BUKTI-BUKTI PROSES REVIEW (PENULIS KORESPONDENSI)

Title	:	Estimation of Above Ground Biomass and carbon stocks
		of Tectona grandis and Gmelina arborea stands in
		Gorontalo Province, Indonesia
Author	:	Yosep Ruslim, Daud Sandalayuk, Rochadi Kristingrum,
		Andi Sahri Alam
Nama Jurnal	:	Biodiversitas
Volume/Nomor/Tahun/Halaman	:	Vol. 22/ No. 3/ 2021/1497-1508
ISSN	:	1412-033X/E-ISSN: 2085-4722
Penerbit	:	Society for Indonesian Biodiversity
DOI	:	10.13057/biodiv/d200904
URL artikel	:	https://smujo.id/biodiv/article/view/7790/4675

Biodiversitas Journal of Biological Diversity	Tasks 🚯	🗣 English 👁 View Site	A yruslim
OJUNI IOUERAL AVITANS	7790 / RUSLIM et al. / Estimation of Above Ground Biomass and carbon stocks of Tectona grandis	s and Gmelina arborea stands in Go	
Submissions	Workflow Publication		
	Submission Review Copyediting Production		
	Submission Files	Q Search	
	Besserial yruslim, Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indon.doc	January Article Text 17,/2021	
	38807-1 nliza, Estimation Above Ground Biomass (AGB) and carbon stocks.doc	January Article Text 25. 2021	
	36808-1 niiza, GUIDANCE FOR AUTHORS.pdf	January Article Text 25, 2021	

Note	From
Dear Bapak Ahmad Dwi Setyawan	yruslim
Managing Editor	2021-01-17 04:30 PM
Biodiversitas	
We send you our submission with a title Estimation Above Ground Biomass (AGB) and	
Carbon Stocks of <i>Tectona grandis</i> and <i>Gmelina arborea</i> in Gorontalo Province, Indonesia	
This study aimed to calculate the stand potential, to calculate the standing biomass and	
carbon stock of Tectona grandis and Gmelina arborea in the Gorontalo area. The objective	
of this study was to know potential standing stock, develop allometric equations for	
estimation AGB by the value of the coefficient of determination that could predict biomass	
and carbon stock in lands after abandonment. This indicated that Tectona grandis more	
potentially than Gmelina arborea plantations in carbon sequestration and biomass	
production, although both of them have an important role in mitigating and climate	
change.	
We hope, could be published in Biodiversitas Journal. Thank you for your attention.	
Kind regards,	

COVERING LETTER

Dear Editor-in-Chief,

I herewith enclosed a research article,

Title:

Estimation Above Ground	Biomass (A	GB) and	Carbon	Stocks	of	Tectona	grandis	and	Gmelina	arborea	in	Gorontalo
Province, Indonesia												

Author(s) name:

Yosep Ruslim, Daud Sandalayuk, Rochadi Kristiningrum, Andi Sahri Alam

Address

(Fill in your institution's name and address, your personal cellular phone and email) ^{1,3}Faculty of Forestry Mulawarman University,Jl. Ki Hajar Dewantara, PO Box 1013, Kampus Gunung Kelua, Samarinda Ulu, Samarinda, 75116 East Kalimantan Province, Indonesia, HP: 081350371028, *email: yruslim@gmail.com; ²Faculty of Forestry, Gorontalo University, Jl. Jend. Sudirman No. 247, Limboto, North Sulawesi, Indonesia ³Faculty of Forestry, Tadulako University, Jl. Soekarno Hatta Km 9. Kampus Bumi Tadulako, Tondo, Mantikulore, Palu 94148. Central Sulawesi, Indonesia

For possibility publication on the journal:

(fill in *Biodiversitas* or *Nusantara Bioscience* or *mention the others*) Biodiversitas

Novelty:

(state your claimed novelty of the findings versus current knowledge)

Forest plantations play a critical role in mitigating the various effects of environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this study revealed that *Tectona grandis* and *Gmelina arborea* has a great potential in promoting carbon sequestration especially when they are allowed to grow older. Favorable growth conditions have high potential of increasing the biomass accumulation of this species. Hence, it is recommended that sustainable management of this plantation should be paramount in securing a cleaner environment and mitigating the effect of climate change in Indonesia.

This study aimed to calculate the stand potential, to calculate the standing biomass and carbon stock of *Tectona* grandis and *Gmelina arborea*a in the Gorontalo area. The objective of this study was to know potential standing stock, develop allometric equations for estimation AGB by the value of the coefficient of determination could predict biomass and carbon stock in lands after abandonment. This indicated that *Tectona grandis* more potentially than *Gmelina arborea* plantations in carbon sequestration and biomass production, although both of them have an important role in mitigating and climate change.

Statements:

This manuscript has not been published and is not under consideration for publication to any other journal or any other type of publication (including web hosting) either by me or any of my co-authors. Author(s) has been read and agree to the Ethical Guidelines.

List of five potential reviewers

(Fill in names of five potential reviewers **that agree to review your manuscpt** and their **email** addresses. He/she should have Scopus ID and come from different institution with the authors; and from at least three different countries)

1. Eagleton, Graham

Department of Planning, Building 15, Ministry of Agriculture, Livestock and Irrigation, Nay Pyi Taw, Myanmar Email: grahameagleton@gmail.com

2. Larson, Thronton

University of Texas Et Elpaso (USA) larson thornton@yahoo.com

	3. Pratiwi Forest Research and Development Center, Gunung Batu Street, Number 5, Bogor; Email: pratiwi.lala@yahoo.com	
	 Hermudananto Room 5.04 Building B. Jalan Agro No.1, Bulaksumur, Yogyakarta 55281 University of Gadjah Mada Email: hermudananto@ugm.ac.id 	
	5. Suryo Hardiwinoto University of Gadjah Mada Bulaksumur Yogyakarta 55281 Email: <u>suryohw@ugm.ac.id</u>	
Pl Sa	ace and date: marinda, January 17, 2021	
Sin (fi Co Yo	ncerely yours, Il in your name, no need scanned autograph) orresponding author osep Ruslim	

Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia

YOSEP RUSLIM^{1,9}, DAUD SANDALAYUK², ROCHADI KRISTININGRUM^{1,}, ANDI SAHRI ALAM³

^{1,3}Faculty of Forestry Mulawarman University, Jl. Ki Hajar Dewantara, PO Box 1013, Kampus Gunung Kelua, Samarinda Ulu, Samarinda, 75116 East Kalimantan Province, Indonesia, Telp/Fax. (0541) 735379, *email: yruslim@gmail.com

²Faculty of Forestry, Gorontalo University, Jl. Jend. Sudirman No. 247, Limboto, North Sulawesi, Indonesia

³Faculty of Forestry, Tadulako University, Jl. Soekarno Hatta Km 9. Kampus Bumi Tadulako, Tondo, Mantikulore, Palu 94148. Central Sulawesi,

Indonesia

Manuscript received: DD MM 2021 (Date of abstract/manuscript submission). Revision accepted: 2021

Abstract. Ruslim Y, Sandalayuk D, Kristiningrum R, Alam AS. 2021. Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia. Plantation forest exploitation has an important role in meeting 12 timber needs and also as carbon sequestration for the environment. The purpose of this study was to calculate the stand potential, to 13 calculate the standing biomass and carbon stock of teak and gmelina in the Gorontalo area. The research object was 4 plots each with an 14 area of 1 hectare. The sampling method used was a systematic random sampling by measuring the diameter and height of a stand, while the data analysis used the potential stand and increment formula of MAI and CAI. Meanwhile, the estimation of biomass and carbon by calculating the aboveground carbon stock (AGB) is then analyzed using simple linear regression to determine the closeness relationship between variables. The results showed that the maximum growth of teak plots 1 and 2 reached a maximum point at the age of 32 and 25 years and the total volume was 307.50 and 254.81 m³ha⁻¹. While the maximum growth of gmelina plots 1 and 2 reaches a maximum point at the age of 15 years and the total volume is 190.54 and 251.80 m³ha⁻¹. The biomass content in teak plots 1 and 2 and gmelina plots 1 and 2 were respectively 267.83; 221.94; 104.03 and 137.48 tonsha⁻¹. Meanwhile, the carbon content in teak plots 1 and 2 and gmelina plots 1 and 2 were respectively 125.88; 104.31; 48.90; and 64.62 tons ha-1. The results of simple regression analysis, the relationship between the two variables shows a very close relationship. This indicated that Tectona grandis more potentialy than Gmelina arborea plantations in carbon sequestration and biomass production although both of thrm have an important role in mitigating and climate change.

25 Key words: Biomass, Carbon, Gmelina arborea, Growth, Tectona grandis

INTRODUCTION

27 Along with the development today the forest is not it only function as a producer wood, but also as a producer 28 environmental services. Forest as a very environmental service producer potentially reducing carbon dioxide in the 29 atmosphere through the process of photosynthesis (Lukito and Rohmatiah 2013). Land use change and its impact on global 30 climate are important factors that make it necessary to improve our knowledge of carbon (C) cycling in forest ecosystems 31 (Derwisch et al. 2009). Birdsey and Pan (2015) had reviewed the function of forest has been changing in recent decades 32 and summarized those implications for global carbon stocks. Forests can play an important role in capturing and storing C 33 from the atmosphere, thereby mitigating CO₂ emissions (e.g., Watson et al. 2000; Houghton 2005). Tropical plantations 34 are of articular interest due to their relatively fast growth. Tesfaye et al. (2016) explains that tropical forests play an important role in global carbon sequestration. However, the increasing rate of deforestation and the impact of land-use 35 36 changes need to be concerned prior to preventing the loss function of tropical forests. The forest degradation process with 37 respect to selective logging, forest fire, and abandonment dynamics occurs over large areas in tropical forests (Pinheiro et 38 al. 2016). Therefore, Ruslim et al (2016), state that development of more effective ways to reduce the illegal harvest 39 activities should be done to protect the tropical forest diversity. More often extrapolations are based on the level of land 40 use (Domec et al. 2015). The amount of this nutrient depletion depends on species characteristics, growth rate, tissue 41 nutrient content, the period of harvesting rotation, the use of harvesting methods and nutrient reserves in the soil (Arias et 42 al. 2011).

43 According to Gonzalez-Benecke et al. 2015; Sharma et al. 2016; Panwar et al. 2017, increasing the rotation length 44 would also increase the biomass carbon stock. Balancing the economic productivity with another ecosystem services such 45 as carbon sequestration need the sustainability of soil health and water resources. This is urgently needed for assessment of 46 the whole potential of biomass carbon stock, and other potentials in order to change management activities (Birdsey and 47 Pan 2015; Law and Waring 2015; Noormets et al. 2015). The ability of fast growing species to absorb carbon more rapidly 48 compared with the slow-growing tree species is one of the reasons for highly plantation of these trees in the private forest 49 lands (Murdivarso 2003; Chauhan et al. 2016a). In addition, forest plantation for wood production, mostly provides 50 environmental services such as water regulator and carbon absorber (Kanninen 2010; Chauhan et al. 2016b).

1

2

Studies regarding the potential of the forest to be very important. Good study regarding potential stands, studies regarding biomass potential and studies regarding carbon potential. One of those factors determine in analyzing forest potential is by method, measurement where to measure potential for biomass and carbon yet some are standard. Based on the setting hindsight can be formulated the following problems: Estimated amount of content carbon is much approximated by its magnitude stand biomass content, this caused by the main result photosynthesis is stored carbohydrates in living plant organs. Karyati et al (2019) stated that 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 availability. 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. There are two the method commonly used to estimate stand carbon content forest, namely by: (1). indirect measurements (indirect measurement) by means of converting biomass by using a specific carbon content figure. This method most used with how to use constant numbers carbon content of 50% of biomass weight (Brown 1997) and 45 % by weight of the biomass (Losi 2003). Direct measurement by means of using tools or methods certain. Usually done with direct burning way since then analyzed with tools carbon analyzer (Kraenzel et al. 2003) and can also by means of carbonation that is burning of carbonaceous materials. Carbon stock at the stand in the surface soil and standing tree mass could represent less than 1% to 60% of total carbon stock of forest ecosystem (Curtis 2008). Carbon stock of fertile soils is higher which could influence carbon stock storage at vegetation biomass (Hairiah and Rahayu 2007). Therefore, this study aimed to calculate the stand potential, to calculate the standing biomass and carbon stock of teak and gmelina in the Gorontalo area. The objective of this study was to develop allometric equations for estimation AGB by the value of the coefficient of determination could predict biomass and carbon stock in lands after abandonment.

MATERIALS AND METHODS

Study area

The experiment was conducted from September 2020 to December 2020 in Gorontalo Province. The field experiments were conducted in four plots of *Tectona grandis* were two plots and *Gmelina arborea* were two plots. The area was located on the coordinate 0° 32 '28 "North Latitude and 123° 03 '36 "East Longitude.



Figure 1. Location studies (in which: $\mathbf{A} = G$. Arborea plot II, $\mathbf{B} = T$.grandis plot I, $\mathbf{C} = G$. Arborea plot I, $\mathbf{D} = T$.grandis plot II)

Research object

The objects to be studied were 2 types of teak and Gmelina stands, each with a plot area of 1 hectare each, so that the number of research plots was 4 plots, with different spacing. Where the *Tectona grandis* plant spacing is 3m x 3m and the

Gmelina arborea spacing is 3m x 4m. Determination of the sample and the location of the study by purposive sampling, with the sampling method using systematic random sampling. Then the data obtained is analyzed mathematically using simple linear regression. To find the closeness of the relationship between age and increment, the polynomial method was used to determine the regression coefficient.

116 Data analysis

115

117 118

127

134

137

Estimating MAI and CAI

Data collection includes diameter, plant species as high as 1.3 m from the soil surface (cm). Carbon (C) storage (kg per year) can be estimated by multiplying the tree biomass (Y: kg) with the general vegetation carbon content, namely (0.46) (Hairiah and Rahayu 2007). Carbon stock calculations were also carried out on cultivated plants *Tectona grandis* (teak) and *Gmelina arborea* (white teak) planted on land by the community.

Maximum production was calculated by analyzing the growth increment of *T. grandis* and *G. arborea* tree in a particular measurement time span (cycle), which included mean annual increment (MAI) and current annual increment (CAI). The increment is defined as an increase in the dimensional growth (height, diameter, base plane, volume) or an increase in the standing stock of a tree, in relation to the tree age or a particular period (Van Gardingen et al. 2003).

$$V = \frac{1}{4}\pi d^2 h f$$

128 in which: V = standing volume, d = diameter at breast height (DBH), h = branch-free height, f = form factor

According to Van Gardingen et al. (2003), to estimate the mean annual increment (MAI) and the current annual increment, the following mathematic formulas were used:

131 MAI =
$$\frac{V_t}{t}$$

132 in which: MAI = Mean annual increment, V_t = Total volume in ages $t_0 - t (m^3)$; t = Ages (years) 133

$$CAI = \frac{V_t - V_{t-1}}{T}$$

135 In which: CAI = Current annual increment, V_t = Total volume in ages $t_0 - t (m^3)$, V_{t-1} = Previous total volume (m^3) , T 136 = Second age $t_0 - t$, minus the first age (in year)

138 The estimation of tree biomass and carbon

According to the Indonesian National Standard [SNI] number 7724 (2011) Determination of Biomass/Mass and stored carbon and Irundu et al (2020) using the following formula:

 $141 \qquad \qquad M = BJ \times V_t \times BEF$

142 In which : $BJ = Specific Gravity, V_t = Total Volume, BEF = Biomass Exfaction Factor (1.3)$

143 $Cb = B \times \% C \text{ Organic}$

144 In which: Cb = Carbon content of biomass (kg), B = Total biomass (kg), % C Organic = Percentage value of carbon 145 content, amounting to 0.47 (Hairiah and Rahayu 2007).

The determination of the biomass potential is calculated by multiplying the biomass obtained per plot with the conversion unit to ton ha⁻¹. According to Adhitya et al. (2013) Calculation of the Biomass content per hectares for aboveground biomass with the following formula:

149 Biomass (kg ha⁻¹) = Biomass (kg m⁻²) x 10,000 m²

150 Biomass and stored carbon have a causal relationship with tree volume values.

151 Determination of the value of biomass and stored carbon can be determined through a volume value approach. 152 According to Ruslianto et al. (2019), determining the causal relationship to the tree dimensions using the general 153 regression formula as follows:

154 $\hat{Y} = a + bX$

155 In which: \hat{Y} = Estimated value of biomass, X = Volume (m³), a, b = regression constant

RESULTS AND DISCUSSION

Estimation of standing volume standing done by using measurement data inventory result tree parameters. From the results of this inventory, data obtained the measurement results of the Dbh parameter, tree height, and tree number data on each plot in the classroom age. The data is further processed to find out the average Dbh, high average, volume each tree, tree density per hectare, and the volume of trees per hectare. Based on the results of data processing, known Dbh and average tree height, so that the average tree volume standing can be known.

163 Growth of Tectona grandis

164 Growth of Tectona grandis Plot I

165 T. *grandis* which was cultivated in plot I at the beginning was planted using a spacing of 3m x 3m, so the initial 166 number of trees was 1,111 trees. However, at a later age, the teak stands experienced a reduction in the number of trees 167 due to natural mortality or due to thinning activities. Based on the teak growth table, the number of trees, diameter, height, 168 total volume and increment of teak can be seen as follows:

169 Table 1. The volume of *T. grandis* in plot I

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	910	3.1	2	0.8	1.10	0.55		0.69	0.96	0.45
4	880	5.9	3.5	0.8	6.73	1.68	2.82	2.40	5.86	2.76
7	750	8.8	5.3	0.8	9.33	2.76	4.20	4.56	16.84	7.91
9	700	10.9	6.3	0.8	2.90	3.66	6.79	6.53	28.66	13.47
10	610	12.4	6.9	0.8	40.88	4.09	7.97	7.36	35.60	16.73
15	600	20.0	7.5	0.7	98.91	6.59	11.61	18.84	86.15	40.49
20	570	26.0	7.8	0.7	165.79	8.29	13.38	30.25	144.40	67.87
25	560	31.0	7.8	0.7	230.66	9.23	12.97	42.25	200.91	94.43
30	550	37.5	7.9	0.6	287.79	9.59	11.43	60.71	250.66	117.81
32	500	40.4	8.0	0.6	307.50	9.61	9.86	64.06	267.83	125.88
34	460	42.0	8.5	0.6	324.86	9.55	8.68	63.70	282.95	132.99
35	400	45.0	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

170Notes: N = Population of *T.grandis* (tree ha⁻¹), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total171Volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area172(m²ha)

Based on the table above, it can be explained that at the plot I in 1 hectare at the age of 2 years there are 910 teak trees with a diameter at 2 years to 35 years of 3.1 to 45 cm. While the height is 2 to 8.7 meters. The total volume from 2 years to 35 years is 1.10 to 331.91 m³ha⁻¹. Meanwhile, the growth increment ranged from 0.55 to 9.61 m³ha⁻¹year⁻¹. The maximum total volume of teak reached at the age of 32 years is 307.50 m³ ha⁻¹ and an increment of 9.61 and 9.86 m³ha⁻¹year⁻¹ with the number of trees per hectare as many as 500 trees.

The graphical relationship between MAI and CAI teak in plot I can be seen in the image below



194

Figure 2. The corellation of MAI and CAI T. grandis in Plot I

According to Dinga (2014), Muliadi et al. (2017), Winarni et al. (2017) and Kristiningrum et al. (2019), the graphs in Figures 2, 3, 4 and 5 exhibits certain characteristics, as follow: CAI curve rapidly reached the peak and from there declined immediately, whereas the MAI curve climbed and declined slowly. Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 32 years. This means that the maximum increment of teak is reached at the age of 32 years. After experiencing a maximum increment at the age of 32 190 years, the teak after the age of 32 years will experience a decline. This is supported by a simple linear regression test with 191 a polynomial type on MAI which has an R^2 value of 99%. This value means that there is a close relationship between age 192 and the MAI increment of 99% and 1% influenced by other factors. Meanwhile, CAI has an R² value of 97%. This value 193 means that there is a close relationship between age and the CAI increment of 97% and 3% is influenced by other factors.

195 Growth of Tectona grandis Plot II

196 T. grandis which was cultivated in plot II at the beginning was planted using a spacing of 3m x 3m, so the initial 197 number of trees was 1,111 trees. However, at a later age, the teak stands experienced a reduction in the number of trees 198 due to natural mortality or due to thinning activities. Based on the teak growth table, the number of trees, diameter, height, 199 total volume and increment of teak can be seen as follows:

Table 2. The volume of *T. grandis* in plot II 200

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	800	3.0	2.0	0.80	0.90	0.45		0.57	0.79	0.37
4	700	6.0	3.7	0.77	5.64	1.41	2.37	1.98	4.91	2.31
7	650	9.0	4.7	0.75	14.57	2.08	2.98	4.13	12.69	5.96
8	630	10.0	5.3	0.74	19.40	2.42	4.83	4.95	16.89	7.94
9	604	12.0	5.8	0.73	28.91	3.21	9.51	6.83	25.18	11.83
10	580	14.0	6.1	0.72	38.87	3.89	9.96	8.92	33.86	15.91
15	560	21.5	7.7	0.72	112.66	7.51	14.76	20.32	98.12	46.12
20	550	26.5	8.5	0.70	180.40	9.02	13.55	30.32	157.13	73.85
25	500	31.6	9.0	0.65	229.28	9.17	9.78	39.19	199.70	93.86
30	400	38.0	9.3	0.60	253.82	8.46	4.91	45.34	221.08	103.91

201 202

Notes: N = Population of *T.grandis* (tree ha⁻¹), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume203 (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area (m²ha)

204

Based on the table above, it can be explained that at plot II in 1 hectare at the age of 2 years there are 800 teak trees with a diameter at 2 years to 30 years of 3.0 to 38 cm. While the height is 2 to 9.3 meters. The total volume from 2 years to 30 years is 0.90 to 229.28 m³ ha⁻¹. Meanwhile, the growth increment ranged from 0.45 to 9.17 m³ ha⁻¹ year⁻¹. The maximum total volume of teak reached at the age of 25 years is 229.28 m³ ha⁻¹ and an increment of 9.17 and 9.78 m³ ha⁻¹ year⁻¹ with the number of trees per hectare as many as 500 trees.

210 The graphical relationship between MAI and CAI teak in plot II can be seen in the image below

211



Figure 3. The corellation of MAI and CAI T. grandis in Plot II

Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 32 years. This means that the maximum increment of teak is reached at the age of 25 years. After experiencing a maximum increment at the age of 25 years, the teak after the age of 25 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has a R^2 value of 95%. This value means that there is a close relationship between age and MAI increment of 95% and 5% influenced by other factors. Meanwhile, CAI has an R^2 value of 88%. This value means that there is a close relationship between age and the CAI increment of 86% and 14% is influenced by other factors. Genetic factors are more dominant in influencing the shape of teak stems (Fofana et al. 2009; Verhaegen et al. 2010) compared to tree diameter and height. This causes teak growth at a young age to be more developed. Meanwhile, according to Murtinah et al. (2015), stated that the growth of teak stands in East Kalimantan generally shows a decline in growth along with the increasing age of the stands;

The highest growth in diameter and height of stands occurred in the early stages of growth, namely in the range of 1-5 years of age, then there was a gradual decline in growth and was seen to decrease after 12 years of age stands; Until the stand was 12 years old, generally teak growth in East Kalimantan showed a higher growth (increment) in diameter and height compared to several teak plant locations in Java. Meanwhile, according to Alam et al. (2017) and Setiawan et al. (2011) who conducted research in Samboja District, East Kalimantan Province, stated that the potential (total volume and increment) respectively, for maximum teak at the age of 25, namely for super teak of 154.32 m³ and 6.17 m³ha⁻¹year⁻¹ and Solomon teak 150.94 m³ and 6.04 m³ ha⁻¹ year⁻¹.

Information in KPH Nganjuk states that the diameter increment of teak from root graft reaches 25-28 cm at the age of 20 years, while the diameter increment of the original plant is only 1-2 cm year⁻¹. According to Susila (2009), the teak increment at the age of 10 in Takari, Kupang Regency is a diameter of 1.4 cm year⁻¹ and a tree height of 1.5 m year⁻¹, while in Polen Timor Tengah Selatan at 8 years old it is lower, namely 1.0 cmyear⁻¹ and 0.8 m year⁻¹. In optimal site conditions, teak volume increment can reach 7.9 - 10 m³ha⁻¹year⁻¹ (Susila 2012). According to Yunianti et al. (2011) stated that in terms of silviculture, plants with long rotation accelerated growth were pursued to meet market demand. The wide spacing produces trees with large appearance in terms of quantity is very profitable, while in terms of wood quality, the accelerated plant species reduce some wood properties, especially strength. The effort taken should be to choose a place to grow that is very suitable for the plant so that even though its growth is accelerated, the quality of the wood remains stable.

242 Growth of Gmelina arborea

243 Growth of G. arborea Plot I

G. arborea which was cultivated in plot I at the beginning was planted using a spacing of 3.5m x 4m, so the initial number of trees was 714 trees. However, at a later age, the *G. arborea* stands experienced a reduction in the number of trees due to natural mortality or due to thinning activities. Based on the *G. arborea* growth table, the number of trees, diameter, height, total volume and increment of *G. arborea* can be seen as follows:

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	660	6	4	0.90	6.71	3.36		1.87	3.67	1.72
4	570	13	5	0.87	32.89	8.22	13.09	7.56	17.96	8.44
6	550	17	5.5	0.88	60.39	10.07	13.75	12.48	32.97	15.50
8	530	21	6	0.82	90.27	11.28	14.94	18.35	49.29	23.17
10	500	23.6	7	0.79	120.89	12.09	15.31	21.86	66.01	31.02
12	470	24.6	9	0.75	150.71	12.56	14.91	22.33	82.29	38.68
15	430	28	10	0.72	190.54	12.70	13.28	26.46	104.03	48.90
20	360	32	12	0.71	248.29	12.41	11.55	28.94	135.57	63.72
25	350	34	14	0.64	284.58	11.38	7.26	31.76	155.38	73.03

248 Table 3. The volume of *G.arborea* in plot I

249 250 251

Notes: N = Population of *G. arborea* (tree ha⁻¹), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area (m²ha) Based on the table above, it can be explained that *G. arborea* at plot I in I hectare at the age of II years there are 660

Based on the table above, it can be explained that *G. arborea* at plot I in I hectare at the age of II years there are 660 teak trees with a diameter at 2 years to 25 years of 6 to 34 cm. While the height is 4 to 14 meters. The total volume from 2 years to 25 years is 6.71 to 284.58 m³ha⁻¹. Meanwhile, the growth increment ranged from 3.36 to 12.70 m³ ha⁻¹ year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years is 190.54 m³ ha⁻¹ and an increment of 12.70 and 13.28 m³ha⁻¹year⁻¹ with the number of trees per hectare as many as 430 trees. The graphical relationship between MAI and CAI *G. arborea* in plot I can be seen in the image below.





Figure 4. The corellation of MAI and CAI G. arborea in Plot I

Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 15 years. This means that the maximum increment of *G. arborea* is reached at the age of 15 years. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has an R² value of 90%. This value means that there is a close relationship between age and the MAI increment of 91% and 9% influenced by other factors. Meanwhile, CAI has an R² value of 98%. This value means that there is a close relationship between age and the CAI increment of 98% and 2% is influenced by other factors.

272 Growth of G. arborea Plot II

Based on the *G. arborea* growth table, the number of trees, diameter, height, total volume and increment of *G. arborea* in Plot II can be seen as follows:

275 Table 4. The volume of *G.arborea* in plot II

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	660	5	3	0.90	3.50	1.75		1.30	1.91	0.90
4	600	13.8	5.3	0.87	41.36	10.34	18.93	8.97	22.58	10.61
6	570	18.5	6.2	0.86	81.65	13.61	20.15	15.31	44.58	20.95
8	540	21.3	8	0.80	123.08	15.39	20.72	19.23	67.20	31.59
10	510	23.5	9.5	0.78	163.83	16.38	20.37	22.11	89.45	42.04
12	470	27	10	0.75	201.72	16.81	18.95	26.90	110.14	51.77
15	450	30	11	0.72	251.80	16.79	16.69	31.79	137.48	64.62
20	380	34	13	0.70	313.80	15.69	12.40	34.48	171.33	80.53
25	370	35.5	15	0.64	351.40	14.06	7.52	36.60	191.86	90.18



279

285 286

271

Notes: N = Population of *G. arborea* (tree ha⁻¹), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area (m²ha)

Based on the table above, it can be explained that *G. arborea* at plot II in 1 hectare at the age of 2 years there are 660 *G. arborea* trees with a diameter at 2 years to 25 years of 5 to 35.5 cm. While the height is 3 to 15 meters. The total volume from 2 years to 25 years is 3.50 to 351.40 m³ha⁻¹. Meanwhile, the growth increment ranged from 1.75 to 16.69 m³ha⁻¹year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years is 251.80 m³ ha⁻¹ and an increment of 16.79 and 16.69 m³ha⁻¹year⁻¹ with the number of trees per hectare as many as 450 trees.

The graphical relationship between MAI and CAI G. arborea in plot II can be seen in the image below



Figure 5. The corellation of MAI and CAI G. arborea in Plot II

289

Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 15 years. This means that the maximum increment of *G. arborea* is reached at the age of 15 years. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has a R² value of 86%. This value means that there is a close relationship between age and MAI increment of 86% and 14% influenced by other factors. Meanwhile, CAI has an R^2 value of 98%. This value means that there is a close relationship between age and the CAI of 98% and 2% is influenced by other factors.

At the age of 10, according to Sandalayuk et al., (2018), the increase in diameter reaches 2.4 cm year⁻¹ and resembles an increase in diameter of Jabon of 2.1 cm year⁻¹. Meanwhile, according to the data above, the increase in gmelina diameter at the age of 10 was 2.36 cm year⁻¹. The maximum total volume of *G. arborea* achieved at the age of 15 years of biological rotation is 190.54 m³ ha⁻¹ and increments of 12.70 and 13.28 m³ ha⁻¹ year⁻¹ and the number of trees is 430. Meanwhile, according to Siarudin and Indrayana (2015) that if *Gmelina arborea* is harvested at the age of 14 years, it has a total volume of 122 m³ ha⁻¹ and a diameter of 15 cm, whereas if harvested at the age of 20 years, the diameter is 20 cm and the total volume is 146 m³ ha⁻¹.



Figure 6. A. *Tectona grandis* stands at the age of 15 years with spacing of 3 m x 3 m at Plot I and B.*Tectona grandis* stands at the age of 15 years with spacing of 3 m x 3 m at Plot II



Figure 7. A. *Gmelina arborea* stands at the age of 15 years with spacing of 3.5 m x 4 m at Plot I and B. *Gmelina arborea* stands at the age of 15 years with spacing of 3.5 m x 4 m at Plot II

333 Carbon and biomass production

334 The increase in CO_2 gas emissions in the air causes an increase in global temperatures on earth. Function forests as 335 carbon sinks in the very atmosphere needed to maintain the earth's temperature apart from forests as biodiversity 336 conservation. Information regarding the amount of carbon absorbed in the plant biomass (carbon stock) in an area becomes 337 very important to know (Trimanto 2014). According to Sardjono et al. (2017), biomass is closely related to the process of 338 photosynthesis. Biomass increases because the plant absorbs CO₂ from the air and transforms it to organic compounds 339 through the process of photosynthesis. The result of photosynthesis is used by plants to grow horizontally and vertically 340 (Adinugroho and Sidiyasa 2009). The intensity of water logging and drought are predicated to increase in dry and rainy 341 season due to climate change (Tong et al. 2016) and potential effects on initial growth and successful forest and land 342 rehabilitation activities.

343 Therefore, the analysis of simple linear regression was needed. To measure the precision of the regression line which 344 was used to identify the variability of data explained by the regression model, the coefficient of determination was 345 required, which was symbolized as R^2 . The maximum value of R^2 as 100%, and the minimum value was 0%, with the 346 following criteria: if the value of R^2 was high, then there was a strong correlation between X and Y or if $R^2 = 0$, then there 347 was no any correlation between X and Y. If the value of R^2 was low, then the correlation between X and Y was weak 348 (Handayani 2010). In addition, if the value of the coefficient of determination (R^2) showed a precise and strong correlation 349 between the independent and dependent variables, then, according to this criterion, it could give greater confidence on the 350 acceptance of the model. The high value of R^2 means that there was a strong correlation between the variables (Grafen and 351 Hails 2002; Arezoo et al. 2014).

352 Mansur and Tuheteru (2011) explain that age was very influential in the production of carbon. If the trees were 353 getting older, their ability to absorb carbon was also high. Measurement of deep forest biomass this research was 354 conducted on the whole tree consists of aboveground biomass (aboveground biomass) includes stems, branches, and leaves. 355 Based on this statement, a relationship between age and carbon is made as shown below. The stand age, in relation to its influence on carbon sequestration, had a very strong and high correlation (R²), the average regression coefficient is 97%. 356 357 Where the regression coefficient of the relationship between age and carbon in teak plot I is 98%, teak plot II is 96%, 358 gmelina plot I is 99% and gmelina plot II is 97%. According to Sugiyono (2012), the coefficient value determination in 359 the range of 80% - 100% means that there is a very strong relationship the dependent variable and the independent variable. 360 This indicated that there was a strong correlation between age and carbon because the value of its coefficient of 361 determination was higher than 90% and the graph of each correlation formed a linear shape. This is in line with research 362 conducted by Sardjono et al (2017) that there is a close relationship between age and carbon in A.cadamba. 363

364

332



Figure 8. The correlation between the stand age and production carbon of T. grandis and G. arborea

Meanwhile, the relationship between carbon and basal area in each type of stand can be seen in the figure below







379

Figure 9. The correlation between the production carbon and basal area of T. grandis and G. arborea

380 Based on the picture above it can be explained that production of carbon in relation to its influence on basal area, had a 381 very strong and high correlation (R²), the average regression coefficient is 97%. Where the regression coefficient of the 382 relationship between carbon and basal area in teak plot I and II are 99%, gmelina plot I is 92% and gmelina plot II is 99%. 383 This indicated that there was a strong correlation between carbon and basal area because the value of its coefficient of 384 determination was higher than 90% and the graph of each correlation formed a linear shape. This means that the 385 regression coefficient of both the relationship between age and carbon and carbon with the basal area has a regression 386 coefficient value above 97%. And the graph of each correlation formed a linear shape. This value means that there is a 387 close relationship between age and carbon of 97% and 3% is influenced by other factors. So is the same relationship 388 between carbon and basal area of about 97% and 3% is influenced by other factors. And the graph of each correlation 389 formed a linear shape.

Meanwhile, the relationship between each stand at its maximum age is related to the total volume, basal area, biomass and carbon can be seen in the table below.

