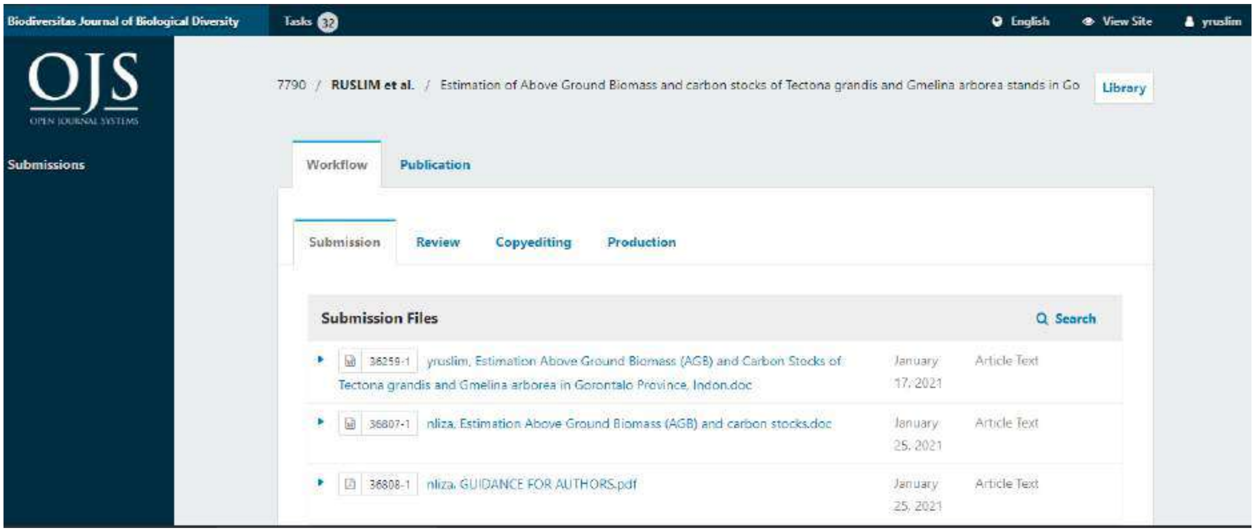
BUKTI-BUKTI PROSES REVIEW (PENULIS KORESPONDENSI)

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



7790 / **RUSLIM et al.** / Estimation of Above Ground Biomass and carbon stocks of Tectona grandis and Gmelina arborea stands in Go

Submission Files

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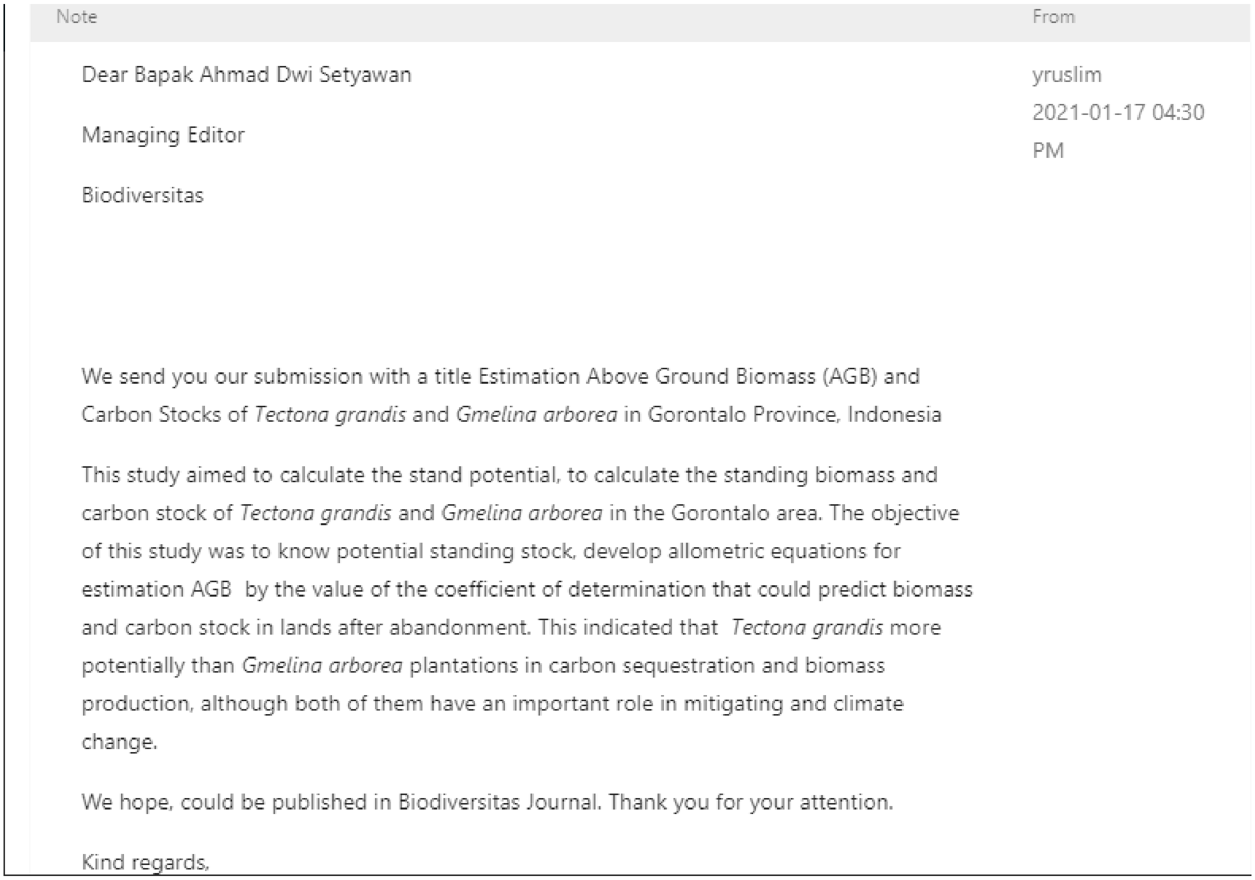

Note

From

Dear Bapak Ahmad Dwi Setyawan

Managing Editor

Biodiversitas

We send you our submission with a title Estimation Above Ground Biomass (AGB) and Carbon Stocks of *Tectona grandis* and *Gmelina arborea* 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,

yruslim
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COVERING LETTER

Dear **Editor-in-Chief,**

I herewith enclosed a research article,

Title:

Estimation Above Ground Biomass (AGB) 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

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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 arboreaa* 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.

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

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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 timber needs and also as carbon sequestration for the environment. The purpose of this study was to calculate the stand potential, to calculate the standing biomass and carbon stock of teak 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 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 m^{3}ha^{-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 m^{3}ha^{-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.

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

INTRODUCTION

Along with the development today the forest is not it only function as a producer wood, but also as a producer environmental services. Forest as a very environmental service producer potentially reducing carbon dioxide in the atmosphere through the process of photosynthesis (Lukito and Rohmatiah 2013). Land use change and its impact on global climate are important factors that make it necessary to improve our knowledge of carbon (C) cycling in forest ecosystems (Derwisch et al. 2009). Birdsey and Pan (2015) had reviewed the function of forest has been changing in recent decades and summarized those implications for global carbon stocks. Forests can play an important role in capturing and storing C from the atmosphere, thereby mitigating CO_2 emissions (e.g., Watson et al. 2000; Houghton 2005). Tropical plantations 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 changes need to be concerned prior to preventing the loss function of tropical forests. The forest degradation process with respect to selective logging, forest fire, and abandonment dynamics occurs over large areas in tropical forests (Pinheiro et al. 2016). Therefore, Ruslim et al (2016), state that development of more effective ways to reduce the illegal harvest activities should be done to protect the tropical forest diversity. More often extrapolations are based on the level of land use (Domec et al. 2015). The amount of this nutrient depletion depends on species characteristics, growth rate, tissue nutrient content, the period of harvesting rotation, the use of harvesting methods and nutrient reserves in the soil (Arias et al. 2011).

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

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 0º 32 '28 "North Latitude and 123º 03 '36 "East Longitude.

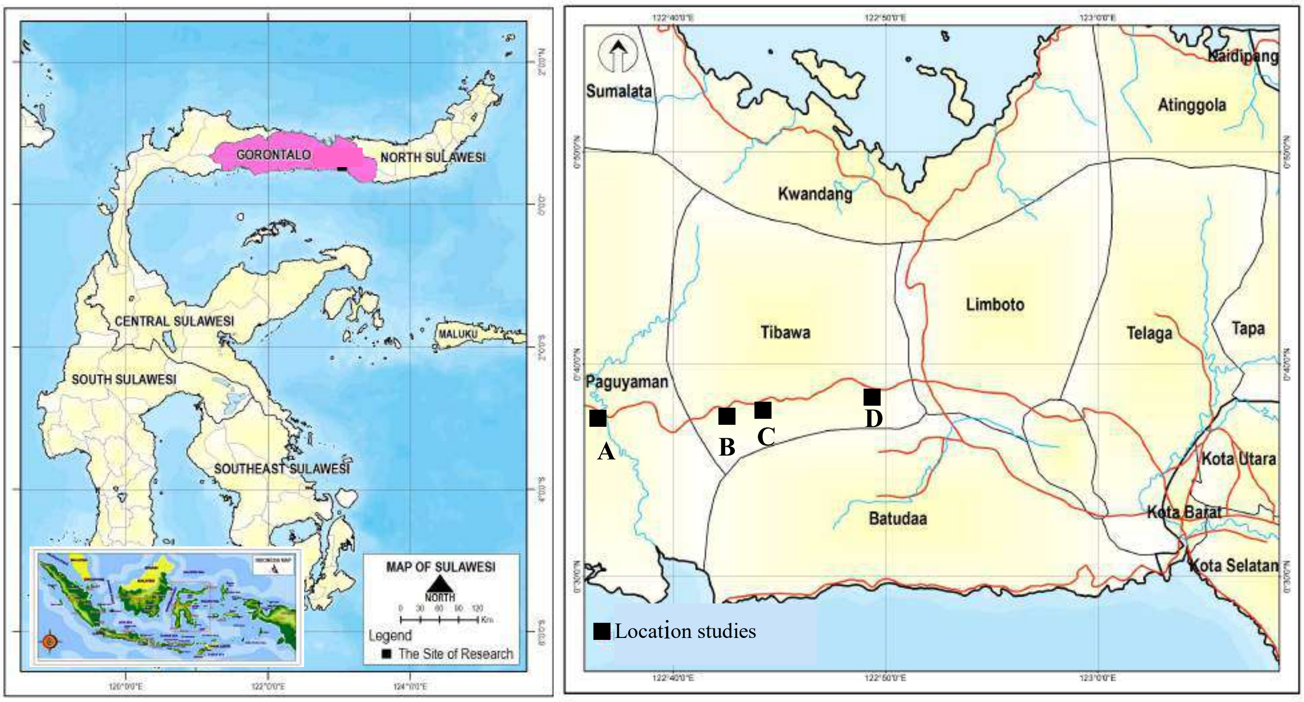

Figure 1. Location studies (in which: **A** = *G. Arborea* plot II, **B** = *T.grandis* plot I**,** **C** = *G. Arborea* plot I , **D** = *T.grandis* plot II)

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.

Data analysis

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).

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

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:

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

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

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:

$M = BJ \times V_t \times BEF$

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

$Cb = B \times \%\ C$ Organic

In which: Cb = Carbon content of biomass (kg), B = Total biomass (kg), % C Organic = Percentage value of carbon 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:

Biomass (kg ha^{-1}) = Biomass (kg m^{-2}) x 10,000 m^2

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

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

$\hat{Y} = a + bX$

In which: $\hat{Y}$ = Estimated value of biomass, X = Volume (m^3), 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.

Growth of *Tectona grandis*

Growth of Tectona grandis Plot I

T. *grandis* which was cultivated in plot I at the beginning was planted using a spacing of 3m x 3m, so the initial number of trees was 1,111 trees. 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. 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

Notes: N = Population of *T.grandis* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^{3} ha^{-1}), MAI = Mean Annual Increment (m^{3} ha^{-1} year^{-1}), CAI = Current Annual Increment (m^{3} ha^{-1} year^{-1}), B.A = Bassal area (m^{2}ha)

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 m^{3}ha^{-1}. Meanwhile, the growth increment ranged from 0.55 to 9.61 m^{3}ha^{-1}year^{-1}. The maximum total volume of teak reached at the age of 32 years is 307.50 m^{3} ha^{-1} and an increment of 9.61 and 9.86 m^{3}ha^{-1}year^{-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

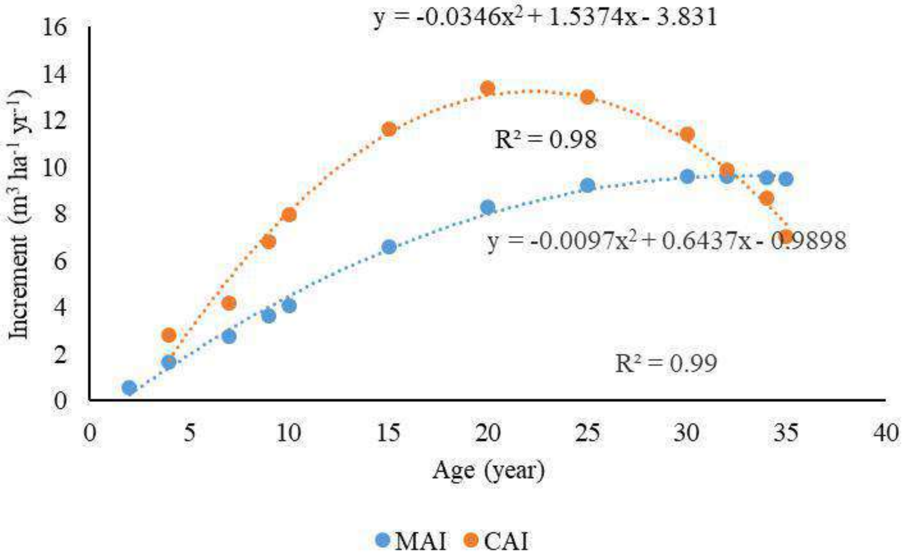

Figure 2. The corellation of MAI and CAI *T. grandis* in Plot I

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 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 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 Plot II

T. grandis which was cultivated in plot II at the beginning was planted using a spacing of 3m x 3m, so the initial number of trees was 1,111 trees. 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. Based on the teak growth table, the number of trees, diameter, height, total volume and increment of teak can be seen as follows:

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**
30	400	38.0	9.3	0.60	253.82	8.46	4.91	45.34	221.08	103.91

Notes: N = Population of *T.grandis* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), B.A = Bassal area (m^{2}ha)

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 m^3 ha^{-1}. Meanwhile, the growth increment ranged from 0.45 to 9.17 m^3 ha^{-1} $year^{-1}$. The maximum total volume of teak reached at the age of 25 years is 229.28 m^3 ha^{-1} and an increment of 9.17 and 9.78 m^3 $ha^{-1}year^{-1}$ with the number of trees per hectare as many as 500 trees.

