-linear model (ln
246 y=a+b ln x) and linear model (y=a+bx). These equations were fitting model to relate dependent variables (leaf, branch,
247 trunk, and AGB) and independent variables (DBH, (DBH²×H), and H) for tree stage. From all tested regression, there are
248 only four equations with relatively high *R*² (>0.400). These equations are “ln (trunk dry biomass) = 0.837 × ln (DBH²×H) –
249 29.45” (*R*²=0.500), “ln (trunk dry biomass) = 1.812 × ln (H) – 0.217” (*R*²=0.461), “ln (AGB) = 0.576 × ln (DBH²×H) –
250 0.301” (*R*²=0.431), and “ln (AGB) = 1.331 × ln (H) – 1.350” (*R*²=0.455). However, the result showed there are very weak
251 relationships between leaves and branches dry biomass of trees and plant dimensions in the abandoned land. The trunk dry
252 biomass and AGB in the tropical secondary forests of different ages (5, 10 and 20 years after abandonment) showed strong
253 correlations (adjusted *R*²= 0.59-0.95) with diameter at breast height (DBH) and height. The leaf and branch dry biomass
254 had weak correlations with height (adjusted *R*²=0.36-0.50) (Karyati et al. 2019). The mixed-species allometric equations
255 showed AGB correlates significantly with diameter at stump height (*R*²=0.78; *P*<0.01) and tree height (*R*²=0.41, *P*<0.05)
256 (Mokria et al. 2018). Generally, the developed allometric equations showed relatively low *R*² (<0.60). This may caused by
257 the high variation sample trees. The variation sample trees lead the variation on wood density, structure, and physiognomy.
258 Parlucha (2017) stated that comparing growth performance for different level of species type (native or exotic) is not
259 conclusive since the growth of trees varies. It is happen from specific species character level and matching with the
260 existing site condition. The regression between the trunk biomass and TAGB and the product of square DBH and height
261 (cm² m) and the natural logarithm of height was illustrated in Figure 6.

262 Results showed that mean prediction errors (MPEs) of the developed one- and two-variable aboveground biomass
263 models were less than 4% and MPEs of the three-component (stem, branch, and foliage) and belowground biomass models
264 were less than 10%.

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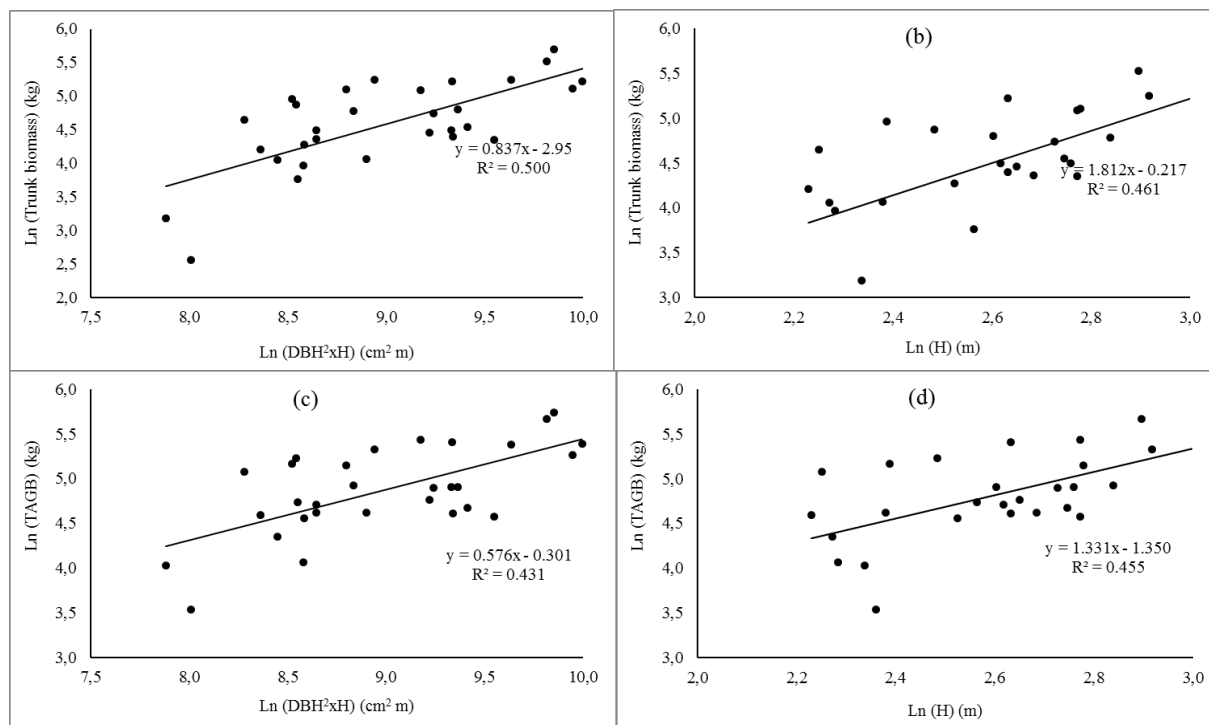
Table 3. The allometric equations for predicting plant part biomass of subject trees in the study site

Dependent variable (y)	Independent variable (x)	Equation	P value	R ²	MPE	TRE	MRE	MRAE
Leaf dry biomass (kg)	DBH (cm)	$\ln y = 0.054 - 3.524 x$	>0.05	0.099	-4.65	89.67	2.99	0.97
	(DBH ² ×H) (cm ² m)	$\ln y = 0.4132 - 5.932 \ln x$	>0.05	0.086	55.16	96.26	3.21	0.97
	H (m)	$y = 0.001 - 17.614 x$	>0.05	0.074	26.85	11.78	3.93	1.02
Branch dry biomass (kg)	DBH (cm)	$\ln y = 0.695 + 0.4687 \ln x$	>0.05	0.060	0.50	6.63	0.22	1.28
	(DBH ² ×H) (cm ² m)	$\ln y = 0.001 + 2.5228 x$	>0.05	0.023	-7.24	87.45	2.91	0.97
	H (m)	$y = 0.001 + 15.097 x$	>0.05	0.014	-20.25	50.84	1.70	1.04
Trunk dry biomass (kg)	DBH (cm)	$\ln y = 1.910 - 1.501 \ln x$	>0.05	0.347	7.43	48.99	1.63	0.96
	(DBH ² ×H) (cm ² m)	$\ln y = 0.837 - 2.945 \ln x$	<0.001	0.500	3.02	20.12	3.71	0.97
	H (m)	$\ln y = 1.812 - 0.217 \ln x$	<0.001	0.461	3.34	21.63	0.72	0.96
Above ground biomass (kg)	DBH (cm)	$\ln y = 1.277 + 0.808 \ln x$	<0.001	0.283	1.03	6.16	0.21	1.19
	(DBH ² ×H) (cm ² m)	$\ln y = 0.576 - 0.301 \ln x$	<0.001	0.431	7.00	43.19	1.44	0.97
	H (m)	$\ln y = 1.331 - 1.350 \ln x$	<0.001	0.455	7.11	43.79	1.46	0.97

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Note: P values of the regression analysis are shown, R² coefficient of determination, MPE mean prediction error, TRE total relative error, MRE mean relative error, MRAE mean relative absolute error, DBH diameter at breast height, H tree height.

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Figure 6. Regression between the trunk biomass (kg) and the product of square DBH and height (cm² m) (a) and the natural logarithm of height (m) (b); Regression between total above ground biomass (TAGB) (kg) and the product of square DBH and height (cm² m) (c) and the natural logarithm of height (m) (d).

