Australian Journal of
Crop Science

AJCS

AJCS 16(07):955-963 (2022) ISSN:1835-2707
doi:10.21475/ajcs.22.16.07.p3639

Analysis of optimum age and maximum increment of forest stands for developing community forests

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Abstract

The community forests are one of the main suppliers of wood needs in the future. They require careful attention to the wood type to be planted, preferably choosing plants that have a short cycle. The demand for wood for the community is increasing, while the supply of timber from state forests to the wood processing industry is decreasing. This research aimed to analyze the optimum age and maximum increment of community forest stands and which species were more profitable. This research was done in a community forest with tropical environmental type. This research was quantitative, calculating the maximum volume cycle and Mean Annual Increment (MAI) values in community forest stands. The results show that the maximum volume increment was found in jabon (*Anthocepalus* sp) stands, namely at the age of 8 years, with a total of 600 trees/ha, an average diameter of 30 cm, an average height of 13 m, a total volume of 330.64 m^3/ha, and a mean annual increment (MAI) of 41.33 m^3/ha/year. Jabon stands at the age of 8 years were suitable for harvest because they reached the maximum volume increment in the soil types of Hapludults Dystrudepts, Haplustepts Haplustalfs, and Endoaquepts Udifluvents.

Keywords: Community forest, nantu, palapi, jabon, super teak, white teak.
Abbreviations: d_Tree diameter; MAI_Mean annual increment (MAI); h_Tree height; K_Tree perimeter; V_Volume.

Introduction

Forests are world assets that have various benefits for life, namely in the form of direct and indirect benefits. Most forests support the incomes of people living within the poverty line (FAO, 2020). About 28% of forests are managed by local communities (Gilmour, 2016). The exploitation of forests for profit has increased deforestation and widespread forest degradation, and fuelwood crises are increasing in developing countries. So, forest conditions are no longer able to provide optimal benefits. This condition is increasingly worrying and has had an impact on decreasing productivity and forest quality, as well as creating critical land everywhere. Especially in Indonesia, forest area is decreasing due to land conversion and overlapping ownership of land areas.

To anticipate this, the eighth World Forestry Congress explicitly raised the theme, "Forests for the People," initiating a tree planting program with the involvement of local communities (Gilmour, 2016). The results of the eighth World Forestry Congress in 1978 identified the impetus for forest use within the framework of the social forestry paradigm. Later, Indonesia started a community forest program to meet the demand for community wood as a source of industrial raw materials.

Community forests are plantations that are built by individuals or cooperatives to increase the potential and quality of production by applying silviculture to ensure the sustainability of forest resources (Gilmour, 2016). Community forest programs were projected to help achieve national and global goals, such as poverty reduction, combating climate change by reducing carbon emissions, and improving forest conditions through afforestation and reforestation (Baynes et al., 2015). Indonesia depends on forest resources. Most Indonesians still depend on forest products for their home energy supply. Community forest management is one of the main focuses of the forestry sector master plan to produce wood, which contributes to poverty alleviation and economic inequality by leveraging the money generated (Oli and Treue, 2015).

Forestry development must be increasingly directed at increasing the use of forests for domestic industries so that they can generate added value and create as many jobs as possible. With developments in the forestry sector, such as the development of community forests, it was hoped that they would play a significant role in increasing the socio-economic conditions of the community and mitigating climate change in several tropical countries (Dieterle and Karsenty, 2020; UNDP, 2017).

Community forests have been cultivated for decades and have proven to be very beneficial, not only for the owner but also for the community and the environment (Nambiar, 2019; World Bank, 2017). There has been a belief that community forests have significant potential in the national forest management arena. This was mainly shown by the inclusion of the potential calculation for community forest products in the supply of raw materials for the wood-processing industry (Hardjanto, 2017). This understanding and belief was manifested in the form of attention and action that led to an increase in the performance of community forest businesses, which have been cultivated by the community on an independent, self-supporting, and self-funding basis (Nugroho, 2014).