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

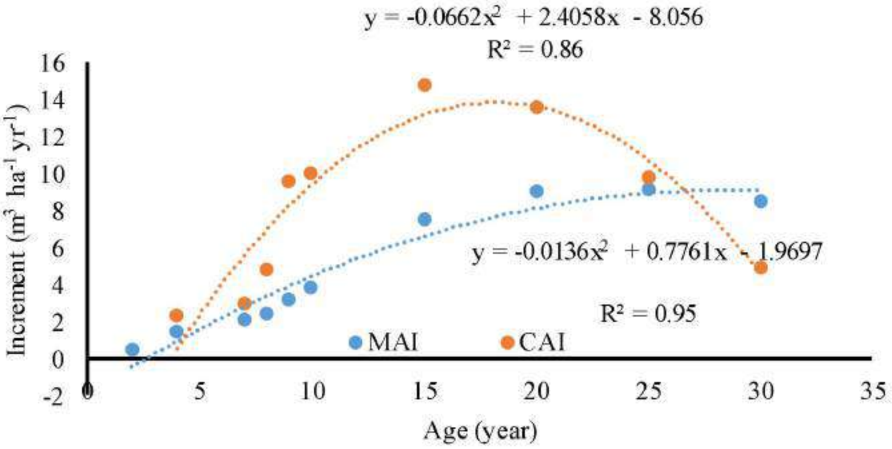

Figure 3. The corellation of MAI and CAI *T. grandis* in Plot II

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 m^3 and 6.17 $m^3ha^{-1}year^{-1}$ and Solomon teak 150.94 m^3 and 6.04 m^3 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 $m^3ha^{-1}year^{-1}$ (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*

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:

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

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

Notes: N = Population of *G. arborea* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), B.A = Bassal area (m^{2}ha)

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 m^{3}ha^{-1}. Meanwhile, the growth increment ranged from 3.36 to 12.70 m^3 ha^{-1} year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years is 190.54 m^3 ha^{-1} and an increment of 12.70 and 13.28 m^{3}ha^{-1}year^{-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.

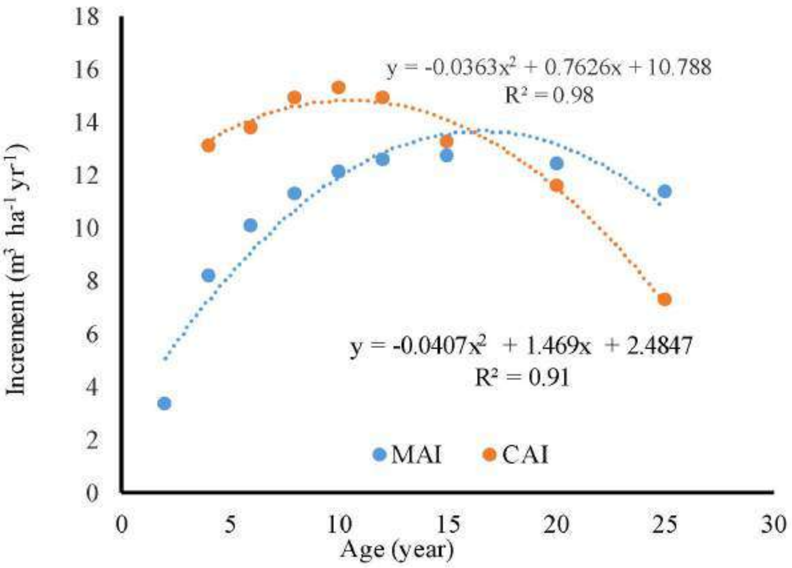

Figure 4. The corellation of MAI and CAI *G. arborea* in Plot I

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 R^2 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 R^2 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.

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:

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

Notes: N = Population of *G. arborea* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), B.A = Bassal area (m^2ha)

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 m^3ha^{-1}. Meanwhile, the growth increment ranged from 1.75 to 16.69 $m^3ha^{-1}year^{-1}$. The maximum total volume of *G. arborea* reached at the age of 15 years is 251.80 m^3 ha^{-1} and an increment of 16.79 and 16.69 $m^3ha^{-1}year^{-1}$ 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

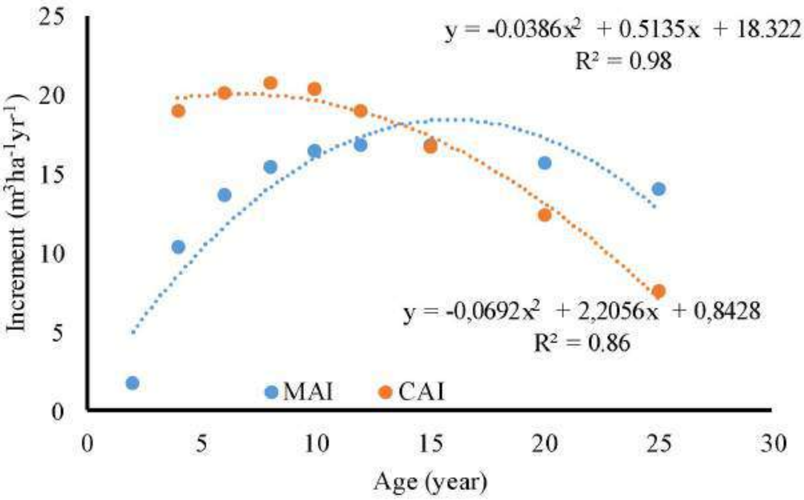

Figure 5. The corellation of MAI and CAI *G. arborea* in Plot II

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 R^2 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 m^3 ha^{-1} and increments of 12.70 and 13.28 m^3 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 m^3 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 m^3 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

Carbon and biomass production

The increase in CO_2 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). According to Sardjono et al. (2017), biomass is closely related to the process of photosynthesis. Biomass increases because the plant absorbs CO_2 from the air and transforms it to organic compounds through the process of photosynthesis. The result of photosynthesis is used by plants to grow horizontally and vertically (Adinugroho and Sidiyasa 2009). The intensity of water logging and drought are predicated to increase in dry and rainy season due to climate change (Tong et al. 2016) and potential effects on initial growth and successful forest and land rehabilitation activities.

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 R^2. The maximum value of R^2 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 $R^2 = 0$, then there 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 (Handayani 2010). In addition, if the value of the coefficient of determination (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).

Mansur and Tuheteru (2011) explain that age was very influential in the production of carbon. If the trees were getting older, their ability to absorb carbon was also high. Measurement of deep forest biomass this research was conducted on the whole tree consists of aboveground biomass (aboveground biomass) includes stems, branches, and leaves. 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 (R^2), the average regression coefficient is 97%. Where the regression coefficient of the relationship between age and carbon in teak plot I is 98%, teak plot II is 96%, gmelina plot I is 99% and gmelina plot II is 97%. According to Sugiyono (2012), the coefficient value determination in the range of 80% - 100% means that there is a very strong relationship the dependent variable and the independent variable. This indicated that there was a strong correlation between age and carbon because the value of its coefficient of determination was higher than 90% and the graph of each correlation formed a linear shape. This is in line with research conducted by Sardjono et al (2017) that there is a close relationship between age and carbon in *A.cadamba.*

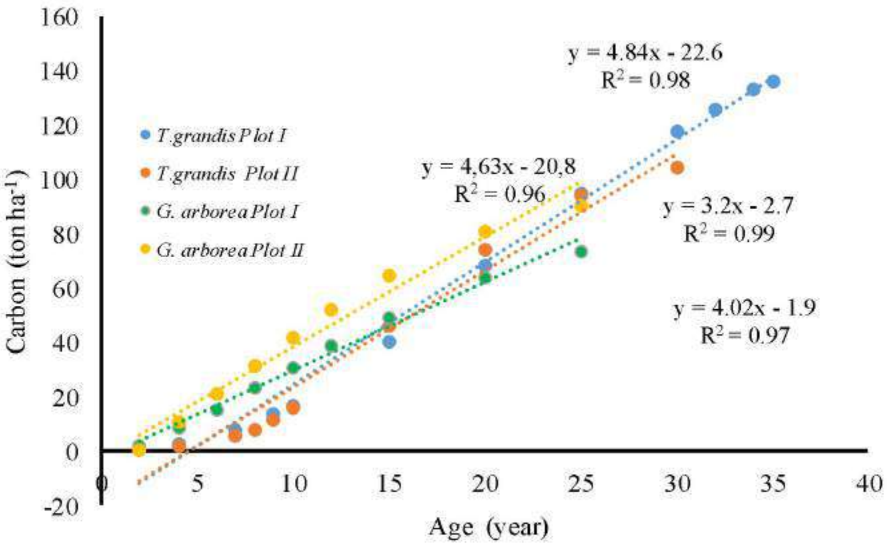

Figure 8. The correlation between the stand age and production carbon of *T. grandis* and *G. arborea*

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

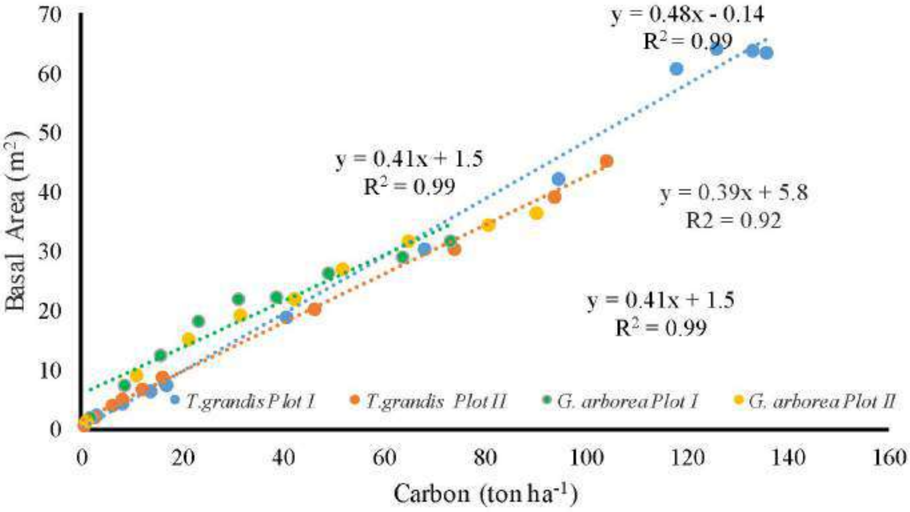

Figure 9. The correlation between the production carbon and basal area of *T. grandis* and *G. arborea*

Based on the picture above it can be explained that production of carbon in relation to its influence on basal area, had a very strong and high correlation (R^2), the average regression coefficient is 97%. Where the regression coefficient of the 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%. This indicated that there was a strong correlation between carbon and basal area because the value of its coefficient of determination was higher than 90% and the graph of each correlation formed a linear shape. This means that the regression coefficient of both the relationship between age and carbon and carbon with the basal area has a regression 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 between carbon and basal area of about 97% and 3% is influenced by other factors. And the graph of each correlation 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.

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

No	Type	Age (yr)	TV (m^3ha^{-1})	BA (m^2ha^{-1})	Biomass (ton ha^{-1})	Carbon (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

Notes: TV = Total volume (m^3 ha^{-1}), BA= Basal area (m^2 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, basal area, biomass and carbon among other stands of 307.5 m^3 ha^{-1}; 64.06 m^2 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 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 m^3 ha^{-1}, basal area 43.56 m^2 ha^{-1}; biomass 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 m^3 ha^{-1}, basal area 31.79 m^2 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 total volume 190.54 m^3 ha^{-1}, basal area 26.46 m^2 ha^{-1}; biomass 104.03 ton ha^{-1} and carbon 48.90 ton ha^{-1}. Whereas according to Trimanto (2014) states that production of *Gmelina arborea* tends to store carbon in large quantities smaller 19.96 ton C ha^{-1} or 2.49 ton C ha^{-1}yr^{-1} compared to production of Tectona grandis which can store as much carbon 114.88 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

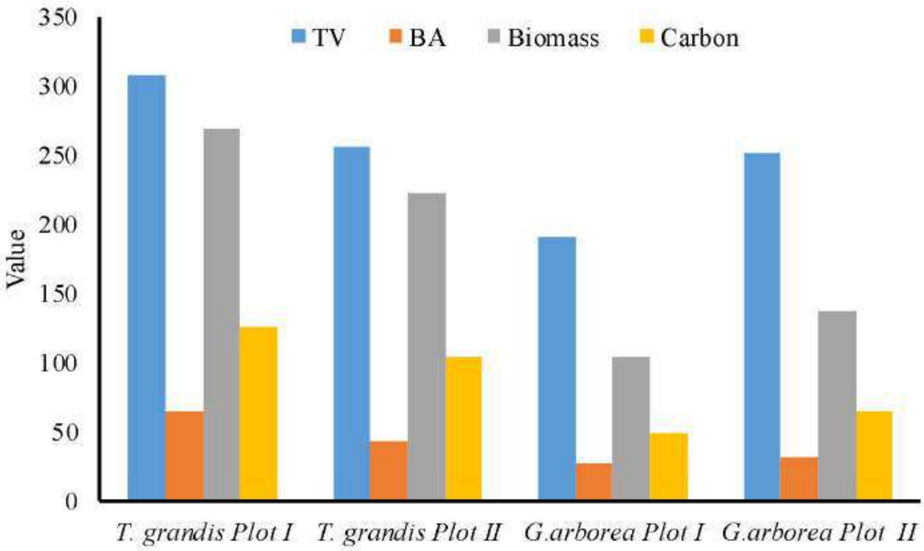

Figure 8. The correlation between total volume, basal area, biomass and carbon each stand

Research result shows that *T. grandis* stands have the highest total stored carbon when compared to *G. arborea*. Fast growth and the ability 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 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 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 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.

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.