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Comparison among various allometric equations

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The estimation of AGB using the developed allometric equation in this study was lower than using the previous developed equations as presented in Table 3. The AGB estimation of 33.31 Mg ha⁻¹ was lower than 115.90, 91.65, 85.60, 76.31, 70.39, 68.08, 63.99, 60.32 Mg ha⁻¹ of AGB calculated using the formulas of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown (1997), Manuri et al. (2017), Basuki et al. (2009), Kiyono and Hastaniah (2008), and Nelson et al. (1999) respectively. The value resulted by the developed allometric equation was similar than those using other previous reported equations, i.e., 38.86 Mg ha⁻¹ (Kenzo et al. 2009a), 39.31 Mg ha⁻¹ (Hashimoto et al. 2004), 49.05 Mg ha⁻¹ (Sierra et al. (2007), 49.63 Mg ha⁻¹ (Kettering et al. 2001), 50.31Mg ha⁻¹ (Karyati et al. 2019), and 5.94 Mg ha⁻¹ (Kenzo et al. 2009b). The comparison between AGB and DBH estimated by previously reported relationships was illustrated in Figure 7.

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The calculation using equations of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown (1997), Basuki et al. (2009), and Kiyono and Hastaniah (2008) resulted the overestimation than the developed allometric equation. This might be caused the low wood density (0.37-0.69) of trees in the study site, because tree species observed in the abandoned land was dominated by pioneer species. The allometric equations for pioneer species may differ

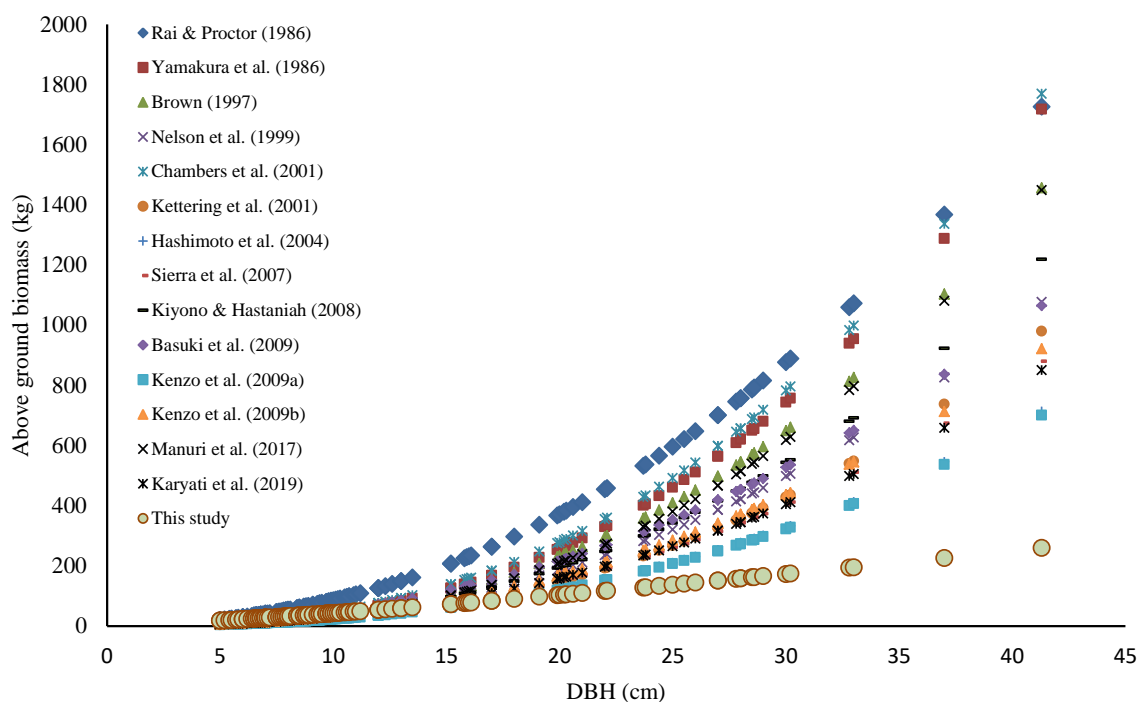
304 significantly caused usually these species has the low wood (Hashimoto et al. 2004). The wood densities of trees were
 305 0.40-0.79 for Brown's equation, 0.32-0.86 for Basuki et al.'s equation, and 0.67 for Kiyono and Hastaniah's equation. The
 306 similar values of AGB were estimated by using equations of Kenzo et al. (2009a) with wood density of 0.35, Kettering et
 307 al. (2001) with wood density of 0.35 to 0.91, Karyati et al. (2019) with wood density of 0.24-0.44, and Kenzo et al.
 308 (2009b) with wood density of 0.35. Kenzo et al. (2009a), Hashimoto et al. (2004), and Karyati et al. (2019) developed
 309 allometric equation for mixed species in tropical forest of Kalimantan, while Kettering et al. (2001) developed allometric
 310 for mixed secondary forest in Sumatra. Sierra et al. (2007) reported allometric equation for tropical forest in Colombia.
 311 The similar tree species in abandoned land of study site and the mixed secondary forest caused the similar estimation of
 312 AGB by using the developed equations. In addition, the species and stand characteristics such as wood density and tree
 313 height effected to AGB variation directly, compare than biogeographical effect to those (Manuri et al. 2017).

314 Furthermore, the effects of main climate variables on above- and below-ground biomass were analyzed. Aboveground
 315 biomass was related to mean annual temperature (MAT), while belowground biomass had no significant relationship with
 316 either MAT or mean annual precipitation (MAP).
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318 **Table 4.** Estimation of AGB using various reported relationships for trees in the study site

No.	Equation	Author	Estimate of AGB (Mg ha ⁻¹)
1	$\ln(\text{AGB})=2.12 \times \ln(\text{DBH})-0.435$	Rai and Proctor (1986)	115.90
2	$\ln(\text{AGB})=2.62 \times \ln(\text{DBH})-2.30$	Yamakura et al. (1986)	85.60
3	$\ln(\text{AGB})=2.53 \times \ln(\text{DBH})-2.13$	Brown (1997)	76.31
4	$\ln(\text{AGB})=2.413 \times \ln(\text{DBH})-1.997$	Nelson et al. (1999)	60.32
5	$\ln(\text{AGB})=2.55 \times \ln(\text{DBH})-2.010$	Chambers et al. (2001)	91.65
6	$\ln(\text{AGB})=2.59 \times \ln(\text{DBH})-2.75$	Kettering et al. (2001)	49.63
7	$\ln(\text{AGB})=2.44 \times \ln(\text{DBH})-2.51$	Hashimoto et al. (2004)	39.31
8	$\ln(\text{AGB})=2.422 \times \ln(\text{DBH})-2.232$	Sierra et al. (2007)	49.05
9	$\text{AGB}=0.1008 \times \text{DBH}^{2.5264}$	Kiyono and Hastaniah (2008)	63.99
10	$\ln(\text{AGB})=2.196 \times \ln(\text{DBH})-1.201$	Basuki et al. (2009)	68.08
11	$\text{AGB}=0.0829 \times \text{DBH}^{2.43}$	Kenzo et al. (2009a)	38.86
12	$\text{AGB}=0.1525 \times \text{DBH}^{2.34}$	Kenzo et al. (2009b)	53.94
13	$\text{AGB}=0.071 \times \text{DBH}^{2.667}$	Manuri et al. (2017)	70.39
14	$\ln(\text{AGB})=2.3207 \times \ln(\text{DBH})-1.89$	Karyati et al. (2019)	50.31
15	$(\text{AGB}) = 12.683 \times (\text{DBH}^2 \times \text{H}) - 38.403$	This study	33.31

319 Note: AGB = above ground biomass ; DBH = diameter at breast height.



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338 **Figure 7.** Comparison among various allometric relationships between above ground biomass (AGB) and diameter at breast height
 339 (DBH) in the study site

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CONCLUSION

341 The using appropriate allometric equations to estimate AGB is needed, because it will give accurate estimation on
 342 AGB in the study site. When specific allometric equation for different land use and land coverage was developed, the users
 343 will choose suitable alternative equations.