Given the importance of community forests' role as suppliers of wood needs in the future, the selection of the wood type to be planted needs to be considered. In Central Sulawesi, Indonesia, several types of community forests exist such as nantu (*Palaquium* sp.), palapi (*Terrictia* sp.), jabon (*Anthocepalus* sp.), super teak (*Tectona grandis*), and white teak (*Gmelina arborea*). The objective of this research was to analyze the optimum age and maximum increment of community forest stands to determine which species are the most profitable.

Results and Discussion

Relationship between age and increment of various community forest stands

The relationship between age and diameter (d) of various community forest stands is shown in Figure 1.

The regression analysis showed that age was positively and significantly correlated at α = 5% with the diameter measured at chest height from various community forest stands. Figure 1 shows that age affected the increase in diameter of nantu (*Palaquium* sp.), palapi (*Terrictia* sp.), jabon (*Anthocepalus* sp.), super teak (*Tectona grandis*), and white teak. The increase rate of diameter of nantu, palapi, jabon, super teak, and white teak increased with age, but the older stands showed smaller increase in diameter. The regression analysis showed that age was positively and significantly correlated at α = 5% on the total height of various community forest stands (Figure 2).

Total height is the difference in height between the tip of the top growth and the base of the tree. Figure 2 shows that age affected the total height of nantu, palapi, jabon, super teak, and white teak trees. The increased rate of total height of nantu, palapi, jabon, super teak, and white teak increased with age, while the older stands showed smaller total height increase.

The increase rate of diameter and total height was relatively different for each type of stand. Stands of different types displayed different growth, with a consequent variation in shape occurring over time (Waterworth et al., 2007; Carlson et al., 2008; Forrester and Smith, 2012; Forrester et al., 2013; Soares et al., 2016).

The increment in stand diameter was the result of secondary growth, namely lateral growth, because of cambium activity in the wood. The diameter was one of the determining factors for selling value because the diameter characteristic affected the volume of wood produced.

The increment of total height resulted from primary growth as a result of the activity of meristem cells located at the growth tips. The total height was used as a reference in the wood trade because it was one of the determining indicators of tree dimensions.

Secondary growth was very dependent on age, whereas older trees had a reduced transport capacity in the vascular system that consequently reduced the energy supply and suppressed primary growth (Bormann, 1965). Increasing age causes a reduction in the width of the ring in anatomy (Schweingruber, 2008). The increase in high initial growth at a young age was due to better care conditions and the supply of resources (Grossnickle, 2012), especially during secondary growth. In addition, most nutrients would be provided for primary growth to reduce the spatial pressure on secondary growth (Savidge, 2009).

The relationship between age and MAI (Mean Annual Increment) of various community forest stands is shown in Figure 3.

Figure 3 shows that the MAI of nantu and palapi increased until the age of 20 years, after which the MAI began to decrease. The MAI of jabon increased until the age of 8 years, and that of super teak increased until the age of 25 years. The MAI of white teak increased until the age of 15 years, after which it began to decrease. This shows that the age limit for increasing production or wood volume was different for each type of community forest stand.

Increasing community forest wood production and the efficient use of resources is one of the goals of silviculture (Mason and Alia, 2000; Pretzsch et al., 2015). This research shows that a high increase in MAI was only occurred at a young age, and it began to decrease after about 8 years to 28 years. These results are relevant to the research of Zhu et al. (2003), Gersonde and O'Hara (2005), and Shu-Hong et al. (2020), in which forest stands reached their maximum increment volume at the age of 14 to 33 years. Environmental factors, such as light intensity, could also affect tree volume growth (Gersonde and O'Hara, 2005).

Economic cycle of various community forest stands

Normal forests had a distribution of age classes from the distribution of the trees size. Furthermore, they had a normal distribution of age classes, characterized by the presence of complete age classes available in the forest so that it was possible to obtain the same yield every year or a certain period according to a predetermined cycle. In theory, an increase in tree volume applies the law of diminishing returns. The volume and increment of various community forest stands varied by type. The economic cycles of various community forest stands are shown in Table 1.