392	Table 5.	The vo	olume, ba	isal area,	biomass and	l carbo	on each stand	
								_

N-	T	Age	TV	BA	Biomass	Carbon
INO	Type	(yr)	$(m^{3}ha^{-1})$	(m^2ha^{-1})	(ton ha ⁻¹)	(ton ha ⁻¹)
1	T. grandis Plot I	32	307.50	64.06	267.83	125.88
2	T. grandis Plot II	25	254.81	43.56	221.94	104.31
3	G.arborea Plot I	15	190.54	26.46	104.03	48.90
4	G.arborea Plot II	15	251.80	31.79	137.48	64.62

393

3 Notes: $TV = Total volume (m^3 ha^{-1})$, BA= Basal area $(m^2 ha^{-1})$

394 Based on the table above, it can be explained that the teak plot I at the age of 32 years has the largest total volume, 395 basal area, biomass and carbon among other stands of 307.5 m³ ha⁻¹; 64.06 m² ha⁻¹; 257.83 ton ha⁻¹ and 125.88 ton ha⁻¹. 396 then followed by teak plot II, gmelina plot II and finally gmelina plot I. This is due to the different fertility rates in each type of stand. The teak plot 2 at the age of 25 years has total volume 254.81 m³ ha⁻¹, basal area 43.56 m² ha⁻¹; biomass 397 221.94 ton ha⁻¹ and carbon 104.31 ton ha⁻¹. G. arborea plot II at the age of 15 years has total volume 251.80 m³ ha⁻¹, basal 398 area 31.79 m² ha⁻¹; biomass 137.48 ton ha⁻¹ and carbon 64.62 ton ha⁻¹, while G. arborea plot 1 at the age of 15 years has 399 total volume 190.54 m³ ha⁻¹, basal area 26.46 m² ha⁻¹; biomass 104.03 ton ha⁻¹ and carbon 48.90 ton ha⁻¹. Whereas 400 401 according to Trimanto (2014) states that production of Gmelina arborea tends to store carbon in large quantities smaller 402 19.96 ton C ha⁻¹ or 2.49 ton C ha⁻¹yr⁻¹ compared to production of Tectona grandis which can store as much carbon 114.88 403 ton C ha⁻¹ or 9.57 ton C ha⁻¹ yr⁻¹.

The graphical relationship between total volume, basal area, biomass and carbon each stand can be seen in the image below

406



407 408 409

410

Figure 8. The correlation between total volume, basal area, biomass and carbon each stand

411 Research result shows that T. grandis stands have the highest total stored carbon when compared to G. arborea. Fast 412 growth and the ability of T. grandis trees to absorb carbon dioxide (CO_2) makes this plant the most stored carbon among 413 tree species other. According to Lubis et al. (2013), the increase in biomass and carbon stored by trees goes hand in hand 414 the increase in the dimensions of the stem includes the diameter and height. This indicates that at diameter and height have 415 a linear relationship. This can be seen from the total volume of each stand. Where T. grandis plot I has the largest total volume among the three types of stands. Forest plantations play a critical role in mitigating the various effects of 416 environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its consequences on 417 418 climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this study revealed that 419 Tectona grandis and Gmelina arborea has a great potential in promoting carbon sequestration especially when they are 420 allowed to grow older. Favorable growth conditions have high potential of increasing the biomass accumulation of this species. Hence, it is recommended that sustainable management of this plantation should be paramount in securing a 421 422 cleaner environment and mitigating the effect of climate change in Indonesia.

423

424

ACKNOWLEDGEMENTS

We would like to express our gratitude to Umbar Sujoko for his help in creating the map of the study site. The authors would like to acknowledge the anonymous reviewers for providing constructive comments to improve the manuscript.

.

428

REFERENCES

429 Adinugroho WC, Sidiyasa K.. 2009. Biomass estimation model of above ground Mahogany (*Swietenia macrophylla* King) Tree. 430 http://wahyukdephut.wordpress.com. [Indonesian].

503

504

- Adhitya PW, Hardiansyah G, Yani A. 2013. Estimation of surface carbon content on a tree in the Ketapang Regency City Forest Area. J of Sustain Forests, 2 (1), 23-32.
- Alam, A.S., Rafiuddin, Setiawan, B. 2017. Financial analysis systems teak and elephant grass agroforestry in Samboja District Kutai Kartanegara Regency, East Kalimantan. Proceedings National Biodiversity Conservation: 136-142.
- Arezoo S, Sankhayan PL, Hofstad O. 2014. A dynamic bio-economic model for community management of goat and oak forests in Zagros, Iran.J Ecol Econ 106: 174-185.
- Arias D, Alvarado J, Richter DJ, Dohrenbusch A. 2011. Productivity, aboveground biomass, nutrient uptake and carbon content in fast growing tree plantations of native and introduced species in the Southern Region of Costa Rica. Biomass Bioenerg 35: 1779-1788.
- Birdsey R, Pan Y. 2015. Trends in management of the world's forests and impacts on carbon stocks. For Ecol Manag 355: 83-90.
- Brown, S. 1997. Estimating biomass and biomass change of tropical forests : A primer, FAO Forestry Paper 134, Rome : Food Agriculture Organisation of the United Nations.
- Chauhan SK, Sharma R, Panwar P, Chander J. 2016a. Short rotation forestry : a path for economic and environmental prosperity. In: Parthiban KT, Seenivasan R (eds.). Forestry Technologies A Complete Value Chain Approach. Vol.1 Scientific Publishers, Jodhpur.
- Chauhan SK, Ritu, Chauhan R. 2016b. Carbon sequestration in plantations. Agroforestry for increased production and livelihood security (Eds. Gupta, S.K., Panwar, P. and Kaushal, R.). New Indian Publishing Agency, New Delhi.
- Derwisch S, Schwendenmann L, Olschewski R, Holscher D. 2009. Estimation and economic evaluation of aboveground carbon storage of Tectona grandis plantationsin Western Panama Sebastian. New Forest 37:227–240.
- Dinga E. 2014. On a possible predictor of the cyclical position of the economy. Procedia Econ Finance8:254-261.
- Domec JC, Ward EJ, Oishi AC, Palmroth S, Radecki A, Bell DM, Miao G, Gavazzi M, Johnson DM, King JS, McNulty, SG, Oren R, Sun G, Noormets A. 2015. Conversion of natural forests to managed forest plantations decreases tree resistance to prolonged droughts. For Ecol Manag 355: 58-71. Fofana IJ, Ofori D, Poitel M, Verhaegen D. 2009. New Forests 37:175-195.
- Grafen A, Hails R. 2002. Modern statistics for the life sciences. Oxford University Press, Oxford.
- Gonzalez-Benecke CA, Samuelson LJ, Martin TA, Cropper Jr WP, Johnsen KH, Stokes TA, Butnor JR, Anderson PH. 2015. Modeling the effects of forest management on in situ and ex situ longleaf pine forest carbon stocks. For Ecol Manag 355: 24-36.
- Handayani. 2010. Regression models. STIE Atma Bhakti, Surakarta. [Indonesian].
- Hairiah K, Rahayu S. 2007. Measurement of carbon stored in different land use. World Agroforestry Center. Bogor.
- Houghton, R.A. 2005. Tropical deforestation as a source of greenhouse gas emissions. In: Tropical Deforestation and Climate Change 2005. Amazon Institute for Environmental Research.
- Irundu D, Beddu MA, Najmawati. 2020. Potential of biomass and carbon stored stands in green open space Polewali City, West Sulawesi. J of Forests and Communities 12 (1): 49-57.
- Kanninen M. 2010. Plantation forests: Global perspectives. In: Bauhus J, Meer PJ v.d., Kanninen M (eds.). Ecosystem Goods and Services from Plantation Forests. Earthscan, London.
- Karyati, Widiati KY, Karmini, Mulyadi R. 2019. Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land. Biodiversitas 20 (12): 3508-3516.[Indonesian]
- Kraenzel M, Castillo A, Moore T, Potvin C. 2003. Carbon storage of harvest age teak (Tectona grandis) plantations, Panama. For Ecol Manage 173:213-225.
- Kristiningrum R, Lahjie A, Masjaya, Yusuf S, Ruslim Y. 2019. Species diversity, stand productivity, aboveground biomass and economic value of mangrove ecosystem in Mentawir Village, East Kalimantan, Indonesia. Biodiversitas 20 (10): 2848-2857. [Indonesian]
- Losi CJ, Thomas GS, Richard C, Juan EM. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. Forest Ecology and Management.
- Lubis, S.H., H.S. Arifin, And I. Samsoedin. 2013. Analysis of tree carbon stocks in forest landscapes city in DKI Jakarta. J of Fores Sos and Econ Research, 10 (1), 1-20.
- Lukito M, Rohmatiah A. 2013. Estimated biomass and carbon of teak 5 year (Case of Nusantara Superior Teak Plantation Forest (JUN) Krowe Village, Lembeyan District, Magetan Regency). Agritek Journal 14(1): 1-23
- Law BE., Waring, RH. 2015. Carbon implications of current and future effects of drought, fire and management on Pacific Northwest forests. For Ecol Manag 355: 4-14.
- Mansur I, Tuheteru FD. 2011. Jabon Tree. Book. Penebar Swadaya. Jakarta..[Indonesian].
- Muliadi M, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2017. Bioeconomic and environmental valuation of dipterocarp estate forest based on local wisdom in Kutai Kartanegara, Indonesia. Biodiversitas18(1): 401-408. [Indonesian].
- Murdiyarso D. 2003. Kyoto Protocol: Its Implications to the developing countries. Book. Publisher: Kompas Gramedia
- Murtinah V, Ruchaemi A, Ruhiyat D. 2015. Forest growth teak plant (Tectona grandis Linn.f.) in East Kalimantan. J Agrifor 14 (2).
- Noormets A, Epron D, Domec JC, McNulty SG, Fox TD, Chen J, Sun G, King JS. 2015. Effects of forest management on productivity and carbon sequestration: a review and hypothesis. For Ecol Manag 355: 124-140.
- Panwar P, Chauhan S, Kaushal R, Das DK, Ajit, Arora G, Chaturvedi OP, Jain AK, Chaturvedi S, Tewari S. 2017. Carbon sequestration potential of poplar-based agroforestry using the CO₂ FIX model in the Indo Gangetic Region of India. Trop Ecol 58 (2): 1-9.
- Pinheiro TF, Escada MIS, Valeriano DN, Hostert P, Gollnow F, Müller H. 2016. Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 Region in Southwestern Pará, Brazil. Earth Interactions 20 (17): 1-26.
- Ruslianto M, Alviani, Maisuri, Irundu. 2019. Biomass allometric model of Rhizophora Apiculata at Polewali Mandar Regency, West Sulawesi Province. Eboni Buleti Journal 1 (1): 11-19.
- Ruslim Y, Sihombing R, Liah Y. 2016. Stand damage due to mono-cable winch and bulldozer yarding in a selectively logged tropical forest. Biodiversitas 17 (1): 222-228.
- Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2020. Carbon absorbtion of *Anthocephalus macrophyllus* and *Swietenia macrophylla*. King in Gorontalo, Indonesia. Jof Biodiversity and Enviro Scie16 (5): 24-30.
- Sandalayuk. D, Soedirman S, Pambudhi F. 2018. Reserves estimating carbon in forest city district village Bongohulawa Gorontalo. .ijrtem. 2(8), 60-63.
- Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2018. Analysis of gmelina and mahogany growth in Gorontalo. J of Forest Reseach. 1 (1): 1-8. Sardjono A, Lahjie AM, Simarangkir BDAS, Kristiningrum R, Ruslim Y. 2017. Carbon sequestration and growth of Anthocephalus cadamba plantation in North Kalimantan. Indonesia. Biodiversitas18(4): 1385-1393.[Indonesian].
- Sharma R, Chauhan SK, Tripathi AM. 2016. Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. Agrofor Syst 90 (4):631-644.
- Setiawan, B., Lahjie A.M., 2011. Financial analysis of agroforestry systems teak, sungkai, and elephant grass in Samboja Kutai District Kartanegara. . Humida Tropical Forestry Vol. 4 (1).
- Setiawan, B., Lahjie A.M, Yusuf, S, Ruslim. 2019. Model of community forest land management production and financial simulation of super teak, solomon teak and sungkai treesin Samboja Kutai Kartanegara East Kalimantan, Indonesia. Energy and Environment Research 9(20): 48-60.
- Siaruddin, M and Indrayana, Y. 2015. Dynamics of carbon stock systems gmelina agroforestry in community forests in Tasikmalaya and Banjar, West Java. Wasian 4 (1): 37-46.

- SNI. 2011. Indonesian National Standard Number 7724. Measurement and calculation of carbon stocks field measurement for forest carbon stock assessment. tandardization Agency. Jakarta. [Indonesian]
- Sugiyono. 2012. Qualitative and uantitative research methods and R&D. Alfabeta. Bandung. [Indonesian].
- Susila IWW. 2009. Teak increment and sandalwood plantation in Nusa East Southeast. J of Plant Forest Research 6 (3): 157-185. Center for Plantation Forest Research and Development. Bogor.
- Susila, IWW. 2012. Estimation model of teak stand volume and increment in Nusa Penida, Klungkung Bali. J of Plant Forest Research 9 (3): 165-178. Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A. 2016. Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. Geoderma 261: 70-79.
- Tong S, Berry HL, Ebi K, Bambrick H, Hu W, Green D, Hanna E, Wang Z, Butler CD. 2016. Climate change, food, water and population health in China. Bull World Health Organ 94:759-765.
- Trimanto. 2014. Vegetation analysis and tree biomass estimation of carbon stocks in Seven Montane Forests of Bawean Island Nature Reserve, East Java. Biology News 13(1): 321-332.
- Van Gardingen PR, McLeish MJ, Philips PD, Fadilah D, Tyrie G, Yasman I. 2003. Financial and ecological analysis of management options for loggedover dipterocarp forest in Indonesia Borneo. For Ecol Manag 183: 1-29.
- Verhaegen D, Fofana IJ, Logossa ZA, Ofori D. 2010. What is the genetic origin of teak (*Tectona grandis* L.) introduced in Africa and in Indonesia. Tree Genetics & Genomes 6:717-733.
- Winarni B, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Tengkawang cultivation model in community forest using agroforestry system in West Kalimantan, Indonesia. Biodiversitas 18(2):765-772. [Indonesian].
- Watson RT, Noble I, Bolin B, Ravindranath NH. 2000. Land use, land -use change and forestry. A spesial report of the international panel of the climate change. Cambridge University Press.
- Yunianti AD, Wahyudi, Siregar, Pari. 2011. Quality of teak clones with different planting distances. J of Wood Sci and Tech Tropical 9 (1): 93-100.

564		SUBMISSION CHECKLIST
565		
566		
567	Ensure that the following items are present:	

The first corresponding author must be accompanied with contact details: Give mark (X) • E-mail address X • Full postal address (incl street name and number (location), city, postal code, state/province, country) X • Phone and facsimile numbers (incl country phone code) X

All necessary files have been uploaded, and contain:

Keywords	Х
Running titles	
All figure captions	Х
All tables (incl title and note/description)	Х

Further considerations

• Manuscript has been "spell & grammar-checked" Better, if it is revised by a professional science editor or a native English speaker	
References are in the correct format for this journal	Х
• All references mentioned in the Reference list are cited in the text, and vice versa	Х
• Colored figures are only used if the information in the text may be losing without those images	Х
• Charts (graphs and diagrams) are drawn in black and white images; use shading to differentiate	Х

Nor Liza (nliza)

YOSEP RUSLIM (yruslim)

Messages	
Note	From
Dear author, Thank you very much for your manuscript submission. Unfortunately, your manuscript does not meet our requirements :	nliza 2021-01-19 05:20 AM
- Please add some international recent journals for your references. At least, you need to cite 80% references come from international scientific journals published in the last 10 years and maximum 10% for Indonesian journals	
- Please follow the guidance for references writing	
- This paper needs to be improved since more than 5% indicate plagiarism. It should less than 5%.	
Kindly check and correct accordingly	
🗅 nliza, GUIDANCE FOR AUTHORS.pdf	
Dear Editor,	yruslim

We are still adding some international journals for our references and improve the journal again. We need still time to submit the revision of our journal again. Thank you for your attention.

yruslim 2021-01-21 03:35 AM

Yosep Ruslim

Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea

by Y. Ruslim

Submission date: 24-Jan-2021 03:39PM (UTC+0700) Submission ID: 1493130515 File name: arborea_in_Gorontalo_Province,_Indonesia_check_similiarity.doc (7.52M) Word count: 9121 Character count: 44883

Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia

4 Abstract. Plantation forest exploitation has an important role in meeting timber needs and also as carbon sequestration for the 5 environment. The purpose of this study was to calculate the stand potential, to calculate the standing biomass and carbon stock of teak 6 and gmelina in the Gorontalo area. The research object was 4 plots each with an area of 1 hectare. The sampling method used was a 7 systematic random sampling by measuring the diameter and height of a stand, while the data analysis used the potential stand and 8 increment formula of MAI and CAI. Meanwhile, the estimation of biomass and carbon by calculating the aboveground carbon stock 9 (AGB) is then analyzed using simple linear regression to determine the closeness relationship between variables. The results showed 10 that the maximum growth of teak plots I and II reached a maximum point at the age of 32 and 25 years and the total volume was 307.50 and 254.81 m³ha⁻¹. While the maximum growth of gmelina plots I and II reaches a maximum point at the age of 15 years and the total 11 12 volume is 190.54 and 251.80 m3ha1. The biomass content in teak plots I and II and gmelina plots I and II were respectively 267.83; 221.94; 104.03 and 137.48 tonsha⁻¹. Meanwhile, the carbon content in teak plots I and II and gmelina plots I and II were respectively 13 14 125.88; 104.31; 48.90; and 64.62 tons ha⁻¹. The results of simple regression analysis, the relationship between the two variables shows a very close relationship. This indicated that Tectona grandis more potentialy than Gmelina arborea plantations in carbon sequestration 15 16 and biomass production although both of thrm have an important role in mitigating and climate change.

17 Key words: Biomass, Carbon, Gmelina arborea, Growth, Tectona grandis

INTRODUCTION

19 Indonesia has renewable natural resources such as plantation forests. These forest resources have the potential as a 20 source of biomass by promoting the planting of fast growing plants. However, until now the existence of fast growing 21plantations requires sustainability (Siregar et al. 2017). Over time, forests do not only function as wood producers, but as environmental service producers, where forests have the opportunity to reduce carbon dioxide in the atmosphere through 22 23 photosynthesis (Lukito and Rohmatiah 2013). This is in line with research conducted by Birdsey and Pan (2015) that there 24 has been a change in forest function in the last few decades and explains its impact on global carbon stocks. Tropical forest 25 in Indonesia has a fast growing nature. Tesfaye et al. (2016) explained that tropical forests have an important role in global carbon sequestration. However, increasing rates of deforestation and impacts of land use change need to be considered 26 27 before preventing the loss of the function of tropical forests. One example is the process of forest degradation caused by 28 non-selective logging, forest fires, and neglected forest development dynamics occurring in large areas in tropical forests 29 (Pinheiro et al. 2016). Therefore, one of the ways that can be used to prevent and reduce illegal logging activities according to Ruslim et al. (2016) is to develop more effective ways to protect tropical forest diversity and pay more 30 attention to land use (Domec et al. 2015). Because this affects the depreciation of the day elements. Where the depreciation 31 of these nutrients depends on the characteristics of the species, growth rate, tissue nutrient content, harvest rotation period, 32 use marvest methods and nutrient reserves in the soil (Arias et al. 2011). 33

34 Biomas and carbon stocks (C) in forest ecosystems have an important role in climate change and mitigation 35 (Calfapietra et al, 2015; Zeng et al, 2018; Pandey et al, 2019). This biomass estimation is very important and aims to 36 calculate the amount and variation of C (Ekholm 2016; Gren and Zeleke 2016; Ruitta et al. 2018; Nonini and Fiala 2019). 37 Biomass is important in determining forest production and sustainable forest management (Rinnamang et al. 2020). 38 Furthermore, according to Gonzalez-Benecke et al. 2015; Sharma et al. 2016; Panwar et al. 2017, states that an increase in 30 rotation length will also result in an increase in biomass and carbon stocks. Where biomass production is influenced by 40 organic matter in the soil. Biomass functions as organic material to maintain soil fertility and soil biotic stability (Lee et al 41 2014). Balancing economic productivity with other ecosystem services such as carbon sequestration requires sustainable fertility of soil and water resources. This is done because of the assessment of all potential biomass carbon stocks, and 42 43 other potential in order to change management activities (Birdsey and Pan 2015; Law and Waring 2015; Noormets et al. 44 2015). The ability of fast-growing stand types to absorb carbon faster than slow-growing stands is one of the strong 45 reasons why it is necessary to plant and cultivate fast-growing stands in plantation forests (Chauhan et al. 2016a). In addition to producing biomass, most plantations produce wood and provide environmental services in the form of water 46 47 management and carbon sinks (Kanninen 2010; Chauhan et al. 2016b). One type of fast growing stands is teak and 48 gmelina. This is because besides being fast growing, Teak (Tectona grandis Linn.f.) is an important commercial stand type 49 and has a high selling value (Warner et al. 2017) and is a type of light wood with a round crown, large leaves, and the stem 50 can be transparent and resistant to fire (Meunpong 2012). Meanwhile, Gmelina arborea Roxb. is one type of plant that is 51 widely developed for industial plantations in tropical regions such as Indonesia, Pakistan, Sri Lanka, and some countries in Southeast Asia. Gmelina is a type of fast growing stand, can live well in the lowlands to an altitude of 1200 m above sea 52 53 level with an average rainfall of 750-5000 mm year-1 (Adinugraha and Setiadi 2018).

18

1

Research on forest potential is very important. This is in line with the statement from Nonini and Fiala (2019) that 54 55 estimating carbon storage in forests is very important to support climate change and mitigation and promote the transition 56 to a low-carbon emission economy. This research includes the potential for the stands, the potential for biomass and 57 carbon. One of the factors that determine the analysis of forest potential is the allometric method, which is measuring the 58 potential of biomass and carbon with standard standards. Based on this background, the following problems can be 59 formulated: how much is the amount of carbon content with the approach of calculating the amount of biomass. This is 60 because carbohydrates are obtained from photosynthesis stored in living plant organs. Karyati et al (2019) stated that the 61 allometric equation for estimating aboveground biomass on this land is still limited. So it is necessary to do this research to 62 analyze the allometric relationship between diameter at breast height, tree height, leaves, branches, stems, and total aboveground biomass (TAGB) in an abandoned land. This is in line with Edson and Wing 2011; Durkaya et al. 2013 63 64 where allometric equations and tree dimensions such as diameter and total height can be used to calculate forest stand 65 biomass. Allometric equations have a very important role in reducing the uncertainty of biomass estimation. This is expected to provide great benefits in implementing climate change mitigation programs, especially in the forestry sector 66 67 (Anitha et al. 2015). There are two methods commonly used to estimate the carbon content of forest stands, namely by: (1), indirect measurement by changing the biomass using a specific carbon content figure. This method is most widely 68 used by using a constant carbon content of 50% of the biomass weight (Brown 1997) and 47% of the biomass weight 69 70 (Kristiningrum et al. 19). Carbon stocks in arable land contain higher carbon storage and vegetation biomass (Hairiah et 71 al.2011). Therefore, this study aims to calculate the stand potential, stand biomass and carbon stocks of teak and gmelina 72 in the Gorontalo region. The aim of this research is to develop an allometric equation for estimating AGB with a 73 coefficient of determination that can predict biomass and carbon stock in the land after being abandoned. 74

MATERIALS AND METHODS

Study area 76

75

77 78

79

80 81

The experiment was conducted from September 2020 to December 2020 in Gorontalo Province. The field experiments were conducted in four plots of Tectona grandis were two plots and Gmelina arborea were two plots. The area was located on the coordinate 0° 32 '28 "North Latitude and 123° 03 '36 "East Longitude.



Figure 1. Location studies (in which: $\mathbf{A} = G$. Arborea plot II, $\mathbf{B} = T$.grandis plot I, $\mathbf{C} = G$. Arborea plot I, $\mathbf{D} = T$.grandis plot II)

109 110 111

Research object

The objects to be studied were 2 types of teak and gmelina stands, each with a plot area of 1 hectare each, so that the 112 113 number of research plots was 4 plots, with different spacing. Where the Tectona grandis plant spacing is 3m x 3m and the 114 *Gmelina arborea* spacing is 3.5m x 4m. Determination of the sample and the location of the study by purposive sampling, 115 with the sampling method using systematic random sampling. Then the data obtained is analyzed mathematically using 116 simple linear regression. To find the closeness of the relationship between age and increment, the polynomial method was 117 used to determine the regression coefficient.

119 Data analysis

120

118

121 Estimating MAI and CAI

Data collection includes diameter, plant species as high as 1.3 m from the soil surface (cm). Carbon (C) storage (kg per year) can be estimated by multiplying the tree biomass (Y: kg) with the general vegetation carbon content, namely (0.46) (Hairiah and Rahayu 2007). Carbon stock calculations were also carried out on cultivated plants *Tectona grandis* (teak) and *Gmelina arborea* (white teak) planted on land by the community.

Maximum production was calculated by analyzing the growth increment of *T. grandis* and *G. arborea* tree in a particular measurement time span (cycle), which included mean annual increment (MAI) and current annual increment (CAI). Van Gardingen et al. (2003) state that the increment is defined as an increase in the dimensional growth (height, diameter, base plane, volume) or an increase in the standing stock of a tree, in relation to the tree age or a particular period

130
$$V = \frac{1}{4}\pi d^2 h f$$

 $\begin{array}{c}
4 \\
131 \\
132 \\
132 \\
133 \\
134 \\
MAI = \frac{V_t}{t}
\end{array}$

135 in which: MAI = Mean annual increment, V_t = Total volume in ages $t_0 - t (m^3)$; t = Ages (years)

140

137 $CAI = \frac{V_t - V_{t-1}}{T}$

138 In which: CAI = Current annual increment, V_t = Total volume in ages $t_0 - t$ (m³), $V_{t,1}$ = Previous total volume (m³), T 139 = Second age $t_0 - t$, minus the first age (in year)

141 The estimation of tree biomass and carbon

The method proposed for estimating biomass and carbon stock is to estimate biomass based on a combination tree
 height, trunk diameter and wood density are used (Chave et al., 2014). According to the Indonesian National Standard [SNI]
 number 7724 (2011) Determination of Biomass/Mass and stored carbon and Irundu et al (2020) using the following
 formula:
 M = BJ × V₁ × BEF

147 In which : BJ = Specific Gravity, Vt = Total Volume, BEF = Biomass Exfaction Factor (1.3)

148 $Cb = B \times \% C$ C manic

149 In which: $Cb = \overline{Carbon}$ content of biomass (kg), B = Total biomass (kg), % C Organic = Percentage value of carbon 150 content, amounting to 0.47 (Hairiah et al. 2011).

The determination of the biomass potential is calculated by multiplying the biomass obtained per plot with the conversion unit to ton ha⁻¹. According to Adhitya et al. (2013) Calculation of the Biomass content per hectares for aboveground biomass with the following formula:

154 Biomass (kg ha⁻¹) = Biomass (kg m⁻²) x 10,000 m²

155 Biomass and stored carbon have a causal relationship with tree volume values.

156 Determination of the value of biomass and stored carbon can be determined through a volume value approach. 157 According to Ruslianto et al. (2019), determining the causal relationship to the tree dimensions using the general 158 regression formula as follows:

159 $\hat{Y} = a + bX$

160 In which: \hat{Y} = Estimated value of biomass, X = Volume (m³), a, b = regression constant

161

162

RESULTS AND DISCUSSION

Estimation of standing volume standing done by using measurement data inventory result tree parameters. From the results of this inventory, data obtained the measurement results of the Dbh parameter, tree height, and tree number data on each plot in the classroom age. The data is further processed to find out the average Dbh, high average, volume each tree, tree density per hectare, and the volume of trees per hectare. Based on the results of data processing, known Dbh and average tree height, so that the average tree volume standing can be known.

168 Growth of Tectona grandis

169 Growth of Tectona grandis Plot I

170 T. grandis which was cultivated in plot I at the beginning was planted using a spacing of 3m x 3m, so the initial 171 number of trees was 1,111 trees. However, at a later age, the teak stands experienced a reduction in the number of trees 172 due to natural mortality or due to thinning activities. Based on the teak growth table, the number of trees, diameter, height,

total volume and increment of teak can be seen as follows:Table 1. The volume of *T. grandis* in plot I

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	910	3.1	2	0.8	1.10	0.55		0.69	0.96	0.45
4	880	5.9	3.5	0.8	6.73	1.68	2.82	2.40	5.86	2.76
7	750	8.8	5.3	0.8	9.33	2.76	4.20	4.56	16.84	7.91
9	700	10.9	6.3	0.8	2.90	3.66	6.79	6.53	28.66	13.47
10	610	12.4	6.9	0.8	40.88	4.09	7.97	7.36	35.60	16.73
15	600	20.0	7.5	0.7	98.91	6.59	11.61	18.84	86.15	40.49
20	570	26.0	7.8	0.7	165.79	8.29	13.38	30.25	144.40	67.87
25	560	31.0	7.8	0.7	230.66	9.23	12.97	42.25	200.91	94.43
30	550	37.5	7.9	0.6	287.79	9.59	11.43	60.71	250.66	117.81
32	500	40.4	8.0	0.6	307.50	9.61	9.86	64.06	267.83	125.88
34	460	42.0	8.5	0.6	324.86	9.55	8.68	63.70	282.95	132.99
35	400	45.0	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

175NotesN = Population of T.grandis (tree ha⁻¹), d = Tree Diameter (cm, h = clear bole height (m), F = form factor, TV = Total176Volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area177(m²ha)

178

179 Based on the table above, it can be explained that at the plot I in 1 hectare at the age of 2 years there are 910 teak trees

180 with a diameter at 2 years to 35 years of 3.1 to 45 cm. While the height is 2 to 8.7 meters. The total volume from 2 years to

181 35 years is 1.10 to 331.91 m³ha⁻¹. Meanwhile, the growth increment ranged from 0.55 to 9.61 m³ha⁻¹year⁻¹. The maximum total volume of teak reached at the age of 32 years is 307.50 m³ ha⁻¹ and an increment of 9.61 and 9.86 m³ha⁻¹year⁻¹ with

183 the number of trees per hectare as many as 500 trees.

The graphical relationship between MAI and CAI teak in plot I can be seen in the image below



186 187

Figure 2. The corellation of MAI and CAI *T. grandis* in Plot I

190 The graphs according to Kristiningrum et al. (2019), Winarni et al. (2017), Muliadi et al. (2017), and Dinga (2014) in 191 Figures 2, 3, 4 and 5 exhibits certain characteristics, as follow: CAI curve rapidly reached the peak and from there declined immediately, whereas the MAI curve climbed and declined slowly. Based on the picture above, it can be explained that 192 193 the MAI and CAI increments of teak initially increased and met at one point, namely the age of 32 years. This means that 194 the maximum increment of teak is reached at the age of 32 years. After experiencing a maximum increment at the age of 195 32 years, the teak after the age of 32 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has an R² value of 99%. This value means that there is a close relationship between 196 age and the MAI increment of 99% and 1% influenced by other factors. Meanwhile, CAI has an R² value of 97%. This 197 198 value means that there is a close relationship between age and the CAI increment of 97% and 3% is influenced by other 199 factors.

200 201 Gro

Growth of Tectona grandis Plot II

202 *T.grandis* which was cultivated in plot II at the beginning was planted using a spacing of 3m x 3m, so the initial 203 number of trees was 1,111 trees. However, at a later age, the teak stands experienced a reduction in the number of trees 204 due to natural mortality or due to thinning activities. Based on the teak growth table, the number of trees, diameter, height, 205 total volume and increment of teak can be seen as follows:

206 Table 2. The volume of *T. grandis* in plot II

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	800	3.0	2.0	0.80	0.90	0.45		0.57	0.79	0.37
4	700	6.0	3.7	0.77	5.64	1.41	2.37	1.98	4.91	2.31
7	650	9.0	4.7	0.75	14.57	2.08	2.98	4.13	12.69	5.96
8	630	10.0	5.3	0.74	19.40	2.42	4.83	4.95	16.89	7.94
9	604	12.0	5.8	0.73	28.91	3.21	9.51	6.83	25.18	11.83
10	580	14.0	6.1	0.72	38.87	3.89	9.96	8.92	33.86	15.91
15	560	21.5	7.7	0.72	112.66	7.51	14.76	20.32	98.12	46.12
20	550	26.5	8.5	0.70	180.40	9.02	13.55	30.32	157.13	73.85
25	500	31.6	9.0	0.65	229.28	9.17	9.78	39.19	199.70	93.86
20	400	28.0	0.2	0.00	052.00	8.46	4.01	45.34	221.08	103.91

²⁰⁷ 208 209

217

Based on the table above, it can be explained that at plot II in 1 hectare at the age of 2 years there are 800 teak trees with a diameter at 2 years to 30 years of 3.0 to 38 cm. While the height is 2 to 9.3 meters. The total volume from 2 years to 30 years is 0.90 to 229.28 m³ ha⁻¹. Meanwhile, the growth increment ranged from 0.45 to 9.17 m³ ha⁻¹ year⁻¹. The maximum total volume of teak reached at the age of 25 years is 229.28 m³ ha⁻¹ and an increment of 9.17 and 9.78 m³ ha⁻¹ 'year⁻¹ with the number of trees per hectare as many as 500 trees.

216 The graphical relationship between MAI and CAI teak in plot II can be seen in the image below



218 219

221

220 Figure 3. The corellation of MAI and CAI T. grandis in Plot II

Based on the picture above, it can be explained that the MAI and CAI increments initiality increased and met at one 222 223 point, namely the age of 32 years. This means that the maximum increment of teak is reached at the age of 25 years. After experiencing a maximum increment at the age of 25 years, the teak after the age of 25 years will experience a decline. This 224 225 is supported by a simple linear regression test with a polynomial type on MAI which has an R² value of 95%. This value 226 means that there is a close relationship between age and MAI increment of 95% and 5% influenced by other factors. Meanwhile, CAI has an R² value of 88%. This value means that there is a close relationship between age and the CAI 227 228 increment of 86% and 14% is influenced by other factors. This causes teak growth at a young age to be more developed. 229 Meanwhile, according to Murtinah et al. (2015), stated that the growth of teak stands in East Kalimantan generally shows a 230 decline in growth along with the increasing age of the stands. The growth of a tree stand both in height and diameter is 231 influenced by climate and soil fertility. In addition, it is also influenced by the space and surface of the canopy, relative 232 humidity and the root system (Juwari et al. 2020a).

The highest growth in diameter and height of stands occurred in the early stages of growth, namely in the range of 1-5 years of age, then there was a gradual decline in growth and was seen to decrease after 12 years of age stands; Until the stand was 12 years old, generally teak growth in East Kalimantan showed a higher growth (increment) in diameter and height compared to several teak plant locations in Java. Meanwhile, according to Alam et al. (2017) and Setiawan et al. (2011) who conducted research in Samboja District, East Kalimantan Province, stated that the potential (total volume and increment) respectively, for maximum teak at the age of 25, namely for super teak of 154.32 m³ and 6.17 m³ha⁻¹year⁻¹ and Solomon teak 150.94 m³ and 6.04 m³ha⁻¹year⁻¹.

Information in KPH Nganjuk states that the diameter increment of teak from root graft reaches 25-28 cm at the age of 20 years, while the diameter increment of the original plant is only 1-2 cm year¹. In optimal site conditions, teak volume increment can reach 7.9 - 10 m³ha⁻¹year⁻¹ (Susila 2012). According to Yunianti et al. (2011) stated that in terms of silviculture, plants with long rotation accelerated growth were pursued to meet market demand. The wide spacing produces trees with large appearance in terms of quantity is very profitable, while in terms of wood quality, the accelerated plant species reduce some wood properties, especially strength. The effort taken should be to choose a place to grow that is very suitable for the plant so that even though its growth is accelerated, the quality of the wood remains stable.