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Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land

Abstract. Karyati, Widiati KY, Karmini, Mulyadi R. 2019. *Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned lands. Biodiversitas x: xx-xx.* The abandoned lands have important role in the ecological function as well as carbon sequestration. The allometric equations to estimate above ground biomass in abandoned land are still limited available. This study objective was to develop allometric relationships between tree size variables (diameter at breast height (DBH) and tree height) and leaf, branch, trunk, and total above ground biomass (TAGB) in abandoned land in East Kalimantan, Indonesia. The correlation coefficients between stem DBH and tree height to leaf and branch indicating a relatively weak relationship. The moderately strong relationships were showed by DBH and tree height to trunk and TAGB. The specific allometric equation of above ground biomass for different land use and land type is needed to estimate the accurate TAGB in the site.

Key words: Abandoned land, allometric equation, biomass, destructive method

Running title: Development of allometric equations in abandoned land

INTRODUCTION

The forest degradation process with respect to selective logging, forest fire, and abandonment dynamics occurs over large areas in tropical forests (Pinheiro et al. 2016). The National Land Affairs Agency identified 7.3 million hectares lands in Indonesia as abandoned lands in 2011 and about 4.8 million hectares was stated as abandoned lands. This area of abandoned lands increase from 2007 as much as 7.1 million hectares outside forest area (Nurlinda et al. 2014). The abandoned land area in East Kalimantan was about 3 million hectares. The abandoned lands provide habitat rotation to succession process in primary-secondary forest that will increase biodiversity (Chokkalingam et al. 2001). The plant composition, diversity, and growth during fallow periods after shifting cultivation was resulted from complex interaction between condition and factor before and after fallow periods, such as disturbance, land history, land management, tree and seed source composition from soil or surrounding forest, soil fertility, and climate factor (Awang Noor et al. 2008; Kendawang et al. 2007; Van Do et al. 2010).

Forest-based land use systems sequester carbon dioxide by storing carbon stored in their biomass (Gorte 2007; Roshetko et al. 2002). The carbon stock in old age stand could different compared to carbon stock in second growth stand that replace it, cause woody biomass in an area could not describe in net ecosystem productivity (Janisch and Harmon 2002). Biomass dynamic in tropical forest play important role to evaluation of global carbon cycle and global climate change (Fearnside 1997; Seiler and Crutzen 1980). During the early succession process, amount of stand biomass increase fastly (Selaya et al. 2007). The carbon sequestration of forest area change constantly with vegetation growth, dead, and decomposition (Gorte 2007); species composition, age structure, and forest health (Harmon et al. 1990). Carbon stock at stand in the surface soil and standing tree mass could represented less than 1% to 60% from total carbon stock of forest ecosystem (Curtis 2008). Carbon stock of fertile soils is higher which could influence to carbon stock storage at vegetation biomass (Hairiah and Rahayu 2007).

Biomass is generally expressed in terms of dry weight and on occasion may be given in terms of ash free dry weight (Moore and Chapman 1986). The 'scaling' relationships, by which the ratios between different aspects of tree size change when small and large trees of the same species are compared generally known as 'allometric' relations (Hairiah et al. 2001). The previous studies had been developed allometric equations to estimate above ground biomass (AGB) in the secondary forests (Hashimoto et al. 2004; Kenzo et al. 2009a; Kenzo et al. 2009b; Ketterings et al. 2001; Kiyono and Hastaniah 2005; Nelson et al. 1999; Sierra et al. 2007; Karyati et al. 2019). However the allometric equations to estimate AGB in abandoned lands is still rare reported. The objective of this study was to develop allometric equations for estimation AGB in fallow lands. Information on the allometric relationships could predict biomass and carbon stock in lands after abandonment.

50 Study site

51 The study was carried out in Salo Cella Village, Muara Badak Sub-district, Kutai Kartanegara Districts, East
 52 Kalimantan Province, Indonesia (Figure 1). This site was located in 0°17'18.7"S 117°18'08.2"E. The study site was
 53 abandoned land after selective logging about 30 years ago. Muara Badak Sub-district has 939.09 km² wide with population
 54 of 57,712 persons including 13 villages. Salo Cella Village is about 10 km from the capital of Sub-district. The capital of
 55 subdistrict was Muara Badak Ulu with 16 m height Above Mean Sea Level (AMSL). Muara Badak received average
 56 amount of 141 mm in rainfall and 11 raindays in 2017 (Statistics Kutai Kartanegara Regency 2018). Most of the
 57 population in this village were farmers' livelihoods. Muara Badak is administratively bordered with Marang Kayu Sub-
 58 district at north side, Anggana Sub-district Samarinda City at south side, Makassar Strait at east side, and Tenggarong
 59 Seberang Sub-district at west side. Muara Badak is one of oil and gas producer. This has also big potency in fishery and
 60 plantation sectors. The area was covered by lowland mixed dipterocarp forest.

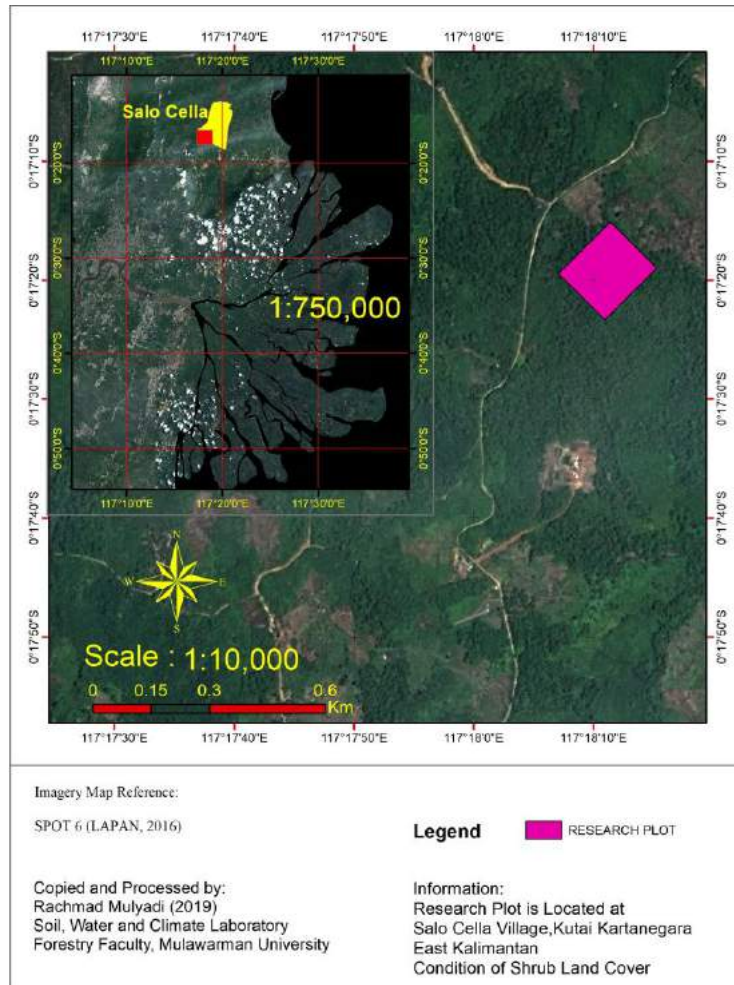


Figure 1. Map of study site in Salo Cella Village, Kutai Kartanegara Districts, East Kalimantan Province, Indonesia.