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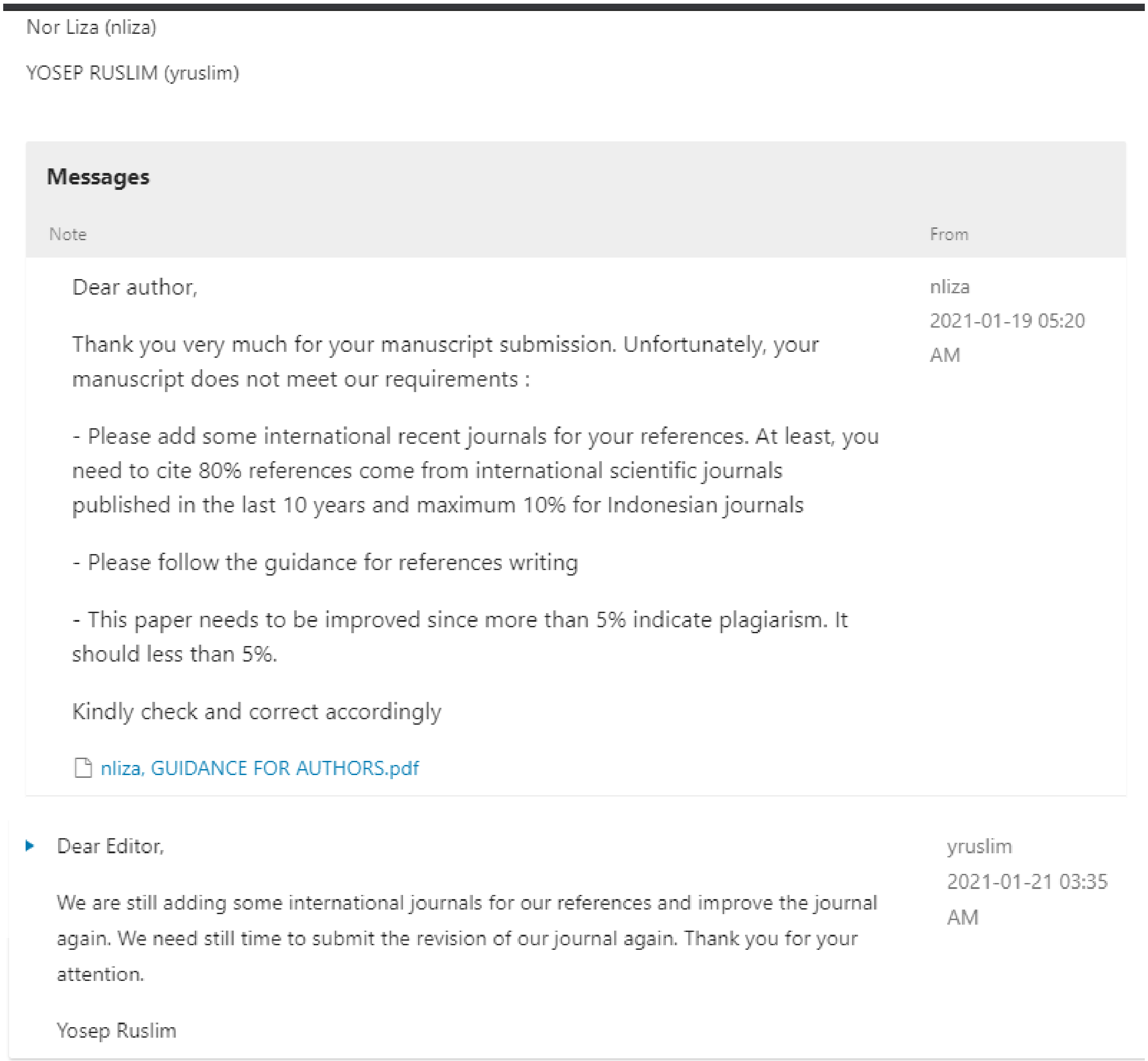

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Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea

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

Abstract. Plantation forest exploitation has an important role in meeting timber needs and also as carbon sequestration for the environment. The purpose of this study was to calculate the stand potential, to calculate the standing biomass and carbon stock of teak 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 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 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 m^3ha^{-1}. While the maximum growth of gmelina plots I and II reaches a maximum point at the age of 15 years and the total volume is 190.54 and 251.80 m^3ha^{-1}. 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 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.

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

INTRODUCTION

Indonesia has renewable natural resources such as plantation forests. These forest resources have the potential as a source of biomass by promoting the planting of fast growing plants. However, until now the existence of fast growing plantations 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 photosynthesis (Lukito and Rohmatiah 2013). This is in line with research conducted by Birdsey and Pan (2015) that there has been a change in forest function in the last few decades and explains its impact on global carbon stocks. Tropical forest 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 before preventing the loss of the function of tropical forests. One example is the process of forest degradation caused by non-selective logging, forest fires, and neglected forest development dynamics occurring in large areas in tropical forests (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 attention to land use (Domec et al. 2015). Because this affects the depreciation of the day elements. Where the depreciation of these nutrients depends on the characteristics of the species, growth rate, tissue nutrient content, harvest rotation period, use of harvest methods and nutrient reserves in the soil (Arias et al. 2011).

Biomass and carbon stocks (C) in forest ecosystems have an important role in climate change and mitigation (Calfapietra et al, 2015; Zeng et al, 2018; Pandey et al, 2019). This biomass estimation is very important and aims to calculate the amount and variation of C (Ekholm 2016; Gren and Zeleke 2016; Ruitta et al. 2018; Nonini and Fiala 2019). Biomass is important in determining forest production and sustainable forest management (Rinnamang et al. 2020). Furthermore, according to Gonzalez-Benecke et al. 2015; Sharma et al. 2016; Panwar et al. 2017, states that an increase in rotation length will also result in an increase in biomass and carbon stocks. Where biomass production is influenced by organic matter in the soil. Biomass functions as organic material to maintain soil fertility and soil biotic stability (Lee et.al 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 other potential in order to change management activities (Birdsey and Pan 2015; Law and Waring 2015; Noormets et al. 2015). The ability of fast-growing stand types to absorb carbon faster than slow-growing stands is one of the strong 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 management and carbon sinks (Kanninen 2010; Chauhan et al. 2016b). One type of fast growing stands is teak and gmelina. This is because besides being fast growing, Teak (*Tectona grandis* Linn.f.) is an important commercial stand type 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 can be transparent and resistant to fire (Meunpong 2012). Meanwhile, *Gmelina arborea* Roxb. is one type of plant that is widely developed for industrial 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 level with an average rainfall of 750-5000 mm $year^{-1}$ (Adinugraha and Setiadi 2018).

Research on forest potential is very important. This is in line with the statement from Nonini and Fiala (2019) that estimating carbon storage in forests is very important to support climate change and mitigation and promote the transition to a low-carbon emission economy.This research includes the potential for the stands, the potential for biomass and carbon. One of the factors that determine the analysis of forest potential is the allometric method, which is measuring the potential of biomass and carbon with standard standards. Based on this background, the following problems can be formulated: how much is the amount of carbon content with the approach of calculating the amount of biomass. This is because carbohydrates are obtained from photosynthesis stored in living plant organs. Karyati et al (2019) stated that the allometric equation for estimating aboveground biomass on this land is still limited. So it is necessary to do this research to 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 where allometric equations and tree dimensions such as diameter and total height can be used to calculate forest stand 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 (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 used by using a constant carbon content of 50% of the biomass weight (Brown 1997) and 47% of the biomass weight (Kristiningrum et al. 2019). Carbon stocks in arable land contain higher carbon storage and vegetation biomass (Hairiah et al.2011). Therefore, this study aims to calculate the stand potential, stand biomass and carbon stocks of teak and gmelina in the Gorontalo region. The aim of this research is to develop an allometric equation for estimating AGB with a coefficient of determination that can predict biomass and carbon stock in the land after being abandoned.

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.

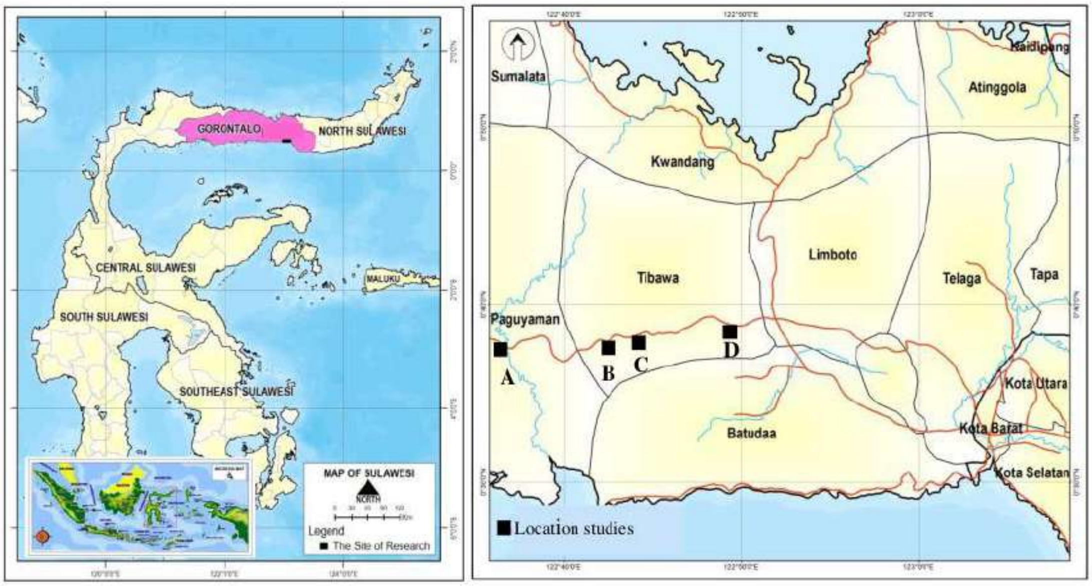

Figure 1. Location studies (in which: **A** = *G. Arborea* plot II, **B** = *T.grandis* plot I, **C** = *G. Arborea* plot I , **D** = *T.grandis* plot II)

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 3.5m 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.

Data analysis

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

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

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:

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

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

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:

$M = BJ \times V_t \times BEF$

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

$Cb = B \times \%\ C$ Organic

In which: Cb = Carbon content of biomass (kg), B = Total biomass (kg), % C Organic = Percentage value of carbon 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:

Biomass (kg ha^{-1}) = Biomass (kg m^{-2}) x 10,000 m^2

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

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

$\hat{Y} = a + bX$

In which: $\hat{Y}$ = Estimated value of biomass, X = Volume (m^3), 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.

Growth of *Tectona grandis*

Growth of Tectona grandis Plot I

T. *grandis* which was cultivated in plot I at the beginning was planted using a spacing of 3m x 3m, so the initial number of trees was 1,111 trees. 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. 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

Notes: N = Population of *T.grandis* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^{3} ha^{-1}), MAI = Mean Annual Increment (m^{3} ha^{-1} year^{1}), CAI = Current Annual Increment (m^{3} ha^{1} year^{1}), B.A = Bassal area (m^{2}ha)

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 m^{3}ha^{-1}. Meanwhile, the growth increment ranged from 0.55 to 9.61 m^{3}ha^{-1}year^{-1}. The maximum total volume of teak reached at the age of 32 years is 307.50 m^{3} ha^{-1} and an increment of 9.61 and 9.86 m^{3}ha^{-1}year^{-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

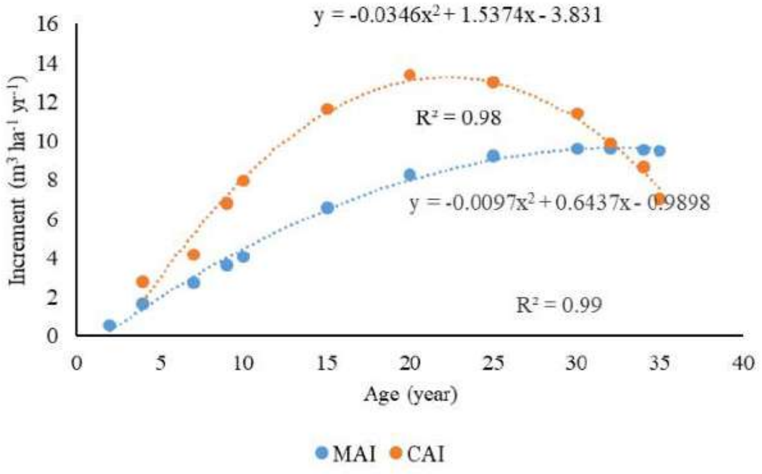

Figure 2. The corellation of MAI and CAI *T. grandis* in Plot I

The graphs according to Kristiningrum et al. (2019), Winarni et al. (2017), Muliadi et al. (2017), and Dinga (2014) 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 of teak 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 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 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 Plot II

T.grandis which was cultivated in plot II at the beginning was planted using a spacing of 3m x 3m, so the initial number of trees was 1,111 trees. 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. Based on the teak growth table, the number of trees, diameter, height, total volume and increment of teak can be seen as follows:

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**
30	400	38.0	9.3	0.60	253.82	8.46	4.91	45.34	221.08	103.91

Notes: N = Population of *T.grandis* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), B.A = Bassal area (m^2ha)

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 m^3 ha^{-1}. Meanwhile, the growth increment ranged from 0.45 to 9.17 m^3 ha^{-1} $year^{-1}$. The maximum total volume of teak reached at the age of 25 years is 229.28 m^3 ha^{-1} and an increment of 9.17 and 9.78 m^3 ha^{-1} $year^{-1}$ with the number of trees per hectare as many as 500 trees.

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

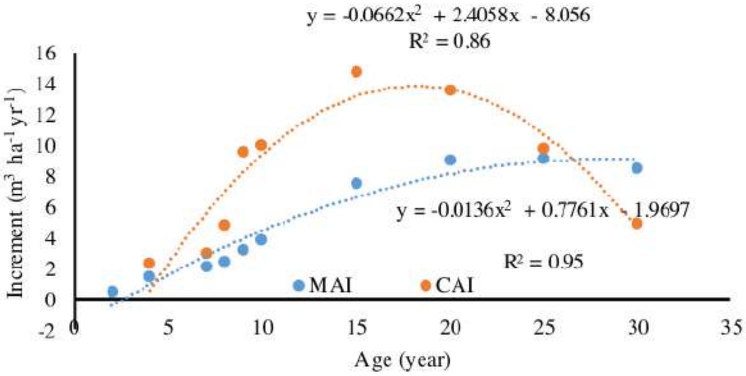

Figure 3. The corellation of MAI and CAI *T. grandis* in Plot II

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 an 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. 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 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 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 m^3 and 6.17 $m^3ha^{-1}year^{-1}$ and Solomon teak 150.94 m^3 and 6.04 m^3 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 $year^{-1}$. In optimal site conditions, teak volume increment can reach 7.9 - 10 $m^3ha^{-1}year^{-1}$ (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*

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:

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

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

Notes: N = Population of *G. arborea* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), B.A = Bassal area (m^2ha)

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 from 2 years to 25 years is 6.71 to 284.58 m^3ha^{-1}. Meanwhile, the growth increment ranged from 3.36 to 12.70 m^3 ha^{-1} $year^{-1}$. The maximum total volume of *G. arborea* reached at the age of 15 years is 190.54 m^3 ha^{-1} and an increment of 12.70 and 13.28 $m^3ha^{-1}year^{-1}$ 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.

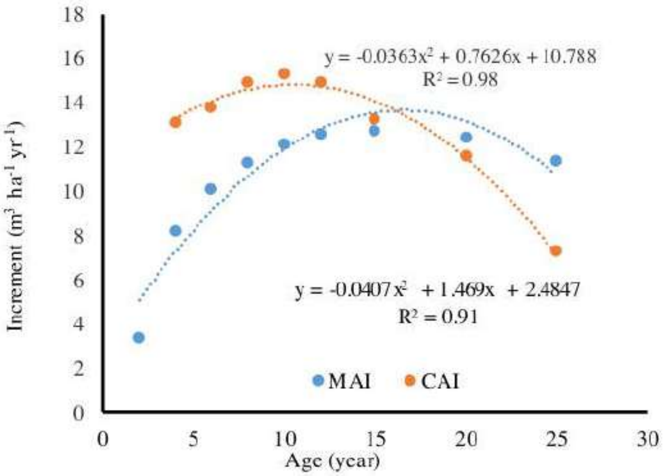

Figure 4. The corellation of MAI and CAI *G. arborea* in Plot I

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 R^2 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 R^2 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.