Growth of Gmelina arborea 247

248 Growth of G. arborea Plot I

249 G. arborea which was cultivated in plot I at the beginning was planted using a spacing of 3.5m x 4m, so the initial 250 number of trees was 714 trees. However, at a later age, the G. arborea stands experienced a reduction in the number of

251 trees due to natural mortality or due to thinning activities. Based on the G. arborea growth table, the number of trees,

252 diameter, height, total volume and increment of G. arborea can be seen as follows: Table 3. The volume of Garborea in plot I 253

Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	660	6	4	0.90	6.71	3.36		1.87	3.67	1.72
4	570	13	5	0.87	32.89	8.22	13.09	7.56	17.96	8.44
6	550	17	5.5	0.88	60.39	10.07	13.75	12.48	32.97	15.50
8	530	21	6	0.82	90.27	11.28	14.94	18.35	49.29	23.17
10	500	23.6	7	0.79	120.89	12.09	15.31	21.86	66.01	31.02
12	470	24.6	9	0.75	150.71	12.56	14.91	22.33	82.29	38.68
15	430	28	10	0.72	190.54	12.70	13.28	26.46	104.03	48.90
20	360	32	12	0.71	248.29	12.41	11.55	28.94	135.57	63.72
25	350	34	14	0.64	284.58	11.38	7.26	31.76	155.38	73.03

254 255

wes: N = Population of G. arborea (tree ha⁻¹), d = Tree Diameter cm), h = clear bole height (m), F = form factor, TV = Total Volume 256 $(\overline{m}^3 ha^{-1})$, MAI = Mean Annual Increment $(\overline{m}^3 ha^{-1} year^{-1})$, CAI = $\overline{Current Annual Increment}$ $(\overline{m}^3 ha^{-1} year^{-1})$, B.A = Bassal area $(\overline{m}^2 ha)$ 257 Based on the table above, it can be explained that G. arborea at plot I in one hectare at the age of two years there are 660 teak trees with a diameter at 2 years to 25 years of 6 to 34 cm. While the height is 4 to 14 meters. The total volume 258 259 from 2 years to 25 years is 6.71 to 284.58 m³ha⁻¹. Meanwhile, the growth increment ranged from 3.36 to 12.70 m³ha⁻¹ 260 year¹. The maximum total volume of G. arborea reached at the age of 15 years is 190.54 m³ ha¹ and an increment of 261 12.70 and 13.28 m3ha-1year-1 with the number of trees per hectare as many as 430 trees. The graphical relationship 262 between MAI and CAI G. arborea in plot I can be seen in the image below.

263 264



267 Figure 4. The corellation of MAI and CAI G. arborea in Plot I 268

Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 15 years. This means that the maximum increment of *G. arborea* is reached at the age of 15 years. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has an R² value of 90%. This value means that there is a close relationship between age and the MAI increment of 91% and 9% influenced by other factors. Meanwhile, CAI has an R² value of 98%. This value means that there is a close relationship between age and the CAI increment of 98% and 2% is influenced by other factors.

276

277 Growth of G. arborea Plot II

278 Based on the *G. arborea* growth table, the number of trees, diameter, height, total volume and increment of *G*.

279 *arborea* in Plot II can be seen as follows:
280 Table 4. The volume of *Garborea* in plot II

abre in the	vorume	01 0 2010	orea m p	10111						
Age	n	d	h	f	TV	MAI	CAI	B.A	Biomass	Carbon
2	660	5	3	0.90	3.50	1.75		1.30	1.91	0.90
4	600	13.8	5.3	0.87	41.36	10.34	18.93	8.97	22.58	10.61
6	570	18.5	6.2	0.86	81.65	13.61	20.15	15.31	44.58	20.95
8	540	21.3	8	0.80	123.08	15.39	20.72	19.23	67.20	31.59
10	510	23.5	9.5	0.78	163.83	16.38	20.37	22.11	89.45	42.04
12	470	27	10	0.75	201.72	16.81	18.95	26.90	110.14	51.77
15	450	30	11	0.72	251.80	16.79	16.69	31.79	137.48	64.62
20	380	34	13	0.70	313.80	15.69	12.40	34.48	171.33	80.53
25	370	35.5	15	0.64	351.40	14.06	7.52	36.60	191.86	90.18
25	370	55.5	15	0.04	551.40	14.00	1.52	20.00	171.00	70.10

281 282 283

284

Notes: N = Population of *G. arborea* (tree ha⁻¹), d = Tree Diameter cm), h = clear bole height (m), F = form factor, TV = Total Volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), B.A = Bassal area (m²ha)

Based on the table above, it can be explained that *G. arborea* at plot II in one hectare at the age of 2 years there are 660 *G. arborea* trees with a diameter at 2 years to 25 years of 5 to 35.5 cm. While the height is 3 to 15 meters. The total volume from 2 years to 25 years is 3.50 to 351.40 m³ha⁻¹. Meanwhile, the growth increment ranged from 1.75 to 16.69 m³ha⁻¹year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years is 251.80 m³ ha⁻¹ and an increment of 16.79 and 16.69 m³ha⁻¹year⁻¹ with the number of trees per hectare as many as 450 trees.

The potential growth of teak stands was better than that of gmelina stands. This is due to differences in spacing and 290 291 density of different trees per hectare. One of the factors that can affect the size of the stand diameter is the density and intensity of sunlight entering the stand. According to Sedjarawan et al. (2014), stand density will affect the light entering 292 293 the vegetation. Stands that receive little sunlight will experience slow growth so that they have a small stem diameter. In addition, the light intensity will also have an influence on cell enlargement and differentiation such as height growth, leaf 294 295 size and the structure of the leaves and stems. The results showed that the increasing age of both teak and gmelina stands, 296 the more the amount of standing carbon stock would also increase. According to Lubis et al. (2013), standing carbon stock 297 increases with the increase in stem diameter and a decrease in carbon stock occurs when the number of stands or density 298 found in that diameter class is only small.

The graphical relationship between MAI and CAI G. arborea in plot II can be seen in the image below



301 302 **Figure 5.** The corellation of MAI and CAI *G. arborea* in Plot II

Based on the picture above, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 15 years. This means that the maximum increment of *G. arborea* is reached at the age of 15 years. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. This is supported by a simple linear regression test with a polynomial type on MAI which has an R^2 value of 86%. This value means that there is a close relationship between age and the MAI increment of 86% and 14% influenced by other factors. Meanwhile, CAI has an R^2 value of 98%. This value means that there is a close relationship between age and the CAI of 98% and 2% is influenced by other factors.

At the age of 10, according to Sandalayuk et al. (2018), the increase in diameter reaches 2.4 cm year⁻¹ and resembles 311 an increase in diameter of Jabon of 2.1 cm year¹. Meanwhile, according to the data above, the increase in gmelina 312 313 diameter at the age of 10 was 2.36 cm year-1. The maximum total volume of G. arborea achieved at the age of 15 years of biological rotation is 190.54 m³ ha⁻¹ and increments of 12.70 and 13.28 m³ ha⁻¹ year⁻¹ and the number of trees is 430. 314 Meanwhile, according to Siarudin and Indrayana (2015) that if Gmelina arborea is harvested at the age of 14 years, it has 315 316 a total volume of 122 m³ha⁻¹ and a diameter of 15 cm, whereas if harvested at the age of 20 years, the diameter is 20 cm 317 and the total volume is 146 m³ ha⁻¹. This means that the age of a stand also influences the biomass and the amount of 318 carbon stored in a stand (Lukito and Rohmatiah 2013). 319



299 300

Figure 6. A. Tectona grandis stands at the age of 15 years with spacing of 3 m x 3 m at Plot I and B.Tectona grandis stands at the age of 15 years with spacing of 3 m x 3 m at Plot II



Figure 7. A. *Gmelina arborea* stands at the age of 15 years with spacing of 3.5 m x 4 m at Plot I and B. *Gmelina arborea* stands at the age of 15 years with spacing of 3.5 m x 4 m at Plot II

348 Carbon and biomass production

The increase in CO2 gas emissions in the air causes an increase in global temperatures on earth. Function forests as carbon sinks in the very atmosphere needed to maintain the earth's temperature apart from forests as biodiversity conservation. Information regarding the amount of carbon absorbed in the plant biomass (carbon stock) in an area becomes very important to know (Trimanto 2014). Carbon dioxide (CO2) is an important component in the photosynthesis process. The carbon dioxide absorbed by the stands will compose carbohydrates as a result of photosynthesis and stored in the form of biomass. Therefore, the amount of standing biomass can be used as a basis for determining the amount of carbon stock or the amount of CO2 absorbed and stored by the stands (Uthballet al. 2017). According to Sardjono et al. (2017), biomass has a very close relationship with the photosynthesis process. Biomass increases because plants absorb CO2 from the air and convert it into organic compounds through the process of photosynthesis. In addition, stands will easily absorb carbon if the soil pH is neutral (Setiawan 2013). Therefore, neutral soil pH also affects the presence of carbon absorption. According to Putri and Wulandari (2015) stated that the omass of a stand can be estimated using an allometric equation whose parameter is the diameter of the stand. The large diameter of the stands causes the greater the biomass and carbon stored, and vice versa, the smaller the stand diameter, the smaller the biomass and carbon stored in it.

The tree allometric equation is one way of measuring forest resources. This can yield some estimates standing volume, biomass and carbon stock. The equation obtained is a statistical model used to explain the relationship between the various components of a tree stand. It gives permission to foresters to take simple measurements of tree stands, such as measuring diameter, height, biomass and carbon (Kasim et al. 2014). Therefore, the analysis of simple linear regression was needed. To measure the precision of the regression line which was used to identify the variability of data explained by the regression model, the coefficient of determination was required, which was symbolized as R². The maximum value of R² as 100%, and the minimum value was 0%, with the following criteria: if the value of R^2 was high, then there was a strong correlation between X and Y or if R²=0, then there was no any correlation between X and Y. If the value of R² was low, then the correlation between X and Y was weak (Handayani 2010: Kristiningrum et al. 2019 and Muliadi et al. 2017). In addition, if the value of the coefficient of determination (\mathbb{R}^2) showed a precise and strong correlation between the independent and dependent variables, then, according to this criterion, it could give greater confidence on the acceptance of the model. The high value of R^2 means that there was a strong correlation between the variables (Grafen and Hails 2002; Arezoo et al. 2014).

375 Mansur and Tuheteru (2011) explain that age was very influential in the production of carbon. If the trees were 376 getting older, their ability to absorb carbon was also high. Measurement of deep forest biomass this research was



 $R^2 = 0.96$



5

10

20 0

-20

394 395

396

398 399

397

Figure 8. The correlation between the stand age and production carbon of T. grandis and G. arborea

20

Age (year)

15

Meanwhile, the relationship between carbon and basal area in each type of stand can be seen in the figure below

25

y = 4.84x - 22.6

 $R^2 = 0.98$

y

30

= 3.2x - 2.7

y = 4.02x - 1.9 $R^2 = 0.97$

35

40

 $R^2 = 0.99$



402 Figure 9. The correlation between the production carbon and basal area of T. grandis and G. arborea 403

404 Based on the picture above, it can be explained that the production of carbon in relation to its influence on basal area, 405 had a very strong and high correlation (R²), the average regression coefficient is 97%. Where the regression coefficient of 406 the relationship between carbon and basal area in teak plot I and II is 99%, gmelina plot I is 92% and gmelina plot II is 99%. This indicated that there was a strong correlation between carbon and basal area because the value of its coefficient 407 of determination was higher than 90% and the graph of each correlation formed a linear shape. This means that the 408 409 regression coefficient of both the relationship between age and carbon and carbon with the basal area has a regression 410 coefficient value above 97%. And the graph of each correlation formed a linear shape. This value means that there is a close relationship between age and carbon of 97% and 3% is influenced by other factors. So is the same relationship 411 between carbon and beat area of about 97% and 3% is influenced by other factors. And the graph of each correlation 412 413 formed a linear shape. This is in line with the research conducted by Kumi et al. (2019) where in their research, they chose 414 teak species and gave results that the teak biomass estimation was very accurate and ignored differences in areas, tree 415 characteristics and diameters that had high, constant ratios, stems and sharp crowns with determination coefficient (R^2 = 0.99) and significant (Bredu and Birigazzi 2014). 416

417 Meanwhile, the relationship between each stand at its maximum age is related to the total volume, basal area, biomass and carbon can be seen in the table below. 418 419

Table 5.	The volume, basal are	a, biomas	s and carbon	each stand		
Na	Trans	Age	TV	BA	Biomass	Carbon
INO	Туре	(yr)	(m³ha-1)	(m ² ha ⁻¹)	(ton ha-1)	(ton ha-1)
1	T. grandis Plot I	32	307.50	64.06	267.83	125.88
2	T. grandis Plot II	25	254.81	43.56	221.94	104.31
3	G.arborea Plot I	15	190.54	26.46	104.03	48.90
4	<i>G.arb<mark>ore</mark>a</i> Plot II	15	251.80	31.79	137.48	64.62

420 Notes: TV = Total volume (m³ ha⁻¹), BA= Basal area (m² ha⁻¹)

Based on the table above, it can be explained that the teak plot I at the age of 32 years has the largest total volume, 421 basal area, biomass and carbon among other stands of 307.5 m³ ha⁻¹; 64.06 m² ha⁻¹; 257.83 ton ha⁻¹ and 125.88 ton ha⁻¹. then followed by teak plot II, gmelina plot II and finally gmelina plot I. This **1** lue to the different fertility rates in each 422 423 type of stand. The teak plot 2 at the age of 25 years has total volume 254.81 m³ ha⁻¹, basal area 43.56 m² ft⁻¹; biomass 424 425 221.94 ton ha⁻¹ and carbon 104.31 to ha⁻¹. G. arborea plot II at the age of 15 years has total volume 251.80 m³ ha⁻¹, basal area 31.79 m² ha⁻¹; to mass 137.48 ton ha⁻¹ and carbon 64.62 ton ha⁻¹, while G. arborea plot 1 at the age of 15 years has 426 427 total volume 190.54 $\frac{m^3}{m^3}$ ha⁻¹, basal area 26.46 $\frac{m^2}{m^2}$ ha⁻¹; biomass 104.03 ton ha⁻¹ and carbon 48.90 ton ha⁻¹. The amount of 428 carbon in gmelina plot one is almost the same as the amount of gmelina arborea in East Kutai District, East Kalimantan, Indonesia as research conducted by Amirta et al (2016). According to Trimanto (2014) states that production of G. arborea 429 430 tends to store carbon in large quantities smaller 19.96 ton C ha⁻¹ or 2.49 ton C ha⁻¹yr¹ compared to production of Tectona 431 grandis which can store as much carbon 114.88 ton C ha⁻¹ or 9.57 ton C ha⁻¹ yr⁻¹. Our results show that both younger 432 stands of teak and gmelina produce higher treedensities when compared with old stands. However, basalt the area of older 433 stands is larger than that of younger stands. This is in line with research conducted by Rinnangmang et al (2020). In 434 addition, the management of stands has a significant effect on the characteristics of the stands and the soil content as a 435 place to grow stands. Therefore, good forest managers must apply intensive forest management practices optimize the 436 benefits of plantations (Kumi et al. 2020).

The graphical relationship between total volume, basal area, biomass and carbon each stand can be seen in the image
 below



440

439

441 442 443

Figure 8. The correlation between total volume, basal area, biomass and carbon each stand

444 Research result shows that T. grandis stands have the highest total stored carbon when compared to G. arborea. Fast 445 growth and the ability of T. grandis trees to absorb carbon dioxide (CO2) makes this plant the most stored carbon among 446 tree species other. According to Lubis et al. (2013), the increase in biomass and carbon stored by trees goes hand in hand 447 the increase in the dimensions of the stem includes the diameter and height. This indicates that at diameter and height have a linear relationship. This can be seen from the total volume of teach stand. Where T. grandis plot I has the largest total 448 449 volume among the three types of stands. Forest plantations play a critical role in mitigating the various effects of 450 environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its consequences on 451 climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this study revealed that 452 Tectona grandis and Gmelina arborea has a great potential in promoting carbon sequestration especially when they are 453 allowed to grow older. Favorable growth conditions have high potential of increasing the biomass accumulation of this 454 species. Hence, it is recommended that sustainable management of this plantation should be paramount in securing a cleaner environment and mitigating the effect of climate change in Indonesia. 455 456

457

ACKNOWLEDGEMENTS

We would like to express our gratitude to Umbar Sujoko for his help in creating the map of the study site. The authors
 would like to acknowledge the anonymous reviewers for providing constructive comments to improve the manuscript.

46 1	REFERENCES
462	Adhitya PW, Hardiansyah G, Yani A. 2013. Estimation of surface carbon content on a tree in the Ketapang Regency City Forest Area. J Sustain Forests,
403 464 465	2 (1), 23-52. Adinugraha HA, Setiadi D. 2018. Selection of Seed Trees of Gmelina arborea Roxb. at Smallholder Forest In Bondowoso, East Java. Tropical Forest J 16(1): 5-12.
466	Alam AS, Rafiuddin, Setiawan, B. 2017. Financial analysis systems teak and elephant grass agroforestry in Samboja District Kutai Kartanegara Regency,
467	East Kalimentan Proceedings National Biodiversity Conservation: 136-142
468	Amirta R, Yuliansyah, Angi EM, Ananto BR, Setyono B, Haqiqi MT, Septiana HA, Lodong M, Oktavianto RN. 2016. Plant diversity and energy potency
469	of community forest in East Kalimantan. Indonesia: Searching for fast growing wood species for energy production. Nusantara Bioscience 8: 22-30
470	[Indonesian].
471	Anitha K, Verchot LV, Joseph S, Herold M, Manuri S, Avitabile V. 2015. A review of forest and tree plantation biomass equations in Indonesia. Annals
472	of Forest Science, 72: 981-997.
473	Arezoo S, Sankhayan PL, Hofstad O. 2014. A dynamic bio-economic model for community management of goat and oak forests in Zagros, Iran.J Ecol
174	Econ 106: 174-185.
175	Arias D, Alvarado J, Richter DJ, Dohrenbusch A. 2011. Productivity, aboveground biomass, nutrient uptake and carbon content in fast growing tree
476	plantations of native and introduced species in the Southern Region of Costa Rica. Biomass Bioenerg 35: 1779-1788.
477	Birdsey R, Pan Y, 2015. Trends in management of the world's forests and impacts on carbon stocks. For Ecol Manag 355: 83-90.
178	Bredu AS, Birigazzi L. 2014. Proceedings of the regional technical workshop on tree volume and biomass allometric equations in west africa. UN-
179	-REDD Programme MRV Report 21, Kumasi, Ghana, Forestry Research Institute of Ghana. Food and Agriculture Organization of the United
180	Nations, Rome, Italy.
181	Brown S. 1997. Estimating biomass and biomass change of tropical forests: A primer, FAO Forestry Paper 134, Rome: Food Agriculture Organisation of
182	the United Nations.
183	Calfapietra C, Barbati A, Perugini L, Fernari B, Guidolotti G, Quatrini A, Corona P, 2015. Carbon mitigation potential of difffferent forest ecosystems
84	under climate change and various in Italy. Ecosyst. Heal Sustain 1 (8): 1–9. Chanan M. 2012. Estimation of carbon stock (c) stored above ground in teak plantations (Tectona grandis Linn, F) (at RPH Sengguruh BKPH Sengguruh
86	KPH Malang Perum Perhutani II East Java). Gamma Journal 7 (2): 61-73 [Indoresian]. Chauhan SK, Sharma R, Panwar P, Chander J. 2016a. Short rotation forestry: a path for economic and environmental prosperity. In: Parthiban KT, Spacingers P, Octo Persenter Technologica A Complete Vidue Obsin Agreement. Vid 1 Scientific Peblishers, Jedhury
89	Chauhan SK, Ritu, Chauhan R, 2016b. Carbon sequestration in plantations. Agroforestry for increased production and livelihood security (Eds. Gupta, SK, Pawyor P, and Kauchal P.) Nawu Jedian Dublichian Agency. Naw Delbi
491	Chave J, Réjou MM, Búrquez A, ChidumayoE, Colgan MS, Deliti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez YrízarA,
192	Mugasha WA, Muller Landau HC, Mencuevini M, Melcon BW, Naomanda A, Noowaira FM, Ortiz ME, Péliesier P, Playan P, Ryan CM.
193	SaldarRJG, Vieilleden G. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Glob. Change Biol 20: 3177–
194	3100
195	Dinga E. 2014. On a possible predictor of the cyclical position of the economy. Proceedia Econ Finance 8:254-261.
196	Domee JC, Ward EJ, Oishi AC, Palmroth S, Kadecki A, Bell DM, Miao G, Gavazzi M, Johnson DM, King JS, McNulty, SG, Oren R, Sun G, Noormets
197	A. 2015. Conversion of natural forests to managed forest plantations decreases tree resistance to prolonged droughts. For Ecol Manag 355: 58-71.
98	Durkaya B, Durkaya A, Makineri E, Karaburk T. 2013. Estimating above ground biomass and carbon stock of individual trees in uneven-aged Uludag Fir stands. Fresenius Environ Bull 22 (2): 428-434.
i01	Edson C, Wing MG, 2011. Airborne Light Detection and Ranging (LiDAR) for individual tree stem location, height, and biomass measurements. Remote Sens 3 (11): 2494-2528.
502	Ekholm T. 2016. Optimal forest rotation age under efficient climate change mitigation. For. Policy Econ. 62: 62–68.
503	Gonzalez-Benecke CA, Samuelson LJ, Martin TA, Cropper Jr WP, Johnsen KH, Stokes TA, Buttor JR, Anderson PH. 2015. Modeling the effects of
504	forest management on in situ and ex situ longleaf pine forest carbon stocks. For Ecol Manag 355: 24-36.
505	Gren IM, Zelcke AA. 2016. Policy design for forest carbon sequestration: a review of the literature. For Policy Econ. 70: 128–136.
506	Handayani. 2010. Regression models. STIE Atma Bhakti, Surakarta. [Indonesian].
507	Hairiah K, Andree A, Rika RS, Subekti R. 2011. Measurement of carbon stock from land level to landscape 2nd edition. Bogor: Agroforestry Center.
508	Irundu D, Beddu MA, Najmawati. 2020. Potential of biomass and carbon stored stands in green open space Polewali City, West Sulawesi. J Forests
509	Communities 12 (1): 49-57.
510	Juwari, Ruhiyat D, Aipassa MI, Ruslim Y. 2020a. Carbon stocks of Rhizhopora apiculata and Sonneratia alba of mangrove forest in Ngurah Rai Forest
511	Park, Bali Province, Indonesia. J Biodiversity Enviro Sci, 16 (3):93-105.
512	Juwari, Ruhiyat D, Aipasaa MI. 2020. Growth analysis of <i>Rhizophora Mucronata mangrove</i> in Ngurah Rai Forest Park (Sanur) Bali Province, Indonesia.
513	Energy Enviro Res. 10 (1): 30-35.
514	Karyati, Widiati KY, Karmini, Mulyadi R. 2019. Development of allometric relationships for estimate above ground biomass of trees in the tropical
515	abandoned land. Biodiversitas 20 (12): 3508-3516.[Indonesian]
516	Kasim AR, Henry M. Danial M, Faiz M, Birigazi L. 2014. Inventory of tree biomass and volume allometric equations in Southeast Asia. FRIM,
517	Kepong, Food and Agriculture Organization of the United Nations, Rome, Italy
518	Kristiningrum R, Lahjie A, Masjaya, Yusuf S, Ruslim Y. 2019. Species diversity, stand productivity, aboveground biomass and economic value of
519	mangrove ecosystem in Mentawir Village, East Kalimantan, Indonesia. Biodiversitas 20 (10): 2848-2857.[Indonesian]
520	Kumi JA, Kyereh B, Ansong M, Ansate W. 2020. Inffluence of management practices on stand biomass, carbon stocks and soil nutrient variability of
521	teak plantations in a dry semi-deciduous forest in Ghana. Elsevier. Trees, Forest and People 3.
23	Lee SY, Primavera JH, Dahdouh-Guebas F, McKee K, Bosire JO, Cannicci S, Diele K, Fromard F, Koedam N, Marchand C, Mendelssohn I, Mukherjee N, Record S. 2014. Ecological role and services of tropical mangrove ecosystems: a reassessment. Global Ecoly and Biography, 23:726-743
24	Lubis SH, Arifin SH, Samsoedin I. 2013. Analysis of tree carbon stocks in fores landscapes city in DKI Jakarta. J of Fores Sos and Econ Research, 10
25	(1):1-20.
26	Lukito M, Rohmatiah A. 2013. Estimated biomass and carbon of teak 5 year (Case of Nusantara Superior Teak Plantation Forest (JUN) Krowe Village,
28	Lembeyan District, Magetan Regency). Agritek Journal 14(1): 1-23 Law BE, Waring, RH. 2015. Carbon implications of current and future effects of drought, fire and management on Pacific Northwest forests. For Ecol
30	Manag 353: 4-14. Mansur I, Tuheteru FD, 2011. Jabon Tree, Book, Penebar Swadaya, Jakarta. [Indonesian].
532 532	Meunpong F. 2012. Futurent and Carbon Storage in Porest Plantation, Prachuap Khiri Khan province, Thailand, [Dissertation]. Kasetsart University, Bangkok, [Thailand] Muliadi M. Lohii A.M. Simemodelia PDAS, Buelin, V. 2017. Dissertation of dimemodely and distribution of dimemodely for the dimemodelia and the distribution of dimemodelia.
534	Muladi M, Lanjie AM, Simarangkir BDAS, Ruslim Y. 2017. Bioeconomic and environmental valuation of dipterocarp estate forest based on local wisdom in Kutai Kartanegara, Indonesia, Biodiversitas18(1): 401-408 [Indonesian].

535 Murtinah V, Ruchaemi A, Ruhiyat D. 2015. Forest growth teak plant (Tectona grandis Linn.f.) in East Kalimantan. J Agrifor 14 (2).

536 Nonini L, Fiala M. 2019. Estimation of carbon storage of forest biomass for voluntary carbon markets: preliminary results. J. For. Res 32(1):329-338

537 538 Noormets A, Epron D, Domec JC, McNulty SG, Fox TD, Chen J, Sun G, King JS 2015. Effects of forest management on productivity and carbon sequestration: a review and hypothesis. For Ecol Manag 355: 124-140. 539

Panwar P, Chauhan S, Kaushal R, Das DK, Ajit, Arora G, Chaturvedi OP, Jain AK, Chaturvedi S, Tewari S. 2017. Carbon sequestration potential of 540 541 poplar-based agroforestry using the CO2 FIX model in the Indo Gangetic Region of India. Trop Ecol 58 (2): 1-9.

Pinheiro TF, Escada MIS, Valeriano DN, Hostert P, Gollnow F, Muller H. 2016. Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 Region in Southwestern Pará, Brazil, Earth Interactions 20 (17): 1-26.

542 543 Rinnamang S, Sirirueang K, Supavetch S, Meunpong P. 2020. Estimation of aboveground biomass using aerial photogrammetry from unmanned aerial vehicles in teak (Tectona grandis) plantation in Thailand. Biodiversitas 21: 2369-2376.[Indonesian]. 544

545 546 Riutta T, Malhi Y, Kho LK, Marthews TR, Huasco WH, Khoo M. 2018. Logging disturbance shift net primary productivity and its allocation in Bornean tropical forest. J. Glob Change Biol 24 (7):2913-2928.

547 Ruslianto M, Alviani, Maisuri, Irundu. 2019. Biomass allometric model of Rhizophora Apiculata at Polewali Mandar Regency, West Sulawesi Province. Eboni Buleti Journal 1 (1): 11-19.[Indonesian].

548 549 550 551 552 Ruslim Y, Sihombing R, Liah Y. 2016. Stand damage due to mono-cable winch and bulldozer yarding in a selectively logged tropical forest. Biodiversitas 17 (1): 222-228. [Indonesian].

Pandey S, Shukla R, Saket R, Verma D. 2019. Enhancing earbon stocks accumulation through forest protection and regeneration. A review. Int. J. Environ, 8 (1): 16-21

553 554 Putri AHM, Wulandari C. 2015, Potential carbon absorption in Shorea javanica in Pekon Gunung Kemala Krui, West Lampung, Sylva Lestari 3 (2): 13-20. [Indonesian]. Polosakan R, Alhamd L, Joeni SR, 2014. Estimated biomass and carbon stored in Pinus merkusii Jungh, & de Vriese In the Pine Forest Mt. Bunder, TN.

555 556 GN Halimun Salak. Biology News. 13 (2): 15-120. [Indonesian].

557 Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2020. Carbon absorbtion of Anthocephalus macrophyllus and Swietenia macrophylla. King in 558 559 Gorontalo, Indonesia. Jof Biodiversity and Enviro Scie16 (5): 24-30.

Sandalayuk. D, Soedirman S, Pambudhi F. 2018. Reserves estimating carbon in forest city district village Bongohulawa Gorontalo. Ijrtem. 2(8), 60-63.

Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2018. Analysis of gmelina and mahogany growth in Gorontalo. J Forest Research. 1 (1): 1-8. 560

561 562 Sardjono A, Lahjie AM, Simarangkir BDAS, Kristiningrum R, Ruslim Y. 2017. Carbon sequestration and growth of Anthocephalus cadamba plantation in North Kalimantan, Indonesia. Biodiversitas18(4): 1385-1393. [Indonesian].

563 564 Sharma R, Chauhan SK, Tripathi AM. 2016. Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. Agrofor Syst 90(4):631-644

565 Setiawan, B., Lahjie A.M., 2011. Financial analysis of agroforestry systems teak, sungkai, and elephant grass in Samboja Kutai District Kartanegara. . 566 567 Humida Tropical Forestry Vol. 4 (1).

Setiawan H. 2013. Ecological status of mangrove forest at various thickness level. Wallace's Journal of Forestry Research 2, 104-120. [Indonesian].

568 Setiawan, B., Lahjie A.M, Yusuf, S, Ruslim, 2019. Model of community forest land management production and financial simulation of super teak, 569 solomon teak and sungkai treesin Samboja Kutai Kartanegara East Kalimantan, Indonesia. Energy and Environment Research 9(20): 48-60.

570 Siaruddin, M and Indrayana, Y. 2015. Dynamics of carbon stock systems gmelina agroforestry in community forests in Tasik malaya and Banjar, West 571 572 573 Java. Wasian 4 (1): 37-46.

SNL 2011. Indonesian National Standard Number 7724. Measurement and calculation of carbon stocks - field measurement for forest carbon stock assessment. tandardization Agency. Jakarta. [Indonesian].

574 575 576 577 Siregar UJ, Narendra BH, Suryana J, Siregar CA, Weston C. 2017. Evaluation on community tree plantations as sustainable source for rural bioenergy in Indonesia. International Conference on Biomass: Technology, Application, and Sustainable Development IOP Conf. Series: Earth and Environmental Science, 65: 1-9.

Sugiyono. 2012. Qualitative and uantitative research methods and R&D. Alfabeta. Bandung. [Indonesian].

578 Susila, IWW. 2012. Estimation model of teak stand volume and increment in Nusa Penida, Klungkung Bali. J of Plant Forest Research 9 (3): 165-178.

579 Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A. 2016. Impact of changes in land use, species and elevation on soil organic carbon and 580 total nitrogen in Ethiopian Central Highlands. Geoderma 261: 70-79. 581 Tong S, Berry HL, Ebi K, Bambrick H, Hu W, Green D, Hanna E, Wang Z, Butler CD. 2016. Climate change, food, water and population health in China.

582 Bull World Health Organ 94:759-765. 583 Trimanto. 2014. Vegetation analysis and tree biomass estimation of carbon stocks in Seven Montane Forests of Bawean Island Nature Reserve, East Java.

584 Biology News 13(1): 321-332. 585

Utbbah Z, Sudiana E, Yani E. 2017. Biomass analysis and carbon stock at various ages of resin stands (Agathis dammara (Lamb.) Rich.) In KPH 586 Banyumas Timur. Scripta Biologica 4(2): 119-124.

587 588 Van Gardingen PR, McLeish MJ, Philips PD, Fadilah D, Tyrie G, Yasman I. 2003. Financial and ecological analysis of management options for loggedover dipterocarp forest in Indonesia Borneo. For Ecol Manag 183: 1-29.

589 Warner AJ, Jamroenprucksa M, Puangchit L. 2017. Buttressing impact on diameter estimation in plantation teak (Tectona grandis Lf.) sample trees in 590 northern Thailand. Agric Nat Resour 51 (6): 520-525.

591 Winarni B, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Tengkawang cultivation model in community forest using agroforestry system in 592 West Kalimantan, Indonesia.Biodiversitas18(2):765-772.[Indonesian].

593 Yunianti AD, Wahyudi, Siregar, Pari. 2011. Quality of teak clones with different planting distances. J of Wood Sci and Tech Tropical 9 (1): 93-100.

594 595 Zeng W. Fu L, Xu M, Wang X, Chen Z, Yao S. 2018. Developing individual tree-based models estimating aboveground biomass of fifive key coniferous species in China. J For Res (5): 1251-1261.