98 Data collection

99 Assessment on biomass in the field

100 Thirty sample trees were chosen in abandoned land. The sample trees were selected to obtain the representative species
 101 of land after abandonment. The selection of sample trees was based on consideration of the species and DBH. The
 102 standing DBH (1.3 m) of selected trees were measured using diameter tape. Measurement of the total height of the sample
 103 tree was completed once the tree had fallen. Felling sample trees were conducted by following the harvesting rules. The
 104 harvested trees were divided into several fractions which every tree fraction was 1 meter length. Then, parts of trees were
 105 separated into leaves and twigs (hereafter called leaves), branches, and main stems in the field as shown in Figure 2.

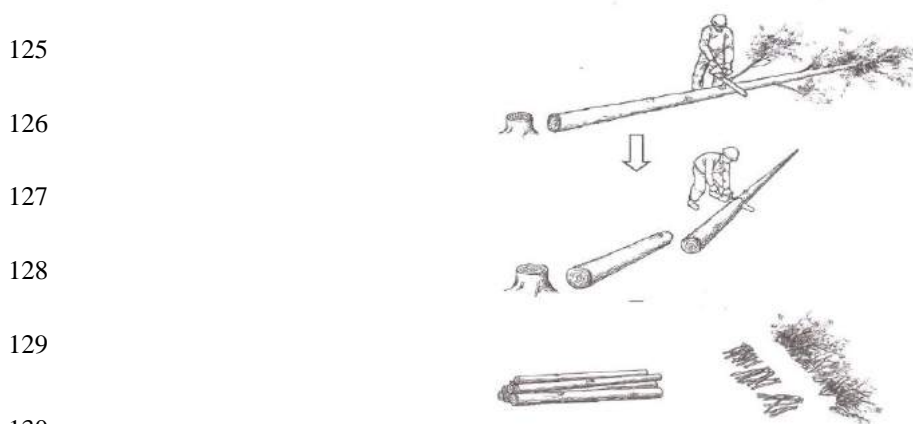
106 Dividing sample tree fractions was accomplished with the following criteria (Ministry of Forestry Indonesia, 2011):

- 107 1) Dividing sample tree fractions was done to separate parts of tree biomass including leaves, branches, and stem. The
 108 flower and fruit parts was not included in the observation, because very few sample trees that have flower and fruit
 109 during observation.
 110 2) Dividing sample tree fraction to be weighed needs to consider the capacity of the available scales.
 111 3) Especially for the stem fraction, the stem was divided into several sections (sub-fractions of the stem) taking into
 112 account the shape, uniformity, and weight of the pieces.

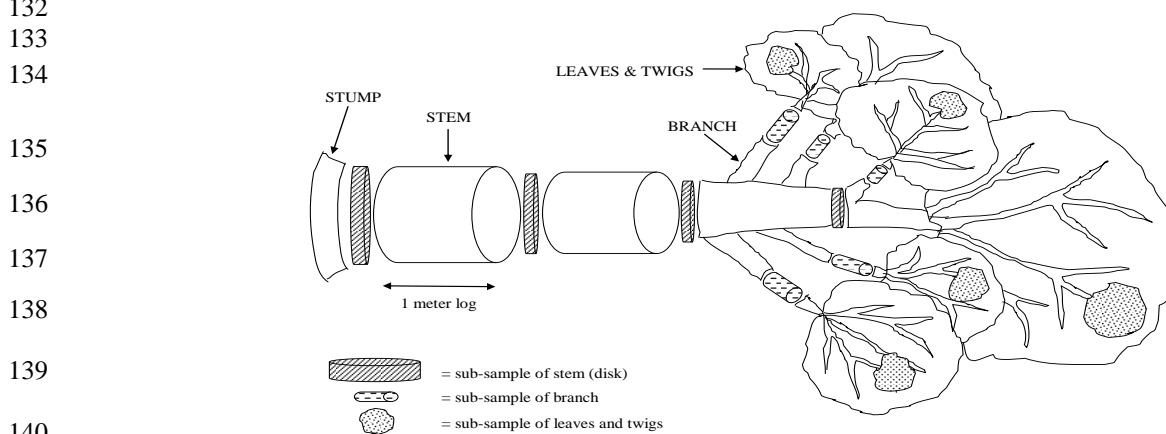
113 The fresh weight of all fractions were taken by the suitable scale in the field. The disk samples of trunk with 2-5 cm
 114 thick were were collected as many as three disk sample if the harvested trees had less than 10 fractions and four disk
 115 samples if more than 10 fractions. Five branch samples of 20-30 cm in length and five leaf samples of 100-300 grams in
 116 weight were taken from each sample tree. Figure 3 illustrates tree components and the position of sub-sample being taken for AGB
 117 assessment. The wood density of each sample tree was conducted from the various literatures.
 118

119 *Analysis of dry-weight in the laboratory*

120 Before oven-dried, all samples were air-dried in the laboratory to determine the moisture content. Then, samples of
 121 stem and branch fractions were dried in an oven at a temperature 105°C for 96 hours until reaching a constant weight.
 122 Samples of leaves were dried in an oven at temperature of 80°C for 48 hours until constant weight was reached. Weighing
 123 the samples of each fraction was performed using an analytical digital weighing scale after drying them in an oven.
 124



131 **Figure 2.** Dividing the trees (Source: Ministry of Forestry Indonesia, 2011).



141 **Figure 3.** Illustration of tree components and the position of sub-sample being taken (Karyati 2013).

142 **Data analysis**

143 The total oven-dry weight of each tree part were determined using the following formula (Hairiah et al. 2001; Hairiah
 144 & Rahayu 2007; Ministry of Forestry Indonesia, 2011):

$$dw = (sdw \times fw) / sfw \quad (1)$$

145 where: dw = total dry weight (kg); sdw = dry weight of the sample (g); fw = total fresh weight (kg); sfw = fresh weight of
 146 the sample (g).

147 The five selected allometric equations of AGB were tested (Equations 2-6):

$$y = a + b x \quad (2)$$

$$y = ax^b \quad (3)$$

$$y = a + b (\ln x) \quad (4)$$

$$(\ln y) = a + b x \quad (5)$$

$$(\ln y) = a + b (\ln x) \quad (6)$$

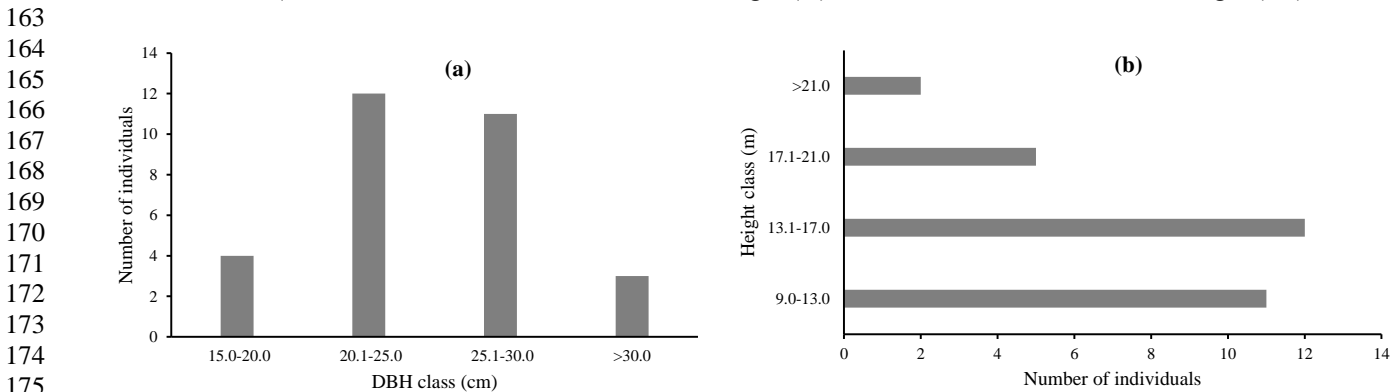
148 where: y = total dry weight or biomass of each plant part, such as trunk, branch, leaf, and total above ground biomass
 149 (TAGB) (kg); x = diameter at breast height (DBH, cm), total height (H, meter), and (DBH²×H) (cm² m); ‘a’ and ‘b’ =
 150 coefficients estimated by regression.