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:

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

Notes: N = Population of *G. arborea* (tree ha^{-1}), d = Tree Diameter (cm), h = clear bole height (m), F = form factor, TV = Total Volume (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), B.A = Bassal area (m^2ha)

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 m^3ha^{-1}. Meanwhile, the growth increment ranged from 1.75 to 16.69 $m^3ha^{-1}year^{-1}$. The maximum total volume of *G. arborea* reached at the age of 15 years is 251.80 m^3 ha^{-1} and an increment of 16.79 and 16.69 $m^3ha^{-1}year^{-1}$ 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 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 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. The results showed that the increasing age of both teak and gmelina stands, the more the amount of standing carbon stock would also increase. According to Lubis et al. (2013), standing carbon stock increases with the increase in stem diameter and a decrease in carbon stock occurs when the number of stands or density 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

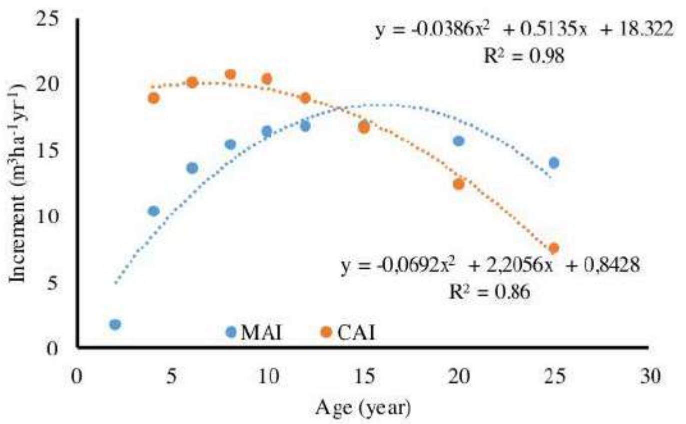

Figure 5. The corellation of MAI and CAI *G. arborea* in Plot II

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 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 m^3 ha^{-1} and increments of 12.70 and 13.28 m^3 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 m^{3}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 m^3 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).

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

Carbon and biomass production

The increase in CO_2 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 (Uthbah et 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 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 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 R^2. The maximum value of R^2 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 $R^2 = 0$, then there 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 (Handayani 2010: Kristiningrum et al. 2019 and Muliadi et al. 2017). In addition, if the value of the coefficient of determination (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).

Mansur and Tuheteru (2011) explain that age was very influential in the production of carbon. If the trees were getting older, their ability to absorb carbon was also high. Measurement of deep forest biomass this research was conducted on the whole tree consists of aboveground biomass (aboveground biomass) includes 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). 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 (R^2), the average regression coefficient is 97%. Where the regression coefficient of the relationship between age and carbon in teak plot I is 98%, teak plot II is 96%, gmelina plot I is 99% and gmelina plot II is 97%. According to Sugiyono (2012), the coefficient value determination in the range of 80% - 100% means that there is a very strong relationship the dependent variable and the independent variable. This indicated that there was a strong correlation between age and carbon because the value of its coefficient of determination was higher than 90% and the graph of each correlation formed a linear shape. This is in line with research conducted by Sardjono et al (2017) that there is a close relationship between age and carbon in *A.cadamba*. While according to Polosakan et al. (2014) and Uthbah et al. (2017) stated that the difference in the amount of biomass above the soil surface was 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.

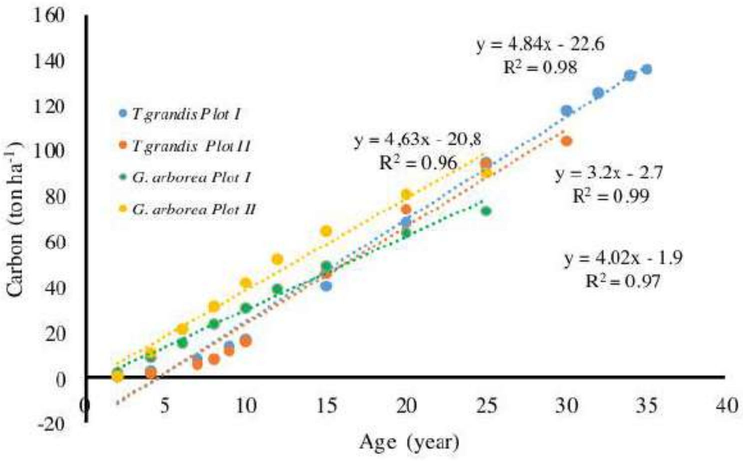

Figure 8. The correlation between the stand age and production carbon of *T. grandis* and *G. arborea*

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

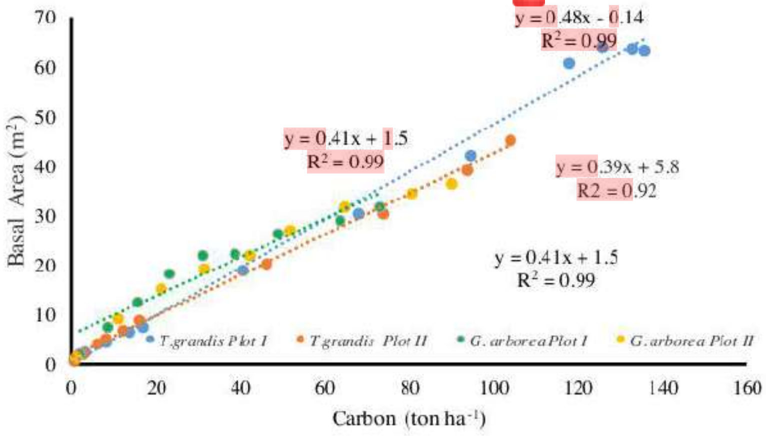

Figure 9. The correlation between the production carbon and basal area of *T. grandis* and *G. arborea*

Based on the picture above, it can be explained that the production of carbon in relation to its influence on basal area, had a very strong and high correlation (R^2), the average regression coefficient is 97%. Where the regression coefficient of 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 of determination was higher than 90% and the graph of each correlation formed a linear shape. This means that the regression coefficient of both the relationship between age and carbon and carbon with the basal area has a regression 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 between carbon and basal area of about 97% and 3% is influenced by other factors. And the graph of each correlation formed a linear shape. This is in line with the research conducted by Kumi et al. (2019) where in their research, they chose teak species and gave results that the 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 (R^2 = 0.99) and significant (Bredu and Birigazzi 2014).

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.

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

No	Type	Age (yr)	TV (m^{3}ha^{-1})	BA (m^{2}ha^{-1})	Biomass (ton ha^{-1})	Carbon (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

Notes: TV = Total volume (m^3 ha^{-1}), BA= Basal area (m^2 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, basal area, biomass and carbon among other stands of 307.5 m^3 ha^{-1}; 64.06 m^2 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 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 m^3 ha^{-1}, basal area 43.56 m^2 ha^{-1}; biomass 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 m^3 ha^{-1}, basal area 31.79 m^2 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 total volume 190.54 m^3 ha^{-1}, basal area 26.46 m^2 ha^{-1}; biomass 104.03 ton ha^{-1} and carbon 48.90 ton ha^{-1}. The amount of 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* tends to store carbon in large quantities smaller 19.96 ton C ha^{-1} or 2.49 ton C ha^{-1}yr^{-1} compared to production of *Tectona 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 stands of teak and gmelina produce higher tree densities when compared with old stands. However, basalt the area of older stands is larger than that of younger stands. This is in line with research conducted by Rinnangmang 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 graphical relationship between total volume, basal area, biomass and carbon each stand can be seen in the image below

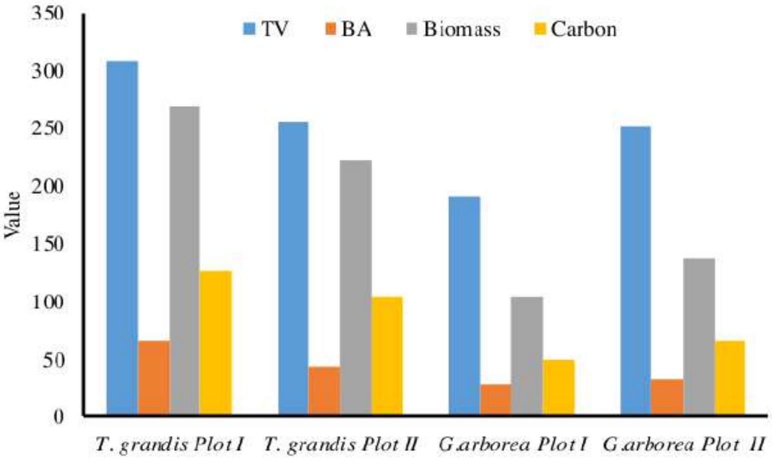

Figure 8. The correlation between total volume, basal area, biomass and carbon each stand

Research result shows that *T. grandis* stands have the highest total stored carbon when compared to *G. arborea*. Fast growth and the ability 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 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 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 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.

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.

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

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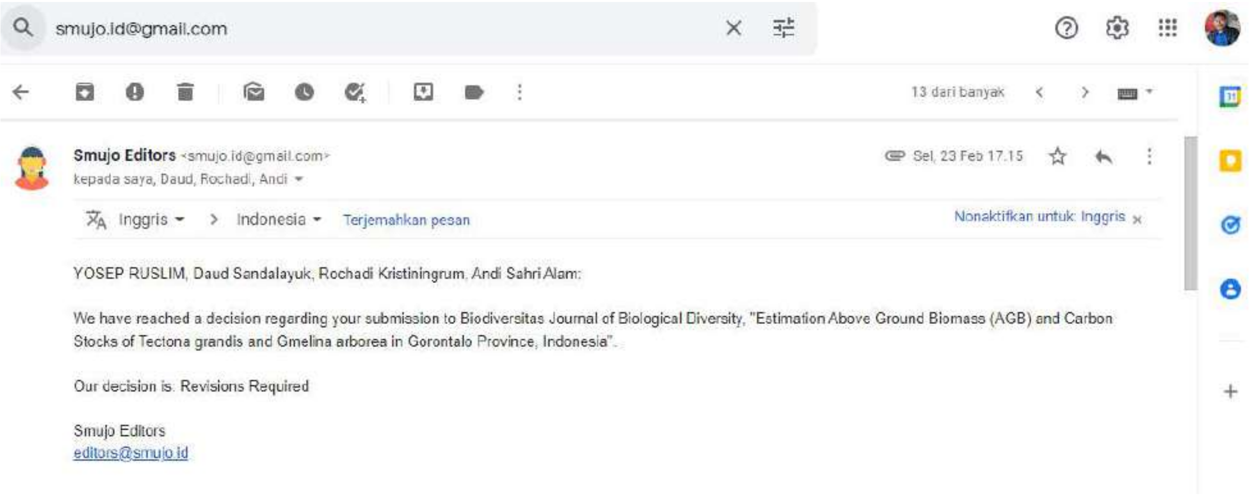

Smujo Editors <smujo.id@gmail.com>
kepada saya, Daud, Rochadi, Andi
Sel, 23 Feb 17.15

YOSEP RUSLIM, Daud Sandalayuk, Rochadi Kristiningrum, Andi Sahri Alam:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia".

Our decision is: Revisions Required

Smujo Editors
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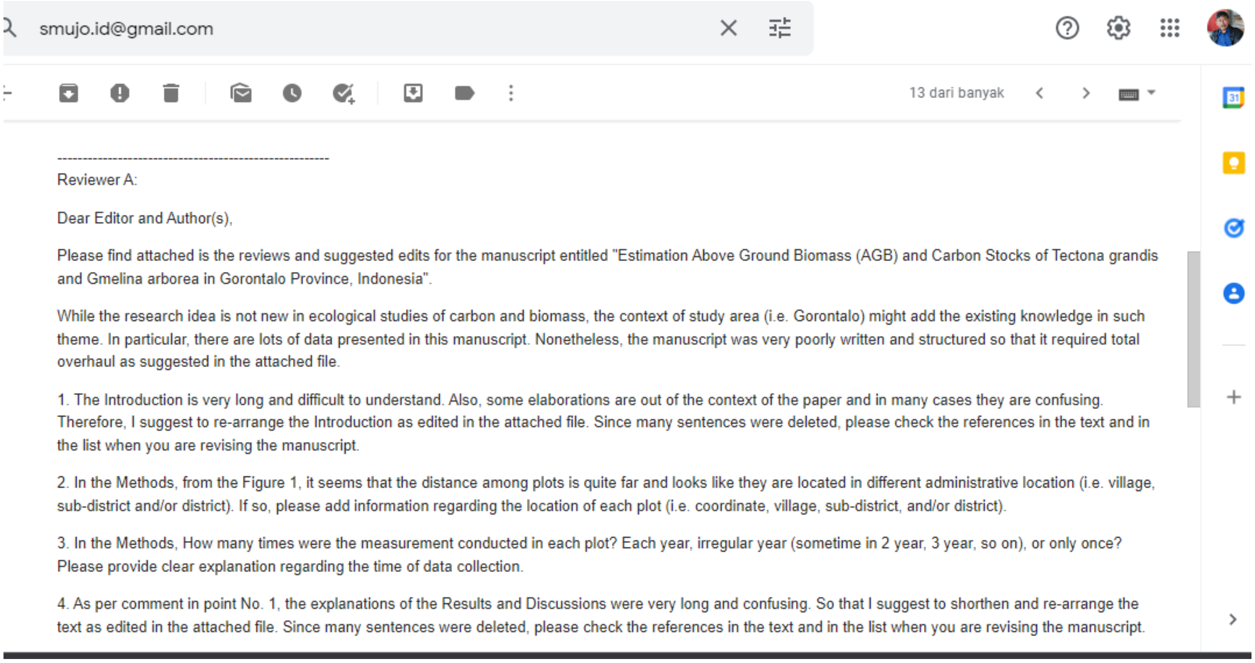

Reviewer A:

Dear Editor and Author(s),

Please find attached is the reviews and suggested edits for the manuscript entitled "Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia".

While the research idea is not new in ecological studies of carbon and biomass, the context of study area (i.e. Gorontalo) might add the existing knowledge in such theme. In particular, there are lots of data presented in this manuscript. Nonetheless, the manuscript was very poorly written and structured so that it required total overhaul as suggested in the attached file.

1. The Introduction is very long and difficult to understand. Also, some elaborations are out of the context of the paper and in many cases they are confusing. Therefore, I suggest to re-arrange the Introduction as edited in the attached file. Since many sentences were deleted, please check the references in the text and in the list when you are revising the manuscript.