596 597

598
Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea

ORIGINALITY REPORT

ORIGINA	ALITY REPORT				
4 SIMILA	% RITY INDEX	% INTERNET SOURCES	4% PUBLICATIONS	% STUDENT	PAPERS
PRIMAR	Y SOURCES				
1	Adnan Ah Mannan, Rahman and Mitiga deodara Altitude in Journal of Publication	nmad, Muhamma Sajjad Saeed, S Uddin, Qijing Liu ation Potential o /i>) Forest Ecos n Kumrat Valley, f Forestry, 2018	ad Amir, Abdu her Sha, Sam I. "The Carbor f Deodar (<i>0 ystem at Diffe Pakistan", Op</i>	I I Ullah, Sinks Cedrus Frent	<1%
2	Makinen, pine stand results an Forest Ec Publication	H "Intensive m ds in southern F id simulated furt cology and Mana	anagement of inland: First e her developm igement, 2005	f Scots mpirical ent", 50825	< 1 %
3	Patricia C Venegas, "Spatially Efficiency Emissions IEEE Inte Sensing S	Oliva, Leonardo E Paulina Vidal, C Refined Biomas Estimations in S s Quantification" rnational Geosc Symposium, 201	Duran, Alejand Claudia Monto ss and Combu Support of For , IGARSS 20 ⁻⁷ ience and Rer 9	dro ya. Istion rest Fires 19 - 2019 mote	<1%

4

Muhdi, A Sahar, D S Hanafiah, A Zaitunah, F W B Nababan. "Analysis of biomass and carbon potential on eucalyptus stand in industrial plantation forest, North Sumatra, Indonesia", IOP Conference Series: Earth and Environmental Science, 2019 Publication

5

Juang Rata Matangaran, Erianto Indra Putra, lis Diatin, Muhammad Mujahid, Qi Adlan. "Residual stand damage from selective logging of tropical forests: A comparative case study in central Kalimantan and West Sumatra, Indonesia", Global Ecology and Conservation, 2019 Publication

6

Peter Tarp. "Economics of converting an evenaged Fagus sylvatica stand to an uneven-aged stand using target diameter harvesting", Scandinavian Journal of Forest Research, 2/1/2005 Publication <1%

L. Rytter. "Productivity and thinning effects in hybrid aspen (Populus tremula L. x P. tremuloides Michx.) stands in southern Sweden", Forestry, 07/01/2005 Publication <1%

uptake and stock potency in Tunda Island mangrove ecosystem, Serang, Banten, Indonesia", IOP Conference Series: Earth and **Environmental Science**, 2020 Publication

9

Safril Kasim, Aminuddin Mane Kandari, Asramid Yasin, La Ode Agus Salim Mando. "A Model to Estimate Stored Carbon in the Upland Forests of the Wanggu Watershed", Journal of Sustainable Development, 2020 Publication

"Tropical Forestry Handbook", Springer Nature, 10 2016 Publication

- N M Ashuri, M P Patria. "Vegetation and carbon 11 stock analysis of mangrove ecosystem in Pancer Cengkrong, Trenggalek, East Java, Indonesia", IOP Conference Series: Earth and **Environmental Science**, 2020 Publication
- "International Business, Trade and Institutional 12 Sustainability", Springer Science and Business Media LLC, 2020 Publication

M VERDINELLI. "Development and feeding 13 efficiency of Malacosoma neustrium larvae reared with Quercus spp. leaves", Annals of



<1%



<1%

<1%

<1%

Publication

14Tron Eid, Erik Tuhus. "Models for individual tree
mortality in Norway", Forest Ecology and
Management, 2001<1%</td>

Publication

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		

s	mujo.i	id@gr	mail.	.com										×	크는					0	Ċ3		-
	۵	0		i I	Î	C)	Cí,	•	•	1							13 dari ba	nyak	<		•	
	Smuj kepad	o Edito a saya,	ors <s Daud</s 	smujo J, Roci	.id@gn hadi, Ar	nail.co ndi =	m>										0	Sel, 23 Fe	b 17.15		4	:	
	Ŕ	Inggri	is -	>	Indor	nesia	-	Terjem	ahkan p	esan								Nor	naktifka	an untuk: I	Inggris	×	L
	YOSE We ha Stocks Our de Smujo	P RUS ave rea s of Tec ecision) Editori s@smu	LIM, ched ctona is: R is: R	Daud a dec grani tevisio	l Sanda dision n dis and ons Rec	alayuk egardi Gme quired	, Roc ing yo lina a	chadi Kr our sub rborea	istining mission in Goro	rum, An- to Biedi ntalo Pr	di Sał iversit ovinci	nri Alam: tas Journal e, Indonesi	of Biologica a"_	I Diversity,	"Estima	ation	Above Grour	id Biomas	as (AGE	3) and Ca	rbon		
																					~~~		
sm	ujo.id@	@gma	ail.co	om		Q	C	X	ŧ		:			×	莊		1	3 dari bar	nvak	(?) <	نوب دوب		
sm	ujo.id@	@gma	il.cc	om	Ŷ	C	C	X.	•	•	:			×	ΞĒ		1	3 dari bar	nyak	() < ;	ئ <u>ي</u> ا		
sm  R	ujo.id@	@gma D rA:		m	Ŷ	0	0	X4+	۲	•	:			×			1	3 dari bar	nyak	<ul> <li></li> <li></li> </ul>	ئ <b>و</b> ن ا		
smi  R D P	ujo.id@	@gma D r A: itor and nd atta	ail.cc	hor(s)	e reviev	<b>(</b> ) ws an	C 	gested	edits fo	the m	÷	cript entitle	d "Estimatio	n Above G	크는 round B	Bioma	1 ass (AGB) an	3 dari bar d Carbon	nyak n Stocks	< : s of Tecto	> E	•••• • •	
smi R D P a	ujo.id@ eviewe ear Edi lease fi nd Gme	@gma D r A: itor and ind atta elina art	ail.cc	hor(s) l is the	e reviev	<b>(</b> ) ws and lo Pro	d sug	gested , Indon	edits fo	Dr the m	anuso	cript entitle	d "Estimatio	n Above G	크는 round B	Bioma	1 ass (AGB) an	3 dari bar d Carbon	nyak n Stocks	<	> e	ndis	
smi R D P a W th o	ujo.id@ eviewe ear Edi lease fi nd Gme /hile the reme. Ir verhaul	@gma P r A: itor and atta elina arl e resea n partici as sug	J Auth cched borea urch io ular,	hor(s) I is the a in G dea is there wed in	e review coronta a not ne are lot the atta	ws and lo Pro ew in e s of d ached	d sug vince ecolo ata p file.	gested , Indon gical str	edits for lesia". udies of ed in this	Dor the m f carbon s manus	: anusc and l script.	cript entitler biomass, tl Nonethele	l "Estimatio le context o ss, the mar	n Above G f study are	Tound B a (i.e. G s very p	Bioma Goror	1 ass (AGB) an ntalo) might a y written and	3 dari bar d Carbon dd the ex structure	nyak n Stocks kisting k d so tha	< : s of Tecto mowledg	> ma gran e in suc red tota	ndis ch	
smu R D P a W th o 1 T th	ujo.id@ all all all all all all all all all all	©gma p r A: itor and nd atta n partic: ar sea n partic: ar sug troduct e, I sug hen yo	J Auth d Auth ached borea arch id augest tion is ggest u are	hor(s) I is the a in G dea is there ted in s very to re- e revis	e review oronta are lot the atta long a arrang	ws and lo Pro ew in e s of d ached and dif	d sug vince ecolog ata p file. ficult Intro	gested gigested gical str to under to under duction pt.	edits fo esia". udies of ed in this erstand. as edit	or the m f carbon s manus . Also, s ed in the	anusc a and l script.	cript entitled biomass, th Nonethele elaboration ched file. S	I "Estimatio le context o ss, the mar s are out of ince many s	n Above G of study are nuscript war the contex sentences	Tound B a (i.e. G s very p t of the were de	Bioma Goror pape	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che	3 dari bar d Carbon dd the ex structured ny cases t ick the ref	n Stocks disting k d so that they are ference	c ;	e in suc red tota ng. ext and	ndis ch il	
Smi R D P a U V th o 1 T T th 2 S	ujo.id@ eviewe ear Edi lease fi nd Gme /hile the verhaul The In herefor ve list w . In the ub-distr	©gma	J Auth ached borea urch id urch id urch id urch id urch id sogest tion is ggest u are ds, fra /or di	hor(s) l is the a in G dea is there wed in s very t to re- e revis om th istrict)	e review are lot the atta long a arrang the e Figur . If so,	ws and lo Pro ew in e s of d ached and dif e the e man re 1, it pleas	d sug vince ecolog ata p file. ficult Introd uscrip seer e add	gested a, Indon gical str to und- duction pt. ms that d inform	edits for esia". udies of d in this erstand. as edit	f carbon     s manus     Also, s     din thd     tance ar	: anusc a and l script. oome e attac mong g the l	cript entitled biomass, th Nonethele elaboration ched file. S plots is qui ocation of d	d "Estimatio te context o ss, the mar s are out of ince many s te far and k each plot (i.	n Above G f study are nuscript war the contex sentences boks like th e. coordina	The second secon	Bioma Goror pape bleted locate	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che ed in differen sub-district, au	3 dari bar d Carbon dd the ex structured by cases t ck the ref t administ nd/or dist	nyak n Stocks disting k diso that they are ference trative I	c ::	e in suc red tota	undis that l ge,	
smu R D P a W th o o 1 T T th 2 s s 3 P	ujo.id@ eviewe eear Edi lease fi dease fi dease fi herefor werhaul The In herefor we list w lin the ub-distr . In the lease p	egma r A: tor and nd atta laina ari e resea n partic as sug troduct e, I sug hen yo Methoc rovide or whethoc	J Auth d Auth dched borea urch io urch io urch io ggest u are ds, fm /or di ds, H clear	hor(s) I is the a in G dea is there a revis om th istrict) low m r expla	e revier oronta a not ne are lot the atta long a arrang ing the e Figur . If so, any tim anation	ws an- lo Pro ew in e s of d ached ached ind dif e the e man re 1, it pleas we regained	d sug vvince ecologiata p file. ficult Introduscrip seer e add ere th rding	gested e, Indon gical str to unde duction pt. ms that d inform the time	edits fc esia". udies of ed in this erstand. as edit the dist the dist	or the m     f carbon     s manus     Also, s     din the     tance ar     garding     nt condu     ta collecc	i anusc a and l script. oome e a attac mong g the l ucted stion.	cript entitled biomass, th Nonethele elaboration ched file. S plots is qu ocation of d in each plot	d "Estimation the context of ss, the mar s are out of ince many s te far and lo sach plot (i t? Each yea	n Above G If study are nuscript war the contex sentences poks like th e. coordina ar, irregular	The second secon	Bioma Goror poorly pape eleter locate ge, s	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che ed in differen ub-district, a utime in 2 yea	3 dari bar d Carbon dd the ex structure ny cases t ick the ref t administ nd/or disti r, 3 year,	n Stocks disting k diso that ference trative I rict). so on),	c confusional control of the second confusion of the second confusion of the second control of the second c	ona gran e in suc red tota ng. ext and i.e. villa once?	ndis ch l ge,	

More detailed comments are provided in the attached file.

Best regards,

Reviewer

Recommendation: Revisions Required

#### Estimation Above Ground Biomass (AGB) and carbon stocks of *Tectona* grandis and *Gmelina arborea* stands in Gorontalo Province, Indonesia

Abstract. Plantation forest plays an important role to fulfill timber needs, while more recently plantation forest is increasingly acknowledged to sequester and store carbon which can mitigate climate change. This study aimed to calculate the stand potential, stand biomass and carbon stocks of teak (Tectona grandis) and gmelina (Gmelina arborea) stands in the context of land after being abandoned in Gorontalo Province, Indonesia. Four plots with size of one hectare each were sampled in which each species (i.e. Teak and Gmelina) consisted of two plots. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded. Data analysis included growth parameters of the stands (i.e., Mean Annual Increment/MAI and Current Annual Increment/CAI) and aboveground biomass and carbon sequestered by the stands. Simple linear regression using polynomial trendline was used to determine the relationship between variables and the degree of the relationship. The results showed that the maximum growth of teak stands at Plots I and II reached a maximum point at the age of 32 and 25 years with the total volume of 307.50 and 254.81 m³ha⁻¹, respectively. While the maximum growth of genelina stands at Plots I and II reached a maximum point at the age of 15 years with the total volume of 190.54 and 251.80 m³ha⁻¹, respectively. The biomass content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 267.83; 221.94; 104.03 and 137.48 tons ha⁻¹. Meanwhile, the carbon content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 125.88; 104.31; 48.90; and 64.62 tons ha-1. The results of the regression analysis suggest that there was strong relationship between carbon sequestered and the age of the stands as well as total basal area. The results of this study suggest that *Tectona grandis* is more potential to be developed as plantation forest than *Gmelina arborea* when aiming carbon sequestration and biomass production,

26 Keywords: Biomass, carbon, Gmelina arborea, growth, Tectona grandis

27

1

2

345678

9 10

11

12

13

14

15

16

17

18

19

24

25

#### INTRODUCTION

28 There is a growing paradigm that forest management is not only aimed to produce timber and non-timber products, but 29 also to deliver various ecosystem services. One of forest ecosystem services is the sequestration of carbon dioxide in the 30 atmosphere through photosynthesis and to store it in forest biomass (Lukito and Rohmatiah 2013). The carbon stored in 31 forest biomass can help mitigate climate change in the form of global warming (Birdsey and Pan, 2015; Calfapietra et al, 32 2015; Zeng et al, 2018; Pandey et al, 2019).

Tesfaye et al. (2016) stated that tropical forests play an important role in global carbon sequestration. Among ecosystems in the world, forests in tropical regions have the highest rate of carbon sequestration due to the large amount of sunlight and water in the regions which is plentiful throughout the year. These conditions are also supported by the climates (i.e., temperature and humidity) that optimal for many tree species to grow. Most of carbon sequestered by the forest is stored in above-ground biomass of the trees.

38 Plantation forestry has the potential to be developed as biomass storage. When developing plantation forest, the 39 estimation of biomass in tree stands is very important to calculate the amount and variation of C (Ekholm 2016; Gren and 40 Zeleke 2016; Ruitta et al. 2018; Nonini and Fiala 2019). Biomass is also important to determine forest production to assess 41 the sustainability aspect of forest management (Rinnamang et al. 2020) since the existence of plantations requires 42 sustainability in terms of financial, ecological and social aspects (Siregar et al. 2017). If achieved across such aspects, 43 sustainable management of plantation forest would result in high production of wood products while could store a large 44 amount of carbon (Wei and Zhou 2019; Cuong et al. 2020). In addition to producing wood and biomass, sustainably 45 managed forest plantations would also provide environmental services in the form of water regulation (Kanninen 2010; 46 Chauhan et al. 2016b; Nemeth et al. 2018).

47 According to Gonzalez-Benecke et al. (2015) Sharma et al. (2016) Panwar et al. (2017), the length of rotation of 48 plantation forest will affect the biomass and carbon stored by the forest. The rotation length is related with the type of tree 49 species planted, either it is fast-growing or slow-growing species. The ability of fast-growing trees to absorb carbon which 50 is faster than slow-growing species is one of the strong reasons why it is necessary to plant and cultivate fast-growing 51 species in plantation forests (Chauhan et al. 2016a).

Deleted[Anonymous Reviewer]: exploitation has Deleted[Anonymous Reviewer]: in meeting ••• Deleted[Anonymous Reviewer]: and also as carbon Formatted[Anonymous Reviewer]: Font: Italic Formatted[Anonymous Reviewer]: Font: Italic Deleted[Anonymous Reviewer]: The purpose of this study .... Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: closeness Deleted[Anonymous Reviewer]: t Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: and Deleted[Anonymous Reviewer]: was Deleted[Anonymous Reviewer]: . Deleted[Anonymous Reviewer]: g Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: s Deleted[Anonymous Reviewer]: and Deleted[Anonymous Reviewer]: is Deleted[Anonymous Reviewer]: . Deleted[Anonymous Reviewer]: t Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: s Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: p Deleted[Anonymous Reviewer]: simple Deleted[Anonymous Reviewer]: , the Deleted[Anonymous Reviewer]: the two variables shows Deleted[Anonymous Reviewer]: This indicated that Deleted[Anonymous Reviewer]: ly Deleted[Anonymous Reviewer]: plantations in Deleted[Anonymous Reviewer]: although both of thrm ha Deleted[Anonymous Reviewer]: Indonesia has renewable ....

Deleted[Anonymous Reviewer]: These forest resources have

52 One type of fast-growing tree species is Gmelina (*Gmelina arborea* Roxb). This tree is widely developed for industrial 53 plantations in tropical regions, such as Indonesia, Pakistan, Sri Lanka, and some countries in Southeast Asia. Gmelina can 54 live well in lowland areas up to an altitude of 1200 m above sea level with an average rainfall of 750-5000 mm year⁻¹ 55 (Adinugraha and Setiadi 2018). Other tree species that is widely cultivated is Teak (*Tectona grandis* Linn.f.). Teak is an 56 important commercial timber tree which has a high selling price (Warner et al. 2017) due to the timber is relatively light 57 with high durability and resistant to fire as well as easy to work on (Meunpong 2012).

58 One important parameter when estimating the biomass of tree stands is allometric equation. Yet, in several regions and

59 particular contexts of land management, the allometric equation is not adequately formulated (Karyati et al., 2019). This

60 study aimed to calculate the stand potential, stand biomass and carbon stocks of Teak and Gmelina stands in the context of

61 land after being abandoned in Gorontalo, Indonesia. We expected that this research can develop allometric equation for

62 estimating AGB with a coefficient of determination that can predict biomass and carbon stock in such land management,

#### **MATERIALS AND METHODS**

#### 64 Study period and area

65 The study, was conducted from September 2020 to December 2020 in Gorontalo Province. The field experiments were

25

Тара

Atinggo

Telaga

Limboto

- 66 conducted at four plots, consisting of two plots of Tectona grandis and two plots of Gmelina arborea (Figure 1), Plot I was
- 67 located at the coordinate of.....in....Village....Sub-district...bla..bla



63



## Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: A = G. arborea plot II, B = T. grandis plot I, C = G. arborea plot I, D = T. grandis plot II. D T. grandis plot II.

#### 75 **Data collection procedure**

76 The determination of the study locations (Figure 1) and the sampling sites was conducted by purposive sampling with

77 the sampling method using systematic random sampling. Each plot of tree stand (Figure 1) had the extent of 1 hectare with

78 different planting distance, The planting distance of *Tectona grandis* stand was 3m x 3m, while that of *Gmelina arborea* 79 was 3.5m x 4m. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded.

#### 80 Data analysis

81 Estimating the growth (MAI and CAI)

82 The maximum production of the stand of *T. grandis* and *G. arborea* was analyzed by calculating the growth increments 83 of tree in a particular measurement time span (cycle), <u>namely</u> mean annual increment (MAI) and current annual increment 84 (CAI). Van Gardingen et al. (2003) state that increment is defined as an increase in the dimensional growth (height, 85 diameter, base plane, volume) or an increase in the standing stock of a tree, in relation to the tree age or a particular period. 86 The volume of the tree was calculated using following equation: 87  $V = \frac{1}{4}\pi d^2 h f$ 

in which: V = standing volume, d = diameter at breast height (DBH), h = branch-free height, f = form factor 89

Deleted[Anonymous Reviewer]: Where biomass productie .... Deleted[Anonymous Reviewer]: Biomass functions as org ... Deleted[Anonymous Reviewer]: Research on forest poten ... Deleted[Anonymous Reviewer]: experiment Deleted[Anonymous Reviewer]: in Deleted[Anonymous Reviewer]: of Deleted[Anonymous Reviewer]: were Deleted[Anonymous Reviewer]: and Deleted[Anonymous Reviewer]: were two plots Deleted[Anonymous Reviewer]: The area was located on Deleted[Anonymous Reviewer]: Location studies Deleted[Anonymous Reviewer]: (in which Deleted[Anonymous Reviewer]: : Deleted[Anonymous Reviewer]: A Formatted[Anonymous Reviewer]: Font: Not Bold Deleted[Anonymous Reviewer]: A Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: ) Deleted[Anonymous Reviewer]: Research object Deleted[Anonymous Reviewer]: The objects to be studied .... Deleted[Anonymous Reviewer]: each, so that the number ... Deleted[Anonymous Reviewer]: spacing Deleted[Anonymous Reviewer]: Where the Deleted[Anonymous Reviewer]: plant spacing Deleted[Anonymous Reviewer]: i Deleted[Anonymous Reviewer]: and the Deleted[Anonymous Reviewer]: spacing is Deleted[Anonymous Reviewer]: Determination of the san ... Formatted[Anonymous Reviewer]: Space Before: 0 pt Deleted[Anonymous Reviewer]: Data collection includes

Deleted[Anonymous Reviewer]: calculated by

Deleted[Anonymous Reviewer]: ing

Deleted[Anonymous Reviewer]: T. grandis and G. arborea

											;	Deleted[Anonymous Reviewer]: mathematic
												Deleted[Anonymous Reviewer]: M
												Deleted[Anonymous Reviewer]: T
	According to Va	n Gardinge	en et al.	(2003), to	estimate 1	the mean a	nnual incr	ement (MA	(I) and the cur	rent annual	$\left  \right  \right $	Deleted[Anonymous Reviewer]:
incren	nent, the following V	g formulas	were use	d:				(		/		Deleted[Anonymous Reviewer]: ;
М	$AI = \frac{v_t}{t}$											Deleted[Anonymous Reviewer]: A
in	which: $MAI = \underline{mg}$	ean annual	incremen	$V_t = tota$	al volume i	in ages t ₀ -	$t (m^3)$ , $t = a$	ge (years)		l	<u> </u>	Delated[Anonymous Reviewer]:
CA	$AI = \frac{V_t - V_{t-1}}{-}$											Deleted[Anonymous Reviewer]. s
	Т											Deleted[Anonymous Reviewer]: 1
in secon	which: $CAI = cur d age t_0 - t$ , minus	rrent annua the first ag	al increme ge (in year	ent, $V_t = t_f$ r)	otal volum	e in ages to	) - t (m ³ ), V	$V_{t-1} = previo$	ous total volum	$e (m^3), T =$	$\leq$	Deleted[Anonymous Reviewer]: C
Estim	ating tree hiomas	and carbo	0 <i>n</i>									Deleted[Anonymous Reviewer]: T
hioma	ree biomass can be	estimated	by incor	porating ti	ree height, tional Star	trunk diam	eter and w	ood density	(Chave et al.,	2014). <u>The</u>		Deleted[Anonymous Reviewer]:
using	the following for	nula:			tioliai Stai		J number	//24 (2011		.t al (2020)		Deleted[Anonymous Reviewer]: P
M in	$= BJ \times V_t \times BEF$ which; <u>M = tree b</u>	oiomass, B.	J = specif	ic gravity,	$V_t = total$	volume, B	EF = <u>B</u> iom	ass Expans	ion Factor (1.3)	)		Deleted[Anonymous Reviewer]:
While	e carbon storage w	as calculat	ed as foll	<u>ow:</u>								Delated[Anonymous Poviewar]: S
Ct	$b = B \times \% C Organwhich: Cb = Car$	nic bon conter	nt of bion	nass (kg),	B = total	biomass (k	ag), % C C	Prganic = P	ercentage value	e of carbon		Deleted[Anonymous Nevlewer]. 5
conter	nt, <u>which is</u> 0.47 (	Hairiah et a	al. 2011).									Deleted[Anonymous Reviewer]: <i>The estimation of</i>
Accor	ne <u>total</u> biomass <u>v</u> rding to Adhitya e	vas, calcula t al. (2013)	ated by m	ultiplying	the bioma	ass obtaine	d per plot	with the co	onversion unit	to ton ha ⁻¹ .		Deleted[Anonymous Reviewer]: The method proposed for
Bioma	ass $(\text{kg ha}^{-1}) = \text{Bic}$	omass (kg r	$m^{-2}$ ) x 10,	000 m ²								Deleted[Anonymous Reviewer]: and carbon stock is to
Bi	iomass and stored	l carbon h	ave a ca	usal relati	onship wi	th tree vol	ume value	s. <u>Therefor</u>	re, the data ob	tained was		Deleted[Anonymous Reviewer]: biomass based on a
trendl	ine was used to d	<u>etermine th</u>	ne regress	sion coeffi	cient. Acco	ording to R	uslianto et	al. (2019),	the relationshi	porynomiai ps between		Deleted[Anonymous Reviewer]: are used
$\hat{\mathbf{y}}$	ass and free diment= a + bX	sions can b	be analyse	as follo	ws:							Deleted[Anonymous Reviewer]: According to the Indon
in	which: Y = Estim	ated value	of bioma	ss, $X = Vo$	olume (m ³ )	a, b = reg	ression con	nstant				Delated[Anonymous Povisuus]. Determination of
												Deleted[Anonymous keviewer]. Determination of
				RESUL	TS AND E	DISCUSSI	ON					Deleted[Anonymous Reviewer]: I
Grow	th of <i>Tectona gra</i>	ndis										Deleted[Anonymous Reviewer]:
Grow	th of Tectona gran	dis <u>at</u> <i>Plot</i>	I			1 / 1		6.2	2 1 1	.1 • •.• 1		Deleted[Anonymous Reviewer]: S
numbe	grandis stands c	ultivated <u>a</u> duals. As the	he stands	grew, it e	nning wer xperienced	a reductio	n in the nu	g of 3m x mber of tre	s due to natura	al mortality		Deleted[Anonymous Reviewer]: G
or thir	nning activity, The	number o	of trees, di	iameter, he	eight, total	volume an	d incremen	it of teak ar	e presented in 7	Table 1.		Deleted[Anonymous Reviewer]: T
Table	1. The table growth	of T. grand	<i>lis</i> in <mark>P</mark> lot I	[								Deleted[Anonymous Reviewer]: V
Age	n	d	h	f	TV	MAI	CAI	BA	Biomass	Carbon 1		Delated (Anonymous Poviouse), D
2	910	3.1	2	0.8	1.10	0.55		0.69	0.96	0.45		Deleted[Anonymous Reviewer]: B
4	880 750	5.9 ° °	3.5	0.8	6.73 0.22	1.68	2.82	2.40	5.86 16.84	2.76		Deleted[Anonymous Reviewer]: f
/ 9	750 700	8.8 10.9	5.5 6.3	0.8	9.33 2.90	2.76 3.66	4.20 6.79	4.56 6.53	28.66	13.47		Deleted[Anonymous Reviewer]: ct
10	610	12.4	6.9	0.8	40.88	4.09	7.97	7.36	35.60	16.73		Formatted[Anonymous Reviewer]: Indent: First line: 0 mm
15	600	20.0	7.5	0.7	98.91	6.59	11.61	18.84	86.15	40.49		Deleted[Anonymous Reviewer]: I
												Deleted[Anonymous Reviewer]: T
												Deleted[Anonymous Reviewer]: amounting to
												Deleteu[Anonymous Reviewer]: amounting to

20	570	26.0	7.8	0.7	165.79	8.29	13.38	30.25	144.40	67.87
25	560	31.0	7.8	0.7	230.66	9.23	12.97	42.25	200.91	94.43
30	550	37.5	7.9	0.6	287.79	9.59	11.43	60.71	250.66	117.81
32	500	40.4	8.0	0.6	307.50	9.61	9.86	64.06	267.83	125.88
34	460	42.0	8.5	0.6	324.86	9.55	8.68	63.70	282.95	132.99
35	400	45.0	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

132Notes: N = number of individuals of T. grandis (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total133volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area134(m²ha)

135

143

Based on the table above, it can be explained that at <u>a one-hectare of plot L there were 910 individuals at the age of 2</u> years trees with the average diameter of 3.1 cm, height of 2 meters and total volume of 1.10 m³ha⁻¹. At the age of 35 years, the number of individuals were reduced to 400 with average diameter of 45 cm, height of 8.7 meters and total volume of 331.91 m³ha⁻¹. Meanwhile, the <u>mean annual increment of volume</u> ranged from 0.55 to 9.61 m³ha⁻¹year⁻¹. The maximum total volume of teak reached at the age of 32 years with 307.50 m³ ha⁻¹ with mean annual increment (MAI) of 9.61 and current annual increment (CAI) of 9.86 m³ha⁻¹year⁻¹ with the number of individuals of 500 trees per hectare. The graphical presentation of MAI and CAI of teak in plot I is presented in Figure 2.



144 145

147

146 Figure 2. The <u>curves</u> of MAI and CAI of *T. grandis* at Plot I

Based on Figure 2, it can be explained that the MAI and CAI increments of teak initially increased and met at one point, namely at the age of 32 years. This means that the maximum increment of teak is reached at the age of 32 years. After experiencing maximum increment at the age of 32 years, the teak will experience a decline after such age. This is supported by a simple linear regression test with a polynomial type on MAI which has an  $R^2$  value of 99%. This value means that there is a close relationship between age and the MAI increment of 99% and 1% influenced by other factors. Meanwhile, CAI has an  $R^2$  value of 97%. This value means that there is a close relationship between age and the CAI increment of 97% and 3% is influenced by other factors.

155 Growth of Tectona grandis <u>at Plot II</u>

Table 2. The table growth of *T. grandis* in Plot JI

156 Similar to Plot I, as many as 1,111 individuals of *T. grandis* were cultivated at plot II at the beginning, but these were 157 reduced to 400 individuals at the age of 30 years. The table of growth of *T. grandis at* Plot II is presented below.

158 159 160

TV f MAI CAI BA d h **Biomass** Carbon Age n 2 800 3.0 2.0 0.80 0.90 0.45 0.57 0.79 4 700 6.0 3.7 0.775.64 1.41 2.37 1.98 4.91 7 650 9.0 4.7 0.75 14.57 2.08 2.98 4.13 12.69 630 10.0 5.3 0.74 19.40 2.42 4.83 4.95 16.89 8 28.91 9 604 12.0 5.8 0.73 3.21 9.51 6.83 25.18 10 580 14.0 6.1 0.72 38.87 3.89 9.96 8.92 33.86

Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: Population of Deleted[Anonymous Reviewer]: T Deleted[Anonymous Reviewer]: D Deleted[Anonymous Reviewer]: T Deleted[Anonymous Reviewer]: V Deleted[Anonymous Reviewer]: . Deleted[Anonymous Reviewer]: B Deleted[Anonymous Reviewer]: s Deleted[Anonymous Reviewer]: a Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: the Deleted[Anonymous Reviewer]: in 1 hectare Deleted[Anonymous Reviewer]: there are 910 teak 0.37 Deleted[Anonymous Reviewer]: a 2.31 Deleted[Anonymous Reviewer]: at 5.96 7.94 Deleted[Anonymous Reviewer]: 2 years to 35 years of 3.1 to 11.83 15.91 🖠 Deleted[Anonymous Reviewer]: . While the height is 2 to

Deleted[Anonymous Reviewer]: . The total



Deleted[Anonymous Reviewer]: This value means that th ...

...

Deleted[Anonymous Reviewer]:

Formatted[Anonymous Reviewer]: Right

#### 200 Growth of Gmelina arborea

201 Growth of G. arborea at Plot I

202 G. arborea cultivated at Plot I at the beginning were planted at a distance of 3.5m x 4m, resulted in the initial number 203 of 714 individuals. Similar to teak, Gmelina stands experienced a reduction in the number of trees due to natural mortality 204 or thinning activity. The number of trees, diameter, height, total volume and increment of Gmelina at Plot I are presented in 205 Table 3.

#### 205

#### 207 **Table 3.** The table growth of G. arborea at Plot I

_	~	'
2	0	8

Age	n	d	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	660	6	4	0.90	6.71	3.36		1.87	3.67	1.72
4	570	13	5	0.87	32.89	8.22	13.09	7.56	17.96	8.44
6	550	17	5.5	0.88	60.39	10.07	13.75	12.48	32.97	15.50
8	530	21	6	0.82	90.27	11.28	14.94	18.35	49.29	23.17
10	500	23.6	7	0.79	120.89	12.09	15.31	21.86	66.01	31.02
12	470	24.6	9	0.75	150.71	12.56	14.91	22.33	82.29	38.68
15	430	28	10	0.72	190.54	12.70	13.28	26.46	104.03	48.90
20	360	32	12	0.71	248.29	12.41	11.55	28.94	135.57	63.72
25	350	34	14	0.64	284.58	11.38	7.26	31.76	155.38	73.03

209Notes: N = number of individuals of G. arborea (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total210volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area211(m²ha)

212

Based Table 3, there were 660 individuals of Gmelina with average diameter of 6 cm at the age of 2 years. At the age, 25 years, the diameter increased to 34 cm, while the height increased from 4 to 14 meters and the total volume enhanced from 6.71 to 284.58 m³ha⁻¹. The MAI ranged from 3.36 to 12.70 m³ ha⁻¹ year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years with 190.54 m³ ha⁻¹ and MAI and CAI of 12.70 and 13.28 m³ha⁻¹year⁻¹, respectively, with the number of trees per hectare were 430 trees. The curves of MAI and CAI of *G. arborea* at Plot I are presented in Figure 4.

218



Figure 4. The curves of MAI and CAI of G. arborea at Plot I

Figure 4 suggests that the MAI and CAI of *G. arborea* initially increased reached the maximum increment at the age of 15 years and then declined after such age. The simple linear regression test with a polynomial type on MAI shows an R² value of 90%, meaning that, there is a close relationship between age and the MAI increment of 91% and 9% was influenced by other factors. Meanwhile, CAI has an R² value of 98%, implying that, there is a close relationship between age and the CAI increment of 98% and 2% was influenced by other factors. Deleted[Anonymous Reviewer]: which was

Formatted[Anonymous Reviewer]: Font: 10 pt

Deleted[Anonymous Reviewer]: in

Deleted[Anonymous Reviewer]: p

Deleted[Anonymous Reviewer]: as

Deleted[Anonymous Reviewer]: using a spacing

Deleted[Anonymous Reviewer]: so

Deleted[Anonymous Reviewer]: of trees was

Deleted[Anonymous Reviewer]: trees

Formatted[Anonymous Reviewer]: Font: 10 pt

Deleted[Anonymous Reviewer]: However, at a later age, 1

Formatted[Anonymous Reviewer]: Indent: First line: 4.8 mm

•••

Formatted[Anonymous Reviewer]: Font: 10 pt

...

Deleted[Anonymous Reviewer]: The volume

Deleted[Anonymous Reviewer]: in

Deleted[Anonymous Reviewer]: p

Deleted[Anonymous Reviewer]:

Deleted[Anonymous Reviewer]:

Deleted[Anonymous Reviewer]: .

Formatted[Anonymous Reviewer]: Right

Deleted[Anonymous Reviewer]: Notes: N = Population of ....

Deleted[Anonymous Reviewer]: on the t

Deleted[Anonymous Reviewer]: above, it c

Deleted[Anonymous Reviewer]: an be explained that G.

Deleted[Anonymous Reviewer]: are

Deleted[Anonymous Reviewer]: teak

Deleted[Anonymous Reviewer]: Based on the G. arborea Deleted[Anonymous Reviewer]: The volume of *G.arbore* 

Deleted[Anonymous Reviewer]: .

Growth of G. arborea <u>at</u> Plot II

The number of trees, diameter, height, total volume and increment of Gmelina at Plot II are presented in Table 4.

Age	n	d	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	660	5	3	0.90	3.50	1.75		1.30	1.91	0.90
4	600	13.8	5.3	0.87	41.36	10.34	18.93	8.97	22.58	10.61
6	570	18.5	6.2	0.86	81.65	13.61	20.15	15.31	44.58	20.95
8	540	21.3	8	0.80	123.08	15.39	20.72	19.23	67.20	31.59
10	510	23.5	9.5	0.78	163.83	16.38	20.37	22.11	89.45	42.04
12	470	27	10	0.75	201.72	16.81	18.95	26.90	110.14	51.77
15	450	30	11	0.72	251.80	16.79	16.69	31.79	137.48	64.62
20	380	34	13	0.70	313.80	15.69	12.40	34.48	171.33	80.53
25	370	35.5	15	0.64	351.40	14.06	7.52	36.60	191.86	90.18

Notes: N = number of individuals of G. arborea (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area  $(m^2ha)$ 

The results in Table 4 shows that at Plot II, there were 660 G. arborea trees per hectare at the age of 2 years with average diameter of 5 cm. At the age of 25 years, the diameter increased to 35.5 cm, while the height increased from 3 to 15 meters and the total volume increased from 3.50 to 351.40 m³ha⁻¹. The MAL ranged from 1.75 to 16.69 m³ha⁻¹year⁻¹. The maximum total volume of G. arborea reached at the age of 15 years with 251.80 m³ ha⁻¹ and MAI and CAI of 16.79 242 and 16.69  $m^3ha^{-1}year^{-1}$ , respectively with the number of trees per hectare was 450.

243 The graphical relationship between MAI and CAI G. arborea in plot II can be seen in the image below 244



#### Figure 5. The curves of MAI and CAI of G. arborea at Plot II

Similar to Gmelina stand at Plot I, the maximum increment of Gmelina at Plot II was reached at the age of 15 years, in which the increment declined after such age. The influence of age is significant as the results of simple linear regression test with a polynomial type on MAI and CAI have an R² value of 86% and 98%, respectively.

According to Sandalayuk et al. (2018) and Sandalayuk et al. (2020), the increase in diameter reached 2.4 cm year⁻¹ at the age of 10, and resembles an increase in diameter of Jabon of 2.1 cm year-1. Meanwhile, according to our result, the increase in Gmelina diameter at the age of 10 was 2.36 cm year⁻¹. The maximum total volume of G. arborea was achieved at the age of 15 years with total volume of 190.54 m³ ha⁻¹ and MAI and CAL of 12.70 and 13.28 m³ ha⁻¹ year⁻¹, respectively with the number of trees is 430. According to Siarudin and Indrayana (2015), if Gmelina arborea is harvested at the age of 14 years, it has a total volume of 122 m³ ha⁻¹ and average diameter of 15 cm, whereas if harvested at the age of 20 years, the diameter is 20 cm and the total volume is 146 m³ ha⁻¹.

259 The graphs presented in Figures 2, 3, 4 and 5 are in line with Kristiningrum et al. (2019), Winarni et al. (2017) and 260 Dinga (2014) in which the growth of T. grandis and G. arborea exhibited certain characteristics, as follow: CAI curve 261 rapidly reached the peak and from there declined immediately, whereas the MAI curve climbed and declined slowly. 262 However, the potential growth of teak stands was better than that of gmelina stands. This is likely due to differences in

Formatted[Anonymous Reviewer]: Right Deleted[Anonymous Reviewer]: Notes: N = Population of .... Deleted[Anonymous Reviewer]: Based on the table above ... Deleted[Anonymous Reviewer]: G. arborea at plot II in  $\bigcirc$ Deleted[Anonymous Reviewer]: are Deleted[Anonymous Reviewer]: a Deleted[Anonymous Reviewer]: at 2 years to 25 years of Deleted[Anonymous Reviewer]: . Deleted[Anonymous Reviewer]: W Deleted[Anonymous Reviewer]: is Deleted[Anonymous Reviewer]: . T Deleted[Anonymous Reviewer]: from 2 years to 25 years is Deleted[Anonymous Reviewer]: Meanwhile, t Deleted[Anonymous Reviewer]: growth increment Deleted[Anonymous Reviewer]: is Deleted[Anonymous Reviewer]: an increment Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: as many as Deleted[Anonymous Reviewer]: trees Deleted[Anonymous Reviewer]: The potential growth of t ... Deleted[Anonymous Reviewer]: The corellation of MAI a ... Deleted[Anonymous Reviewer]: Based on the picture abo

Deleted[Anonymous Reviewer]: G. arborea

229

230

234

235

241

245 246

spacing and density per hectare. One of the factors that can affect the size of the stand diameter is the density and intensity of sunlight entering the stand. According to Sedjarawan et al. (2014), stand density will affect the light entering the vegetation. Stands that receive little sunlight will experience slow growth so that they have a small stem diameter. In addition, the light intensity will also have an influence on cell enlargement and differentiation such as height growth, leaf size and the structure of the leaves and stems.