According to Hasid (2011), the distribution of fast and slow-growing tree species lies in the increment. A tree is considered slow growing if it had an increment of less than 15 m^3/ha/year, while a tree was considered fast growing if its increment was greater than 15 m^3/ha/year (Hasid, 2011). Table 2 shows that jabon is a fast-growing tree because it has an increment of 41.33 m^3/ha/year, while nantu, palapi, super teak, and white teak are slow-growing species because they have an increment of less than 15 m^3/ha/year.

According to the economic cycle, nantu could be harvested at the age of 20 years and had a total volume of 181.02

m^3/ha/year and an increment of 9.05 m^3/ha/year, while the average diameter was 33 cm and the average increase in diameter was 1.65 cm/year (Table 2). Palapi could be harvested at the age of 20 years and had a total volume of 147.46 m^3/ha and an increment of 7.37 m^3/ha/year, while the average diameter was 30 cm and the average increase in diameter was 1.5 cm/year. Jabon could be harvested at the age of 8 years, having a total volume of 330.64 m^3/ha and an increment of 41.33 m^3/ha/year, while the average diameter was 30 cm and the average increase in diameter was 3.75 cm/year. For super teak, the harvest estimate was at the age of 25 years for a total volume of 220 m^3/ha and an increment of 8.82 m^3/ha/year, while the average diameter was 40 cm and the average increase in diameter was 1.6 cm/year. White teak could be harvested at the age of 15 years and had a total volume of 191.96 m^3/ha and an increment of 12.80 m^3/ha/year, while the average diameter was 30 cm and the average increase in diameter was 2 cm/year. The results of this research show that investment in growing resources was different between each type of community forest stand.

Business feasibility of various community forest stands

The income levels of various community forest stands are shown in Figure 4 using the Business as Usual (BAU) system (Dyllick and Katrin, 2015), which is a business without considering the value of time.

Figure 4 shows that the nantu trees could be harvested at the age of 20 years with a total volume of 181.02 m^3/ha/year and 350 trees/ha. However, for harvesting, the trees were divided by diameter class. There were more trees with a diameter of 29 to 37 cm than other diameters. Trees with this diameter had a total volume of 100 m^3/ha with as many as 200 trees/ha, generating an income of IDR 83,779,000 with a selling price of IDR 1,050,000/m^3. Trees with a diameter of more than 38 cm had a density of 80 trees/ha with a total volume of 41.21 m^3/ha and a wood price of IDR 1,200,000/m^3, resulting in an income of IDR 55,619,000. Trees with a diameter of less than 28 cm had a density of 85 trees/ha with a total volume of 21.03 m^3/ha. The income from trees of this diameter was IDR 14,900,000 with a selling price of IDR 800,000/m^3. The income obtained from thinning carried out at the age of 15 years for 80 trees with a total volume of 25.99 m^3/ha resulted in an income of IDR 8,232,000 with a wood price of IDR 700,000/m^3.

When palapi trees were harvested at the age of 20 years, a total volume of 147.46 m^3/ha with 330 trees/ha were obtained. Trees with a diameter of 26 to 34 cm had more total trees than the other diameters, with a total volume of 59 m^3/ha, 170 trees/ha, an income of IDR 48,731,000, and a selling price of IDR 800,000/m^3. Trees that had a diameter of more than 35 cm had a percentage of the total trees greater than that of those with a diameter of less than 25 cm. Trees with a diameter of more than 35 cm had a total volume and income greater than that of those with a diameter of less than 25 cm. Palapi trees with a diameter of less than 25 cm had a density of 65 trees/ha with a total volume of 21 m^3/ha, generating an income of IDR 9,591,000 and a selling price of IDR 600,000/m^3. Palapi tree with a diameter of more than 35 cm had a total volume of 38 m^3/ha but resulted in an income of IDR 41,047,000 with a wood price of IDR 1,000,000. The income obtained from thinning carried out at the age of 15 years with 90 trees/ha and a total volume of 25 m^3/ha resulted in an income of IDR 7,000,000 and a wood price of IDR 700,000/m^3.