2. In the Methods, from the Figure 1, it seems that the distance among plots is quite far and looks like they are located in different administrative location (i.e. village, sub-district and/or district). If so, please add information regarding the location of each plot (i.e. coordinate, village, sub-district, and/or district).

3. In the Methods, How many times were the measurement conducted in each plot? Each year, irregular year (sometime in 2 year, 3 year, so on), or only once? Please provide clear explanation regarding the time of data collection.

4. As per comment in point No. 1, the explanations of the Results and Discussions were very long and confusing. So that I suggest to shorten and re-arrange the text as edited in the attached file. Since many sentences were deleted, please check the references in the text and in the list when you are revising the manuscript.

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 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 m^{3}ha^{-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 m^{3}ha^{-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.

Plantation forestry has the potential to be developed as biomass storage. 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; Ruitta 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 (Kanninen 2010; 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 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 species in plantation forests (Chauhan et al. 2016a).

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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* (Figure 1). Plot I was located at the coordinate of……in….Village….Sub-district…bla..bla

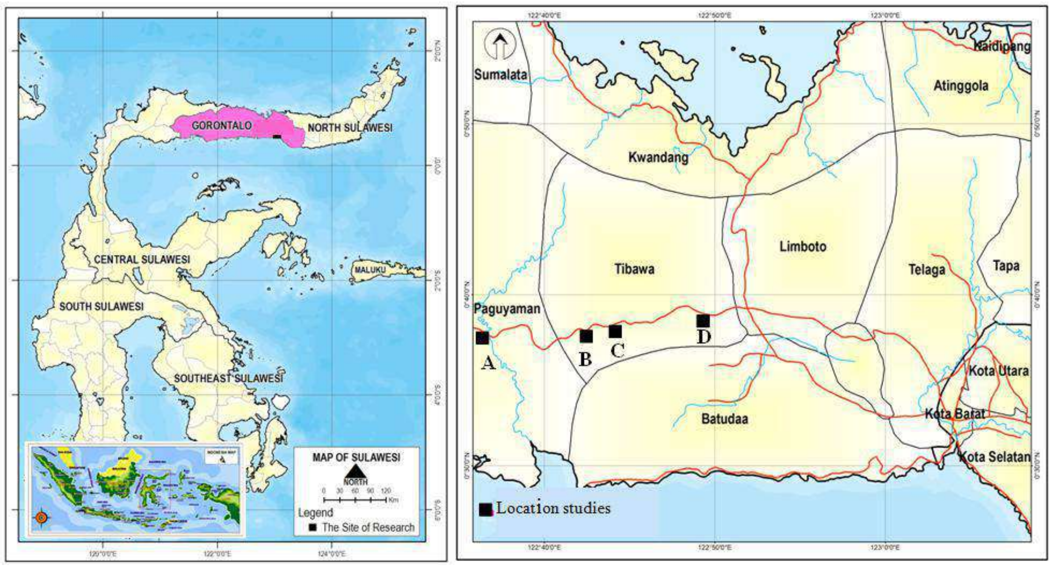

Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: **A** = *G. arborea* plot II, **B** = *T. grandis* plot I, **C** = *G. arborea* plot I, **D** = *T. grandis* plot II

Data collection procedure

The determination of the study locations (Figure 1) and the sampling sites was conducted by purposive sampling with the sampling method using systematic random sampling. 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 x 3m, while that of *Gmelina arborea* 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.

Data analysis

Estimating the growth (MAI and CAI)

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:

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

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

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

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

in which: MAI = mean annual increment, V_t = total volume in ages t_0 - t (m^3), t = age (years)

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

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)

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, BJ = specific gravity, V_t = total volume, 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}) x 10,000 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. According to Ruslianto et al. (2019), the relationships between biomass and tree dimensions can be analysed as follows:

$\hat{Y} = a + bX$

in which: $\hat{Y}$ = Estimated value of biomass, X = Volume (m^3), 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 x 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.

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

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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

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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 m^{3}ha^{-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 m^{3}ha^{-1}. Meanwhile, the mean annual increment of volume ranged from 0.55 to 9.61 m^{3}ha^{-1}year^{-1}. The maximum total volume of teak reached at the age of 32 years with 307.50 m^3 ha^{-1} with mean annual increment (MAI) of 9.61 and current annual increment (CAI) of 9.86 m^{3}ha^{-1}year^{-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.

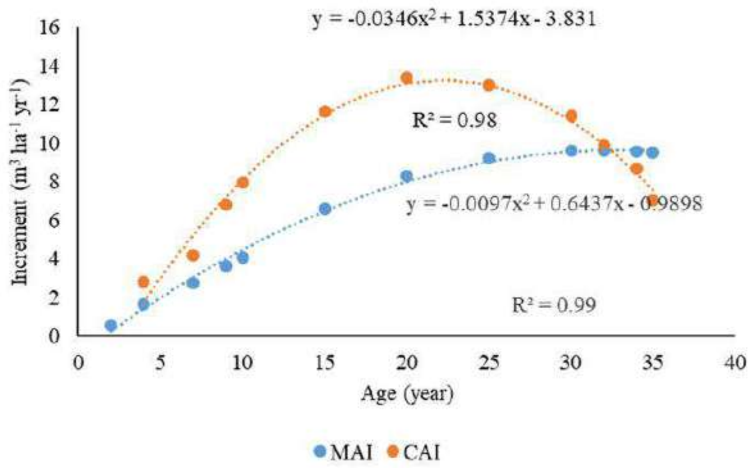

Figure 2. The curves of MAI and CAI of *T. grandis* at Plot I

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.

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. The table of growth of *T. grandis at* Plot II is presented below.

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

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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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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 m^3 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 m^3 ha^{-1}. The growth increment ranged from 0.45 to 9.17 m^3 ha^{-1} year^{-1} with the maximum total volume of teak reached at the age of 25 years with 229.28 m^3 ha^{-1} and MAI dan CAI of 9.17 and 9.78 m^3 ha^{-1}year^{-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.

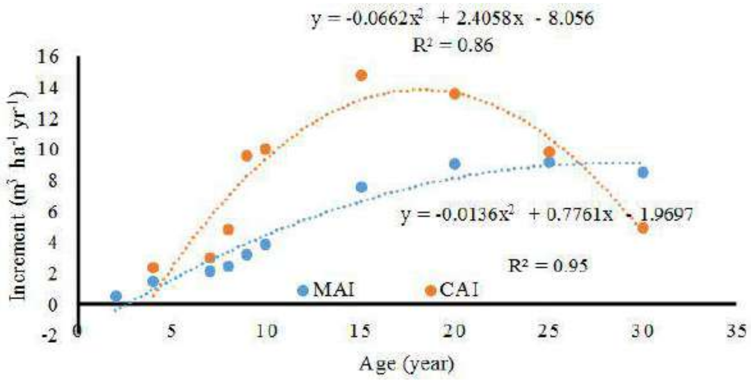

Figure 3. The curves of MAI and CAI of *T. grandis* at Plot II

Based on Figure 3, the maximum increment of teak was reached at the age of 25 years and then declined after such age. The curves also suggest that there is a close relationship between age and MAI and CAI in which both parameters have high R^2 value of 95% and 88%, respectively.

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. (2015) 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) and Setiawan et al. (2011) 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 m^3 and 6.17 m^{3}ha^{-1}year^{-1}, respectively while those in Solomon teak were 150.94 m^3 and 6.04 m^3 ha^{-1} year^{-1}, respectively.

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 m^{3}ha^{-1}year^{-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.

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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 x 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.

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

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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 m^{3}ha^{-1}. The MAI ranged from 3.36 to 12.70 m^3 ha^{-1} year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years with 190.54 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 m^{3}ha^{-1}year^{-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.

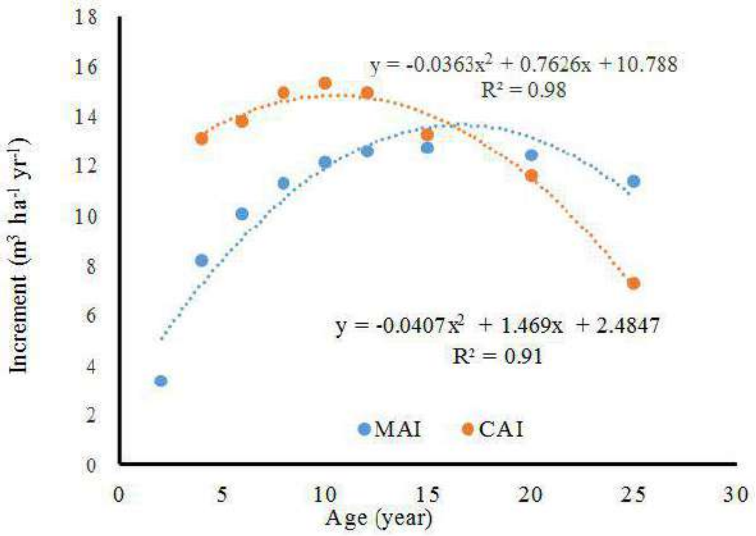

Figure 4. The curves of MAI and CAI of *G. arborea* at Plot I

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 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.

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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.

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	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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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 m^{3}ha^{-1}. The MAI ranged from 1.75 to 16.69 m^{3}ha^{-1}year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years with 251.80 m^3 ha^{-1} and MAI and CAI of 16.79 and 16.69 m^{3}ha^{-1}year^{-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 the image below

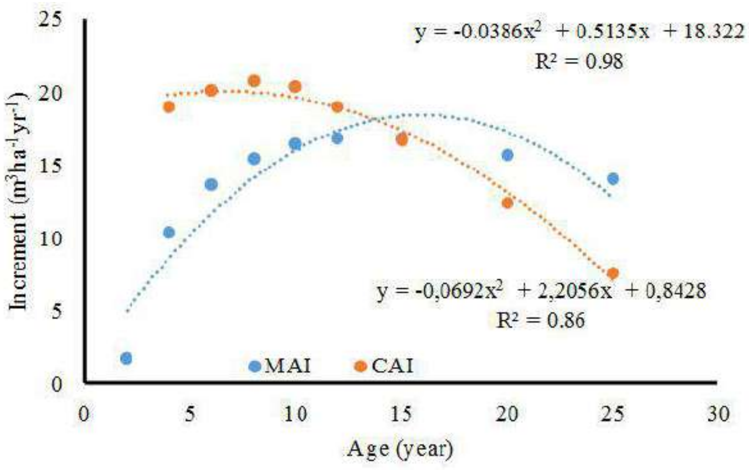

Figure 5. The curves of MAI and CAI of *G. arborea* at Plot II

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 R^2 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 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 m^3 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 m^3 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 m^3 ha^{-1}.

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

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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.

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 x 4 m: **A)** stands at Plot I; **B)** stands at Plot II.

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.

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No	**Type**	**Age (yr)**	**TV (m^3ha^{-1})**	**BA (m^2ha^{-1})**	**Biomass (ton ha^{-1})**	**Carbon (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

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

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 m^3 ha^{-1}; 64.06 m^2 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 m^3 ha^{-1}, basal area 43.56 m^2 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 m^3 ha^{-1}, basal area 31.79 m^2 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 m^3 ha^{-1}, basal area 26.46 m^2 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 $ha^{-1}yr^{-1}$ 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 Rinnangmang 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.

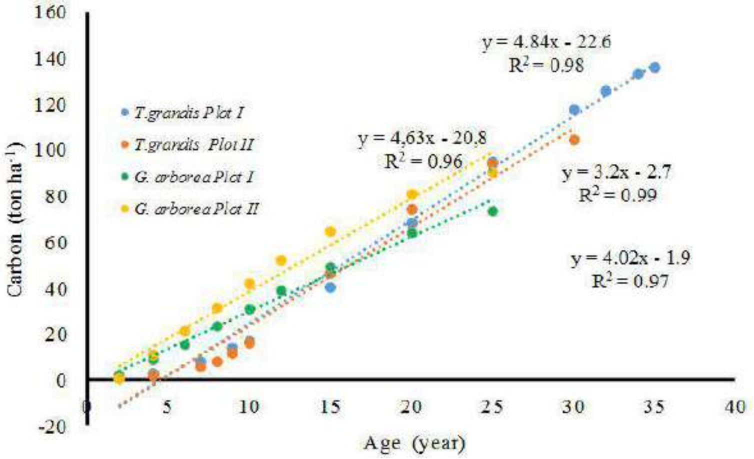

Figure 8. The correlation between the stand age and carbon sequestered at the stands of *T. grandis* and *G. arborea*

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

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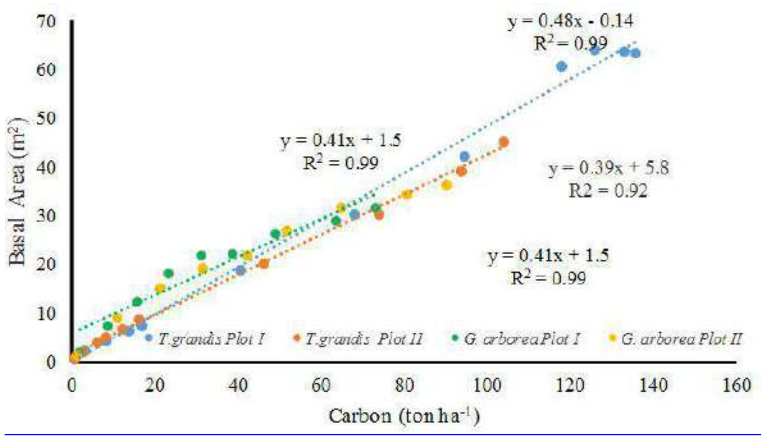

Figure 9. The correlation between basal area and carbon sequestered at the stands of *T. grandis* and *G. arborea*

Based on Figures 8 and 9, carbon sequestered has strong relationships with age and basal area, which is indicated by high correlation value (R^2). This result is in line with the research conducted by Kumi et al. (2019) 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 ($R^2 = 0.99$) and significant (Bredu and Birigazzi 2014).

The increase in CO_2 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 CO_2 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 CO_2 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 (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 (2017) 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 (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 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 *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.

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.