- 268 269
- 269 270



271 272 273 **Figure 6**. <u>Stands of *Tecto*</u> 274

Figure 6. Stands of *Tectona grandis* at the age of 15 years with spacing of 3 m x 3 m; A) stands at Plot I; B) stands at Plot II.





Figure 7. <u>Stands of *Gmelina arborea* at the age of 15 years with spacing of 3.5 m x 4 m: A)</u> stands at Plot I. B) stands at Plot II.

#### 279 <u>Tree biomass and carbon sequestered</u>

280 The calculations of the total volume, basal area, biomass and carbon are presented in Table 5.

281

282 <u>Table 5. The total volume, basal area, biomass and carbon of each stand.</u>

Formatted[Anonymous Reviewer]: Font: Italic

Formatted[Anonymous Reviewer]: Font: Bold

Deleted[Anonymous Reviewer]: .

Deleted[Anonymous Reviewer]: Tectona grandis

Deleted[Anonymous Reviewer]: at the age of 15 years with spacing of 3 m x 3 m

Deleted[Anonymous Reviewer]: and

Formatted[Anonymous Reviewer]: Font: Bold

Deleted[Anonymous Reviewer]: .

Deleted[Anonymous Reviewer]: Tectona grandis

Deleted[Anonymous Reviewer]: the age of 15 years with spacing of 3 m x 3 m at

Deleted[Anonymous Reviewer]: A.

Formatted[Anonymous Reviewer]: Font: Bold

Deleted[Anonymous Reviewer]: at the age of 15 years with spacing of 3.5 m x 4 m

Deleted[Anonymous Reviewer]: and

Formatted[Anonymous Reviewer]: Font: Bold

Deleted[Anonymous Reviewer]: .

Deleted[Anonymous Reviewer]: Gmelina arborea

Deleted[Anonymous Reviewer]: the age of 15 years with spacing of 3.5 m x 4 m at

Deleted[Anonymous Reviewer]: C

Deleted[Anonymous Reviewer]: and biomass production

283								
	No	Tuna	Age	<u>TV</u>	<u>BA</u>	<b>Biomass</b>	<u>Carbon</u>	
	<u>INU</u>	<u>Type</u>	<u>(yr)</u>	<u>(m³ha⁻¹)</u>	<u>(m²ha-¹)</u>	<u>(ton ha⁻¹)</u>	<u>(ton ha⁻¹)</u>	
	<u>1</u>	<u>T. grandis Plot I</u>	32	307.50	<u>64.06</u>	<u>267.83</u>	125.88	
	<u>2</u>	<u>T. grandis Plot II</u>	25	254.81	43.56	<u>221.94</u>	104.31	
	<u>3</u>	<u>G. arborea Plot I</u>	<u>15</u>	<u>190.54</u>	<u>26.46</u>	<u>104.03</u>	<u>48.90</u>	
	<u>4</u>	<u>G. arborea Plot_II</u>	<u>15</u>	251.80	<u>31.79</u>	<u>137.48</u>	<u>64.62</u>	
284	Notes	: TV = Total volume (m3 ha-1).	BA = Basal area	$(m^2 ha^{-1})$				

285

286 Table 5 demonstrates that the teak stand at Plot I with the age of 32 years had the largest total volume, basal area, 287 biomass and carbon among other stands of 307.5 m³ ha⁻¹; 64.06 m² ha⁻¹; 257.83 ton ha⁻¹ and 125.88 ton ha⁻¹, respectively, 288 then followed by teak Plot II, gmelina Plot II and finally gmelina Plot I. These differences are due to the different fertility 289 level in each type of stand. The teak at Plot 2 at the age of 25 years had a total volume of 254.81 m³ ha⁻¹, basal area 43.56 290 m² ha⁻¹; biomass 221.94 ton ha⁻¹ and carbon 104.31 ton ha⁻¹. G. arborea at Plot II at the age of 15 years had a total volume 291 of 251.80 m³ ha⁻¹, basal area 31.79 m² ha⁻¹; biomass 137.48 ton ha⁻¹ and carbon 64.62 ton ha⁻¹, while G. arborea at Plot 1 292 at the age of 15 years had a total volume 190.54 m³ ha⁻¹, basal area 26.46 m² ha⁻¹; biomass 104.03 ton ha⁻¹ and carbon 293 48.90 ton ha⁻¹.

294 The amount of carbon in gmelina Plot I is almost the same as the amount of Gmelina arborea in East Kutai District, 295 East Kalimantan, Indonesia (Amirta et al, 2016). Trimanto (2014) stated that G. arborea tends to store carbon smaller with 296 19.96 ton C ha⁻¹ or 2.49 ton C ha⁻¹yr⁻¹ compared to T. grandis which can store carbon of 114.88 ton C ha⁻¹ or 9.57 ton C 297 ha⁻¹ yr⁻¹. Our results show that both younger stands of teak and gmelina produce higher tree densities when compared with 298 older stands. However, the basal area of older stands is larger than that of younger stands. This is in line with research 299 conducted by Rinnangmang et al (2020). In addition, the management of stands has a significant effect on the 300 characteristics of the stands and the soil content as a place to grow stands. Therefore, good forest managers must apply 301 intensive forest management practices optimize the benefits of plantations (Kumi et al. 2020). 302 The relationship between stand age and carbon sequestered in each type of stand is presented in Figure 8.

y = 4.84x - 22.6

 $R^2 = 0.98$ 

v

30

= 3.2x - 2.7

y = 4.02x - 1.9 $R^2 = 0.97$ 

35

40

 $R^2 = 0.99$ 

v = 4.63x - 20.8

 $R^2 = 0.96$ 

20

Age (year)

25

160

140

120

20

-20

• T.grandis Plat I

• T.grandis Plot II

G. arbore a Plot I

G. arborea Plot II



Formatted[Anonymous Reviewer]: Font: (Default)Times New Roman





304 305



10

Figure 8. The correlation between the stand age and carbon sequestered at the stands of T. grandis and G. arborea

15

307 308

306



311 Figure 9. The correlation between basal area and carbon sequestered at the stands of *T. grandis* and *G. arborea* 

312

309 310

313 Based on Figures 8 and 9, carbon sequestered has strong relationships with age and basal area, which is indicated by 314 high correlation value (R²). This result is in line with the research conducted by Kumi et al. (2019) in which teak biomass 315 estimation was very accurate and ignored differences in areas, tree characteristics and diameters that had high, constant 316 ratios, stems and sharp crowns with determination coefficient ( $R^2 = 0.99$ ) and significant (Bredu and Birigazzi 2014). 317 The increase in CO₂ gas emissions in the air causes an increase in global temperatures on earth. Information regarding 318 the amount of carbon absorbed in the plant biomass (carbon stock) in an area becomes very important information 319 (Trimanto 2014). On the other hand, CO₂ is an important component in the photosynthesis process and the carbon dioxide 320 absorbed by forest stands compose carbohydrates as a result of photosynthesis which will be stored in the form of biomass. 321 Therefore, the amount of above-ground biomass can be used as a basis for determining the amount of carbon stock or the 322 amount of CO₂ absorbed and stored by the stands (Uthbah et al. 2017). According to Sardjono et al. (2017), biomass has a 323 very strong relationship with photosynthesis process. Biomass increases because plants absorb CO₂ from the air and 324 convert it into organic compounds through the process of photosynthesis.

Putri and Wulandari (2015) stated that the biomass of a stand can be estimated using an allometric equation whose parameter is the diameter of the stand. The large diameter of the stands causes the greater the biomass and carbon stored, and vice versa, the smaller the stand diameter, the smaller the biomass and carbon stored in it. The tree allometric equation can yield some estimates on standing volume, biomass and carbon stock. The equation obtained is a statistical model used to explain the relationship between the various components of a tree stand. It allows foresters to take simple measurements of tree stands, such as measuring diameter, height, biomass and carbon (Kasim et al. 2014).

Tuheteru (2011) explain that age is very influential in the sequestration of carbon. If the trees are getting older, their 331 332 ability to absorb carbon is also high. Measurement of forest biomass in this research was conducted on the whole tree, 333 consisted of aboveground biomass of stems, branches, and leaves. In addition, it turns out that the number of trees per 334 hectare and the density of the stands greatly affect the presence of biomass and carbon. This means that the denser and 335 healthier the stand, the greater the amount of biomass and carbon, (Juwari et al. 2020b). This is in line with research 336 conducted by Krisnawati et al (2017) that there is a close relationship between age and carbon in A. cadamba. While 337 Polosakan et al. (2014) and Uthbah et al. (2011) stated that the difference in the amount of biomass above the soil surface 338 is influenced by the age of the stands. Stand age has an effect on biomass because stand age affects the volume of stems 339 and density of stand wood. The older the stand, the higher the volume and density of wood stands.

340 The results of this study show that T. grandis stands had higher total stored carbon compared to G. arborea. The ability 341 of T. grandis trees to absorb carbon dioxide  $(CO_2)$  makes this plant the most stored carbon among tree species other. According to Lubis et al. (2013), the increase in biomass and carbon stored by trees goes hand in hand with the increase in 342 343 the dimensions of the stem includes the diameter and height. Forest plantations play a critical role in mitigating the various 344 effects of environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its 345 consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this 346 study revealed that Tectona grandis and Gmelina arborea has a great potential in promoting carbon sequestration 347 especially when they are allowed to grow older. Favorable growth conditions have high potential of increasing the biomass 348 accumulation of this species. Hence, it is recommended that sustainable management of this plantation should be 349 paramount in securing a cleaner environment and mitigating the effect of climate change in Indonesia.

350

#### **ACKNOWLEDGEMENTS**

We would like to express our gratitude to Umbar Sujoko for his help in creating the map of the study site. The authors would like to acknowledge the anonymous reviewers for providing constructive comments to improve the manuscript.

Formatted[Anonymous Reviewer]: Normal Deleted[Anonymous Reviewer]: . Function forests as carb ... Deleted[Anonymous Reviewer]: to know Deleted[Anonymous Reviewer]: Carbon dioxide ( Deleted[Anonymous Reviewer]: ) Deleted[Anonymous Reviewer]: . T Deleted[Anonymous Reviewer]: the Deleted[Anonymous Reviewer]: will Deleted[Anonymous Reviewer]: and Deleted[Anonymous Reviewer]: standing Deleted[Anonymous Reviewer]: close Deleted[Anonymous Reviewer]: the Deleted[Anonymous Reviewer]: Therefore, neutral soil pl Deleted[Anonymous Reviewer]: According to Deleted[Anonymous Reviewer]: Deleted[Anonymous Reviewer]: is one way of measuring .... Deleted[Anonymous Reviewer]: gives permission to Deleted[Anonymous Reviewer]: Therefore, the analysis o Deleted[Anonymous Reviewer]: was Deleted[Anonymous Reviewer]: production Deleted[Anonymous Reviewer]: were Deleted[Anonymous Reviewer]: was Deleted[Anonymous Reviewer]: deep Deleted[Anonymous Reviewer]: s Deleted[Anonymous Reviewer]: (aboveground biomass) Deleted[Anonymous Reviewer]: includes Deleted[Anonymous Reviewer]: . Deleted[Anonymous Reviewer]: Based on this statement, . Deleted[Anonymous Reviewer]: according to Deleted[Anonymous Reviewer]: was ••• Deleted[Anonymous Reviewer]: Formatted[Anonymous Reviewer]: Normal Formatted[Anonymous Reviewer]: Normal

Formatted[Anonymous Reviewer]: Normal

353

#### REFERENCES

354	Adhitya PW, Hardiansyah G, Yani A. 2013. Estimation of surface carbon content on a tree in the Ketanang Regency City Forest Area. J. Sustain Forests.	
355	2(1), 23-32.	
356	Adinugraha HA, Setiadi D. 2018. Selection of Seed Trees of Gmelina arborea Roxb. at Smallholder Forest In Bondowoso, East Java. Tropical Forest J	
357	16(1): 6-12.	
358	Alam AS, Rafiuddin, Setiawan, B. 2017. Financial analysis systems teak and elephant grass agroforestry in Samboja District Kutai Kartanegara Regency,	
359	East Kalimantan. Proceedings National Biodiversity Conservation: 136-142.	
361	Amira R, Yuliansyan, Angi EM, Anano BR, Selyono B, Hadidi MI, Sepuana HA, Lodong M, Okavianio KN. 2010. Plant diversity and energy potency of community forest in Fast Kalimantan Indonesia: Searching for fast growing wood species for energy production Nuscatera Bioscience 8: 22-30	
362	Indonesian]	
363	Anitha K, Verchot LV, Joseph S, Herold M, Manuri S, Avitabile V. 2015. A review of forest and tree plantation biomass equations in Indonesia. Ann For	
364	Sci, 72: 981-997.	
365	Arezoo S, Sankhayan PL, Hofstad O. 2014. A dynamic bio-economic model for community management of goat and oak forests in Zagros, Iran.J Ecol	
366	Econ 106: 174-185.	
368	Arias D, Alvarado J, Richter DJ, Dohrenbusch A. 2011. Productivity, aboveground biomass, nutrient uptake and carbon content in fast growing tree	
369	Birdsev R Pan Y 2015 Trends in management of the world's forests and impacts on carbon stocks. For Ecol Manag 355: 83-90	
370	Bredu AS, Birigazzi L. 2014. Proceedings of the regional technical workshop on tree volume and biomass allometric equations in west africa. UN-	
371	-REDD Programme MRV Report 21, Kumasi, Ghana, Forestry Research Institute of Ghana. Food and Agriculture Organization of the United	
372	Nations, Rome, Italy.	
373	Brown S. 1997. Estimating biomass and biomass change of tropical forests: A primer, FAO Forestry Paper 134, Rome: Food Agriculture Organisation of	
3/4	the United Nations.	
375	under climate change and various in Italy. Ecocyst. Heal Sustain 1 (8): 1. 9	
377	Chauban SK, Sharma R, Panwar P, Chander J. 2016a. Short rotation forestry: a path for economic and environmental prosperity. In: Parthiban KT.	
378	Seenivasan R (eds.), Forestry Technologies - A Complete Value Chain Approach. Vol.1 Scientific Publishers, Jodhpur.	
379	Chauhan SK, Ritu, Chauhan R. 2016b. Carbon sequestration in plantations. Agroforestry for increased production and livelihood security (Eds. Gupta,	
380	S.K., Panwar, P. and Kaushal, R.). New Indian Publishing Agency, New Delhi.	
381	Chave J, Réjou MM, Búrquez A, ChidumayoE, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez YrízarA,	Formattad[Anonymous Daviawar], Indenasian
382	Mugasha WA, Muller Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz ME, Pelissier R, Ploton P, Ryan CM, SaldarRJG, Wildan C. 2014. Length and the strength of the strength o	Formatted[Anonymous Reviewer]: Indonesian
384	Vienicen G. 2014. improved anometric models to estimate the aboveground biomass of tropical trees. Glob. Change Biol 20: 51/7–5190.	
385	confera Forests 11/284): 1-14	
386	Dinga E. 2014. On a possible predictor of the cyclical position of the economy. Procedia Econ Finance 8:254-261.	
387	Domec JC, Ward EJ, Oishi AC, Palmroth S, Radecki A, Bell DM, Miao G, Gavazzi M, Johnson DM, King JS, McNulty, SG, Oren R, Sun G, Noormets	
388	A. 2015. Conversion of natural forests to managed forest plantations decreases tree resistance to prolonged droughts. For Ecol Manag 355: 58-71.	
389	Durkaya B, Durkaya A, Makineci E, Karaburk T. 2013. Estimating above ground biomass and carbon stock of individual trees in uneven-aged Uludag	
390	FIT Stands. Fresentus Environ Bull 22 (2): 428-434. Edson C. Wing MG, 2011. Airborne Light Detection and Ranging (LiDAR) for individual tree stem location, height, and hiomass measurements. Remote	
392	Sens 3 (11): 2494-2528.	
393	Ekholm T. 2016. Optimal forest rotation age under eficient climate change mitigation. For Policy Econ. 62: 62-68.	
394	Gonzalez-Benecke CA, Samuelson LJ, Martin TA, Cropper Jr WP, Johnsen KH, Stokes TA, Butnor JR, Anderson PH. 2015. Modeling the effects of	
395	forest management on in situ and ex situ longleaf pine forest carbon stocks. For Ecol Manag 355: 24-36.	
390 307	Gren IM, Zeleke AA. 2016. Policy design for forest carbon sequestration: a review of the literature. For Policy Econ. /0: 128–156.	
398	Hairiah K. Andree A. Rika RS. Subekti R. 2011. Measurement of carbon stock from land level to landscape 2nd edition. Boyor: Agroforestry Center	
399	Irundu D, Beddu MA, Najmawati. 2020. Potential of biomass and carbon stored stands in green open space Polewali City, West Sulawesi. J Forests	
400	Communities 12 (1): 49-57.	
401	Juwari, Ruhiyat D, Aipassa MI, Ruslim Y. 2020a. Carbon stocks of <i>Rhizhopora apiculata</i> and <i>Sonneratia alba</i> of mangrove forest in Ngurah Rai Forest	
402	Park, Bali Province, Indonesia. J Biodivers Environ Sci, 16(3): 93-105.	
403	Juwari, Kuhiyat D, Aipasaa MI. 2020. Growth analysis of <i>Rhizophora Mucronata m</i> angrove in Ngurah Rai Forest Park (Sanur) Bali Province, Indonesia.	
405	Energy Environces, 10 (1), 50-55. Karvati Widiati KV Karmini Mulyadi R 2019 Development of allometric relationships for estimate above ground biomass of trees in the tropical	
406	abandoned land. Biodiversitas 20 (12): 3508-3516.[Indonesian]	
407	Kasim AR, Henry M. Danial M, Faiz M, Birigazi L. 2014. Inventory of tree biomass and volume allometric equations in Southeast Asia. FRIM, Kepong,	
408	Food and Agriculture Organization of the United Nations, Rome, Italy	
409	Krisnawati H, Kallio M, Kanninen M. 2011. Anthocephalus cadamba Miq. Ecology, silviculture and productivity. CIFOR.	
410	mangrove ecosystem in Mentawir Village Fast Kalimantan Indonesia Biodiversity, stand productivity, aboveground biomass and economic value of	
412	Kum JA, Kvereh B, Ansong M, Ansate W. 2020. Influence of management practices on stand biomass. carbon stocks and soil nutrient variability of	
413	teak plantations in a dry semi-deciduous forest in Ghana. Elsevier. Trees, Forest and People 3.	
414	Lee SY, Primavera JH, Dahdouh-Guebas F, McKee K, Bosire JO, Cannicci S, Diele K, Fromard F, Koedam N, Marchand C, Mendelssohn I, Mukherjee	
415	N, Record S. 2014. Ecological role and services of tropical mangrove ecosystems: a reassessment. Global Ecoly and Biography, 23:726-743	
410	Lubis SH, Arifin SH, Samsoedin I. 2013. Analysis of tree carbon stocks in forest landscapes city in DKI Jakarta. J Forest Sos Econ Research, 10 (1):1-	
418	20. Lukito M. Rohmatiah A. 2013. Estimated biomass and carbon of teak 5 year (Case of Nusantara Superior Teak Plantation Forest (IUN) Krowe Village.	
419	Lembevan District, Magetan Regency). Agritek J 14(1): 1-23	
420	Law BE., Waring, RH. 2015. Carbon implications of current and future effects of drought, fire and management on Pacific Northwest forests. For Ecol	
421	Manag 355: 4-14.	
422 423	Meunpong P. 2012. Nutrient and Carbon Storage in Forest Plantation, Prachuap Khiri Khan province, Thailand. Kasetsart University, Bangkok, Thailand	
424	Nemeth R. Feher S. Koman S. 2018. Utilization of fast growing plantation timber as bioenergy in Hungary JOP Conf Ser: Earth Environ Sei159	
425	012029.	
426	Nonini L, Fiala M. 2019. Estimation of carbon storage of forest biomass for voluntary carbon markets: preliminary results. J. For. Res 32(1):329-338	

sequestration: a review and hypothesis. For Ecol Manag 355: 124-140. Panwar P, Chauhan S, Kaushal R, Das DK, Ajit, Arora G, Chaturvedi OP, Jain AK, Chaturvedi S, Tewari S. 2017. Carbon sequestration potential of poplar-based agroforestry using the CO₂ FIX model in the Indo Gangetic Region of India. Trop Ecol 58 (2): 1-9. Pinheiro TF, Escada MIS, Valeriano DN, Hostert P, Gollnow F, Müller H. 2016. Forest degradation associated with logging frontier expansion in the Amazon: The BR-163 Region in Southwestern Pará, Brazil. Earth Interactions 20 (17): 1-26. Rinnamang S, Sirirueang K, Supavetch S, Meunpong P. 2020. Estimation of aboveground biomass using aerial photogrammetry from unmanned aerial vehicles in teak (Tectona grandis) plantation in Thailand. Biodiversitas 21: 2369-2376 [Indonesian]. Riutta T, Malhi Y, Kho LK, Marthews TR, Huasco WH, Khoo M. 2018. Logging disturbance shift net primary productivity and its allocation in Bornean tropical forest. J. Glob Change Biol 24 (7):2913-2928. Ruslianto M, Alviani, Maisuri, Irundu. 2019. Biomass allometric model of Rhizophora Apiculata at Polewali Mandar Regency, West Sulawesi Province. Eboni Buleti Journal 1 (1): 11-19 [Indonesian]. Pandey S, Shukla R, Saket R, Verma D. 2019. Enhancing carbon stocks accumulation through forest protection and regeneration. A review. Int. J. Environ. 8 (1): 16-21 Putri AHM, Wulandari C. 2015. Potential carbon absorption in Shorea javanica in Pekon Gunung Kemala Krui, West Lampung. Sylva Lestari 3 (2): 13-20. [Indonesian]. Polosakan R, Alhand L, Joeni SR. 2014. Estimated biomass and carbon stored in Pinus merkusii Jungh. & de Vriese In the Pine Forest Mt. Bunder, TN. GN Halimun Salak. Biology News. 13 (2): 15-120. [Indonesian]. Sandalayuk. D, Soedirman S, Pambudhi F. 2018. Reserves estimating carbon in forest city district village Bongohulawa Gorontalo. Ijrtem. 2(8), 60-63. Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2020. Carbon absorbtion of Anthocephalus macrophyllus and Swietenia macrophylla. King in Gorontalo, Indonesia, J Biodivers Environ Sci16 (5): 24-30. Sharma R, Chauhan SK, Tripathi AM. 2016. Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. Agrofor Syst 90 (4):631-644. Setiawan, B., Lahjie A.M., 2011. Financial analysis of agroforestry systems teak, sungkai, and elephant grass in Samboja Kutai District Kartanegara. Humida Tropical Forestry Vol. 4 (1) [Indonesian]. Setiawan, B., Lahjie A.M, Yusuf, S, Ruslim. 2019. Model of community forest land management production and financial simulation of super teak, solomon teak and sungkai treesin Samboja Kutai Kartanegara East Kalimantan, Indonesia. Energy and Environment Research 9(20): 48-60. Siaruddin, M and Indrayana, Y. 2015. Dynamics of carbon stock systems gmelina agroforestry in community forests in Tasikmalaya and Banjar, West Java. Wasian 4 (1): 37-46 [Indonesian]. SNI. 2011. Indonesian National Standard Number 7724. Measurement and calculation of carbon stocks - field measurement for forest carbon stock assessment. tandardization Agency. Jakarta. [Indonesian]. Siregar UJ, Narendra BH, Suryana J, Siregar CA, Weston C. 2017. Evaluation on community tree plantations as sustainable source for rural bioenergy in Indonesia. International Conference on Biomass: Technology, Application, and Sustainable Development IOP Conf. Series: Earth and Environmental Scie, 65: 1-9. Sousa VB, Cardoso S, Quilho T, Pereira H. 2011. Growth and ring width variability of teak, Tectona grandis (Verbenaceae) in an unmanaged forest East Timor. Int J Trop Biol 60(1): 483-494. Sugiyono. 2012. Qualitative and quantitative research methods and R&D. Alfabeta. Bandung. [Indonesian]. Susila, IWW. 2012. Estimation model of teak stand volume and increment in Nusa Penida, Klungkung Bali. J Plant Forest Research 9 (3): 165-178. Tacconi L, Rodrigues RJ, Maryudi A. 2019. Law enforcement and deforestation: Lessons for Indonesia and Brazil. Forest Policy Econ 108 (2019) 101943 Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A. 2016. Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. Geoderma 261: 70-79. Tong S, Berry HL, Ebi K, Bambrick H, Hu W, Green D, Hanna E, Wang Z, Butler CD. 2016. Climate change, food, water and population health in China. Bull World Health Organ 94:759-765. Trimanto. 2014. Vegetation analysis and tree biomass estimation of carbon stocks in Seven Montane Forests of Bawean Island Nature Reserve, East Java. Biology News 13(1): 321-332. Uthbah Z, Sudiana E, Yani E. 2017. Biomass analysis and carbon stock at various ages of resin stands Agathis dammara (Lamb.) Rich.) In KPH Banyumas Timur. Scripta Biologica 4(2): 119-124. Van Gardingen PR, McLeish MJ, Philips PD, Fadilah D, Tyrie G, Yasman I. 2003. Financial and ecological analysis of management options for loggedover dipterocarp forest in Indonesia Borneo. For Ecol Manag 183: 1-29.

Noormets A, Epron D, Domec JC, McNulty SG, Fox TD, Chen J, Sun G, King JS. 2015. Effects of forest management on productivity and carbon

 $\begin{array}{r} 427\\ 428\\ 429\\ 430\\ 4312\\ 433\\ 434\\ 435\\ 436\\ 437\\ 438\\ 439\\ 440\\ 4412\\ 443\\ 4445\\ 446\\ 447\\ 4489\\ 451\\ 455\\ 456\\ 457\\ 458\\ 459\\ 451\\ 455\\ 456\\ 457\\ 458\\ 459\\ 451\\ 456\\ 457\\ 458\\ 459\\ 460\\ 461\\ 462\\ 463\end{array}$ 

482

483

484

485

Warner AJ, Jamroenprucksa M, Puangchit L. 2017. Buttressing impact on diameter estimation in plantation teak (*Tectona grandis* L.f.) sample trees in northern Thailand. Agric Nat Resour 51 (6): 520-525.

Wei RP, Zhu W. 2019. Adaptability and growth of a fast-growing Neolamarckia cadamba (Robx.) Bosser clone in the South Subtropical Region of China. Open J Forestry 9, 419-438.

Winarni B, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Tengkawang cultivation model in community forest using agroforestry system in West Kalimantan, Indonesia.Biodiversitas18(2):765-772.[Indonesian].

Yunianti AD, Wahyudi, Siregar, Pari. 2011. Quality of teak clones with different planting distances. J Wood Sci Tech Tropical 9 (1): 93-100.

Zeng W, Fu L, Xu M, Wang X, Chen Z, Yao S. 2018. Developing individual tree-based models estimating aboveground biomass of five key coniferous species in China. J For Res (5): 1251–1261.

s	mujo.i	id@gr	mail.	.com										×	크는					0	Ċ3		-
	۵	0		i I	Î	C	)	Cí,	•	•	1							13 dari ba	nyak	<		•	
	Smuj kepad	o Edito a saya,	ors <s Daud</s 	smujo J, Roci	.id@gn hadi, Ar	nail.co ndi =	m>										0	Sel, 23 Fe	b 17.15		4	:	
	Ŕ	Inggri	is -	>	Indor	nesia	-	Terjem	ahkan p	esan								Nor	naktifka	an untuk: I	Inggris	×	L
	YOSE We ha Stocks Our de Smujo	P RUS ave rea s of Tec ecision ) Editori s@smu	LIM, ched ctona is: R is: R	Daud a dec grani tevisio	l Sanda dision n dis and ons Rec	alayuk egardi Gme quired	, Roc ing yo lina a	chadi Kr our sub rborea	istining mission in Goro	rum, An- to Biedi ntalo Pr	di Sał iversit ovinci	nri Alam: tas Journal e, Indonesi	of Biologica a"_	I Diversity,	"Estima	ation	Above Grour	id Biomas	as (AGE	3) and Ca	rbon		
																					~~~		
sm	ujo.id@	@gma	ail.co	om		Q	C	X	ŧ		:			×	莊		1	3 dari bar	nvak	(?) <	نوب دوب		
sm	ujo.id@	@gma	il.cc	om	Ŷ	C	C	X.	•	•	:			×	Ŧ		1	3 dari bar	nyak	() < ;	ئ <u>ي</u> ا		
sm R	ujo.id@	@gma D rA:		m	Ŷ	C	0	X4+	۲	•	:			×			1	3 dari bar	nyak	 	ئ ي ن ا		
smi R D P	ujo.id@	@gma D r A: itor and nd atta	ail.cc	hor(s)	e reviev	() ws an	C 	gested	edits fo	the m	÷	cript entitle	d "Estimatio	n Above G	크는 round B	Bioma	1 ass (AGB) an	3 dari bar d Carbon	nyak n Stocks	< : s of Tecto	> E	•••• • •	
smi R D P a	ujo.id@ eviewe ear Edi lease fi nd Gme	@gma D r A: itor and ind atta elina art	ail.cc	hor(s) l is the	e reviev	() ws and lo Pro	d sug	gested , Indon	edits fo	D or the m	anuso	cript entitle	d "Estimatio	n Above G	크는 round B	Bioma	1 ass (AGB) an	3 dari bar d Carbon	nyak n Stocks	< : s of Tecto	> e	ndis	
smi R D P a W th o	ujo.id@ eviewe ear Edi lease fi nd Gme /hile the reme. Ir verhaul	@gma P r A: itor and atta elina arl e resea n partici as sug	J Auth cched borea urch io ular,	hor(s) I is the a in G dea is there wed in	e review coronta a not ne are lot the atta	ws and lo Pro ew in e s of d ached	d sug vince ecolo ata p file.	gested , Indon gical str	edits for lesia". udies of ed in this	Dor the m f carbon s manus	: anusc and l script.	cript entitler biomass, tl Nonethele	l "Estimatio le context o ss, the mar	n Above G f study are	Tound B a (i.e. G s very p	Bioma Goror	1 ass (AGB) an ntalo) might a y written and	3 dari bar d Carbon dd the ex structure	nyak n Stocks kisting k d so tha	< : s of Tecto mowledg	> ma gran e in suc red tota	ndis ch	
smu R D P a W th o 1 T th	ujo.id@ all all all all all all all all all all	©gma p r A: itor and nd atta n partic: ar sea n partic: ar sug troduct e, I sug hen yo	J Auth d Auth ached borea arch id augest tion is ggest u are	hor(s) I is the a in G dea is there ted in s very to re- e revis	e review oronta are lot the atta long a arrang	ws and lo Pro ew in e s of d ached and dif	d sug vince ecolog ata p file. ficult Intro	gested gigested gical str to under to under duction pt.	edits fo esia". udies of ed in this erstand. as edit	or the m f carbon s manus . Also, s ed in the	anusc a and l script.	cript entitled biomass, th Nonethele elaboration ched file. S	I "Estimatio le context o ss, the mar s are out of ince many s	n Above G of study are nuscript war the contex sentences	Tound B a (i.e. G s very p t of the were de	Bioma Goror pape	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che	3 dari bar d Carbon dd the ex structured ny cases t ick the ref	n Stocks disting k d so that they are ference	c ;	e in suc red tota ng. ext and	ndis ch il	
Smi R D P a U V th o 1 T T th 2 S	ujo.id@ eviewe ear Edi lease fi nd Gme /hile the verhaul The In herefor ve list w . In the ub-distr	©gma	J Auth ached borea urch id urch id urch id urch id urch id sogest tion is ggest u are ds, fra /or di	hor(s) l is the a in G dea is there wed in s very t to re- e revis om th istrict)	e review are lot the atta long a arrang the e Figur . If so,	ws and lo Pro ew in e s of d ached and dif e the e man re 1, it pleas	d sug vince ecolog ata p file. ficult Introd uscrip seer e add	gested a, Indon gical str to und- duction pt. ms that d inform	edits for esia". udies of d in this erstand. as edit	f carbon s manus Also, s din thd tance ar	: anusc a and l script. oome e attac mong g the l	cript entitled biomass, th Nonethele elaboration ched file. S plots is qui ocation of d	d "Estimatio te context o ss, the mar s are out of ince many s te far and k each plot (i.	n Above G f study are nuscript war the contex sentences boks like th e. coordina	The second secon	Bioma Goror pape bleted locate	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che ed in differen sub-district, au	3 dari bar d Carbon dd the ex structured by cases t ck the ref t administ nd/or dist	nyak n Stocks disting k diso that they are ference trative I	c ::	e in suc red tota	undis th ll ge,	
smu R D P a W th o o 1 T T th 2 s s 3 P	ujo.id@ eviewe eear Edi lease fi dease fi dease fi herefor werhaul The In herefor we list w lin the ub-distr . In the lease p	egma r A: tor and nd attai lina arl e resea n partic as sug troduct e, I sug hen yo Methoc rovide of rovide	J Auth d Auth dched borea urch io urch io urch io ggest u are ds, fm /or di ds, H clear	hor(s) I is the a in G dea is there a revis om th istrict) low m r expla	e revier oronta a not ne are lot the atta long a arrang ing the e Figur . If so, any tim anation	ws an- lo Pro ew in e s of d ached ached ind dif e the e man re 1, it pleas we regained	d sug vvince ecologiata p file. ficult Introduscrip seer e add ere th rding	gested e, Indon gical str to unde duction pt. ms that d inform the time	edits fc eesia". udies of ed in this erstand. as edit the dist the dist	or the m f carbon s manus Also, s din the tance ar garding nt condu ta collecc	i anusc a and l script. oome e a attac mong g the l ucted stion.	cript entitled biomass, th Nonethele elaboration ched file. S plots is qu ocation of d in each plot	d "Estimation the context of ss, the mar s are out of ince many s te far and lo sach plot (i t? Each yea	n Above G If study are nuscript war the contex sentences poks like th e. coordina ar, irregular	The second secon	Bioma Goror poorly pape eleter locate ge, s	1 ass (AGB) an ntalo) might a y written and er and in mar d, please che ed in differen ub-district, a utime in 2 yea	3 dari bar d Carbon dd the ex structure ny cases t ick the ref t administ nd/or disti r, 3 year,	n Stocks disting k diso that ference trative I rict). so on),	c confusional control of the second confusion of the second confusion of the second control of the second c	ona gran e in suc red tota ng. ext and i.e. villa once?	ndis ch l ge,	

More detailed comments are provided in the attached file.