151 All regression analysis was carried out using SPSS version 18 for windows (SPSS Japan, Tokyo, Japan). The R² value
 152 and P value were determined to evaluate precision among all tested allometric equations. The indices of relative errors
 153 such as mean prediction error (MPE), mean relative error (MRE), and mean relative absolute error (MRAE) were also
 154 assessed for model evaluation.

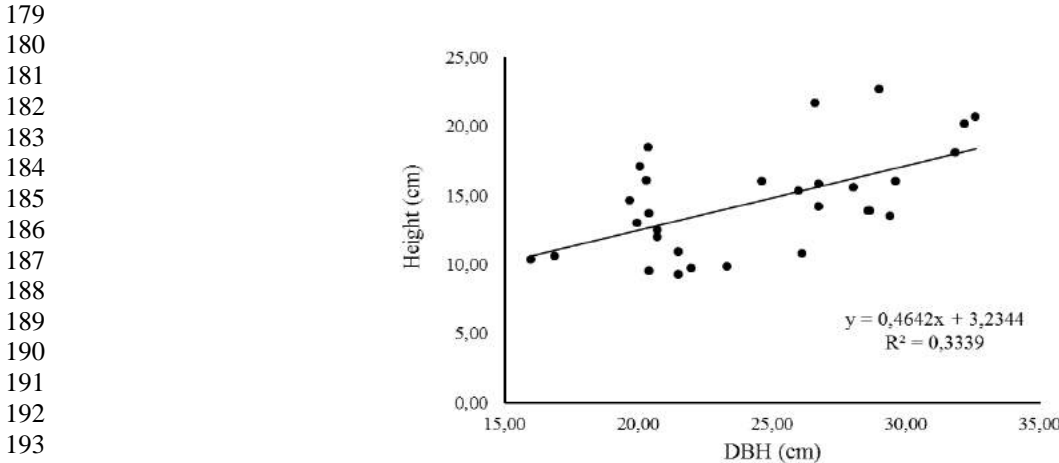
155 RESULTS AND DISCUSSION

156 Selected samples of trees

157 Thirty trees with DBH of ≥ 15 cm were harvested and measured to determine above ground parts in the study site as
 158 represent in Table 1. The DBH and height classes of selected sample trees for assessment AGB are illustrated in Figure 4.
 159 The DBH range was 16.0-32.6 cm and height was 9.3-22.7 m for selective sample trees. The relationship between DBH
 160 and total height of sample trees for assessment AGB in the study site is presented in Figure 5. The illustration showed that
 161 an increase in DBH was followed by an increase in total height. The equations of this relationship was “H=0.4642
 162 (DBH)+3.2344” (n=30; R²=0.3339). As stated ‘H’ is total height (m) and ‘DBH’ is diameter at breast height (cm).



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178 **Figure 4.** The distributions of (a) DBH classes and (b) height classes of sample trees to developed allometric equations.



196 **Figure 5.** The DBH and total height of sample trees to developed allometric equations.

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198 **Tree variables**

199 Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters
 200 of destructive biomass are summarized in Table 1. The minimum and maximum weight of branches biomass, trunk biomass,
 201 and TAGB were 3.92-34.18 kg; 12.84-296.72 kg, and 34.28-308.98 respectively. The DBH of sample trees ranged 16.00-
 202 32.00 cm, with the height ranged 9.30-22.70 m. The wood densities of sample trees ranged 0.37-0.69 g cm⁻³. The result
 203 showed that there were strong correlation ($P < 0.01$) among trunk biomass to DBH and tree height as well as TAGB and
 204 tree height. The correlation ($P < 0.05$) was showed by TAGB and DBH. The strong correlation ($P < 0.01$) was also showed
 205 between DBH and tree height. However, the leaf and branch biomass were not correlated with DBH and tree height
 206 significantly ($P > 0.05$). In addition, the wood density was not also correlated to plant part biomass (leaf, branch, trunk, and
 207 TAGB) and tree dimensions (DBH and height).
 208

209 **Table 1.** Pearson's correlation between DBH, height, wood density and branches biomass, trunk biomass, TAGB and parameters of
 210 destructive biomass
 211

	Pearson's correlation			Mean	Range
	DBH (cm)	H (m)	WD (g cm ⁻³)		
Leaf biomass (kg)	-0.303 ^{ns}	-0.198 ^{ns}	0.262 ^{ns}	12.43	1.37 - 45.59
Branch biomass (kg)	0.205 ^{ns}	-0.072 ^{ns}	0.208 ^{ns}	16.99	3.92 - 34.18
Trunk biomass (kg)	0.527 ^{**}	0.768 ^{**}	0.027 ^{ns}	116.55	12.84 - 296.72
TAGB (kg)	0.494 [*]	0.710 ^{**}	0.098 ^{ns}	145.97	34.28 - 308.98
DBH (cm)	1	0.578 ^{**}	-0.357 ^{ns}	24.35	16.00 - 32.00
H (m)	0.578 ^{**}	1	-0.184 ^{ns}	14.54	9.30 - 22.70
WD (g cm ⁻³)	-0.357 ^{ns}	-0.184 ^{ns}	1	0.53	0.37 - 0.69

Note: ^{ns} is not significant at the 0.05 level ($P > 0.05$); * and **Correlation are significant at the 0.05 and 0.01 level (2-tailed) respectively