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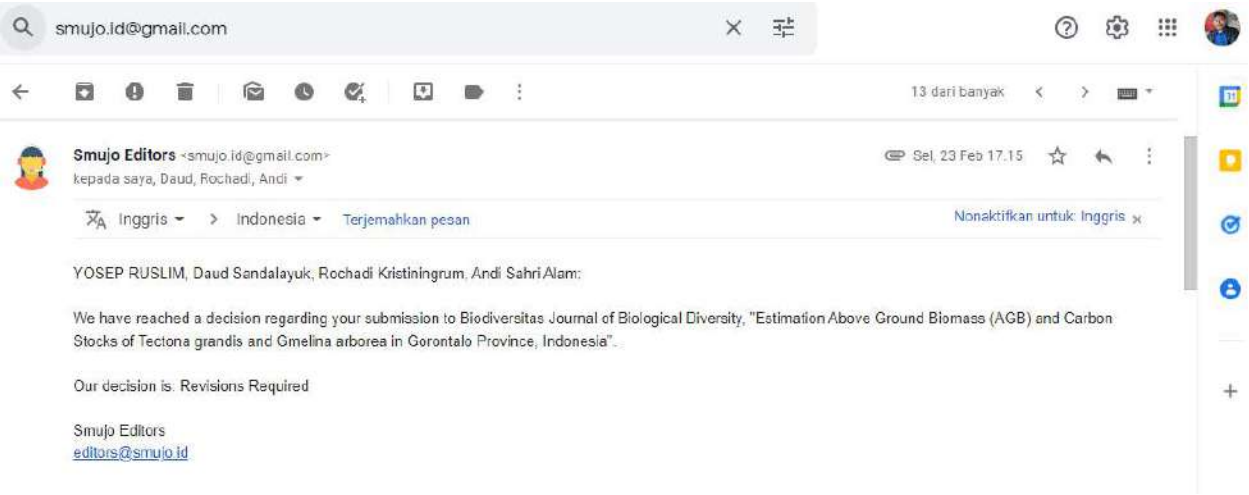

Smujo Editors <smujo.id@gmail.com>
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YOSEP RUSLIM, Daud Sandalayuk, Rochadi Kristiningrum, Andi Sahri Alam:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia".

Our decision is: Revisions Required

Smujo Editors
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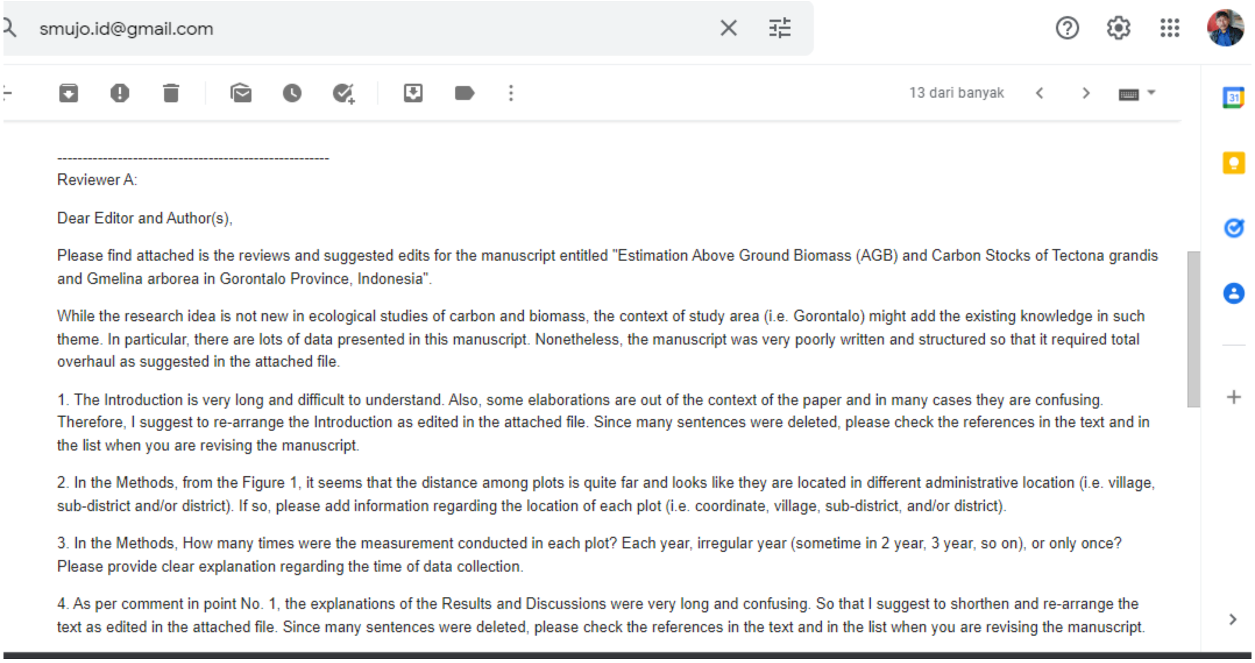

Reviewer A:

Dear Editor and Author(s),

Please find attached is the reviews and suggested edits for the manuscript entitled "Estimation Above Ground Biomass (AGB) and Carbon Stocks of Tectona grandis and Gmelina arborea in Gorontalo Province, Indonesia".

While the research idea is not new in ecological studies of carbon and biomass, the context of study area (i.e. Gorontalo) might add the existing knowledge in such theme. In particular, there are lots of data presented in this manuscript. Nonetheless, the manuscript was very poorly written and structured so that it required total overhaul as suggested in the attached file.

1. The Introduction is very long and difficult to understand. Also, some elaborations are out of the context of the paper and in many cases they are confusing. Therefore, I suggest to re-arrange the Introduction as edited in the attached file. Since many sentences were deleted, please check the references in the text and in the list when you are revising the manuscript.

2. In the Methods, from the Figure 1, it seems that the distance among plots is quite far and looks like they are located in different administrative location (i.e. village, sub-district and/or district). If so, please add information regarding the location of each plot (i.e. coordinate, village, sub-district, and/or district).

3. In the Methods, How many times were the measurement conducted in each plot? Each year, irregular year (sometime in 2 year, 3 year, so on), or only once? Please provide clear explanation regarding the time of data collection.

4. As per comment in point No. 1, the explanations of the Results and Discussions were very long and confusing. So that I suggest to shorten and re-arrange the text as edited in the attached file. Since many sentences were deleted, please check the references in the text and in the list when you are revising the manuscript.

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 m^3ha^{-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 m^3ha^{-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 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 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 $122^{o}36’12.888’’$E and $0^{o}37’47.828’$N. Plot B was located at $122^{o}42’22.942’’$E and $0^{o}37’43.117’$N. Plot C was located at $122^{o}43’51.600’’$E and $0^{o}37’55.966’$N. Plot D was located at $122^{o}49’15.397’’$E and $0^{o}38’46.017’$N (Figure 1).

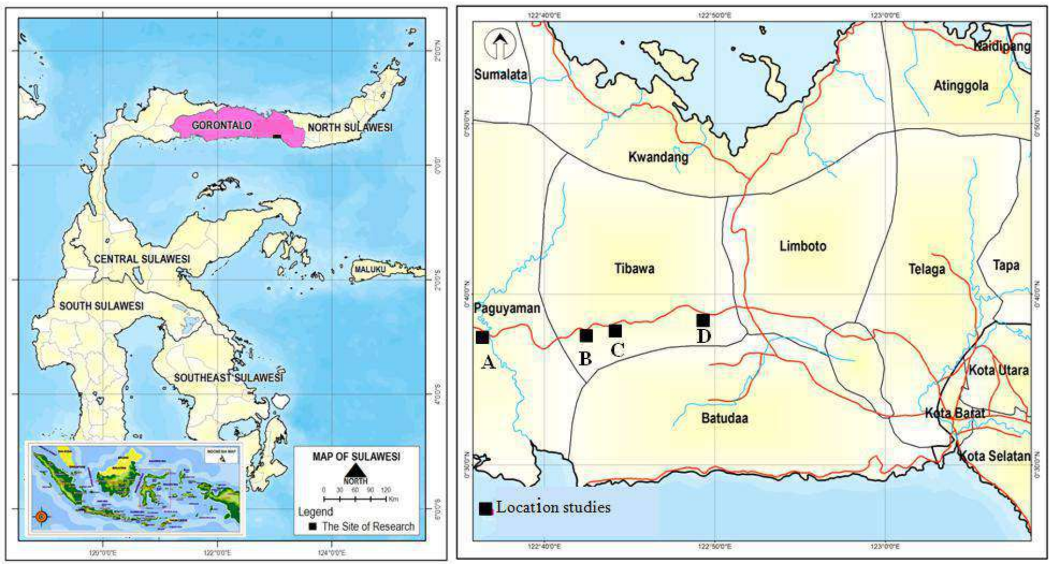

Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: **A** = *G. arborea* plot II, **B** = *T. grandis* plot I, **C** = *G. arborea* plot I, **D** = *T. grandis* plot II.

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 ~~x~~ 3m, while that of *Gmelina arborea* 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. 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.

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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:

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

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

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

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

in which: MAI = mean annual increment, V_t = total volume in ages t_0 - t (m^3), t = age (years)

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

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)

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 = total volume (m^3), BEF = Biomass Expansion Factor (1.3)

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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}) × 10,000 m^2

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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:

$\hat{Y} = a + bX$

in which: $\hat{Y}$ = Estimated value of biomass, X = Volume (m^3), a, b = regression constant

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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 × 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.

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	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), BA = Basal Area (m^2ha)

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 m^3ha^{-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 m^3ha^{-1}. Meanwhile, the mean annual increment of volume ranged from 0.55 to 9.61 $m^3ha^{-1}year^{-1}$. The maximum total volume of teak reached at the age of 32 years with 307.50 m^3 ha^{-1} with mean annual increment (MAI) of 9.61 and current annual increment (CAI) of 9.86 $m^3ha^{-1}year^{-1}$ 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.

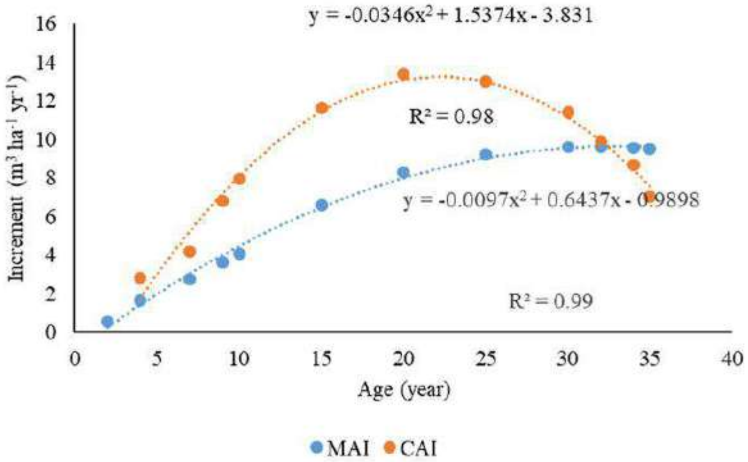

Figure 2. The curves of MAI and CAI of *T. grandis* at Plot I

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.

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 below.

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), BA = Basal Area (m^2ha)

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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 m^3 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 m^3 ha^{-1}. The growth increment ranged from 0.45 to 9.17 m^3 ha^{-1} $year^{-1}$ with the maximum total volume of teak reached at the age of 25 years with 229.28 m^3 ha^{-1} and MAI dan CAI of 9.17 and 9.78 m^3 $ha^{-1}year^{-1}$, 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.

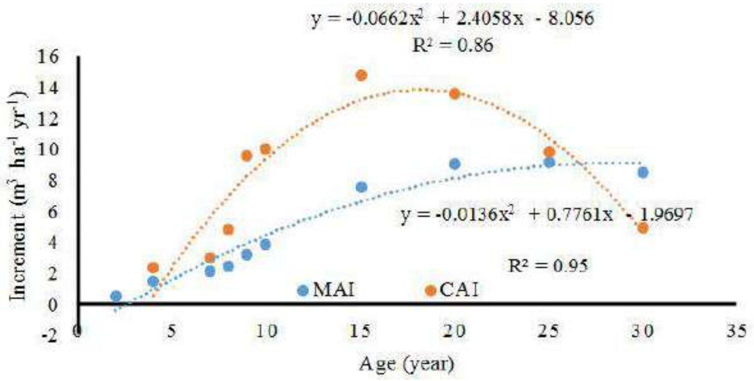

Figure 3. The curves of MAI and CAI of *T. grandis* at Plot II

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 R^2 value of 95% and. This value means that there is a close relationship between age and MAI increment of

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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).

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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 m^3 and 6.17 $m^3ha^{-1}year^{-1}$, respectively while those in Solomon teak were 150.94 m^3 and 6.04 m^3 ha^{-1} $year^{-1}$, respectively.

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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 $m^3ha^{-1}year^{-1}$ (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 x 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 as follows:

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

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), BA = Basal Area (m^2ha)

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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 m^3ha^{-1}. The MAI ranged from 3.36 to 12.70 m^3 ha^{-1} $year^{-1}$. The maximum total volume of *G. arborea* reached at the age of 15 years with 190.54 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 $m^3ha^{-1}year^{-1}$, 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.

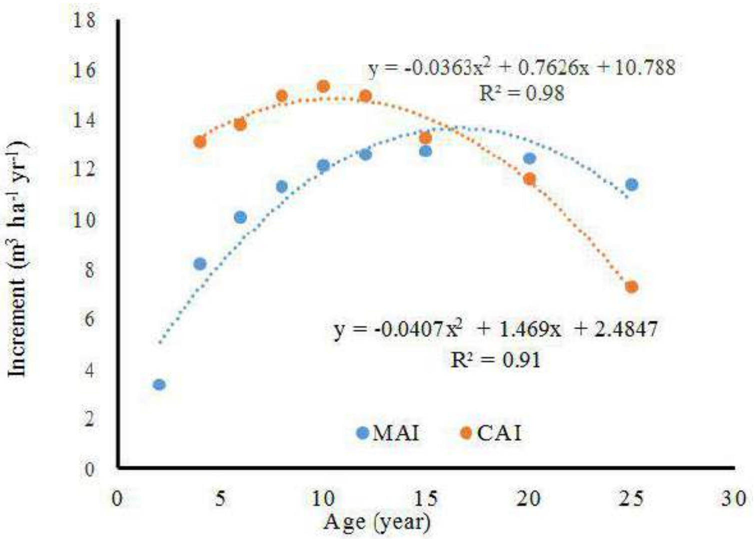

Figure 4. The curves of MAI and CAI of *G. arborea* at Plot I

Figure 4 suggests that the MAI and CAI of *G. arborea* initially increased reached 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.

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	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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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 m^{3}ha^{-1}. The MAI ranged from 1.75 to 16.69 m^{3}ha^{-1}year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years with 251.80 m^3 ha^{-1} and MAI and CAI of 16.79 and 16.69 m^{3}ha^{-1}year^{-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 the image below

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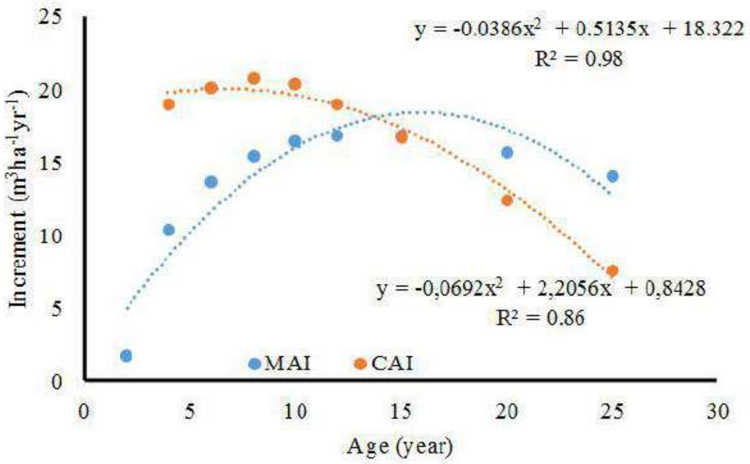

Figure 5. The curves of MAI and CAI of *G. arborea* at Plot II

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 R^2 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 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 m^3 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 m^3 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 m^3 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.