Best regards,

Reviewer

Recommendation: Revisions Required

Estimation Above Ground Biomass (AGB) and carbon stocks of *Tectona* grandis and Gmelina arborea stands in Gorontalo Province, Indonesia

Abstract. Plantation forest plays an important role to fulfill timber needs, while more recently plantation forest is increasingly acknowledged to sequester and store carbon which can mitigate climate change and also as carbon sequestration for the environment. This study aimed to calculate the stand potential, stand biomass and carbon stocks of teak (Tectona grandis) and gmelina (Gmelina arborea) stands in the context of land after being abandoned in Gorontalo Province, Indonesia. Four plots with size of one hectare each were sampled in which each species (i.e. Teak and Gmelina) consisted of two plots. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded. Data analysis included growth parameters of the stands (i.e., Mean Annual Increment/MAI and Current Annual Increment/CAI) and above-ground biomass and carbon sequestered by the stands. Simple linear regression using polynomial trendline was used to determine the relationship between variables and the degree of the relationship. The results showed that the maximum growth of teak stands at Plots I and II reached a maximum point at the age of 32 and 25 years with the total volume of 307.50 and 254.81 m³ha⁻¹, respectively. While the maximum growth of gmelina stands at Plots I and II reached a maximum point at the age of 15 years with the total volume of 190.54 and 251.80 m³ha⁻¹, respectively. The biomass content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 267.83; 221.94; 104.03 and 137.48 tons ha⁻¹. Meanwhile, the carbon content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 125.88; 104.31; 48.90; and 64.62 tons ha⁻¹. The results of the regression analysis suggest that there was strong relationship between carbon sequestered and the age of the stands as well as total basal area. The results of this study suggest that Tectona grandis is more potential to be developed as plantation forest than Gmelina arborea when aiming carbon sequestration and biomass production.

Keywords: Biomass, carbon, Gmelina arborea, growth, Tectona grandis

INTRODUCTION

There is a growing paradigm that forest management is not only aimed to produce timber and non-timber products, but also to deliver various ecosystem services. One of forest ecosystem services is the sequestration of carbon dioxide in the atmosphere through photosynthesis and to store it in forest biomass (Lukito and Rohmatiah 2013). The carbon stored in forest biomass can help mitigate climate change in the form of global warming (Birdsey and Pan, 2015; Calfapietra et al, 2015; Zeng et al. 2018; Pandey et al. 2019).

Tesfaye et al. (2016) stated that tropical forests play an important role in global carbon sequestration. Among 34 ecosystems in the world, forests in tropical regions have the highest rate of carbon sequestration due to the large amount of 35 sunlight and water in the regions which is plentiful throughout the year. These conditions are also supported by the 36 climates (i.e., temperature and humidity) that optimal for many tree species to grow. Most of carbon sequestered by the 37 forest is stored in above-ground biomass of the trees.

38 Indonesia has renewable natural resources such as plantation forests. Plantation forestry has the potential to be 39 developed as biomass storage by promoting the planting of fast growing plants. When developing plantation forest, the 40 estimation of biomass in tree stands is very important to calculate the amount and variation of C (Ekholm 2016; Gren and 41 Zeleke 2016; Riutta et al. 2018; Nonini and Fiala 2019). Biomass is also important to determine forest production to assess 42 the sustainability aspect of forest management (Rinnamang et al. 2020) since the existence of plantations requires 43 sustainability in terms of financial, ecological and social aspects (Siregar et al. 2017). If achieved across such aspects, 44 sustainable management of plantation forest would result in high production of wood products while could store a large 45 amount of carbon (Wei and Zhou 2019; Cuong et al. 2020). In addition to producing wood and biomass, sustainably 46 managed forest plantations would also provide environmental services in the form of water regulation (Chauhan et al. 47 2016b; Nemeth et al. 2018).

48 According to Gonzalez-Benecke et al. (2015), Sharma et al. (2016), Panwar et al. (2017), the length of rotation of 49 plantation forest will affect the biomass and carbon stored by the forest. The rotation length is related with the type of tree 50 species planted, either it is fast-growing or slow-growing species. The ability of fast-growing trees to absorb carbon which is faster than slow-growing species is one of the strong reasons why it is necessary to plant and cultivate fast-growing 51

52 species in plantation forests (Chauhan et al. 2016a). 53 One type of fast-growing tree species is Gmelina (*Gmelina arborea* Roxb). This tree is widely developed for industrial 54 plantations in tropical regions, such as Indonesia, Pakistan, Sri Lanka, and some countries in Southeast Asia. Gmelina can 55 live well in lowland areas up to an altitude of 1200 m above sea level with an average rainfall of 750-5000 mm year⁻¹ 56 (Adinugraha and Setiadi 2018). Other tree species that is widely cultivated is Teak (*Tectona grandis* Linn.f.). Teak is an 57 important commercial timber tree which has a high selling price (Warner et al. 2017) due to the timber is relatively light

58 with high durability and resistant to fire as well as easy to work on (Meunpong 2012).

59 One important parameter when estimating the biomass of tree stands is allometric equation. Yet, in several regions and 60 particular contexts of land management, the allometric equation is not adequately formulated (Karyati et al., 2019). This 61 study aimed to calculate the stand potential, stand biomass and carbon stocks of Teak and Gmelina stands in the context of 62 land after being abandoned in Gorontalo, Indonesia. We expected that this research can develop allometric equation for

63 estimating AGB with a coefficient of determination that can predict biomass and carbon stock in such land management.

64

MATERIALS AND METHODS

65 Study period and area

The study was conducted from September 2020 to December 2020 in Gorontalo Province. The field experiments were conducted at four plots, consisting of two plots of *Tectona grandis* and two plots of *Gmelina arborea*. Location plot A was Gmelina in Dulupi Village, Boalemo Regency. Location plot B was Teak in the village of Bakti, Wono District, Boalemo Regency. Location plot C was Gmelina, Bakti Village, Wono District, Boalemo Regency and location plot D was Teak in Haya-Haya Village, Gorontalo District. The coordinate of plot A was located at 122°36'12.888''E and 0°37'47.828'N. Plot B was located at 122°42'22.942''E and 0°37'43.117'N. Plot C was located at 122°43'51.600''E and 20°37'55.966'N. Plot D was located at 122°49'15.397''E and 0°38'46.017'N (Figure 1).





74 75 76 77 78

Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: $\mathbf{A} = G$. *arborea* plot II, $\mathbf{B} = T$. *grandis* plot I, $\mathbf{C} = G$. *arborea* plot I, $\mathbf{D} = T$. *grandis* plot II.

78 79

80 **Data collection procedure**

81 The determination of the study locations (Figure 1). Each plot of tree stand (Figure 1) had the extent of 1 hectare with 82 different planting distance. The planting distance of *Tectona grandis* stand was $3m \times 3m$, while that of *Gmelina arborea* 83 was 3.5m × 4m. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded. Data 84 collection related to diameter and height was carried out from 2 until 15 year. Measurements were carried out twice a year. 85 While those over 15 years of age are simulated mathematically using simple linear regression to find the closeness of the 86 regression coefficient relationship between age and increment. This study is also based on research conducted by Sist et al. 87 (2003), that the formation of arithmetic simulation models and logical operations on the yield cycle and sustainable 88 harvesting in lowland dipterocarp mixed forest on the island of East Kalimantan can be estimated using simple linear 89 regression. 90

Formatted[Yosep Ruslim]: Font color: Auto

Deleted[Yosep Ruslim]: x

Deleted[Yosep Ruslim]: x

Formatted[Yosep Ruslim]: Font color: Auto

Formatted[Yosep Ruslim]: Font color: Auto

91 92 93 94 95 96 97 98 99 100 101 102	Data analysis <i>Estimating the growth (MAI and CAI)</i> The data collection includes diameter, plant species as high as 1.3 m from the soil surface (cm). Carbon (C) storage (kg per year) can be estimated by multiplying the tree biomass (Y: kg) with the general vegetation carbon content, namely (0.46) (Hairiah and Rahayu 2007). Carbon stock calculations were also carried out on cultivated plants <i>Tectona grandis</i> (teak) and <i>Gmelina arborea</i> (white teak) planted on land by the community. The maximum production of the stand of <i>T. grandis</i> and <i>G. arborea</i> was analyzed by calculating the growth increments of tree in a particular measurement time span (cycle), namely mean annual increment (MAI) and current annual increment (CAI). Van Gardingen et al. (2003) state that increment is defined as an increase in the dimensional growth (height, diameter, base plane, volume) or an increase in the standing stock of a tree, in relation to the tree age or a particular period. The volume of the tree was calculated using following equation: $V = \frac{1}{\pi} d^2 b f$	
102 103 104 105 106 107	in which: V = standing volume, d = diameter at breast height (DBH), h = branch-free height, f = form factor According to Van Gardingen et al. (2003), to estimate the mean annual increment (MAI) and the current annual increment, the following formulas were used: $MAI = \frac{V_t}{t}$	Deleted[Anonymous Reviewer]: $\frac{1}{4}\pi d^2hf$
108 109 110 111 112 113	in which: MAI = mean annual increment, V _t = total volume in ages t ₀ - t (m ³), t = age (years) $CAI = \frac{V_t - V_{t-1}}{T}$ in which: CAI = current annual increment, V _t = total volume in ages t ₀ - t (m ³), V _{t-1} = previous total volume (m ³), T = second age t ₀ - t, minus the first age (in year)	
114 115 116 117 118 119 120	<i>Estimating tree biomass and carbon</i> Tree biomass can be estimated by incorporating tree height, trunk diameter and wood density (Chave et al. 2014). The biomass was calculated according to Indonesian National Standard [SNI] number 7724 (2011) and Irundu et al. (2020) using the following formula: $M = BJ \times V_t \times BEF$ in which: M = tree biomass (kg), BJ = specific gravity (kg m ⁻³), V _t = total volume (m ³), BEF = Biomass Expansion Factor (1.3)	Deleted[Yosep Ruslim]: ,
121 122 123 124 125 126	While carbon storage was calculated as follow: Cb = B × % C Organic in which: Cb = Carbon content of biomass (kg), B = total biomass (kg), % C Organic = Percentage value of carbon content, which is 0.47 (Hairiah et al. 2011). The total biomass (kg), B = total biomass (kg), % C Organic = Percentage value of carbon	
127 128 129 130 131 132 133 134 135 136	The total biomass was calculated by multiplying the biomass obtained per plot with the conversion unit to ton ha ⁻¹ . According to Adhitya et al. (2013), the calculation of the biomass content per hectares was as follow: Biomass (kg ha ⁻¹) = Biomass (kg m ⁻²) $\leq 10,000 \text{ m}^2$ Biomass and stored carbon have a causal relationship with tree volume values. Therefore, the data obtained was analyzed mathematically using simple linear regression to find relationship between age and increment, while polynomial trendline was used to determine the regression coefficient. Determination of the value of biomass and stored carbon can be determined through a volume value approach. According to Ruslianto et al. (2019), the relationships between biomass and tree dimensions can be analysed as follows: $\hat{Y} = a + bY$	Deleted[Yosep Ruslim]: x
137 138	in which: \hat{Y} = Estimated value of biomass, X = Volume (m ³), a, b = regression constant	Deleted[Anonymous Reviewer]:

RESULTS AND DISCUSSION

140 Growth of Tectona grandis

141 Growth of Tectona grandis at Plot I

142 T. grandis stands cultivated at Plot I at the beginning were planted at a spacing of $3m \times 3m$, resulted in the initial 143 number of 1,111 individuals. As the stands grew, it experienced a reduction in the number of trees due to natural mortality 144 or thinning activity. The number of trees, diameter, height, total volume and increment of teak are presented in Table 1.

139

146

147 Table 1. The table growth of T. grandis in Plot I

Age	n	d	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	910	3.1	2	0.8	1.10	0.55		0.69	0.96	0.45
4	880	5.9	3.5	0.8	6.73	1.68	2.82	2.40	5.86	2.76
7	750	8.8	5.3	0.8	9.33	2.76	4.20	4.56	16.84	7.91
9	700	10.9	6.3	0.8	2.90	3.66	6.79	6.53	28.66	13.47
10	610	12.4	6.9	0.8	40.88	4.09	7.97	7.36	35.60	16.73
15	600	20.0	7.5	0.7	98.91	6.59	11.61	18.84	86.15	40.49
20	570	26.0	7.8	0.7	165.79	8.29	13.38	30.25	144.40	67.87
25	560	31.0	7.8	0.7	230.66	9.23	12.97	42.25	200.91	94.43
30	550	37.5	7.9	0.6	287.79	9.59	11.43	60.71	250.66	117.81
32	500	40.4	8.0	0.6	307.50	9.61	9.86	64.06	267.83	125.88
34	460	42.0	8.5	0.6	324.86	9.55	8.68	63.70	282.95	132.99
35	400	45.0	87	0.6	331 91	9 48	7.05	63 59	289.10	135.88

149 Notes: N = number of individuals of T. grandis (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total 150 volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area 151 (m²ha)

152

Based on the table above, it can be explained that at a one-hectare of plot I there were 910 individuals at the age of 2 153 years trees with the average diameter of 3.1 cm, height of 2 meters and total volume of 1.10 m³ha⁻¹. At the age of 35 years,

154 the number of individuals were reduced to 400 with average diameter of 45 cm, height of 8.7 meters and total volume of

155 331.91 m³ha⁻¹. Meanwhile, the mean annual increment of volume ranged from 0.55 to 9.61 m³ha⁻¹year⁻¹. The maximum

156 total volume of teak reached at the age of 32 years with 307.50 m³ ha⁻¹ with mean annual increment (MAI) of 9.61 and

157 current annual increment (CAI) of 9.86 m³ha⁻¹year⁻¹ with the number of individuals of 500 trees per hectare.

158 The graphical presentation of MAI and CAI of teak in plot I is presented in Figure 2.

159





162 Figure 2. The curves of MAI and CAI of T. grandis at Plot I

163 164

Based on Figure 2, it can be explained that the MAI and CAI increments of teak initially increased and met at one point, namely at the age of 32 years. This means that the maximum increment of teak is reached at the age of 32 years. After experiencing maximum increment at the age of 32 years, the teak will experience a decline after such age. This is

165 166

¹⁴⁵

167 supported by a simple linear regression test with a polynomial type on MAI which has an R^2 value of 99%. This value

168 means that there is a close relationship between age and the MAI increment of 99% and 1% influenced by other factors.

169 Meanwhile, CAI has an R^2 value of 97%. This value means that there is a close relationship between age and the CAI 170 increment of 97% and 3% is influenced by other factors.

171 *Growth of* Tectona grandis at *Plot II*

Similar to Plot I, as many as 1,111 individuals of *T. grandis* were cultivated at plot II at the beginning, but these were reduced to 400 individuals at the age of 30 years. However, at a later age, the teak stands experienced a reduction in the

174 <u>number of trees due to natural mortality or due to thinning activities.</u> The table of growth of *T. grandis at* Plot II is 175 presented below.

175 pr 176

177 **Table 2.** The table growth of *T. grandis* in Plot II

178

Age	n	D	h	f	TV	MAI	CAI	BA	Biomass	Carbon		Deleted[Aponymous Reviewer];
2	800	3.0	2.0	0.80	0.90	0.45		0.57	0.79	0.37		Deleteu[Allohymous Reviewer].
4	700	6.0	3.7	0.77	5.64	1.41	2.37	1.98	4.91	2.31 <		Formatted[Anonymous Reviewer]
7	650	9.0	4.7	0.75	14.57	2.08	2.98	4.13	12.69	5.96 <		
8	630	10.0	5.3	0.74	19.40	2.42	4.83	4.95	16.89	7.94 💎		Formatted[Anonymous Reviewer
9	604	12.0	5.8	0.73	28.91	3.21	9.51	6.83	25.18	11.83	È.	Formatted[Anonymous Reviewer
10	580	14.0	6.1	0.72	38.87	3.89	9.96	8.92	33.86	15.91		Tormattea[Anonymous neviewer
15	560	21.5	7.7	0.72	112.66	7.51	14.76	20.32	98.12	46.12		Formatted[Anonymous Reviewer
20	550	26.5	8.5	0.70	180.40	9.02	13.55	30.32	157.13	73.85		
25	500	31.6	9.0	0.65	229.28	9.17	9.78	39.19	199.70	93.86		Formatted[Anonymous Reviewer
30	400	38.0	9.3	0.60	253.82	8.46	4.91	45.34	221.08	103.91	$\left(\begin{array}{c} 1 & 1 \\ 0 & 1 \end{array} \right)$	Formatted[Anonymous Reviewer

179Notes: N = number of individuals of T. grandis (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total180volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area181(m²ha)

182 183 The results in Table 2 showed that at Plot II there were 800 individuals of teak at the age of 2 years with average 184 diameter of 3 cm, height of 2 meters and total volume of 0.90 m³ ha⁻¹. At the age of 30 years, the number of individuals 185 were reduced to 400 trees with average diameter of 38 cm, height of 9.3 meters and total volume of 229.28 m³ ha⁻¹. The

growth increment ranged from 0.45 to 9.17 m³ ha⁻¹ year⁻¹ with the maximum total volume of teak reached at the age of 25

years with 229.28 m³ ha⁻¹ and MAI dan CAI of 9.17 and 9.78 m³ ha⁻¹year⁻¹, respectively with the number of trees per
 hectare as many as 500 trees.

189 The graphical presentation of MAI and CAI of teak at Plot II can be seen in Figure 3.

190





194

193 Figure 3. The curves of MAI and CAI of *T. grandis* at Plot II

Based on Figure 3, it can be explained that the MAI and CAI increments initially increased and met at one point, namely the age of 32 years. This means that the maximum increment of teak was reached at the age of 25 years and then declined after such age. After experiencing a maximum increment at the age of 25 years, the teak after the age of 25 years will experience a decline. The curves also suggest that there is a close relationship between age and MAI and CAI in which both parameters have high This is supported by a simple linear regression test with a polynomial type on MAI which has an R² value of 95% and. This value means that there is a close relationship between age and MAI increment of

	,	
	Formatted[Anonymous Reviewer]:	Right
Ì	Formatted[Anonymous Reviewer]:	Right
ĺ	Formatted[Anonymous Reviewer]:	Right
Ì	Formatted[Anonymous Reviewer]:	Right

Deleted[Yosep Ruslim]:

201 95% and 5% influenced by other factors. Meanwhile, CAI has an R² value of 88%, respectively. This value means that 202 there is a close relationship between age and the CAI increment of 86% and 14% is influenced by other factors.

203 The growth pattern as shown in Figures and 3 suggests that teak growth at a young age is to be more developed. Sousa 204 et al_{*} (2011) stated that the growth of teak stands in East Timor generally shows a decline in growth along with the 205 increasing age of the stands. The growth of a tree stand, both in height and diameter, is influenced by climate and soil 206 fertility. In addition, it is also influenced by the space and surface of the canopy, relative humidity and the root system 207 (Juwari et al. 2020a).

208 The highest growth in diameter and height of the teak stands occurred in the early stages of growth, namely in the 209 range of 1-5 years of age, then there was a gradual decline in growth and was seen to decrease after 12 years of age stands. Until the stand was 12 years old, generally teak growth in East Kalimantan showed a higher growth (increment) in 210 211 diameter and height compared to several teak plant locations in Java. Alam et al. (2017), Setiawan et al. (2011) and 212 Setiawan et al. (2019) who conducted research in Samboja District, East Kalimantan Province, stated that the potential of 213 total volume and increment of "Super" teak at the age of 25 were 154.32 m³ and 6.17 m³ha⁻¹year⁻¹, respectively while 214 those in Solomon teak were 150.94 m³ and 6.04 m³ ha⁻¹ year⁻¹, respectively.

215 Other study in Nganjuk, East Java stated that the diameter increment of teak cultivated from root graft reached 25-28 216 cm at the age of 20 years, while the diameter increment of the original plant is only 1-2 cm year⁻¹. In optimal site 217 conditions, teak volume increment can reach 7.9 - 10 m³ha⁻¹year⁻¹ (Susila 2012). Yunianti et al. (2011) stated that in terms 218 of silviculture, plants with long rotation were modified to accelerate its growth in order to meet market demand. The wide 219 spacing will produce trees with big appearance, and in terms of quantity is very profitable, while in terms of wood quality, 220 plants modified to accelerate its growth will reduce its wood properties, especially the strength. As such, the effort taken 221 should be to choose a place to grow that is very suitable for the plant so that even though its growth is accelerated, the 222 quality of the wood remains stable.

223 Growth of Gmelina arborea

224 Growth of G. arborea at Plot I

225 G. arborea cultivated at Plot I at the beginning were planted at a distance of $3.5 \text{ m} \times 4 \text{ m}$, resulted in the initial number 226 of 714 individuals. Similar to teak, Gmelina stands experienced a reduction in the number of trees due to natural mortality 227 or thinning activity. The number of trees, diameter, height, total volume and increment of Gmelina at Plot I are presented in 228 Table 3. However, at a later age, the G. arborea stands experienced a reduction in the number of trees due to natural 229 mortality or due to thinning activities. Based on the G. arborea growth table, the number of trees, diameter, height, total 230 volume and increment of G. arborea can be seen as follows: 231

232 Table 3. The table growth of G. arborea at Plot I 233

Age	n	D	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	660	6	4	0.90	6.71	3.36		1.87	3.67	1.72
4	570	13	5	0.87	32.89	8.22	13.09	7.56	17.96	8.44
6	550	17	5.5	0.88	60.39	10.07	13.75	12.48	32.97	15.50
8	530	21	6	0.82	90.27	11.28	14.94	18.35	49.29	23.17
10	500	23.6	7	0.79	120.89	12.09	15.31	21.86	66.01	31.02
12	470	24.6	9	0.75	150.71	12.56	14.91	22.33	82.29	38.68
15	430	28	10	0.72	190.54	12.70	13.28	26.46	104.03	48.90
20	360	32	12	0.71	248.29	12.41	11.55	28.94	135.57	63.72
25	350	34	14	0.64	284.58	11.38	7.26	31.76	155.38	73.03

Notes: N = number of individuals of G. arborea (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area (m²ha)

Based Table 3, there were 660 individuals of Gmelina with average diameter of 6 cm at the age of 2 years. At the age 239 25 years, the diameter increased to 34 cm, while the height increased from 4 to 14 meters and the total volume enhanced from 6.71 to 284.58 m³ha⁻¹. The MAI ranged from 3.36 to 12.70 m³ ha⁻¹ year⁻¹. The maximum total volume of G. arborea reached at the age of 15 years with 190.54 m³ ha⁻¹ and MAI and CAI of 12.70 and 13.28 m³ha⁻¹year⁻¹, respectively, with 242 the number of trees per hectare were 430 trees. The curves of MAI and CAI of G. arborea at Plot I are presented in Figure 243 4

Deleted[Yosep Ruslim]:

Formatted[Yosep Ruslim]: Font color: Auto

Formatted[Yosep Ruslim]: Font color: Auto

Deleted[Yosep Ruslim]: and

Deleted[Yosep Ruslim]: x

Deleted[Yosep Ruslim]: Formatted[Yosep Ruslim]: Indonesian Deleted[Anonymous Reviewer]: . Formatted[Anonymous Reviewer]: Right Formatted[Anonymous Reviewer]: Right

240 241

244



257

249 Figure 4 suggests that the MAI and CAI of G. arborea initially increased reached and met at one point, namely the age 250 of 15 years. This means reached the maximum increment at the age of 15 years and then declined after such age. After 251 experiencing a maximum increment at the age of 15 years, the G. arborea after the age of 15 years will experience a 252 decline. The simple linear regression test with a polynomial type on MAI shows an R^2 value of 90%, meaning that there is 253 a close relationship between age and the MAI increment of 91% and 9% was influenced by other factors. Meanwhile, CAI 254 has an R² value of 98%, implying that there is a close relationship between age and the CAI increment of 98% and 2% was 255 influenced by other factors.

256 Growth of G. arborea at Plot II

The number of trees, diameter, height, total volume and increment of Gmelina at Plot II are presented in Table 4.

258 259 260 Table 4. The table growth of G. arborea at Plot II

Figure 4. The curves of MAI and CAI of G. arborea at Plot I

Deleted[Apenymous Poviewer]:		Carbon	Biomass	BA	CAI	MAI	TV	F	h	d	n	Age
Deleteu[Anonymous Reviewer].	•	0.90	1.91	1.30		1.75	3.50	0.90	3	5	660	2
Formatted[Anonymous Reviewer]: Right	•	10.61	22.58	8.97	18.93	10.34	41.36	0.87	5.3	13.8	600	4
	 	20.95	44.58	15.31	20.15	13.61	81.65	0.86	6.2	18.5	570	6
Formatted[Anonymous Reviewer]: Right		31.59	67.20	19.23	20.72	15.39	123.08	0.80	8	21.3	540	8
Formatted[Anonymous Reviewer]: Right		42.04	89.45	22.11	20.37	16.38	163.83	0.78	9.5	23.5	510	10
		51.77	110.14	26.90	18.95	16.81	201.72	0.75	10	27	470	12
Formatted[Anonymous Reviewer]: Right		64.62	137.48	31.79	16.69	16.79	251.80	0.72	11	30	450	15
		80.53	171.33	34.48	12.40	15.69	313.80	0.70	13	34	380	20
Formatted[Anonymous Reviewer]: Right		90.18	191.86	36.60	7.52	14.06	351.40	0.64	15	35.5	370	25

(m²ha)

266 267

268

269

The results in Table 4 shows that at Plot II, there were 660 G. arborea trees per hectare at the age of 2 years with average diameter of 5 cm. At the age of 25 years, the diameter increased to 35.5 cm, while the height increased from 3 to 15 meters and the total volume increased from 3.50 to 351.40 m³ha⁻¹. The MAI ranged from 1.75 to 16.69 m³ha⁻¹year⁻¹. The maximum total volume of G. arborea reached at the age of 15 years with 251.80 m³ ha⁻¹ and MAI and CAI of 16.79 and 16.69 m³ha⁻¹year⁻¹, respectively with the number of trees per hectare was 450_{\bullet}

volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area

270 The graphical relationship between MAI and CAI G. arborea in plot II can be seen in the image below

271

Formatted[Yosep Ruslim]: Indonesian

Deleted[Yosep Ruslim]: .

Formatted[Anonymous Reviewer]: Right

Formatted[Anonymous Reviewer]: Right

Formatted[Anonymous Reviewer]: Right

Formatted[Anonymous Reviewer]: Right



Figure 5. The curves of MAI and CAI of G. arborea at Plot II

Similar to Gmelina stand at Plot I, the maximum increment of Gmelina at Plot II was reached at the age of 15 years, in which the increment declined after such age. After experiencing a maximum increment at the age of 15 years, the G. arborea after the age of 15 years will experience a decline. The influence of age is significant as the results of simple linear regression test with a polynomial type on MAI and CAI have an R² value of 86% and 98%, respectively.

According to Sandalayuk et al. (2018) and Sandalayuk et al. (2020), the increase in diameter reached 2.4 cm year⁻¹ at the age of 10, and resembles an increase in diameter of Jabon of 2.1 cm year⁻¹. Meanwhile, according to our result, the increase in Gmelina diameter at the age of 10 was 2.36 cm year⁻¹. The maximum total volume of G. arborea was achieved at the age of 15 years of biological rotation with total volume of 190.54 m³ ha⁻¹ and MAI and CAI of 12.70 and 13.28 m³ ha⁻¹ year⁻¹, respectively with the number of trees is 430. According to Siarudin and Indravana (2015), if *Gmelina arborea* is harvested at the age of 14 years, it has a total volume of $122 \text{ m}^3 \text{ ha}^{-1}$ and average diameter of 15 cm, whereas if harvested at the age of 20 years, the diameter is 20 cm and the total volume is 146 m³ ha⁻¹. This means that the age of a stand also 287 influences the biomass and the amount of carbon stored in a stand (Lukito and Rohmatiah 2013). This means that the age 288 of a stand also influences the biomass and the amount of carbon stored in a stand (Lukito and Rohmatiah 2013), 289

290 The graphs presented in Figures 2, 3, 4 and 5 are in line with Kristiningrum et al. (2019), Winarni et al. (2017) and 291 Dinga (2014) in which the growth of T. grandis and G. arborea exhibited certain characteristics, as follow: CAI curve 292 rapidly reached the peak and from there declined immediately, whereas the MAI curve climbed and declined slowly. 293 However, the potential growth of teak stands was better than that of gmelina stands. This is likely due to differences in 294 spacing and density per hectare. One of the factors that can affect the size of the stand diameter is the density and intensity 295 of sunlight entering the stand. According to Sedjarawan et al. (2014), stand density will affect the light entering the 296 vegetation. Stands that receive little sunlight will experience slow growth so that they have a small stem diameter. In 297 addition, the light intensity will also have an influence on cell enlargement and differentiation such as height growth, leaf 298 size and the structure of the leaves and stems. 299

Deleted[Yosep Ruslim]:

Formatted[Yosep Ruslim]: Font: Not Bold

Formatted[Yosep Ruslim]: Indonesian

Formatted[Anonymous Reviewer]: Font: Italic

Formatted[Anonymous Reviewer]: Font: Italic

300 301

272 273



Figure 6. Stands of *Tectona grandis* at the age of 15 years with spacing of 3 m_x×3 m: A) stands at Plot I; B) stands at Plot II.



Figure 7. Stands of *Gmelina arborea* at the age of 15 years with spacing of 3.5 m × 4 m: A) stands at Plot I; B) stands at Plot II.

Deleted[Yosep Ruslim]: x

Tree biomass and carbon sequestered

The calculations of the total volume, basal area, biomass and carbon are presented in Table 5.

Table 5. The total volume, basal area, biomass and carbon of each stand.

Ne	Tune	Age	TV	BA	Biomass	Carbon
INO	Type	(yr)	(m ³ ha ⁻¹)	(m ² ha ⁻¹)	(ton ha ⁻¹)	(ton ha ⁻¹)
1	T. grandis Plot I	32	307.50	64.06	267.83	125.88
2	T. grandis Plot II	25	254.81	43.56	221.94	104.31
3	<i>G. arborea</i> Plot I	15	190.54	26.46	104.03	48.90

Deleted[Yosep Ruslim]: x

4 G. <i>arborea</i> Flot II 15 251.80 51.79 157.48 04.02
--

315 Notes: $TV = Total volume (m^3 ha^{-1})$, $BA = Basal area (m^2 ha^{-1})$

316

317 Table 5 demonstrates that the teak stand at Plot I with the age of 32 years had the largest total volume, basal area, 318 biomass and carbon among other stands of 307.5 m³ ha⁻¹; 64.06 m² ha⁻¹; 257.83 ton ha⁻¹ and 125.88 ton ha⁻¹, respectively, 319 then followed by teak Plot II, gmelina Plot II and finally gmelina Plot I. These differences are due to the different fertility 320 level in each type of stand. The teak at Plot 2 at the age of 25 years had a total volume of 254.81 m³ ha⁻¹, basal area 43.56 321 m² ha⁻¹; biomass 221.94 ton ha⁻¹ and carbon 104.31 ton ha⁻¹. G. arborea at Plot II at the age of 15 years had a total volume 322 of 251.80 m³ ha⁻¹, basal area 31.79 m² ha⁻¹; biomass 137.48 ton ha⁻¹ and carbon 64.62 ton ha⁻¹, while G. arborea at Plot 1 323 at the age of 15 years had a total volume 190.54 m³ ha⁻¹, basal area 26.46 m² ha⁻¹; biomass 104.03 ton ha⁻¹ and carbon 324 48.90 ton ha⁻¹.

325 The amount of carbon in gmelina Plot I is almost the same as the amount of Gmelina arborea in East Kutai District, 326 East Kalimantan, Indonesia (Amirta et al 2016). Trimanto (2014) stated that G. arborea tends to store carbon smaller with 327 19.96 ton C ha⁻¹ or 2.49 ton C ha⁻¹yr⁻¹ compared to T. grandis which can store carbon of 114.88 ton C ha⁻¹ or 9.57 ton C 328 ha⁻¹ yr⁻¹. Our results show that both younger stands of teak and gmelina produce higher tree densities when compared with 329 older stands. However, the basal area of older stands is larger than that of younger stands. This is in line with research 330 conducted by Rinnamang et al. (2020). In addition, the management of stands has a significant effect on the characteristics 331 of the stands and the soil content as a place to grow stands. Therefore, good forest managers must apply intensive forest

Deleted[Yosep Ruslim]: ,

Formatted[Yosep Ruslim]: Font color: Auto

332 management practices optimize the benefits of plantations (Kumi et al. 2020). 333

The relationship between stand age and carbon sequestered in each type of stand is presented in Figure 8. 160



334 335

Figure 8. The correlation between the stand age and carbon sequestered at the stands of T. grandis and G. arborea 336

337 Meanwhile, the relationship between basal area and carbon sequestered in each type of stand is presented in Figure 9.

338 339



340 341

342 Figure 9. The correlation between basal area and carbon sequestered at the stands of T. grandis and G. arborea 343

344 Based on Figures 8 and 9, carbon sequestered has strong relationships with age and basal area, which is indicated by 345 high correlation value (R²). This result is in line with the research conducted by Kumi et al. (2020) in which teak biomass

346 estimation was very accurate and ignored differences in areas, tree characteristics and diameters that had high, constant 347 ratios, stems and sharp crowns with determination coefficient ($R^2 = 0.99$) and significant (Bredu and Birigazzi 2014).

348 The increase in CO₂ gas emissions in the air causes an increase in global temperatures on earth. Information regarding 349 the amount of carbon absorbed in the plant biomass (carbon stock) in an area becomes very important information 350 (Trimanto 2014). On the other hand, CO_2 is an important component in the photosynthesis process and the carbon dioxide 351 absorbed by forest stands compose carbohydrates as a result of photosynthesis which will be stored in the form of biomass. 352 Therefore, the amount of above-ground biomass can be used as a basis for determining the amount of carbon stock or the 353 amount of CO₂ absorbed and stored by the stands (Uthbah et al. 2017). According to Sardjono et al. (2017), biomass has a 354 very strong relationship with photosynthesis process. Biomass increases because plants absorb CO₂ from the air and 355 convert it into organic compounds through the process of photosynthesis.

356 Putri and Wulandari (2015) stated that the biomass of a stand can be estimated using an allometric equation whose 357 parameter is the diameter of the stand. The large diameter of the stands causes the greater the biomass and carbon stored, 358 and vice versa, the smaller the stand diameter, the smaller the biomass and carbon stored in it. The tree allometric equation 359 can yield some estimates on standing volume, biomass and carbon stock. The equation obtained is a statistical model used 360 to explain the relationship between the various components of a tree stand. It allows foresters to take simple measurements 361 of tree stands, such as measuring diameter, height, biomass and carbon (Kasim et al. 2014).

362 Tuheteru (2011) explain that age is very influential in the sequestration of carbon. If the trees are getting older, their ability to absorb carbon is also high. Measurement of forest biomass in this research was conducted on the whole tree, 363 364 consisted of aboveground biomass of stems, branches, and leaves. In addition, it turns out that the number of trees per 365 hectare and the density of the stands greatly affect the presence of biomass and carbon. This means that the denser and 366 healthier the stand, the greater the amount of biomass and carbon (Juwari et al. 2020b). This is in line with research 367 conducted by Krisnawati et al (2017) that there is a close relationship between age and carbon in A. cadamba. While 368 Polosakan et al. (2014) and Uthbah et al. (2011) stated that the difference in the amount of biomass above the soil surface 369 is influenced by the age of the stands. Stand age has an effect on biomass because stand age affects the volume of stems 370 and density of stand wood. The older the stand, the higher the volume and density of wood stands.

371 The results of this study show that T. grandis stands had higher total stored carbon compared to G. arborea. The ability 372 of T. grandis trees to absorb carbon dioxide (CO_2) makes this plant the most stored carbon among tree species other. 373 According to Lubis et al. (2013), the increase in biomass and carbon stored by trees goes hand in hand with the increase in 374 the dimensions of the stem includes the diameter and height. Forest plantations play a critical role in mitigating the various 375 effects of environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its 376 consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this 377 study revealed that $T_{grandis}$ and $G_{grandis}$ are great potential in promoting carbon sequestration especially when they 378 are allowed to grow older. Favorable growth conditions have high potential of increasing the biomass accumulation of this 379 species. Hence, it is recommended that sustainable management of this plantation should be paramount in securing a 380 cleaner environment and mitigating the effect of climate change in Indonesia.