212
 213
 214 Thirty sample trees with DBH of > 15 cm were selected in the study site, with consideration of the species. These
 215 selected trees didnot considering individuals with damaged crowns or broken trunks. Almost 90% of the selected trees
 216 were categorized as the dominant species in terms of density and Importance Value Index (IVI) as observed in the current
 217 study, while few selected trees represented the rare species. There were 10 species of 10 genera of 9 families selected in
 218 study site. Eight sample trees were *Pterospermum javanicum* (Malvaceae). There were 5 sample trees of *Glochidion*
 219 *obscurum* (Euphorbiaceae) and 4 sample trees of *Bridelia glauca* (Phyllanthaceae). Three sample trees were *Vatica*
 220 *javanica* (Dipterocarpaceae). The species of *Ficus septica* (Moraceae), *Trema orientalis* (Cannabaceae), *Archidendron*
 221 *jiringa* (Fabaceae), *Vernonia arborea* (Asteraceae) were selected for two sample trees respectively. One sampe tree was
 222 *Heliciopsis artocarpoides* (Proteaceae) as well as *Artocarpus elasticus* (Moraceae). The range of dry weight was 1.37-
 223 45.59 kg for leaf, 3.92-34.18 kg for branch, 12.84-296.72 kg for trunk, and 34.28-308.98 kg for TAGB in this site (Table
 224 2). The result showed that there are diverse variation among different species. The different tree species tends to has the
 225 different structure (growth, stratification, and crown cover) and physiognomy. The largest sample tree was *Artocarpus*
 226 *elasticus* with DBH of 32.60 cm. This species had the dry weight of leaf, branch, trunk, and TAGB were 14.15, 20.23,
 227 183.51, and 217.89 kg respectively. On the other hand, the smallest selected tree was *Archidendron jiringa* with DBH of
 228 16.00 cm. This species obtained 22.95 kg of leaf dry biomass, 9.27 kg of branch dry biomass, 24.09 kg of trunk dry
 229 biomass, and 56.30 kg of TAGB. *Pterospermum javanicum* with 22.70 m height was the tallest sample trees. This sample
 230 tree had the highest trunk dry biomass (296.72 kg) and TAGB (308.98 kg). Contrarly, the other sample tree of
 231 *Pterospermum javanicum* had the lowest trunk dry biomass (12.84 kg) and TAGB (34.28 kg). The shortest sampe tree with
 232 9.30 m height was *Bridelia glauca*. The lowest leaf dry biomass (1.37 kg) and branch dry biomass (3.92 kg) were showed
 233 by *Vernonia arborea*. Meanwhile, the other sample tree of *Archidendron jiringa* had the highest leaf dry biomass (45.59
 234 kg). The highest branch dry biomass (34.18 kg) was showed by *Glochidion obscurum*.
 235

236 **Table 2.** All data sets for develop allometric equations in abandoned lands
 237

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
1	Malvaceae	<i>Pterospermum javanicum</i>	31.85	18.10	5.68	32.61	249.73	288.01	0.53
2	Malvaceae	<i>Pterospermum javanicum</i>	20.06	17.10	9.31	9.39	119.09	137.80	0.53
3	Malvaceae	<i>Pterospermum javanicum</i>	28.98	22.70	3.86	8.39	296.72	308.98	0.53
4	Moraceae	<i>Ficus septica</i>	32.17	20.20	5.70	19.70	166.63	192.03	0.39
5	Moraceae	<i>Ficus septica</i>	28.03	15.60	1.92	10.47	93.98	106.38	0.39
6	Cannabaceae	<i>Trema orientalis</i>	26.75	14.16	7.37	22.89	86.11	116.36	0.44
7	Proteaceae	<i>Heliciopsis artocarpoides</i>	21.97	9.70	9.95	9.88	57.62	77.44	0.65
8	Phyllanthaceae	<i>Bridelia glauca</i>	28.66	13.90	6.78	12.37	80.76	99.91	0.50
9	Phyllanthaceae	<i>Bridelia glauca</i>	20.70	12.50	6.93	16.74	71.55	95.22	0.50
10	Cannabaceae	<i>Trema orientalis</i>	26.11	10.80	13.97	29.02	58.17	101.16	0.44
11	Malvaceae	<i>Pterospermum javanicum</i>	29.62	16.00	8.76	10.12	77.63	96.52	0.53

Tree No.	Family	Species	DBH (cm)	H (m)	Leaves (kg)	Branches (kg)	Trunk (kg)	TAGB (kg)	WD (g cm ⁻³)
12	Malvaceae	<i>Pterospermum javanicum</i>	16.88	10.60	6.88	14.56	12.84	34.28	0.53
13	Phyllanthaceae	<i>Bridelia glauca</i>	26.75	15.80	12.89	33.00	89.17	135.07	0.50
14	Euphorbiaceae	<i>Glochidion obscurum</i>	26.00	15.30	10.65	8.34	114.02	133.01	0.67
15	Euphorbiaceae	<i>Glochidion obscurum</i>	20.40	13.70	11.88	9.24	89.41	110.53	0.67
16	Fabaceae	<i>Archidendron jiringa</i>	16.00	10.36	22.95	9.27	24.09	56.30	0.42
17	Dipterocarpaceae	<i>Vatica javanica</i>	19.95	13.00	38.71	32.40	43.01	114.11	0.69
18	Euphorbiaceae	<i>Glochidion obscurum</i>	19.70	14.65	8.64	14.25	78.32	101.21	0.67
19	Fabaceae	<i>Archidendron jiringa</i>	24.60	16.00	45.59	22.73	160.89	229.21	0.42
20	Dipterocarpaceae	<i>Vatica javanica</i>	20.70	12.00	39.17	16.92	129.92	186.01	0.69
21	Euphorbiaceae	<i>Glochidion obscurum</i>	20.39	9.50	20.97	34.18	104.42	159.57	0.67
22	Dipterocarpaceae	<i>Vatica javanica</i>	28.60	13.90	7.66	29.95	184.53	222.14	0.69
23	Euphorbiaceae	<i>Glochidion obscurum</i>	21.50	10.90	11.24	21.63	142.13	175.00	0.67
24	Moraceae	<i>Artocarpus elasticus</i>	32.60	20.70	14.15	20.23	183.51	217.89	0.46
25	Asteraceae	<i>Vernonia arborea</i>	23.30	9.82	1.37	3.92	52.70	57.99	0.37
26	Asteraceae	<i>Vernonia arborea</i>	29.40	13.50	3.79	9.83	121.02	134.64	0.37
27	Phyllanthaceae	<i>Bridelia glauca</i>	21.50	9.30	14.28	17.31	67.24	98.83	0.50
28	Malvaceae	<i>Pterospermum javanicum</i>	20.29	16.10	4.04	3.94	163.39	171.38	0.53
29	Malvaceae	<i>Pterospermum javanicum</i>	20.36	18.50	6.66	8.55	189.90	205.12	0.53
30	Malvaceae	<i>Pterospermum javanicum</i>	26.60	21.70	11.19	17.72	187.95	216.85	0.53
Average			24.35	14.54	12.43	16.99	116.55	145.96	0.53
Minimum			16.00	9.30	1.37	3.92	12.84	34.28	0.37
Maximum			32.60	22.70	45.59	34.18	296.72	308.98	0.69
Standard deviation			4.66	3.75	10.93	9.13	65.59	66.98	0.11

Note: DBH=diameter at breast height; H=total height; TAGB=total above ground biomass; WD=wood density.

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The developed allometric equations

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The results of regression analyses for predicting plant part biomass of subject trees from diameter at breast height (DBH) and total height (H) using data all studied individuals are shown in Table 3. The relationships between DBH, (DBH²×H), and height of trees as independent variables were not significant to related leaf and branch dry biomass (*P* value > 0.05) as well as DBH to trunk dry biomass. This means that the DBH, (DBH²×H), height of trees were not a good predictor to leaf and branch dry biomass based on the goodness of fit. Similarly DBH was not also good predictor to trunk dry biomass. The correlations between (DBH²×H) and height of trees to trunk dry biomass and TAGB showed moderately strong relationships as well as DBH to TAGB (*P* value < 0.001).