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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.

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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.

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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.

No	**Type**	**Age (yr)**	**TV (m^3ha^{-1})**	**BA (m^2ha^{-1})**	**Biomass (ton ha^{-1})**	**Carbon (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

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

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 m^3 ha^{-1}; 64.06 m^2 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 m^3 ha^{-1}, basal area 43.56 m^2 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 m^3 ha^{-1}, basal area 31.79 m^2 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 m^3 ha^{-1}, basal area 26.46 m^2 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^{-1}yr^{-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).

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

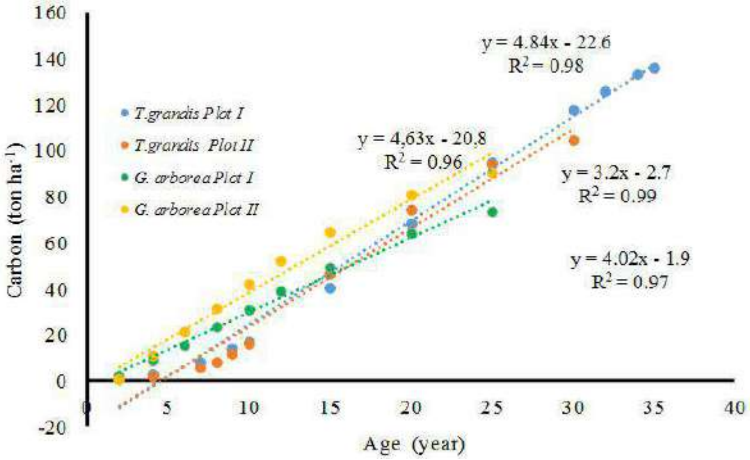

Figure 8. The correlation between the stand age and carbon sequestered at the stands of *T. grandis* and *G. arborea*

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

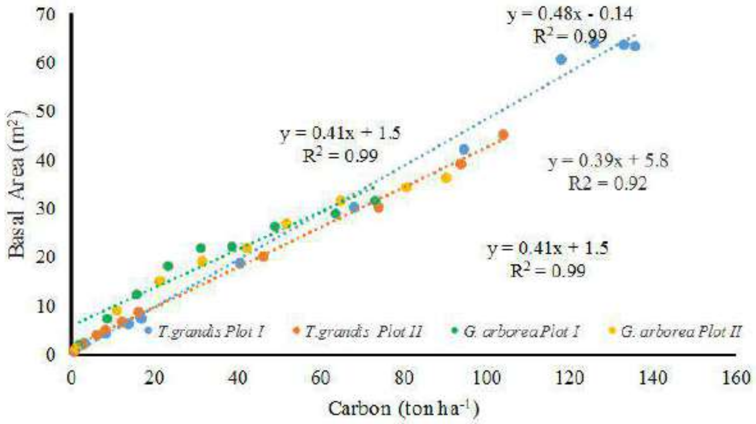

Figure 9. The correlation between basal area and carbon sequestered at the stands of *T. grandis* and *G. arborea*

Based on Figures 8 and 9, carbon sequestered has strong relationships with age and basal area, which is indicated by high correlation value (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 ($R^2 = 0.99$) and significant (Bredu and Birigazzi 2014).

The increase in CO_2 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 CO_2 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 CO_2 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 (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 (2017) 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 (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 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 *T grandis* 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.

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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.

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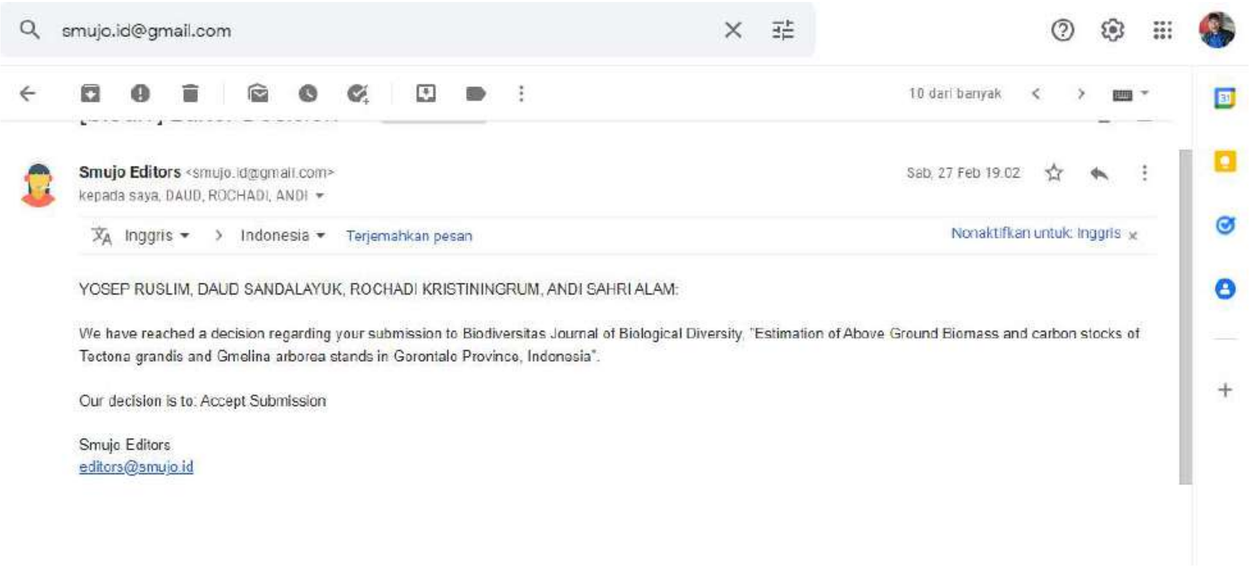

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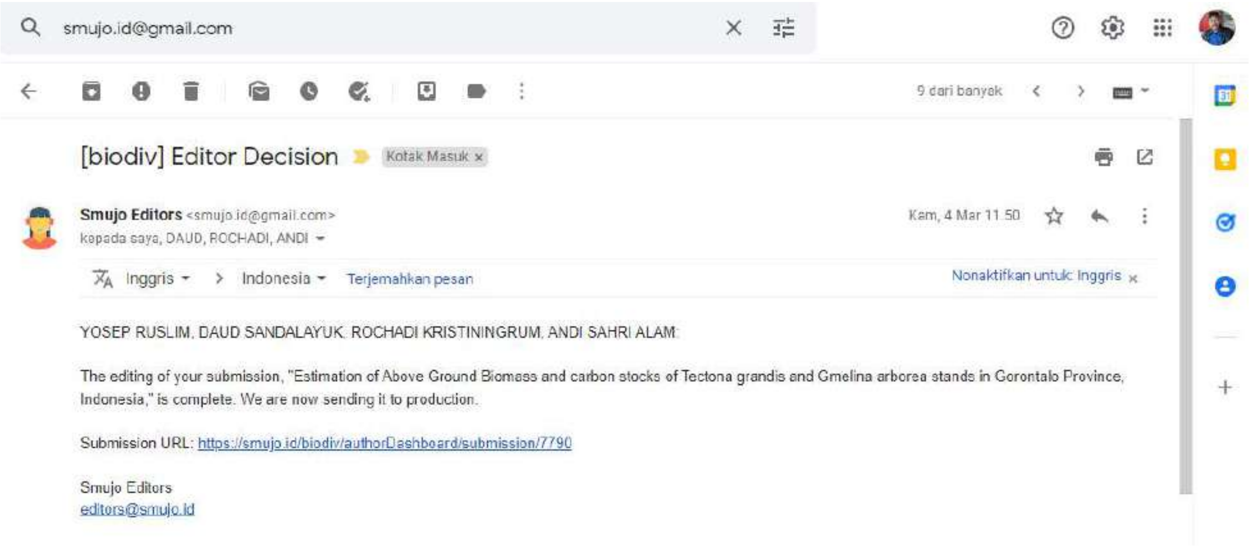

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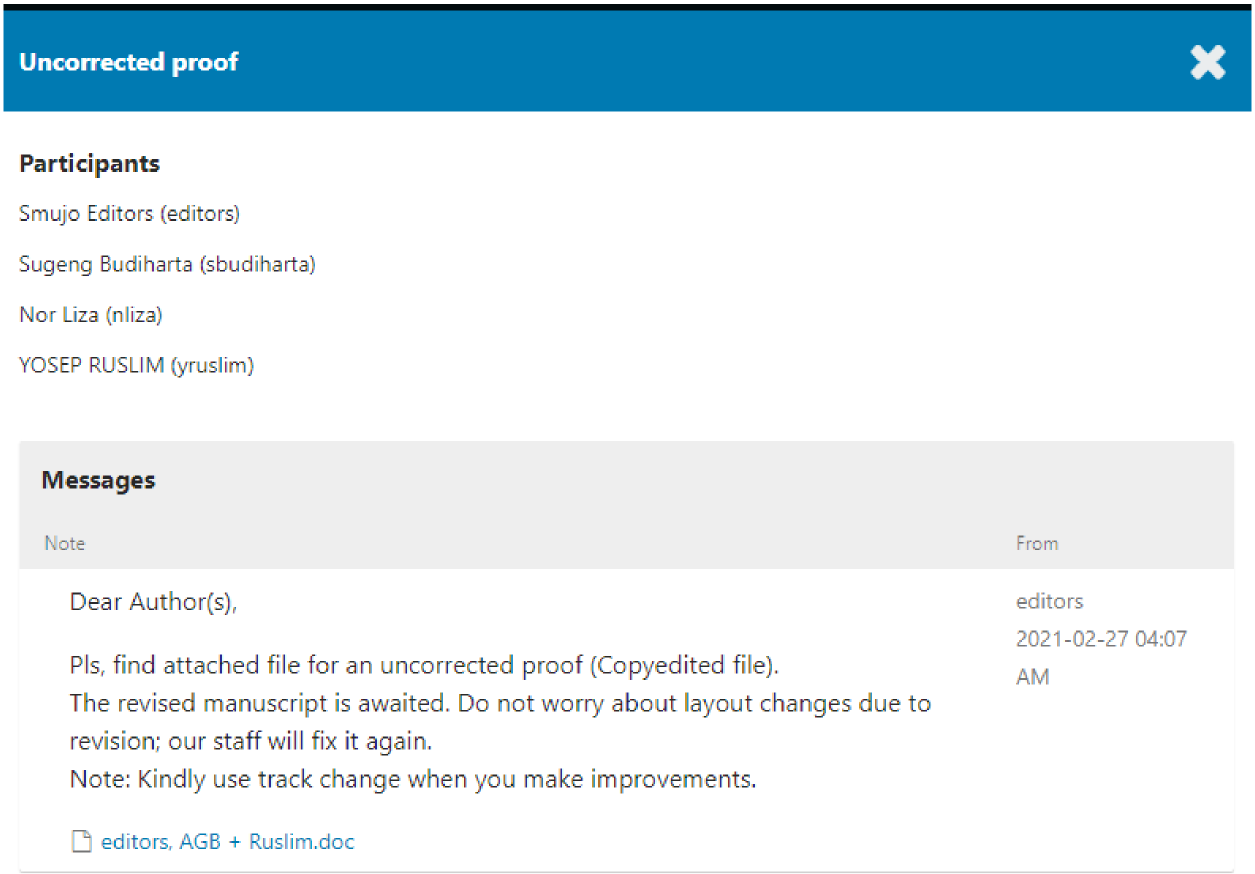

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BIODIVERSITAS
Volume 22, Number 3, March 2021
Pages: xxxx

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d2203xx

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

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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 m^3ha^{-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 m^3ha^{-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 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 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 × 3m, while that of *Gmelina arborea* 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 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:

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

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:

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

in which: MAI = mean annual increment, V_t = total volume in ages t_0 - t (m^3), t = age (years)

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

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)

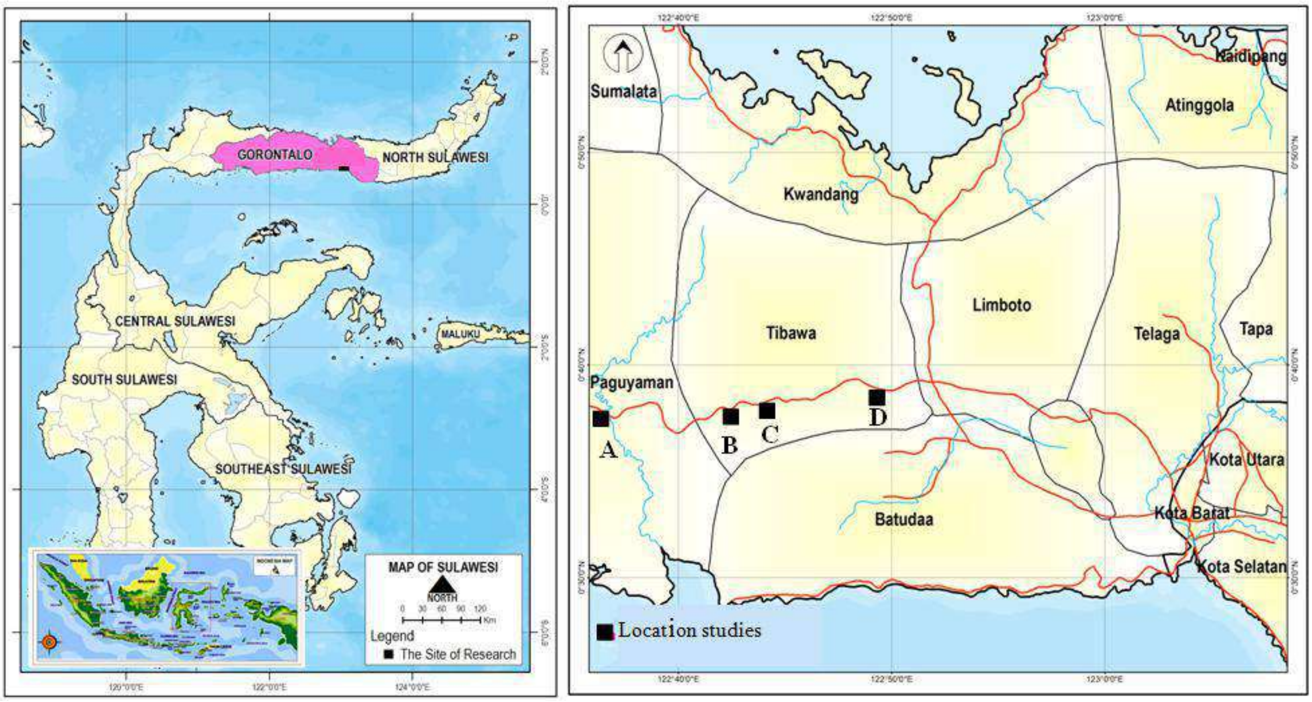

Figure 1. Map of study sites in Gorontalo Province, Indonesia. Notes: **A** = *G. arborea* plot II, **B** = *T. grandis* plot I, **C** = *G. arborea* plot I, **D** = *T. grandis* plot II.