381

ACKNOWLEDGEMENTS

382 We would like to express our gratitude to Umbar Sujoko and Muhammad Rafii Nur Fauzan for his help in creating the 383 map of the study site. The authors would like to acknowledge Karyati, Rita Diana and anonymous reviewers for providing 384 constructive comments to improve the manuscript.

385

REFERENCES

- Adhitya PW, Hardiansyah G, Yani A. 2013. Estimation of surface carbon content on a tree in the Ketapang Regency City Forest Area. J Sustain Forests, 2(1), 23-32.
- Adinugraha HA, Setiadi D. 2018. Selection of Seed Trees of Gmelina arborea Roxb. at Smallholder Forest In Bondowoso, East Java. Tropical Forest J 16(1): 6-12.
- Alam AS, Rafiuddin, Setiawan, B. 2017. Financial analysis systems teak and elephant grass agroforestry in Samboja District Kutai Kartanegara Regency, East Kalimantan. Proceedings National Biodiversity Conservation: 136-142.
- Amirta R, Yuliansvah, Angi EM, Ananto BR, Setyono B, Haqiqi MT, Septiana HA, Lodong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast growing wood species for energy production. Nusantara Bioscience 8: 22-30. [Indonesian].
- Birdsey R, Pan Y. 2015. Trends in management of the world's forests and impacts on carbon stocks. For Ecol Manag 355: 83-90.
- 386 387 388 390 391 392 393 394 395 396 397 398 399 Bredu AS, Birigazzi L. 2014. Proceedings of the regional technical workshop on tree volume and biomass allometric equations in west africa. UN--REDD Programme MRV Report 21, Kumasi, Ghana, Forestry Research Institute of Ghana. Food and Agriculture Organization of the United Nations, Rome, Italy,
- Calfapietra C, Barbati A, Perugini L, Ferrari B, Guidolotti G, Quatrini A, Corona P, 2015. Carbon mitigation potential of diffferent forest ecosystems 400 under climate change and various in Italy. Ecosyst. Heal Sustain 1 (8): 1-9.
- 401 Chauhan SK, Sharma R, Panwar P, Chander J. 2016a. Short rotation forestry: a path for economic and environmental prosperity. In: Parthiban KT, 402 Seenivasan R (eds.). Forestry Technologies - A Complete Value Chain Approach. Vol.1 Scientific Publishers, Jodhpur.

Deleted[Yosep Ruslim]: .

Deleted[Yosep Ruslim]: ectona

Deleted[Yosep Ruslim]: *melina*

Deleted[Yosep Ruslim]: Anitha K, Verchot LV, Joseph S, Herold M, Manuri S, Avitabile V. 2015. A review of forest and tree plantation biomass equations in Indonesia. Ann For Sci, 72: 981-997.

Arezoo S, Sankhayan PL, Hofstad O. 2014. A dynamic bioeconomic model for community management of goat and oak forests in Zagros, Iran.J Ecol Econ 106: 174-185.

Arias D, Alvarado J, Richter DJ, Dohrenbusch A. 2011. Productivity, aboveground biomass, nutrient uptake and carbon content in fast growing tree plantations of native and introduced species in the Southern Region of Costa Rica. Biomass Bioenerg 35: 1779-1788.

Deleted[Yosep Ruslim]: Brown S. 1997. Estimating biomass and biomass change of tropical forests: A primer, FAO Forestry Paper 134, Rome: Food Agriculture Organisation of the United Nations.

$\begin{array}{r} 403 \\ 404 \\ 405 \\ 406 \\ 407 \\ 408 \\ 409 \\ 410 \end{array}$	 Chauhan SK, Ritu, Chauhan R. 2016b. Carbon sequestration in plantations. Agroforestry for increased production and livelihood security (Eds. Gupta, S.K., Panwar, P. and Kaushal, R.). New Indian Publishing Agency, New Delhi. Chave J, Réjou MM, Búrquez A, ChidumayoE, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez YrízarA, Mugasha WA, Muller Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz ME, Pélissier R, Ploton P, Ryan CM, SaldarRJG, Vieilleden G. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Glob. Change Biol 20: 3177–3190. Cuong T, Chinch TTQ, Zhang Y, Xie Y. 2020. Economic performance of forest plantation in Vietnam: <i>Eucalyptus, Acacia mangium</i>, and <i>Manglietia conifera</i>. Forests 11(284): 1-14. 		Formatted[Anonymous Reviewer]: Indonesian
411	Ekholm T. 2016. Optimal forest rotation age under efficient climate change mitigation. For Policy Econ. 62: 62–68.		- 1
412	Gonzalez-Benecke CA, Samuelson LJ, Martin TA, Cropper Jr WP, Johnsen KH, Stokes TA, Butnor JR, Anderson PH. 2015. Modeling the effects of		Deleted[Yosep Ruslim]: Domec JC, Ward EJ, Oishi AC,
413	forest management on in situ and ex situ longleaf pine forest carbon stocks. For Ecol Manag 355: 24-36. Gren IM, Zeleke AA. 2016. Policy design for forest carbon sequestration: a review of the literature. For Policy Econ. 70: 128–136.		Palmroth S, Radecki A, Bell DM, Miao G, Gavazzi M,
415	Hairiah K, Rahayu S. 2007. Pengukuran karbon tersimpan diberbagai macam penggunaan lahan. World Agroforestry Centre. ICRAF Southeast Asia		Johnson DM, King JS, McNulty, SG, Oren R, Sun G,
410	regional, University of Brawijaya [Indonesian]. Hairiah K, Andree A, Rika RS, Subekti R. 2011. Measurement of carbon stock from land level to landscape 2nd edition. Bogor: Agroforestry Center.	X	Noormets A. 2015. Conversion of natural forests to managed
418	Irundu D, Beddu MA, Najmawati. 2020. Potential of biomass and carbon stored stands in green open space Polewali City, West Sulawesi. J Forests		forest plantations decreases tree resistance to prolonged
419	Communities 12 (1): 49-57. Juwari, Ruhiyat D, Aipassa MI, Ruslim Y. 2020a. Carbon stocks of <i>Rhizhopora apiculata</i> and <i>Sonneratia alba</i> of mangrove forest in Ngurah Rai Forest	$\langle \rangle$	
421	Park, Bali Province, Indonesia. J Biodivers Environ Sci, 16(3): 93-105.		Deleted[Yosep Ruslim]: Handayani. 2010. Regression models.
422	Energy Enviro Res. 10 (1): 30-35.		STIE Atma Bhakti, Surakarta. [Indonesian].
424	Karyati, Widiati KY, Karmini, Mulyadi R. 2019. Development of allometric relationships for estimate above ground biomass of trees in the tropical		
423	Abandoned land. Biodiversitas 20 (12): 5508-5510.[Indonesian] Kasim AR, Henry M. Danial M, Faiz M, Birigazi L. 2014. Inventory of tree biomass and volume allometric equations in Southeast Asia. FRIM, Kepong,		Deleted[Yosep Ruslim]: Hairiah K, Rahayu S. 2007.
427	Food and Agriculture Organization of the United Nations, Rome, Italy		Pengukuran karbon tersimpan diberbagai macam penggunaan
428	Krisnawati H, Kalilo M, Kanninen M. 2011. Anthocephalus cadamba Miq. Ecology, silviculture and productivity. CIFOR. Kristiningrum R, Lahjie A, Masjaya, Yusuf S, Ruslim Y. 2019. Species diversity, stand productivity, aboveground biomass and economic value of		lahan, World Agroforestry Centre, ICRAF Southeast Asia
430	mangrove ecosystem in Mentawir Village, East Kalimantan, Indonesia. Biodiversitas 20 (10): 2848-2857. [Indonesian]		regional University of Brawijaya
431 432	Kumi JA, Kyereh B, Ansong M, Ansate W. 2020. Infilluence of management practices on stand biomass, carbon stocks and soil nutrient variability of teak plantations in a dry semi-deciduous forest in Ghana. Elsevier Trees, Forest and People 3.		regional, University of Drawijaya
433	Lubis SH, Arifin SH, Samsoedin I. 2013. Analysis of tree carbon stocks in forest landscapes city in DKI Jakarta. J Forest Sos Econ Research, 10 (1):1-		Formatted[Yosep Ruslim]: Indonesian
434 435	20. Lukito M, Rohmatiah A. 2013. Estimated biomass and carbon of teak 5 year (Case of Nusantara Superior Teak Plantation Forest (JUN) Krowe Village,		
436	Lembeyan District, Magetan Regency). Agritek J 14(1): 1-23		Deleted[Yosep Ruslim]: Lee SY, Primavera JH, Dahdouh-
437	Meunpong P. 2012. Nutrient and Carbon Storage in Forest Plantation, Prachuap Khiri Khan province, Thailand. Kasetsart University, Bangkok, Thailand [Dissertation].	\	Guebas F, McKee K, Bosire JO, Cannicci S, Diele K, Fromard
439	Nemeth R, Feher S, Koman S. 2018. Utilization of fast growing plantation timber as bioenergy in Hungary. IOP Conf Ser: Earth Environ Sci159		F. Koedam N. Marchand C. Mendelssohn I. Mukheriee N.
440 441	012029. Nonini L, Fiala M. 2019. Estimation of carbon storage of forest biomass for voluntary carbon markets: preliminary results. J. For. Res 32(1):329–338		Record S 2014 Ecological role and services of tropical
442	Noormets A, Epron D, Domec JC, McNulty SG, Fox TD, Chen J, Sun G, King JS. 2015. Effects of forest management on productivity and carbon		menomous assurance a massagement Clabal Easty and
443	sequestration: a review and hypothesis. For Ecol Manag 355: 124-140. Panwar P, Chauhan S, Kaushal R, Das DK, Ajit, Arora G, Chaturvedi OP, Jain AK, Chaturvedi S, Tewari S. 2017. Carbon sequestration potential of		mangrove ecosystems: a reassessment. Global Ecoly and
445	poplar-based agroforestry using the CO ₂ FIX model in the Indo Gangetic Region of India. Trop Ecol 58 (2): 1-9.		Deleted[Yosen Ruslim]: Law BE., Waring, RH, 2015, Carbon
446 447	Kinnamang S, Sirirueang K, Supavetch S, Meunpong P. 2020. Estimation of aboveground biomass using aerial photogrammetry from unmanned aerial vehicles in teak (Tectona grandis) plantation in Thailand. Biodiversitas 21: 2369-2376 [Indonesian].		implications of current and future effects of drought fire and
448	Riutta T, Malhi Y, Kho LK, Marthews TR, Huasco WH, Khoo M. 2018. Logging disturbance shift net primary productivity and its allocation in Bornean		
449 450	tropical forest. J. Glob Change Biol 24 (7):2913–2928. Ruslianto M, Alviani, Maisuri, Irundu. 2019. Biomass allometric model of <i>Rhizophora Apiculata</i> at Polewali Mandar Regency, West Sulawesi Province.		management on Pacific Northwest forests. For Ecol Manag
451	Eboni Buleti Journal 1 (1): 11-19 [Indonesian].		355: 4-14.
452 453	Pandey S, Shukla R, Saket R, Verma D. 2019. Enhancing carbon stocks accumulation through forest protection and regeneration. A review. Int. J. Environ. 8 (1): 16–21		Delated Vecan Buslim): Dinhaira TE Escada MIS, Valariana
454	Putri AHM, Wulandari C. 2015. Potential carbon absorption in <i>Shorea javanica</i> in Pekon Gunung Kemala Krui, West Lampung. Sylva Lestari 3 (2): 13-		Deleted[10sep Rushin]. Finiteiro IF, Escada Mis, Valenano
433	20. [Indonesian]. Polosakan R, Alhamd L, Joeni SR. 2014. Estimated biomass and carbon stored in Pinus merkusii Jungh. & de Vriese In the Pine Forest Mt. Bunder, TN.		DN, Hostert P, Gollnow F, Müller H. 2016. Forest degradation
457	GN Halimun Salak. Biology News. 13 (2): 15-120. [Indonesian].		associated with logging frontier expansion in the Amazon: The
458 459	Sandalayuk, D, Soedirman S, Pambudhi F. 2018. Reserves estimating carbon in forest city district village Bongohulawa Gorontalo. Ijrtem. 2(8), 60-63. Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2020. Carbon absorbtion of <i>Anthocephalus macrophyllus</i> and <i>Swietenia macrophylla</i> . King in		BR-163 Region in Southwestern Pará, Brazil. Earth
460	Gorontalo, Indonesia. J Biodivers Environ Sci16 (5): 24-30.		Interactions 20 (17): 1-26.
461	in North Kalimantan, Indonesian, Biodiversitas 18(4): 1385-1393. [Indonesian].	and the second se	
463	Sedjarawan W, Akhbar, Arianingsih I. 2014. Biomassa dan karbon pohon di atas permukaan tanah ditepi jalan taman nasional Lore Lindu. Warta Rimba	\mathbb{N}	Formatted[Yosep Ruslim]: Font color: Auto
464 465	2(1) 105-115. [Indonesian]. Sharma R, Chauhan SK, Tripathi AM. 2016. Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. Agrofor Syst	1/1	
466	90 (4):631-644.		Formatted[Yosep Ruslim]: Font color: Auto
467 468	Setiawan, B., Lahjie A.M., 2011. Financial analysis of agroforestry systems teak, sungkai, and elephant grass in Samboja Kutai District Kartanegara. Humida Tropical Forestry Vol. 4 (1) [Indonesian].		Formatted[Yosen Ruslim]: Font color: Black
469	Setiawan, B., Lahjie A.M, Yusuf, S, Ruslim. 2019. Model of community forest land management production and financial simulation of super teak,		
470 471	solomon teak and sungkai treesin Samboja Kutai Kartanegara East Kalimantan, Indonesia. Energy and Environment Research 9(20): 48-60. Siaruddin, M and Indrayana, Y. 2015. Dynamics of carbon stock systems genelina agroforestry in community forests in Tasikmalaya and Baniar. West		
472	Java. Wasian 4 (1): 37-46 [Indonesian].		
473 474	SNI. 2011. Indonesian National Standard Number //24. Measurement and calculation of carbon stocks - field measurement for forest carbon stock assessment. tandardization Agency. Jakarta. [Indonesian].		
475	Siregar UJ, Narendra BH, Suryana J, Siregar CA, Weston C. 2017. Evaluation on community tree plantations as sustainable source for rural bioenergy in		
470	Environmental Scie, 65: 1-9.		

- Sist, P; P. Nicolas dan Fleury S.G. 2003. Sustainable cutting cycle and yields In a lowland mixed dipterocarp forest of borneo. INRA, EDP Sciences: 1- 12 Sousa VB, Cardoso S, Quilho T, Pereira H. 2011. Growth and ring width variability of teak, Tectona grandis (Verbenaceae) in an unmanaged forest East Timor. Int J Trop Biol 60(1): 483-494.
- Susila, IWW. 2012. Estimation model of teak stand volume and increment in Nusa Penida, Klungkung Bali. J Plant Forest Research 9 (3): 165-178.
- Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A. 2016. Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. Geoderma 261: 70-79.
- Trimanto. 2014. Vegetation analysis and tree biomass estimation of carbon stocks in Seven Montane Forests of Bawean Island Nature Reserve, East Java.
 Biology News 13(1): 321-332.
- Uthbah Z, Sudiana E, Yani E. 2017. Biomass analysis and carbon stock at various ages of resin stands *Agathis dammara* (Lamb.) Rich.) In KPH Banyumas Timur. Scripta Biologica 4(2): 119-124.
- Van Gardingen PR, McLeish MJ, Philips PD, Fadilah D, Tyrie G, Yasman I. 2003. Financial and ecological analysis of management options for loggedover dipterocarp forest in Indonesia Borneo. For Ecol Manag 183: 1-29.
- Warner AJ, Jamroenprucksa M, Puangchit L. 2017. Buttressing impact on diameter estimation in plantation teak (*Tectona grandis* L.f.) sample trees in northern Thailand. Agric Nat Resour 51 (6): 520-525.
- Wei RP, Zhu W. 2019. Adaptability and growth of a fast-growing Neolamarckia cadamba (Robx.) Bosser clone in the South Subtropical Region of China. Open J Forestry 9, 419-438.
- Winarni B, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Tengkawang cultivation model in community forest using agroforestry system in West Kalimantan, Indonesia.Biodiversitas18(2):765-772.[Indonesian].
- 497 Yunianti AD, Wahyudi, Siregar, Pari. 2011. Quality of teak clones with different planting distances. J Wood Sci Tech Tropical 9 (1): 93-100.
- Zeng W, Fu L, Xu M, Wang X, Chen Z, Yao S. 2018. Developing individual tree-based models estimating aboveground biomass of five key coniferous species in China. J For Res (5): 1251–1261.

Deleted[Yosep Ruslim]:

Formatted[Yosep Ruslim]: Font: (Asian) Batang, 8 pt, Indonesian, (Complex)Arabic(Saudi Arabia)

Deleted[Yosep Ruslim]: Sugiyono. 2012. Qualitative and quantitative research methods and R&D. Alfabeta. Bandung. [Indonesian].

Deleted[Yosep Ruslim]: Tacconi L, Rodrigues RJ, Maryudi A. 2019. Law enforcement and deforestation: Lessons for Indonesia and Brazil. Forest Policy Econ 108 (2019) 101943.

Deleted[Yosep Ruslim]: Tong S, Berry HL, Ebi K, Bambrick H, Hu W, Green D, Hanna E, Wang Z, Butler CD. 2016. Climate change, food, water and population health in China. Bull World Health Organ 94:759-765.

smujo.id@gmail.com	× ∃≞	◎ 🕸 🎟
		10 dari banyak < > 📷 👻
Smujo Editors <smujo.id@gmail.com> kepada saya, DAUD, ROCHADI, ANDI -</smujo.id@gmail.com>		Sab, 27 Feb 19.02 🟠 🔦 🗄
🛱 Inggris 🔹 🔺 Indonesia 👻 Terjemahkan pesan		Nonaktifkan untuk: Inggris 😠
YOSEP RUSLIM, DAUD SANDALAYUK, ROCHADI KRISTININGRUM, ANDI SAHRI We have reached a decision regarding your submission to Biodiversitas Journal of Bi Tectona grandis and Gmelina arborea stands in Gorontalo Province, Indonesia*. Our decision is to: Accept Submission Smujo Editors	ALAM: ological Diversity, "Estimation of Ab	ove Ground Biomass and carbon stocks of
<u>eaitors@smujo.id</u>		
<u>sonors@amho.rd</u>		
2010/2@3mUj0.19		
smujo.id@gmail.com	× ==	@ \$ ≣
smujo.id@gmail.com	× ∃≟) dari banyak < 👌 💼 🗸
smujo.id@gmail.com	× 荘	⑦ 🕸 🗰 9 dari banyek < > ■ ~ 膏 🛙
smujo.id@gmail.com	× 3‡	 ⑦ 9 dari banyek < > ■ ~ ● Z Kam, 4 Mar 11.50 ☆ < ;
smujo.id@gmail.com	× ==	Ø dari banyak < > = - 9 dari banyak < > = - 9 dari banyak < > = - E Kam, 4 Mar 11.50 ☆ < :
smujo.id@gmail.com	× 3₽	9 dari banyak >
smujo.id@gmail.com	× 로드 ALAM: pocks of Tectona grandis and Gmelir	 9 dari banyek 9 dari b
smujo.id@gmail.com Smujo.id@gmail.com [biodiv] Editor Decision Kotak Masuk × Smujo Editors <smujo.id@gmail.com> kapada saya, DAUD, ROCHADI, ANDI = X_A Inggris - > Indonesia - Terjemahkan pesan YOSEP RUSLIM, DAUD SANDALAYUK. ROCHADI KRISTININGRUM, ANDI SAHRI The editing of your submission, "Estimation of Above Ground Biomess and carbon sto Indonesia," is complete. We are now sending it to production. Submission URL: <u>https://smujo.id/biodi//authorDashboard/submission/7790</u></smujo.id@gmail.com>	ALAM:	9 dari banyak > 9 dari banyak > 9 dari banyak > • • <

Uncorrected proof

Participants

Smujo Editors (editors) Sugeng Budiharta (sbudiharta) Nor Liza (nliza) YOSEP RUSLIM (yruslim)

Messages	
Note	From
Dear Author(s), Pls, find attached file for an uncorrected proof (Copyedited file). The revised manuscript is awaited. Do not worry about layout changes due to revision; our staff will fix it again. Note: Kindly use track change when you make improvements. C editors, AGB + Ruslim.doc	editors 2021-02-27 04:07 AM

Estimation Above Ground Biomass (AGB) and carbon stocks of *Tectona* grandis and *Gmelina arborea* stands in Gorontalo Province, Indonesia

YOSEP RUSLIM^{1,}, DAUD SANDALAYUK², ROCHADI KRISTININGRUM¹, ANDI SAHRI ALAM³

¹Faculty of Forestry, Universitas Mulawarman. Jl. Ki Hajar Dewantara, PO Box 1013, Kampus Gunung Kelua, Samarinda Ulu, Samarinda 75116, East Kalimantan Province, Indonesia, Telp/Fax. (0541) 735379, *email: yruslim@gmail.com

²Faculty of Forestry, Universitas Negeri Gorontalo. Jl. Jend. Sudirman No. 247, Limboto, North Sulawesi, Indonesia

³Faculty of Forestry, Universitas Tadulako. Jl. Soekarno Hatta Km 9. Kampus Bumi Tadulako, Tondo, Mantikulore, Palu 94148. Central Sulawesi,

Indonesia

Manuscript received: 17 January 2021. Revision accepted: xxx February 2021.

Abstract. Ruslim Y, Sandalayuk D, Kristiningrum R, Alam AS. 2021. Estimation Above Ground Biomass (AGB) and carbon stocks of Tectona grandis and Gmelina arborea stands in Gorontalo Province, Indonesia. Biodiversitas 22: xxxx. Plantation forest plays an important role to fulfill timber needs, while more recently plantation forest is increasingly acknowledged to sequester and store carbon which can mitigate climate change and also as carbon sequestration for the environment.. This study aimed to calculate the stand potential, stand biomass and carbon stocks of teak (Tectona grandis) and gmelina (Gmelina arborea) stands in the context of land after being abandoned in Gorontalo Province, Indonesia. Four plots with size of one hectare each were sampled in which each species (i.e. Teak and Gmelina) consisted of two plots. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded. Data analysis included growth parameters of the stands (i.e., Mean Annual Increment/MAI and Current Annual Increment/CAI) and above-ground biomass and carbon sequestered by the stands. Simple linear regression using polynomial trendline was used to determine the relationship between variables and the degree of the relationship. The results showed that the maximum growth of teak stands at Plots I and II reached a maximum point at the age of 32 and 25 years with the total volume of 307.50 and 254.81 m³ha⁻¹, respectively. While the maximum growth of gmelina stands at Plots I and II reached a maximum point at the age of 15 years with the total volume of 190.54 and 251.80 m³ha⁻¹, respectively. The biomass content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 267.83; 221.94; 104.03 and 137.48 tons ha⁻¹. Meanwhile, the carbon content in teak stands at Plots I and II and gmelina stands at Plots I and II were respectively 125.88; 104.31; 48.90; and 64.62 tons ha⁻¹. The results of the regression analysis suggest that there was strong relationship between carbon sequestered and the age of the stands as well as total basal area. The results of this study suggest that Tectona grandis is more potential to be developed as plantation forest than Gmelina arborea when aiming carbon sequestration and biomass production.

Keywords: Biomass, carbon, Gmelina arborea, growth, Tectona grandis

INTRODUCTION

There is a growing paradigm that forest management is not only aimed to produce timber and non-timber products, but also to deliver various ecosystem services. One of forest ecosystem services is the sequestration of carbon dioxide in the atmosphere through photosynthesis and to store it in forest biomass (Lukito and Rohmatiah 2013). The carbon stored in forest biomass can help mitigate climate change in the form of global warming (Birdsey and Pan 2015; Calfapietra et al. 2015; Zeng et al. 2018; Pandey et al. 2019).

Tesfaye et al. (2016) stated that tropical forests play an important role in global carbon sequestration. Among ecosystems in the world, forests in tropical regions have the highest rate of carbon sequestration due to the large amount of sunlight and water in the regions which is plentiful throughout the year. These conditions are also supported by the climates (i.e., temperature and humidity) that optimal for many tree species to grow. Most of carbon sequestered by the forest is stored in above-ground biomass of the trees.

Indonesia has renewable natural resources such as plantation forests. Plantation forestry has the potential to be developed as biomass storage by promoting the planting of fast growing plants. When developing plantation forest, the estimation of biomass in tree stands is very important to calculate the amount and variation of C (Ekholm 2016; Gren and Zeleke 2016; Riutta et al. 2018; Nonini and Fiala 2019). Biomass is also important to determine forest production to assess the sustainability aspect of forest management (Rinnamang et al. 2020) since the existence of plantations requires sustainability in terms of financial, ecological and social aspects (Siregar et al. 2017). If achieved across such aspects, sustainable management of plantation forest would result in high production of wood products while could store a large amount of carbon (Wei and Zhou 2019; Cuong et al. 2020). In addition to producing wood and biomass, sustainably managed forest plantations would also provide environmental services in the form of water regulation (Chauhan et al. 2016b; Nemeth et al. 2018).

According to Gonzalez-Benecke et al. (2015), Sharma et al. (2016), Panwar et al. (2017), the length of rotation of plantation forest will affect the biomass and carbon stored by the forest. The rotation length is related with the type of tree species planted, either it is fast-growing or slowgrowing species. The ability of fast-growing trees to absorb carbon which is faster than slow-growing species is one of the strong reasons why it is necessary to plant and cultivate fast-growing species in plantation forests (Chauhan et al. 2016a).

One type of fast-growing tree species is Gmelina (*Gmelina arborea* Roxb). This tree is widely developed for industrial plantations in tropical regions, such as Indonesia, Pakistan, Sri Lanka, and some countries in Southeast Asia. Gmelina can live well in lowland areas up to an altitude of 1200 m above sea level with an average rainfall of 750-5000 mm year⁻¹ (Adinugraha and Setiadi 2018). Other tree species that is widely cultivated is Teak (*Tectona grandis* Linn.f.). Teak is an important commercial timber tree which has a high selling price (Warner et al. 2017) due to the timber is relatively light with high durability and resistant to fire as well as easy to work on (Meunpong 2012).

One important parameter when estimating the biomass of tree stands is allometric equation. Yet, in several regions and particular contexts of land management, the allometric equation is not adequately formulated (Karyati et al. 2019). This study aimed to calculate the stand potential, stand biomass and carbon stocks of Teak and Gmelina stands in the context of land after being abandoned in Gorontalo, Indonesia. We expected that this research can develop allometric equation for estimating AGB with a coefficient of determination that can predict biomass and carbon stock in such land management.

MATERIALS AND METHODS

Study period and area

The study was conducted from September 2020 to December 2020 in Gorontalo Province. The field experiments were conducted at four plots, consisting of two plots of *Tectona grandis* and two plots of *Gmelina arborea*. Location plot A was Gmelina in Dulupi Village, Boalemo Regency. Location plot B was Teak in the village of Bakti, Wono District, Boalemo Regency. Location plot C was Gmelina, Bakti Village, Wono District, Boalemo Regency and location plot D was Teak in Haya-Haya Village, Gorontalo District. The coordinate of plot A was located at 122°36'12.888''E and 0°37'47.828'N. Plot B was located at 122°42'22.942''E and 0°37'43.117'N. Plot C was located at 122°43'51.600''E and 0°37'55.966'N. Plot D was located at 122°49'15.397''E and 0°38'46.017'N (Figure 1).

Data collection procedure

The determination of the study locations (Figure 1). Each plot of tree stand (Figure 1) had the extent of 1 hectare with different planting distance. The planting distance of *Tectona grandis* stand was $3m \times 3m$, while that of *Gmelina arborea* was $3.5m \times 4m$. In each plot, the diameter at the breast high (1.3 m) and the height of each individual were recorded. Data collection related to diameter and height was carried out from 2 until 15 year. Measurements were carried out twice a year. While those over 15 years of age are simulated mathematically using simple linear regression to find the closeness of the regression coefficient relationship between age and increment. This study is also based on research conducted by Sist et al. (2003), that the formation of arithmetic simulation models and logical operations on the yield cycle and sustainable harvesting in lowland dipterocarp mixed forest on the island of East Kalimantan can be estimated using simple linear regression.

Data analysis

Estimating the growth (MAI and CAI)

The data collection includes diameter, plant species as high as 1.3 m from the soil surface (cm). Carbon (C) storage (kg per year) can be estimated by multiplying the tree biomass (Y: kg) with the general vegetation carbon content, namely (0.46) (Hairiah and Rahayu 2007). Carbon stock calculations were also carried out on cultivated plants *Tectona grandis* (teak) and *Gmelina arborea* (white teak) planted on land by the community.

The maximum production of the stand of *T. grandis* and *G. arborea* was analyzed by calculating the growth increments of tree in a particular measurement time span (cycle), namely mean annual increment (MAI) and current annual increment (CAI). Van Gardingen et al. (2003) state that increment is defined as an increase in the dimensional growth (height, diameter, base plane, volume) or an increase in the standing stock of a tree, in relation to the tree age or a particular period. The volume of the tree was calculated using following equation:

$$V = \frac{1}{4}\pi d^2hf$$

in which: V = standing volume, d = diameter at breast height (DBH), h = branch-free height, f = form factor

According to Van Gardingen et al. (2003), to estimate the mean annual increment (MAI) and the current annual increment, the following formulas were used:

$$MAI = \frac{V_t}{t}$$

in which: MAI = mean annual increment, V_t = total volume in ages t_0 - t (m³), t = age (years)

$$CAI = \frac{V_t - V_{t-1}}{T}$$

in which: CAI = current annual increment, V_t = total volume in ages $t_0 - t$ (m³), V_{t-1} = previous total volume (m³), T = second age $t_0 - t$, minus the first age (in year)



Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: $\mathbf{A} = G$. *arborea* plot II, $\mathbf{B} = T$. *grandis* plot I, $\mathbf{C} = G$. *arborea* plot I, $\mathbf{D} = T$. *grandis* plot II.

Estimating tree biomass and carbon

Tree biomass can be estimated by incorporating tree height, trunk diameter and wood density (Chave et al. 2014). The biomass was calculated according to Indonesian National Standard [SNI] number 7724 (2011) and Irundu et al. (2020) using the following formula:

 $M = BJ \times V_t \times BEF$

in which: M = tree biomass (kg), BJ = specific gravity (kg m⁻³), $V_t = \text{total volume (m³)}$, BEF = Biomass Expansion Factor (1.3)

While carbon storage was calculated as follow:

 $Cb = B \times \% C Organic$

in which: Cb = Carbon content of biomass (kg), B = total biomass (kg), % C Organic = Percentage value of carbon content, which is 0.47 (Hairiah et al. 2011).

The total biomass was calculated by multiplying the biomass obtained per plot with the conversion unit to ton ha⁻¹. According to Adhitya et al. (2013), the calculation of the biomass content per hectares was as follow:

Biomass (kg ha⁻¹) = Biomass (kg m⁻²) \times 10,000 m²

Biomass and stored carbon have a causal relationship with tree volume values. Therefore, the data obtained was analyzed mathematically using simple linear regression to find relationship between age and increment, while polynomial trendline was used to determine the regression coefficient. Determination of the value of biomass and stored carbon can be determined through a volume value approach. According to Ruslianto et al. (2019), the relationships between biomass and tree dimensions can be analysed as follows:

 $\hat{\mathbf{Y}} = \mathbf{a} + \mathbf{b}\mathbf{X}$

in which: \hat{Y} = Estimated value of biomass, X = Volume (m³), a, b = regression constant

RESULTS AND DISCUSSION

Growth of Tectona grandis

Growth of Tectona grandis at Plot I

T. grandis stands cultivated at Plot I at the beginning were planted at a spacing of $3m \times 3m$, resulted in the initial number of 1,111 individuals. As the stands grew, it experienced a reduction in the number of trees due to natural mortality or thinning activity. The number of trees, diameter, height, total volume and increment of teak are presented in Table 1.

Based on the table above, it can be explained that at a one-hectare of plot I there were 910 individuals at the age of 2 years trees with the average diameter of 3.1 cm, height of 2 meters and total volume of 1.10 m³ha⁻¹. At the age of 35 years, the number of individuals were reduced to 400 with average diameter of 45 cm, height of 8.7 meters and total volume of 331.91 m³ha⁻¹. Meanwhile, the mean annual increment of volume ranged from 0.55 to 9.61 m³ha⁻¹ year⁻¹. The maximum total volume of teak reached at the age of 32 years with 307.50 m³ ha⁻¹ with mean annual increment (MAI) of 9.61 and current annual increment (CAI) of 9.86 m³ha⁻¹ with the number of individuals of 500 trees per hectare.

The graphical presentation of MAI and CAI of teak in plot I is presented in Figure 2.
Age	n	d	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	910	3.1	2	0.8	1.10	0.55		0.69	0.96	0.45
4	880	5.9	3.5	0.8	6.73	1.68	2.82	2.40	5.86	2.76
7	750	8.8	5.3	0.8	9.33	2.76	4.20	4.56	16.84	7.91
9	700	10.9	6.3	0.8	2.90	3.66	6.79	6.53	28.66	13.47
10	610	12.4	6.9	0.8	40.88	4.09	7.97	7.36	35.60	16.73
15	600	20.0	7.5	0.7	98.91	6.59	11.61	18.84	86.15	40.49
20	570	26.0	7.8	0.7	165.79	8.29	13.38	30.25	144.40	67.87
25	560	31.0	7.8	0.7	230.66	9.23	12.97	42.25	200.91	94.43
30	550	37.5	7.9	0.6	287.79	9.59	11.43	60.71	250.66	117.81
32	500	40.4	8.0	0.6	307.50	9.61	9.86	64.06	267.83	125.88
34	460	42.0	8.5	0.6	324.86	9.55	8.68	63.70	282.95	132.99
35	400	45.0	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

Table 1. The table growth of T. grandis in Plot I

Notes: N = number of individuals of *T. grandis* (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area (m²ha)

Table 2. The table growth of *T. grandis* in Plot II

Age	n	D	h	f	TV	MAI	CAI	BA	Biomass	Carbon
2	800	3.0	2.0	0.80	0.90	0.45		0.57	0.79	0.37
4	700	6.0	3.7	0.77	5.64	1.41	2.37	1.98	4.91	2.31
7	650	9.0	4.7	0.75	14.57	2.08	2.98	4.13	12.69	5.96
8	630	10.0	5.3	0.74	19.40	2.42	4.83	4.95	16.89	7.94
9	604	12.0	5.8	0.73	28.91	3.21	9.51	6.83	25.18	11.83
10	580	14.0	6.1	0.72	38.87	3.89	9.96	8.92	33.86	15.91
15	560	21.5	7.7	0.72	112.66	7.51	14.76	20.32	98.12	46.12
20	550	26.5	8.5	0.70	180.40	9.02	13.55	30.32	157.13	73.85
25	500	31.6	9.0	0.65	229.28	9.17	9.78	39.19	199.70	93.86
30	400	38.0	9.3	0.60	253.82	8.46	4.91	45.34	221.08	103.91

Notes: N = number of individuals of *T. grandis* (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area (m²ha)



Figure 2. The curves of MAI and CAI of T. grandis at Plot I



Figure 3. The curves of MAI and CAI of T. grandis at Plot II

Based on Figure 2, it can be explained that the MAI and CAI increments of teak initially increased and met at one point, namely at the age of 32 years. This means that the maximum increment of teak is reached at the age of 32 years. After experiencing maximum increment at the age of 32 years, the teak will experience a decline after such age. This is supported by a simple linear regression test with a polynomial type on MAI which has an R^2 value of 99%. This value means that there is a close relationship between age and the MAI increment of 99% and 1% influenced by other factors. Meanwhile, CAI has an R^2 value of 97%. This value means that there is a close relationship between age and the CAI increment of 97% and 3% is influenced by other factors.