The selected allometric equations to estimate above ground biomass of trees were dominated by log-linear model ($y=a+b \ln x$) and linear model ($y=a+bx$). These equations were fitting model to relate dependent variables (leaf, branch, trunk, and AGB) and independent variables (DBH, (DBH²×H), and H) for tree stage. From all tested regression, there are only four equations with relatively high *R*² (>0.400). These equations are “ln (trunk dry biomass) = 0.837 × ln (DBH²×H) – 29.45” (*R*²=0.500), “ln (trunk dry biomass) = 1.812 × ln (H) – 0.217” (*R*²=0.461), “ln (AGB) = 0.576 × ln (DBH²×H) – 0.301” (*R*²=0.431), and “ln (AGB) = 1.331 × ln (H) – 1.350” (*R*²=0.455). However, the result showed there are very weak relationships between leaves and branches dry biomass of trees and plant dimensions in the abandoned land. The trunk dry biomass and AGB in the tropical secondary forests of different ages (5, 10 and 20 years after abandonment) showed strong correlations (adjusted *R*²= 0.59-0.95) with diameter at breast height (DBH) and height. The leaf and branch dry biomass had weak correlations with height (adjusted *R*²=0.36-0.50) (Karyati et al. 2019). The mixed-species allometric equations showed AGB correlates significantly with diameter at stump height (*R*²=0.78; *P*<0.01) and tree height (*R*²=0.41, *P*<0.05) (Mokria et al. 2018). Generally, the developed allometric equations showed relatively low *R*² (<0.60). This may caused by the high variation sample trees. The variation sample trees lead the variation on wood density, structure, and physiognomy. Parlucha (2017) stated that comparing growth performance for different level of species type (native or exotic) is not conclusive since the growth of trees varies. It is happen from specific species character level and matching with the existing site condition. The regression between the trunk biomass and TAGB and the product of square DBH and height (cm² m) and the natural logarithm of height was illustrated in Figure 6.

The results showed that mean prediction errors (MPEs) of the developed aboveground biomass models ranged 4.7% to 26.9%. These values were higher than reported by Zeng et al. (2017). Zeng et al. (2017) stated that mean prediction errors (MPEs) of the developed one- and two-variable aboveground biomass models were less than 4%. The mean relative errors (MRE) for predicting plant part biomass of subject trees in the study site ranged 7.2% to 39.3%. These MRE were also higher than reported for lowland tropical forests of the Indo-Malay region (MRE ranged 3.2% to 33.6%) (Manuri et al. 2017). The mean relative absolute error (MRAE) of developed allometric equations ranged 28.4% to 35.7%. Similarly, the range of MRAE for aboveground biomass models were 26.6-41.5% as reported by Manuri et al. (2017).

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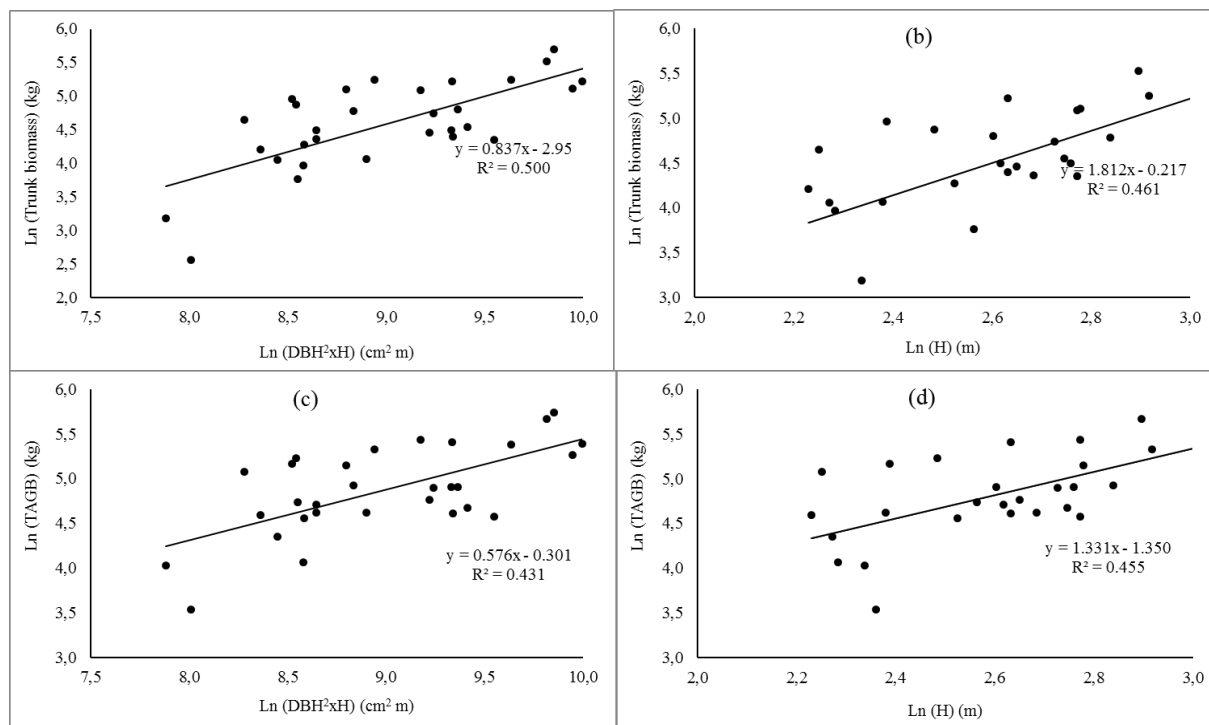
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Table 3. The allometric equations for predicting plant part biomass of subject trees in the study site

Dependent variable (y)	Independent variable (x)	Equation	P value	R ²	MPE	MRE	MRAE
Leaf dry biomass (kg)	DBH (cm)	$\ln y = 0.054 - 3.524 x$	>0.05	0.099	0.047	0.299	0.292
	(DBH ² ×H) (cm ² m)	$\ln y = 0.4132 - 5.932 \ln x$	>0.05	0.086	0.252	0.321	0.291
	H (m)	$y = 0.001 - 17.614 x$	>0.05	0.074	0.269	0.393	0.306
Branch dry biomass (kg)	DBH (cm)	$\ln y = 0.695 + 0.4687 \ln x$	>0.05	0.060	0.150	0.220	0.284
	(DBH ² ×H) (cm ² m)	$\ln y = 0.001 + 2.5228 x$	>0.05	0.023	0.172	0.291	0.290
	H (m)	$y = 0.001 + 15.097 x$	>0.05	0.014	0.202	0.170	0.311
Trunk dry biomass (kg)	DBH (cm)	$\ln y = 1.910 - 1.501 \ln x$	>0.05	0.347	0.174	0.163	0.289
	(DBH ² ×H) (cm ² m)	$\ln y = 0.837 - 2.945 \ln x$	<0.001	0.500	0.030	0.371	0.291
	H (m)	$\ln y = 1.812 - 0.217 \ln x$	<0.001	0.461	0.033	0.072	0.289
Above ground biomass (kg)	DBH (cm)	$\ln y = 1.277 + 0.808 \ln x$	<0.001	0.283	0.130	0.210	0.357
	(DBH ² ×H) (cm ² m)	$\ln y = 0.576 - 0.301 \ln x$	<0.001	0.431	0.070	0.144	0.289
	H (m)	$\ln y = 1.331 - 1.350 \ln x$	<0.001	0.455	0.071	0.146	0.290

277 Note: P values of the regression analysis are shown, R² coefficient of determination, MPE mean prediction error, MRE mean relative
278 error, MRAE mean relative absolute error, DBH diameter at breast height, H tree height.
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288 Figure 6. Regression between the trunk biomass (kg) and the product of square DBH and height (cm² m) (a) and the
289 natural logarithm of height (m) (b); Regression between total above ground biomass (TAGB) (kg) and the product of
290 square DBH and height (cm² m) (c) and the natural logarithm of height (m) (d).