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 = total volume (m^3), 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}) × 10,000 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:

$\hat{Y} = a + bX$

in which: $\hat{Y}$ = Estimated value of biomass, X = Volume (m^3), 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 × 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 m^3ha^{-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 m^3ha^{-1}. Meanwhile, the mean annual increment of volume ranged from 0.55 to 9.61 $m^3ha^{-1}year^{-1}$. The maximum total volume of teak reached at the age of 32 years with 307.50 m^3 ha^{-1} with mean annual increment (MAI) of 9.61 and current annual increment (CAI) of 9.86 $m^3ha^{-1}year^{-1}$ 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.

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	8.7	0.6	331.91	9.48	7.05	63.59	289.10	135.88

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), BA = Basal Area (m^2ha)

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} $year^{-1}$), CAI = Current Annual Increment (m^3 ha^{-1} $year^{-1}$), BA = Basal Area (m^2ha)

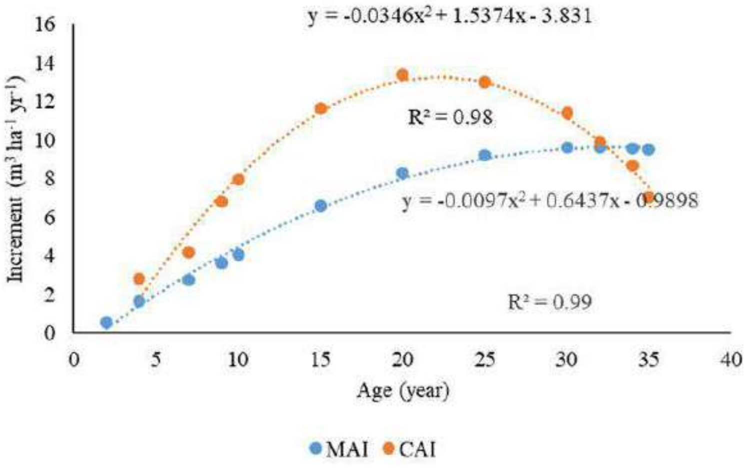

Figure 2. The curves of MAI and CAI of *T. grandis* at Plot I

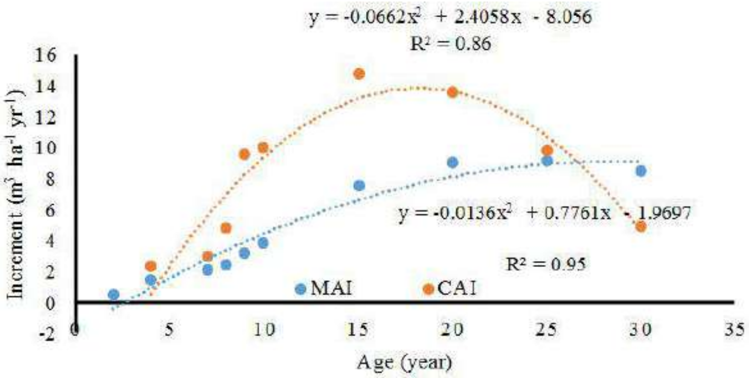

Figure 3. The curves of MAI and CAI of *T. grandis* at Plot II

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 m^3 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 m^3 ha^{-1}. The growth increment ranged from 0.45 to 9.17 m^3 ha^{-1} $year^{-1}$ with the maximum total volume of teak reached at the age of 25 years with 229.28 m^3 ha^{-1} and MAI dan CAI of 9.17 and 9.78 m^3 $ha^{-1}year^{-1}$, 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 m^3 and 6.17 $m^3ha^{-1}year^{-1}$, respectively while those in Solomon teak were 150.94 m^3 and 6.04 m^3 ha^{-1} $year^{-1}$, respectively.

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

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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

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	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 (m^3 ha^{-1}), MAI = Mean Annual Increment (m^3 ha^{-1} year^{-1}), CAI = Current Annual Increment (m^3 ha^{-1} year^{-1}), BA = Basal Area (m^{2}ha)

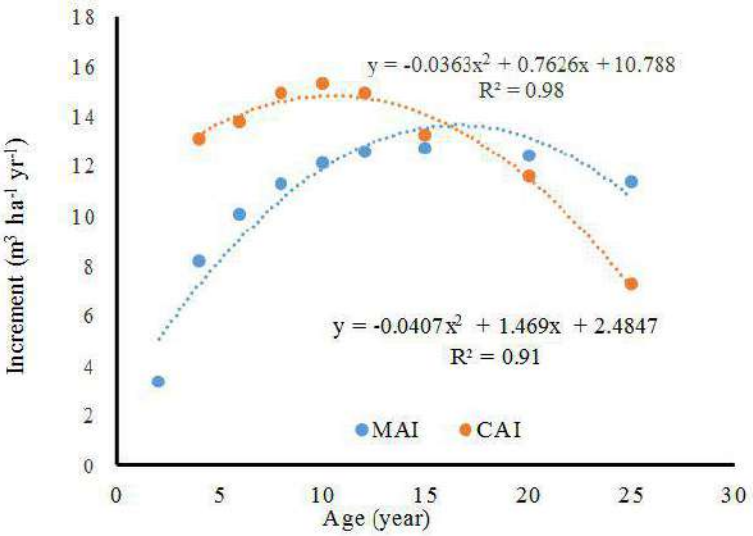

Figure 4. The curves of MAI and CAI of *G. arborea* at Plot I

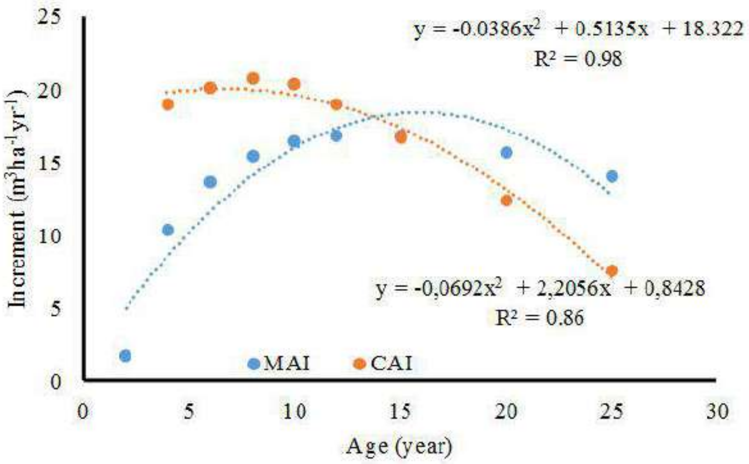

Figure 5. The curves of MAI and CAI of *G. arborea* at Plot II

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 m^{3}ha^{-1}year^{-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 × 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 m^{3}ha^{-1}. The MAI ranged from 3.36 to 12.70 m^3 ha^{-1} year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years with 190.54 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 m^{3}ha^{-1}year^{-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 m^{3}ha^{-1}. The MAI ranged from 1.75 to 16.69 m^{3}ha^{-1}year^{-1}. The maximum total volume of *G. arborea* reached at the age of 15 years with 251.80 m^3 ha^{-1} and MAI and CAI of 16.79 and 16.69 m^{3}ha^{-1}year^{-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 stand

No	**Type**	**Age**	**TV**	**BA**	**Biomass**	**Carbon**
		(yr)	**(m^3ha^{-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

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

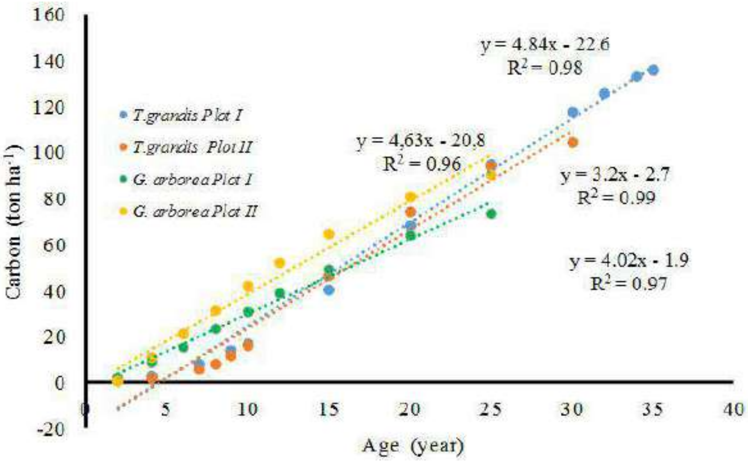

Figure 8. The correlation between the stand age and carbon sequestered at the stands of *T. grandis* and *G. arborea*

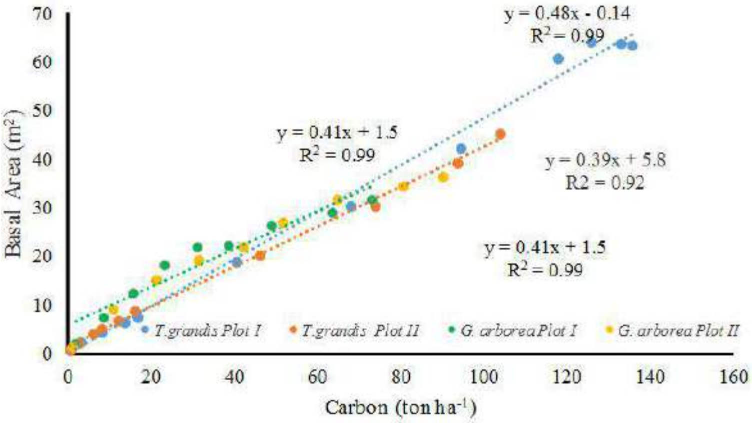

Figure 9. The correlation between basal area and carbon sequestered at the stands of *T. grandis* and *G. arborea*

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 m^3 ha^{-1} and MAI and CAI of 12.70 and 13.28 m^3 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 m^3 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 m^3 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 m^3 ha^{-1}; 64.06 m^2 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 m^3 ha^{-1}, basal area 43.56 m^2 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 m^3 ha^{-1}, basal area 31.79 m^2 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 m^3 ha^{-1}, basal area 26.46 m^2 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 $ha^{-1}yr^{-1}$ 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 (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 ($R^2 = 0.99$) and significant (Bredu and Birigazzi 2014).

The increase in CO_2 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 CO_2 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 CO_2 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 (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 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 *T grandis* 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.

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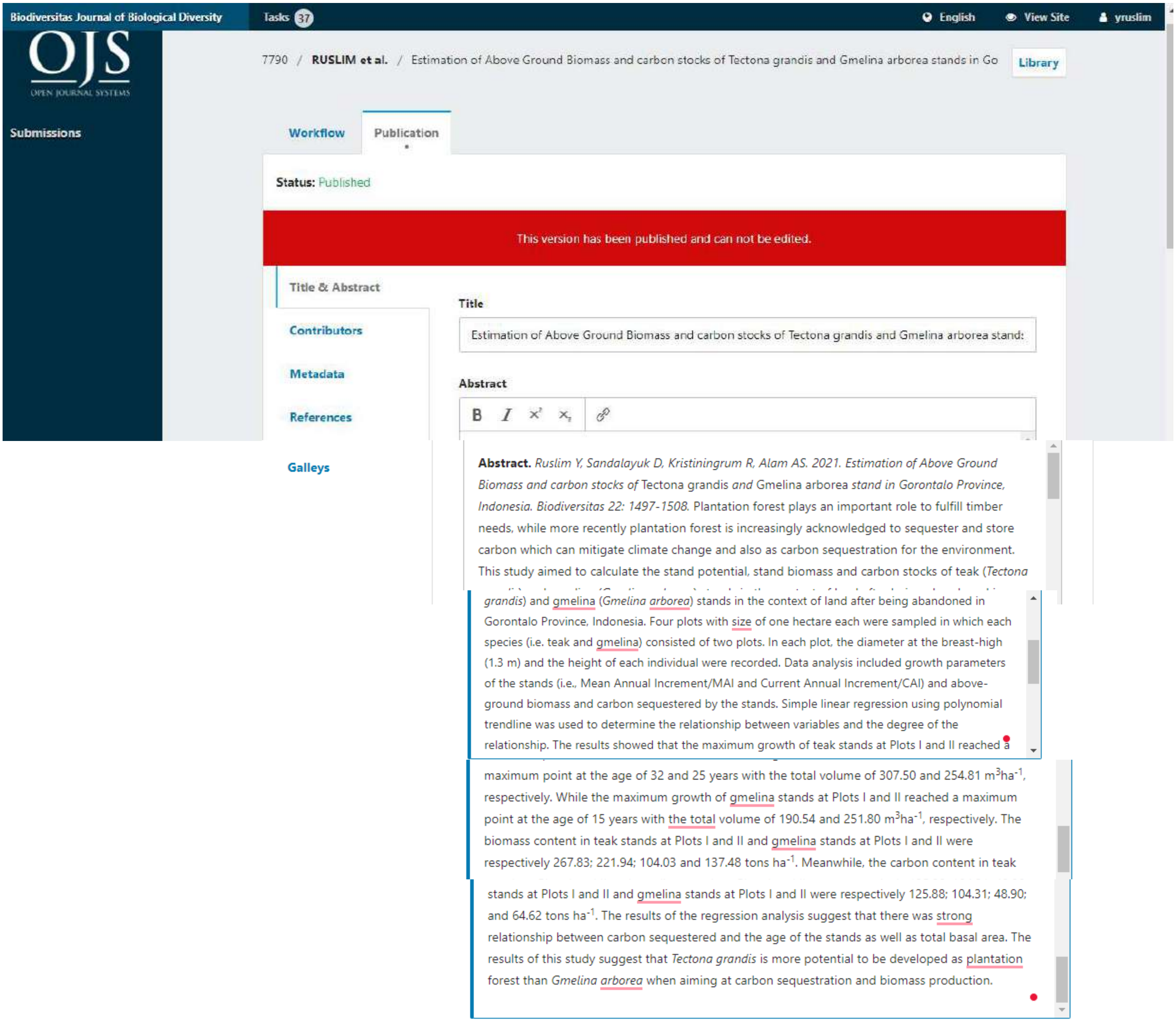

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Title

Estimation of Above Ground Biomass and carbon stocks of Tectona grandis and Gmelina arborea stand:

Abstract

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 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 m^3ha^{-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 m^3ha^{-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 at carbon sequestration and biomass production.