Growth of Tectona grandis at Plot II

Similar to Plot I, as many as 1,111 individuals of *T. grandis* were cultivated at plot II at the beginning, but these were reduced to 400 individuals at the age of 30 years. However, at a later age, the teak stands experienced a reduction in the number of trees due to natural mortality or due to thinning activities. The table of growth of *T. grandis at* Plot II is presented in Table 2.

The results in Table 2 showed that at Plot II there were 800 individuals of teak at the age of 2 years with average diameter of 3 cm, height of 2 meters and total volume of 0.90 m³ ha⁻¹. At the age of 30 years, the number of individuals were reduced to 400 trees with average diameter of 38 cm, height of 9.3 meters and total volume of 229.28 m³ ha⁻¹. The growth increment ranged from 0.45 to 9.17 m³ ha⁻¹ year⁻¹ with the maximum total volume of teak reached at the age of 25 years with 229.28 m³ ha⁻¹ and MAI dan CAI of 9.17 and 9.78 m³ ha⁻¹year⁻¹, respectively with the number of trees per hectare as many as 500 trees.

The graphical presentation of MAI and CAI of teak at Plot II can be seen in Figure 3.

Based on Figure 3, it can be explained that the MAI and CAI increments initially increased and met at one point,

namely the age of 32 years. This means that the maximum increment of teak was reached at the age of 25 years and then declined after such age. After experiencing a maximum increment at the age of 25 years, the teak after the age of 25 years will experience a decline. The curves also suggest that there is a close relationship between age and MAI and CAI in which both parameters have high This is supported by a simple linear regression test with a polynomial type on MAI which has an R^2 value of 95% and. This value means that there is a close relationship between age and MAI increment of 95% and 5% influenced by other factors. Meanwhile, CAI has an R^2 value of 88%, respectively. This value means that there is a close relationship between age and the CAI increment of 86% and 14% is influenced by other factors.

The growth pattern as shown in Figures and 3 suggests that teak growth at a young age is to be more developed. Sousa et al. (2011) stated that the growth of teak stands in East Timor generally shows a decline in growth along with the increasing age of the stands. The growth of a tree stand, both in height and diameter, is influenced by climate and soil fertility. In addition, it is also influenced by the space and surface of the canopy, relative humidity and the root system (Juwari et al. 2020a).

The highest growth in diameter and height of the teak stands occurred in the early stages of growth, namely in the range of 1-5 years of age, then there was a gradual decline in growth and was seen to decrease after 12 years of age stands. Until the stand was 12 years old, generally teak growth in East Kalimantan showed a higher growth (increment) in diameter and height compared to several teak plant locations in Java. Alam et al. (2017), Setiawan et al. (2011) and Setiawan et al. (2019) who conducted research in Samboja District, East Kalimantan Province, stated that the potential of total volume and increment of "Super" teak at the age of 25 were 154.32 m³ and 6.17 m³ha⁻¹year⁻¹, respectively while those in Solomon teak were 150.94 m³ and 6.04 m³ha⁻¹year⁻¹, respectively.

Age	n	D	h	f	TV	MAI	CAI	BA	Biomass	Carbon	
2	660	6	4	0.90	6.71	3.36		1.87	3.67	1.72	
4	570	13	5	0.87	32.89	8.22	13.09	7.56	17.96	8.44	
6	550	17	5.5	0.88	60.39	10.07	13.75	12.48	32.97	15.50	
8	530	21	6	0.82	90.27	11.28	14.94	18.35	49.29	23.17	
10	500	23.6	7	0.79	120.89	12.09	15.31	21.86	66.01	31.02	
12	470	24.6	9	0.75	150.71	12.56	14.91	22.33	82.29	38.68	
15	430	28	10	0.72	190.54	12.70	13.28	26.46	104.03	48.90	
20	360	32	12	0.71	248.29	12.41	11.55	28.94	135.57	63.72	
25	350	34	14	0.64	284.58	11.38	7.26	31.76	155.38	73.03	

Table 3. The table growth of G. arborea at Plot I

Notes: N = number of individuals of *G. arborea* (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area (m²ha)

Table 4. The table growth of G. arborea at Plot II

Age	n	d	h	F		TV	MAI	CAI	BA	Biomass	Carbon
2	660)	5	3	0.90	3.50	1.75		1.30	1.91	0.90
4	600	13	.8 5.	3	0.87	41.36	10.34	18.93	8.97	22.58	10.61
6	570	18	.5 6.	2	0.86	81.65	13.61	20.15	15.31	44.58	20.95
8	540	21	.3	8	0.80	123.08	15.39	20.72	19.23	67.20	31.59
10	510	23	.5 9.	5	0.78	163.83	16.38	20.37	22.11	89.45	42.04
12	470) 2	.7 1	0	0.75	201.72	16.81	18.95	26.90	110.14	51.77
15	450) 3	0 1	1	0.72	251.80	16.79	16.69	31.79	137.48	64.62
20	380) 3	4 1	3	0.70	313.80	15.69	12.40	34.48	171.33	80.53
25	370	35	.5 1	5	0.64	351.40	14.06	7.52	36.60	191.86	90.18

Notes: N = number of individuals of *G. arborea* (tree ha⁻¹), d = tree diameter (cm), h = clear bole height (m), F = form factor, TV = total volume (m³ ha⁻¹), MAI = Mean Annual Increment (m³ ha⁻¹ year⁻¹), CAI = Current Annual Increment (m³ ha⁻¹ year⁻¹), BA = Basal Area (m²ha)



Figure 4. The curves of MAI and CAI of G. arborea at Plot I



Figure 5. The curves of MAI and CAI of G. arborea at Plot II

Other study in Nganjuk, East Java stated that the diameter increment of teak cultivated from root graft reached 25-28 cm at the age of 20 years, while the diameter increment of the original plant is only 1-2 cm year⁻¹. In optimal site conditions, teak volume increment can reach 7.9 - 10 m³ha⁻¹year⁻¹ (Susila 2012). Yunianti et al. (2011) stated that in terms of silviculture, plants with long rotation were modified to accelerate its growth in order to meet market demand. The wide spacing will produce trees with big appearance, and in terms of quantity is very profitable, while in terms of wood quality, plants modified to accelerate its growth will reduce its wood properties, especially the strength. As such, the effort taken should be to choose a place to grow that is very suitable for the plant so that even though its growth is accelerated, the quality of the wood remains stable.

Growth of Gmelina arborea

Growth of G. arborea at Plot I

G. arborea cultivated at Plot I at the beginning were planted at a distance of $3.5m \times 4m$, resulted in the initial number of 714 individuals. Similar to teak, Gmelina stands experienced a reduction in the number of trees due to natural mortality or thinning activity. The number of trees, diameter, height, total volume and increment of Gmelina at Plot I are presented in Table 3. However, at a later age, the *G. arborea* stands experienced a reduction in the number of trees, due to natural mortality or due to thinning activities. Based on the *G. arborea* growth table, the number of trees, diameter, height, total volume and increment of *G. arborea* can be seen in Table 3.

Based Table 3, there were 660 individuals of Gmelina with average diameter of 6 cm at the age of 2 years. At the age 25 years, the diameter increased to 34 cm, while the height increased from 4 to 14 meters and the total volume enhanced from 6.71 to 284.58 m³ha⁻¹. The MAI ranged from 3.36 to 12.70 m³ ha⁻¹ year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years with 190.54 m³ ha⁻¹ and MAI and CAI of 12.70 and 13.28 m³ha⁻¹

¹year⁻¹, respectively, with the number of trees per hectare were 430 trees. The curves of MAI and CAI of *G. arborea* at Plot I are presented in Figure 4.

Figure 4 suggests that the MAI and CAI of *G. arborea* initially increased reached and met at one point, namely the age of 15 years. This means reached the maximum increment at the age of 15 years and then declined after such age. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. The simple linear regression test with a polynomial type on MAI shows an R^2 value of 90%, meaning that there is a close relationship between age and the MAI increment of 91% and 9% was influenced by other factors. Meanwhile, CAI has an R^2 value of 98%, implying that there is a close relationship between age and the CAI increment of 98% and 2% was influenced by other factors.

Growth of G. arborea at Plot II

The number of trees, diameter, height, total volume and increment of Gmelina at Plot II are presented in Table 4.

The results in Table 4 shows that at Plot II, there were 660 *G. arborea* trees per hectare at the age of 2 years with average diameter of 5 cm. At the age of 25 years, the diameter increased to 35.5 cm, while the height increased from 3 to 15 meters and the total volume increased from 3.50 to 351.40 m³ha⁻¹. The MAI ranged from 1.75 to 16.69 m³ha⁻¹year⁻¹. The maximum total volume of *G. arborea* reached at the age of 15 years with 251.80 m³ ha⁻¹ and MAI and CAI of 16.79 and 16.69 m³ha⁻¹year⁻¹, respectively with the number of trees per hectare was 450.

The graphical relationship between MAI and CAI *G. arborea* in plot II can be seen in Figure 5. Similar to Gmelina stand at Plot I, the maximum increment of Gmelina at Plot II was reached at the age of 15 years, in which the increment declined after such age. After experiencing a maximum increment at the age of 15 years, the *G. arborea* after the age of 15 years will experience a decline. The influence of age is significant as the results of simple linear regression test with a polynomial type on MAI and CAI have an R^2 value of 86% and 98%, respectively.



Figure 6. Stands of *Tectona grandis* at the age of 15 years with spacing of 3 m × 3 m: A) stands at Plot I; B) stands at Plot II



Figure 7. Stands of *Gmelina arborea* at the age of 15 years with spacing of 3.5 m × 4 m: A) stands at Plot I; B) stands at Plot II.

Table 5. The total volume, basal area, biomass and carbon of each st	and
--	-----

No	Tuno	Age	TV	BA	Biomass	Carbon
140	Туре	(yr)	(m ³ ha ⁻¹)	(m^2ha^{-1})	(ton ha ⁻¹)	(ton ha ⁻¹)
1	T. grandis Plot I	32	307.50	64.06	267.83	125.88
2	T. grandis Plot II	25	254.81	43.56	221.94	104.31
3	G. arborea Plot I	15	190.54	26.46	104.03	48.90
4	<i>G. arborea</i> Plot II	15	251.80	31.79	137.48	64.62

Notes: $TV = Total volume (m^3 ha^{-1})$, $BA = Basal area (m^2 ha^{-1})$



Figure 8. The correlation between the stand age and carbon sequestered at the stands of T. grandis and G. arborea



Figure 9. The correlation between basal area and carbon sequestered at the stands of T. grandis and G. arborea

According to Sandalayuk et al. (2018) and Sandalayuk et al. (2020), the increase in diameter reached 2.4 cm year⁻¹ at the age of 10, and resembles an increase in diameter of Jabon of 2.1 cm year⁻¹. Meanwhile, according to our result, the increase in Gmelina diameter at the age of 10 was 2.36 cm year⁻¹. The maximum total volume of G. arborea was achieved at the age of 15 years of biological rotation with total volume of 190.54 m³ ha⁻¹ and MAI and CAI of 12.70 and 13.28 m³ ha⁻¹ year⁻¹, respectively with the number of trees is 430. According to Siarudin and Indrayana (2015), if Gmelina arborea is harvested at the age of 14 years, it has a total volume of 122 m³ ha⁻¹ and average diameter of 15 cm, whereas if harvested at the age of 20 years, the diameter is 20 cm and the total volume is 146 m³ ha⁻¹. This means that the age of a stand also influences the biomass and the amount of carbon stored in a stand (Lukito and Rohmatiah 2013). This means that the age of a stand also influences the biomass and the amount of carbon stored in a stand (Lukito and Rohmatiah 2013).

The graphs presented in Figures 2, 3, 4 and 5 are in line with Kristiningrum et al. (2019), Winarni et al. (2017) and Dinga (2014) in which the growth of *T. grandis* and *G. arborea* exhibited certain characteristics, as follow: CAI

curve rapidly reached the peak and from there declined immediately, whereas the MAI curve climbed and declined slowly. However, the potential growth of teak stands was better than that of gmelina stands. This is likely due to differences in spacing and density per hectare. One of the factors that can affect the size of the stand diameter is the density and intensity of sunlight entering the stand. According to Sedjarawan et al. (2014), stand density will affect the light entering the vegetation. Stands that receive little sunlight will experience slow growth so that they have a small stem diameter. In addition, the light intensity will also have an influence on cell enlargement and differentiation such as height growth, leaf size and the structure of the leaves and stems.

Tree biomass and carbon sequestered

The calculations of the total volume, basal area, biomass and carbon are presented in Table 5.

Table 5 demonstrates that the teak stand at Plot I with the age of 32 years had the largest total volume, basal area, biomass and carbon among other stands of 307.5 m³ ha⁻¹; 64.06 m² ha⁻¹; 257.83 ton ha⁻¹ and 125.88 ton ha⁻¹, respectively, then followed by teak Plot II, gmelina Plot II

and finally gmelina Plot I. These differences are due to the different fertility level in each type of stand. The teak at Plot 2 at the age of 25 years had a total volume of 254.81 m³ ha⁻¹, basal area 43.56 m² ha⁻¹; biomass 221.94 ton ha⁻¹ and carbon 104.31 ton ha⁻¹. *G. arborea* at Plot II at the age of 15 years had a total volume of 251.80 m³ ha⁻¹, basal area 31.79 m² ha⁻¹; biomass 137.48 ton ha⁻¹ and carbon 64.62 ton ha⁻¹, while *G. arborea* at Plot 1 at the age of 15 years had a total volume 190.54 m³ ha⁻¹, basal area 26.46 m² ha⁻¹; biomass 104.03 ton ha⁻¹ and carbon 48.90 ton ha⁻¹.

The amount of carbon in gmelina Plot I is almost the same as the amount of Gmelina arborea in East Kutai District, East Kalimantan, Indonesia (Amirta et al. 2016). Trimanto (2014) stated that G. arborea tends to store carbon smaller with 19.96 ton C ha⁻¹ or 2.49 ton C ha⁻¹yr⁻¹ compared to T. grandis which can store carbon of 114.88 ton C ha⁻¹ or 9.57 ton C ha⁻¹ yr⁻¹. Our results show that both younger stands of teak and gmelina produce higher tree densities when compared with older stands. However, the basal area of older stands is larger than that of younger stands. This is in line with research conducted by Rinnamang et al. (2020). In addition, the management of stands has a significant effect on the characteristics of the stands and the soil content as a place to grow stands. Therefore, good forest managers must apply intensive forest management practices optimize the benefits of plantations (Kumi et al. 2020).

The relationship between stand age and carbon sequestered in each type of stand is presented in Figure 8. Meanwhile, the relationship between basal area and carbon sequestered in each type of stand is presented in Figure 9.

Based on Figures 8 and 9, carbon sequestered has strong relationships with age and basal area, which is indicated by high correlation value (\mathbb{R}^2). This result is in line with the research conducted by Kumi et al. (2020) in which teak biomass estimation was very accurate and ignored differences in areas, tree characteristics and diameters that had high, constant ratios, stems and sharp crowns with determination coefficient ($\mathbb{R}^2 = 0.99$) and significant (Bredu and Birigazzi 2014).

The increase in CO₂ gas emissions in the air causes an increase in global temperatures on earth. Information regarding the amount of carbon absorbed in the plant biomass (carbon stock) in an area becomes very important information (Trimanto 2014). On the other hand, CO_2 is an important component in the photosynthesis process and the carbon dioxide absorbed by forest stands compose carbohydrates as a result of photosynthesis which will be stored in the form of biomass. Therefore, the amount of above-ground biomass can be used as a basis for determining the amount of carbon stock or the amount of CO₂ absorbed and stored by the stands (Uthbah et al. 2017). According to Sardjono et al. (2017), biomass has a very strong relationship with photosynthesis process. Biomass increases because plants absorb CO2 from the air and convert it into organic compounds through the process of photosynthesis.

Putri and Wulandari (2015) stated that the biomass of a stand can be estimated using an allometric equation whose parameter is the diameter of the stand. The large diameter

of the stands causes the greater the biomass and carbon stored, and vice versa, the smaller the stand diameter, the smaller the biomass and carbon stored in it. The tree allometric equation can yield some estimates on standing volume, biomass and carbon stock. The equation obtained is a statistical model used to explain the relationship between the various components of a tree stand. It allows foresters to take simple measurements of tree stands, such as measuring diameter, height, biomass and carbon (Kasim et al. 2014).

Tuheteru and Husna (2011) explain that age is very influential in the sequestration of carbon. If the trees are getting older, their ability to absorb carbon is also high. Measurement of forest biomass in this research was conducted on the whole tree, consisted of aboveground biomass of stems, branches, and leaves. In addition, it turns out that the number of trees per hectare and the density of the stands greatly affect the presence of biomass and carbon. This means that the denser and healthier the stand, the greater the amount of biomass and carbon (Juwari et al. 2020b). This is in line with research conducted by Krisnawati et al. (2011) that there is a close relationship between age and carbon in A. cadamba. While Polosakan et al. (2014) and Uthbah et al. (2011) stated that the difference in the amount of biomass above the soil surface is influenced by the age of the stands. Stand age has an effect on biomass because stand age affects the volume of stems and density of stand wood. The older the stand, the higher the volume and density of wood stands.

The results of this study show that T. grandis stands had higher total stored carbon compared to G. arborea. The ability of T. grandis trees to absorb carbon dioxide (CO₂) makes this plant the most stored carbon among tree species other. According to Lubis et al. (2013), the increase in biomass and carbon stored by trees goes hand in hand with the increase in the dimensions of the stem includes the diameter and height. Forest plantations play a critical role in mitigating the various effects of environmental degradation and increasing absorption of carbon dioxide in the atmosphere and also its consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. The outcome of this study revealed that Tgrandis and G. arborea has a great potential in promoting carbon sequestration especially when they are allowed to grow older. Favorable growth conditions have high potential of increasing the biomass accumulation of this species. Hence, it is recommended that sustainable management of this plantation should be paramount in securing a cleaner environment and mitigating the effect of climate change in Indonesia.

ACKNOWLEDGEMENTS

We would like to express our gratitude to Umbar Sujoko and Muhammad Rafii Nur Fauzan for his help in creating the map of the study site. The authors would like to acknowledge Karyati, Rita Diana and anonymous reviewers for providing constructive comments to improve the manuscript.

REFERENCES

- Adhitya PW, Hardiansyah G, Yani A. 2013. Estimation of surface carbon content on a tree in the Ketapang Regency City forest area. J Sustain For 2 (1): 23-32.
- Adinugraha HA, Setiadi D. 2018. Selection of seed trees of *Gmelina* arborea Roxb. at smallholder forest in Bondowoso, East Java. Tropical Forest J 16 (1): 6-12. DOI: http: //dx.doi.org/10.20527/jht.v6i1.5099
- Alam AS, Rafiuddin, Setiawan, B. 2017. Financial analysis systems teak and elephant grass agroforestry in Samboja District Kutai Kartanegara Regency, East Kalimantan. Proceedings National Biodiversity Conservation.
- Amirta R, Yuliansyah, Angi EM, Ananto BR, Setyono B, Haqiqi MT, Septiana HA, Lodong M, Oktavianto RN. 2016. Plant diversity and energy potency of community forest in East Kalimantan, Indonesia: Searching for fast growing wood species for energy production. Nusantara Biosci 8 (1): 22-30. https://doi.org/ 10.13057/nusbiosci/n080106 [Indonesian]
- Birdsey R, Pan Y. 2015. Trends in management of the world's forests and impacts on carbon stocks. For Ecol Manag 355: 83-90. https://doi.org/10.1016/j.foreco.2015.04.031
- Bredu AS, Birigazzi L. 2014. Proceedings of the regional technical workshop on tree volume and biomass allometric equations in west africa. UN--REDD Programme MRV Report 21, Kumasi, Ghana, Forestry Research Institute of Ghana. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Calfapietra C, Barbati A, Perugini L, Ferrari B, Guidolotti G, Quatrini A, Corona P. 2015. Carbon mitigation potential of difffferent forest ecosystems under climate change and various in Italy. Ecosyst. Heal Sustain 1 (8): 1-9. https://doi.org/10.1890/EHS15-0023
- Chauhan SK, Sharma R, Panwar P, Chander J. 2016a. Short rotation forestry: a path for economic and environmental prosperity. In: Parthiban KT, Seenivasan R (eds). Forestry Technologies - A Complete Value Chain Approach. Vol.1 Scientific Publishers, Jodhpur.
- Chauhan SK, Ritu, Chauhan R. 2016b. Carbon Sequestration in Plantations. Agroforestry for Increased Production and Livelihood Security. New Indian Publishing Agency, New Delhi.
- Chave J, Réjou MM, Búrquez A, ChidumayoE, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez YrízarA, Mugasha WA, Muller Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz ME, Pélissier R, Ploton P, Ryan CM, SaldarRJG, Vieilleden G. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Glob Change Biol 20 (10): 3177-3190. https://doi.org/10.1111/gcb.12629
- Cuong T, Chinch TTQ, Zhang Y, Xie Y. 2020. Economic performance of forest plantation in Vietnam: *Eucalyptus, Acacia mangium,* and *Manglietia conifera*. Forests 11 (284): 1-14. https://doi.org/10.3390/f11030284
- Dinga E. 2014. On a possible predictor of the cyclical position of the economy. Procedia Econ Finance 8: 254-261. https:// doi.org/10.1016/S2212-5671(14)00088-4
- Ekholm T. 2016. Optimal forest rotation age under eficient climate change mitigation. For Policy Econ. 62: 62-68. https://doi.org/ 10.1016/j.forpol.2015.10.007
- Gonzalez-Benecke CA, Samuelson LJ, Martin TA, Cropper Jr WP, Johnsen KH, Stokes TA, Butnor JR, Anderson PH. 2015. Modeling the effects of forest management on in situ and ex situ longleaf pine forest carbon stocks. For Ecol Manag 355: 24-36. https://doi.org/10.1016/j.foreco.2015.02.029
- Gren IM, Zeleke AA. 2016. Policy design for forest carbon sequestration: A review of the literature. For Policy Econ 70: 128-136. https://doi.org/10.1016/j.forpol.2016.06.008
- Hairiah K, Rahayu S. 2007. Pengukuran Karbon Tersimpan diberbagai Macam Penggunaan Lahan. World Agroforestry Centre. ICRAF Southeast Asia Regional, Bogor. [Indonesian]
- Hairiah K, Andree A, Rika RS, Subekti R. 2011. Measurement of carbon stock from land level to landscape 2nd edition. Agroforestry Center, Bogor. [Indonesian]
- Irundu D, Beddu MA, Najmawati. 2020. Potential of biomass and carbon stored stands in green open space Polewali City, West Sulawesi. J Forests Communities 12 (1): 49-57

- Juwari, Ruhiyat D, Aipassa MI, Ruslim Y. 2020a. Carbon stocks of *Rhizhopora apiculata* and *Sonneratia alba* of mangrove forest in Ngurah Rai Forest Park, Bali Province, Indonesia. J Biodivers Environ Sci 16 (3): 93-105.
- Juwari, Ruhiyat D, Aipasaa MI. 2020. Growth analysis of *Rhizophora Mucronata mangrove in Ngurah Rai Forest Park (Sanur) Bali Province, Indonesia. Energy Enviro Res 10 (1): 30-35.*
- Karyati, Widiati KY, Karmini, Mulyadi R. 2019. Development of allometric relationships for estimate above ground biomass of trees in the tropical abandoned land. Biodiversitas 20 (12): 3508-3516. https://doi.org/10.13057/biodiv/d201207 [Indonesian]
- Kasim AR, Henry M. Danial M, Faiz M, Birigazi L. 2014. Inventory of tree biomass and volume allometric equations in Southeast Asia. FRIM, Kepong, Food and Agriculture Organization of the United Nations, Rome, Italy
- Krisnawati H, Kallio M, Kanninen M. 2011. Anthocephalus cadamba Miq. Ecology, silviculture and productivity. CIFOR.
- Kristiningrum R, Lahjie A, Masjaya, Yusuf S, Ruslim Y. 2019. Species diversity, stand productivity, aboveground biomass and economic value of mangrove ecosystem in Mentawir Village, East Kalimantan, Indonesia. Biodiversitas 20 (10): 2848-2857. https:// doi.org/10.13057/biodiv/d201010 [Indonesian]
- Kumi JA, Kyereh B, Ansong M, Ansate W. 2020. Influence of management practices on stand biomass, carbon stocks and soil nutrient variability of teak plantations in a dry semi-deciduous forest in Ghana. Trees For People 3, 100049. https:// doi.org/10.1016/j.tfp.2020.100049
- Lubis SH, Arifin SH, Samsoedin I. 2013. Analysis of tree carbon stocks in forest landscapes city in DKI Jakarta. J Forest Sos Econ Research, 10 (1):1-20.
- Lukito M, Rohmatiah A. 2013. Estimated biomass and carbon of teak 5 year (Case of Nusantara Superior Teak Plantation Forest (JUN) Krowe Village, Lembeyan District, Magetan Regency). Agritek J 14 (1): 1-23. https://doi.org/10.12988/asb.2017.7924
- Meunpong P. 2012. Nutrient and Carbon Storage in Forest Plantation, Prachuap Khiri Khan province, Thailand. Kasetsart University, Bangkok, Thailand. [Dissertation]. Kasetsart University, Bangkok, Thailand.
- Nemeth R, Feher S, Koman S. 2018. Utilization of fast growing plantation timber as bioenergy in Hungary. 2018 4th International Conference on Environment and Renewable Energy (ICERE 2018). Da Nang, Vietnam, 25-27 February 2018.
- Nonini L, Fiala M. 2019. Estimation of carbon storage of forest biomass for voluntary carbon markets: Preliminary results. J For Res 32 (1): 329-338. https://doi.org/10.1007/s11676-019-01074-w
- Panwar P, Chauhan S, Kaushal R, Das DK, Ajit, Arora G, Chaturvedi OP, Jain AK, Chaturvedi S, Tewari S. 2017. Carbon sequestration potential of poplar-based agroforestry using the CO₂ FIX model in the Indo Gangetic Region of India. Trop Ecol 58 (2): 1-9.
- Rinnamang S, Sirirueang K, Supavetch S, Meunpong P. 2020. Estimation of aboveground biomass using aerial photogrammetry from unmanned aerial vehicles in teak (*Tectona grandis*) plantation in Thailand. Biodiversitas 21 (6): 2369-2376. https://doi.org/10.13057/biodiv/d210605
- Riutta T, Malhi Y, Kho LK, Marthews TR, Huasco WH, Khoo M. 2018. Logging disturbance shift net primary productivity and its allocation in Bornean tropical forest. J. Glob Change Biol 24 (7): 2913-2928. https://doi.org/10.1111/gcb.14068
- Ruslianto M, Alviani, Maisuri, Irundu. 2019. Biomass allometric model of *Rhizophora Apiculata* at Polewali Mandar Regency, West Sulawesi Province. Buletin Eboni 1 (1): 11-19. [Indonesian]
- Pandey S, Shukla R, Saket R, Verma D. 2019. Enhancing carbon stocks accumulation through forest protection and regeneration. A review. Int J Environ 8 (1): 16-21
- Putri AHM, Wulandari C. 2015. Potential carbon absorption in *Shorea javanica* in Pekon Gunung Kemala Krui, West Lampung. Sylva Lestari 3 (2): 13- 20. DOI: http://dx.doi.org/10.23960/jsl2313-20 [Indonesian]
- Polosakan R, Alhamd L, Joeni SR. 2014. Estimated biomass and carbon stored in *Pinus merkusii* Jungh. & de Vriese in the pine forest Mt. Bunder, TN. GN Halimun Salak. Biol News 13 (2): 15-120. [Indonesian]
- Sandalayuk. D, Soedirman S, Pambudhi F. 2018. Reserves estimating carbon in forest city district village Bongohulawa Gorontalo. IJRTEM 2 (8): 60-63.

- Sandalayuk D, Lahjie AM, Simarangkir BDAS, Ruslim Y. 2020. Carbon absorbtion of Anthocephalus macrophyllus and Swietenia macrophylla. King in Gorontalo, Indonesia. J Biodivers Environ Sci 16 (5): 24-30. http://www.innspub.net
- Sardjono A, Lahjie AM, Simarangkir BDAS, Kristiningrum R, Ruslim Y. 2017. Carbon sequestration and growth of *Anthocephalus cadamba* plantation in North Kalimantan, Indonesian. Biodiversitas 18 (4): 1385-1393. DOI: 10.13057/biodiv/d180414[Indonesian]
- Sedjarawan W, Akhbar, Arianingsih I. 2014. Biomassa dan karbon pohon di atas permukaan tanah ditepi jalan taman nasional Lore Lindu. J Warta Rimba 2 (1): 105-115. [Indonesian]
- Sharma R, Chauhan SK, Tripathi AM. 2016. Carbon sequestration potential in agroforestry system in India: An analysis for carbon project. Agrofor Syst 90 (4): 631-644. doi: 10.4172/2157-7617.1000131
- Setiawan B, Lahjie AM. 2011. Financial analysis of agroforestry systems teak, sungkai, and elephant grass in Samboja Kutai District Kartanegara. Humida Trop For 4 (1) [Indonesian]
- Setiawan B, Lahjie AM, Yusuf S, Ruslim. 2019. Model of community forest land management production and financial simulation of super teak, solomon teak and sungkai trees in Samboja Kutai Kartanegara East Kalimantan, Indonesia. Energy Environ Res 9 (20): 48-60.
- SNI. 2011. Indonesian National Standard Number 7724. Measurement and calculation of carbon stocks - field measurement for forest carbon stock assessment. Standardization Agency, Jakarta. [Indonesian]
- Siregar UJ, Narendra BH, Suryana J, Siregar CA, Weston C. 2017. Evaluation on community tree plantations as sustainable source for rural bioenergy in Indonesia. IOP Conf Ser: Earth Environ Sci. International Conference on Biomass: Technology, Application, and Sustainable Development. Bogor, Indonesia, 10-11 October 2016.
- Sist P, Nicolas P, Fleury SG. 2003. Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of borneo. Ann For Sci 60 (8): 803-814. DOI: 10.1051/forest:2003075
- Sousa VB, Cardoso S, Quilho T, Pereira H. 2011. Growth and ring width variability of teak, *Tectona grandis* (Verbenaceae) in an unmanaged forest East Timor. Int J Trop Biol 60 (1): 483-494. ISSN-0034-7744
- Susila IWW. 2012. Estimation model of teak stand volume and increment in Nusa Penida, Klungkung Bali. J Plant For Res 9 (3): 165-178.

- Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A. 2016. Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. Geoderma 261: 70-79. https://doi.org/10.1016/j.geoderma.2015.06.022
- Tuheteru FD, Husna. 2011. Growth and biomass *Albizia saponaria* on local arbuscular mycorriazhae fungi from Southeast Sulawesi. J Sivikultur Tropika 2(3): 143-148.[Indonesian]
- Trimanto. 2014. Vegetation analysis and tree biomass estimation of carbon stocks in Seven Montane Forests of Bawean Island Nature Reserve, East Java. Biol News 13 (1): 321-332. [Indonesian]
- Uthbah Z, Sudiana E, Yani E. 2017. Biomass analysis and carbon stock at various ages of resin stands *Agathis dammara* (Lamb.) Rich.) in KPH Banyumas Timur. Scr Biol 4 (2): 119-124. DOI: 10.20884/1.sb.2017.4.2.404
- Van Gardingen PR, McLeish MJ, Philips PD, Fadilah D, Tyrie G, Yasman I. 2003. Financial and ecological analysis of management options for logged-over dipterocarp forest in Indonesia Borneo. For Ecol Manag 183 (1-3): 1-29. https://doi.org/10.1016/S0378-1127(03)00097-5
- Warner AJ, Jamroenprucksa M, Puangchit L. 2017. Buttressing impact on diameter estimation in plantation teak (*Tectona grandis* L.f.) sample trees in northern Thailand. Agric Nat Resour 51 (6): 520-525. https://doi.org/10.1016/j.anres.2018.01.001
- Wei RP, Zhu W. 2019. Adaptability and growth of a fast-growing Neolamarckia cadamba (Robx.) Bosser clone in the south subtropical region of China. Open J Forestry 9, 419-438. https://doi.org/10.4236/ojf.2019.94024
- Winarni B, Lahjie AM, Simarangkir BDAS, Yusuf S, Ruslim Y. 2017. Tengkawang cultivation model in community forest using agroforestry system in West Kalimantan, Indonesia. Biodiversitas 18 (2): 765-772. https://doi.org/10.13057/biodiv/d180249 [Indonesian]
- Yunianti AD, Wahyudi, Siregar, Pari. 2011. Quality of teak clones with different planting distances. J Wood Sci Tech Trop 9 (1): 93-100. [Indonesian]
- Zeng W, Fu L, Xu M, Wang X, Chen Z, Yao S. 2018. Developing individual tree-based models estimating aboveground biomass of five key coniferous species in China. J For Res 29 (5): 1251-1261. DOI: 10.1007/s11676-017-0538-9

liodiversitas Journal of Biological Diversity	Tasks 🛐	 English 	View Site
OPEN JOUERNAL SYSTEMS	7790 / RUSLIM et al. /	Estimation of Above Ground Biomass and carbon stocks of Tectona grandis and Gmelina arb <mark>o</mark> rea stands in Go	Library
ubmissions	Workflow Publ	cation	
	Status: Published		
		This version has been published and can not be edited.	
	Title & Abstract	Title	
	Contributors	Estimation of Above Ground Biomass and carbon stocks of Tectona grandis and Gmelina arborea s	tand:
	Metadata	Abstract	
	References	B I × ² × ₁ &	

Galleys

Abstract. Ruslim Y. Sandalayuk D, Kristiningrum R, Alam AS. 2021. Estimation of Above Ground Biomass and carbon stocks of Tectona grandis and Gmelina arborea stand in Gorontalo Province, Indonesia. Biodiversitas 22: 1497-1508. Plantation forest plays an important role to fulfill timber needs, while more recently plantation forest is increasingly acknowledged to sequester and store carbon which can mitigate climate change and also as carbon sequestration for the environment. This study aimed to calculate the stand potential, stand biomass and carbon stocks of teak (*Tectona* grandis) and gmelina (*Gmelina arborea*) stands in the context of land after being abandoned in Gorontalo Province, Indonesia. Four plots with size of one hectare each were sampled in which each yruslin

species (i.e. teak and gmelina) consisted of two plots. In each plot, the diameter at the breast-high (1.3 m) and the height of each individual were recorded. Data analysis included growth parameters of the stands (i.e., Mean Annual Increment/MAI and Current Annual Increment/CAI) and above-ground biomass and carbon sequestered by the stands. Simple linear regression using polynomial trendline was used to determine the relationship between variables and the degree of the relationship. The results showed that the maximum growth of teak stands at Plots I and II reached **\$**

maximum point at the age of 32 and 25 years with the total volume of 307.50 and 254.81 m³ha⁻¹, respectively. While the maximum growth of <u>gmelina</u> stands at Plots I and II reached a maximum point at the age of 15 years with <u>the total</u> volume of 190.54 and 251.80 m³ha⁻¹, respectively. The biomass content in teak stands at Plots I and II and <u>gmelina</u> stands at Plots I and II were respectively 267.83; 221.94; 104.03 and 137.48 tons ha⁻¹. Meanwhile, the carbon content in teak

stands at Plots I and II and gmelina stands at Plots I and II were respectively 125.88; 104.31; 48.90; and 64.62 tons ha⁻¹. The results of the regression analysis suggest that there was strong relationship between carbon sequestered and the age of the stands as well as total basal area. The results of this study suggest that *Tectona grandis* is more potential to be developed as <u>plantation</u> forest than *Gmelina arborea* when aiming at carbon sequestration and biomass production.