291 Comparison among various allometric equations

292 The estimation of AGB using the developed allometric equation in this study was lower than using the previous
293 developed equations as presented in Table 3. The AGB estimation of 33.31 Mg ha⁻¹ was lower than 115.90, 91.65, 85.60,
294 76.31, 70.39, 68.08, 63.99, 60.32 Mg ha⁻¹ of AGB calculated using the formulas of Rai and Proctor (1986), Chambers et al.
295 (2001), Yamakura et al. (1986), Brown (1997), Manuri et al. (2017), Basuki et al. (2009), Kiyono and Hastaniah (2008),
296 and Nelson et al. (1999) respectively. The value resulted by the developed allometric equation was similar than those using
297 other previous reported equations, i.e., 38.86 Mg ha⁻¹ (Kenzo et al. 2009a), 39.31 Mg ha⁻¹ (Hashimoto et al. 2004), 49.05
298 Mg ha⁻¹ (Sierra et al. (2007), 49.63 Mg ha⁻¹ (Kettering et al. 2001), 50.31Mg ha⁻¹ (Karyati et al. 2019), and 5.94 Mg ha⁻¹
299 (Kenzo et al. 2009b). The comparison between AGB and DBH estimated by previously reported relationships was
300 illustrated in Figure 7.

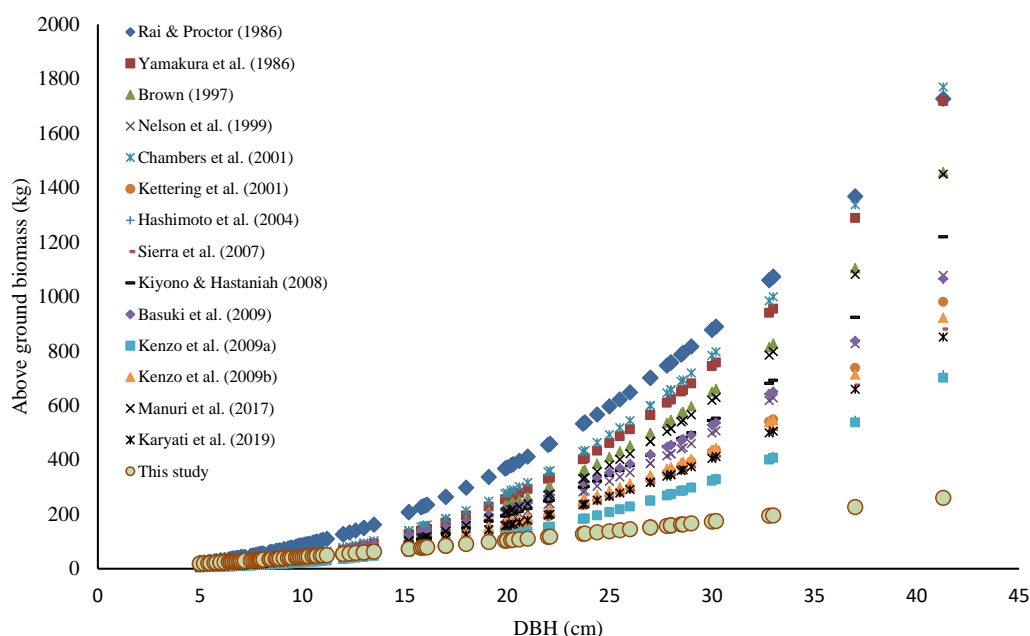
301 The calculation using equations of Rai and Proctor (1986), Chambers et al. (2001), Yamakura et al. (1986), Brown
302 (1997), Basuki et al. (2009), and Kiyono and Hastaniah (2008) resulted the overestimation than the developed allometric
303 equation. This might be caused the low wood density (0.37-0.69) of trees in the study site, because tree species observed in
304 the abandoned land was dominated by pioneer species. The allometric equations for pioneer species may differ

305 significantly caused usually these species has the low wood (Hashimoto et al. 2004). The wood densities of trees were
 306 0.40-0.79 for Brown's equation, 0.32-0.86 for Basuki et al.'s equation, and 0.67 for Kiyono and Hastaniah's equation. The
 307 similar values of AGB were estimated by using equations of Kenzo et al. (2009a) with wood density of 0.35, Kettering et
 308 al. (2001) with wood density of 0.35 to 0.91, Karyati et al. (2019) with wood density of 0.24-0.44, and Kenzo et al.
 309 (2009b) with wood density of 0.35. Kenzo et al. (2009a), Hashimoto et al. (2004), and Karyati et al. (2019) developed
 310 allometric equation for mixed species in tropical forest of Kalimantan, while Kettering et al. (2001) developed allometric
 311 for mixed secondary forest in Sumatra. Sierra et al. (2007) reported allometric equation for tropical forest in Colombia.
 312 The similar tree species in abandoned land of study site and the mixed secondary forest caused the similar estimation of
 313 AGB by using the developed equations. The species and stand characteristics such as wood density and tree height
 314 effected to AGB variation directly, meanwhile biogeographical region only slightly effected to the accuracy of AGB
 315 equations (Manuri et al. 2017). In addition, aboveground biomass was also related to mean annual temperature (MAT)
 316 (Zeng et al. 2017).
 317

318 **Table 4.** Estimation of AGB using various reported relationships for trees in the study site

No.	Equation	Author	Estimate of AGB (Mg ha ⁻¹)
1	$\ln(\text{AGB})=2.12 \times \ln(\text{DBH})-0.435$	Rai and Proctor (1986)	115.90
2	$\ln(\text{AGB})=2.62 \times \ln(\text{DBH})-2.30$	Yamakura et al. (1986)	85.60
3	$\ln(\text{AGB})=2.53 \times \ln(\text{DBH})-2.13$	Brown (1997)	76.31
4	$\ln(\text{AGB})=2.413 \times \ln(\text{DBH})-1.997$	Nelson et al. (1999)	60.32
5	$\ln(\text{AGB})=2.55 \times \ln(\text{DBH})-2.010$	Chambers et al. (2001)	91.65
6	$\ln(\text{AGB})=2.59 \times \ln(\text{DBH})-2.75$	Kettering et al. (2001)	49.63
7	$\ln(\text{AGB})=2.44 \times \ln(\text{DBH})-2.51$	Hashimoto et al. (2004)	39.31
8	$\ln(\text{AGB})=2.422 \times \ln(\text{DBH})-2.232$	Sierra et al. (2007)	49.05
9	$\text{AGB}=0.1008 \times \text{DBH}^{2.5264}$	Kiyono and Hastaniah (2008)	63.99
10	$\ln(\text{AGB})=2.196 \times \ln(\text{DBH})-1.201$	Basuki et al. (2009)	68.08
11	$\text{AGB}=0.0829 \times \text{DBH}^{2.43}$	Kenzo et al. (2009a)	38.86
12	$\text{AGB}=0.1525 \times \text{DBH}^{2.34}$	Kenzo et al. (2009b)	53.94
13	$\text{AGB}=0.071 \times \text{DBH}^{2.667}$	Manuri et al. (2017)	70.39
14	$\ln(\text{AGB})=2.3207 \times \ln(\text{DBH})-1.89$	Karyati et al. (2019)	50.31
15	$(\text{AGB}) = 12.683 \times (\text{DBH}^2 \times \text{H}) - 38.403$	This study	33.31

319 Note: AGB = above ground biomass ; DBH = diameter at breast height.



334
 335
 336 **Figure 7.** Comparison among various allometric relationships between above ground biomass (AGB) and diameter at breast height
 337 (DBH) in the study site

338

CONCLUSION

339 This study provides allometric equations to estimate above ground biomass in the tropical abandoned lands after
 340 selective logging that characterized by mixed species. The specific allometric equation for different types of abandoned
 341 lands was needed. Because the using appropriate allometric model will determine the accurate estimation of above ground
 342 biomass in the site.

343

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