When jabon wood was harvested at the age of 8 years, it had a total volume of 330.64 m^3/ha with 600 trees/ha. Most trees had a diameter of more than 33 cm, with a total volume of 134 m^3/ha and 200 trees/ha. The income was IDR 116,312,000, and the selling price of wood was IDR 900,000/m^3. There were more trees with a diameter of 24 to 32 cm than a diameter of less than 23 cm. Trees with a diameter of 24 to 32 cm had a total volume and income greater than that of trees with a diameter of less than 23 cm. Jabon trees that had a diameter of less than 23 cm had a density of 165 trees/ha with a total volume of 37 m^3/ha, an income of IDR 9,286,000, and a selling price of IDR 500,000/m^3. Jabon trees with a diameter of 24 to 32 cm had a total volume of 92 m^3/ha, generating an income of IDR 50,825,000 with a wood price of IDR 700,000. The income obtained from thinning carried out at the age of 6 years with a total of 100 trees/ha and a total volume of 36 m^3/ha resulted in an income of IDR 8,448,000 with a wood price of IDR 600,000/m^3.

When super teak trees were harvested at the age of 25 years, they had a total volume of 220 m^3/ha/year and a density of 300 trees/ha. Most trees had a diameter of more than 35 cm, with a total volume of 14 m^3/ha, 130 trees/ha, an income of IDR 394,993,000, and a selling price of IDR 2,700,000/m^3. There were more trees with a diameter of 26 to 34 cm than trees with a diameter of less than 23 cm. Trees with a diameter of 26 to 34 cm had a total volume and income greater than those with a diameter of less than 25 cm. Super teak trees that had a diameter of less than 25 cm comprised of 50 trees/ha with a total volume of 106 m^3/ha, an income of IDR 3,517,000, and a selling price of IDR 1,700,000/m^3. A super teak tree with a diameter of 26 to 34 cm had a total volume of 57 m^3/ha, generating an income of IDR 60,765,000 with a wood price of IDR 2,200,000. The income obtained from thinning carried out at the age of 20 years with a total of 40 trees and a total volume of 20 m^3/ha resulted in an income of IDR 7,968,000 with a wood price of IDR 1,200,000/m^3.

White teak trees harvested at the age of 15 years had a total volume of 191.96 m^3/ha/year and a density of 380 trees/ha. Most trees had a diameter of more than 28 cm with a total volume of 128 m^3/ha, 265 trees/ha, an income of IDR 116,992,000, and a selling price of wood of IDR 1,000,000/m^3. More trees had a diameter of 21 to 27 cm than a diameter of less than 20 cm. Trees with a diameter of 21 to 27 cm had a total volume and income greater than those of trees with a diameter of less than 20 cm. White teak trees that had a diameter of less than 20 cm had a density of 25 trees with a total volume of 3.87 m^3/ha, generating an income of IDR 2,585,000 and a selling price of IDR 700,000/m^3. Trees with a diameter of 21 to 27 cm had a total volume of 21 m^3/ha with as many as 90 trees/ha, resulting in an income of IDR 25,926,000 at a price of wood of IDR 800,000. The income obtained from thinning carried out at the age of 10 years with a total of 120 trees and a total volume of 35.4 m^3/ha resulted in an income of IDR 3,984,000 and a wood price of IDR 600,000/m^3.

Financially, the fast-growing type (jabon) was more profitable than the slow-growing types. The fast-growing species (jabon) had a business scale with a smaller area than the slow-growing trees (nantu, palapi, super teak, and white teak), giving jabon

Table 1. Economic cycles of various community forest stands.

Sample plot	Age (years)	d (cm)	h (m)	TV (m3)	MAI (m3/ha/year)	Description
Nantu	20	33	11	181.02	9.05	Slow growing
Palapi	20	30	11.5	147.46	7.37	Slow growing
Jabon	8	30	13	330.64	41.33	Fast growing
Super Teak	25	40	13	220	8.82	Slow growing
White Teak	15	30	13	191.96	12.8	Slow growing

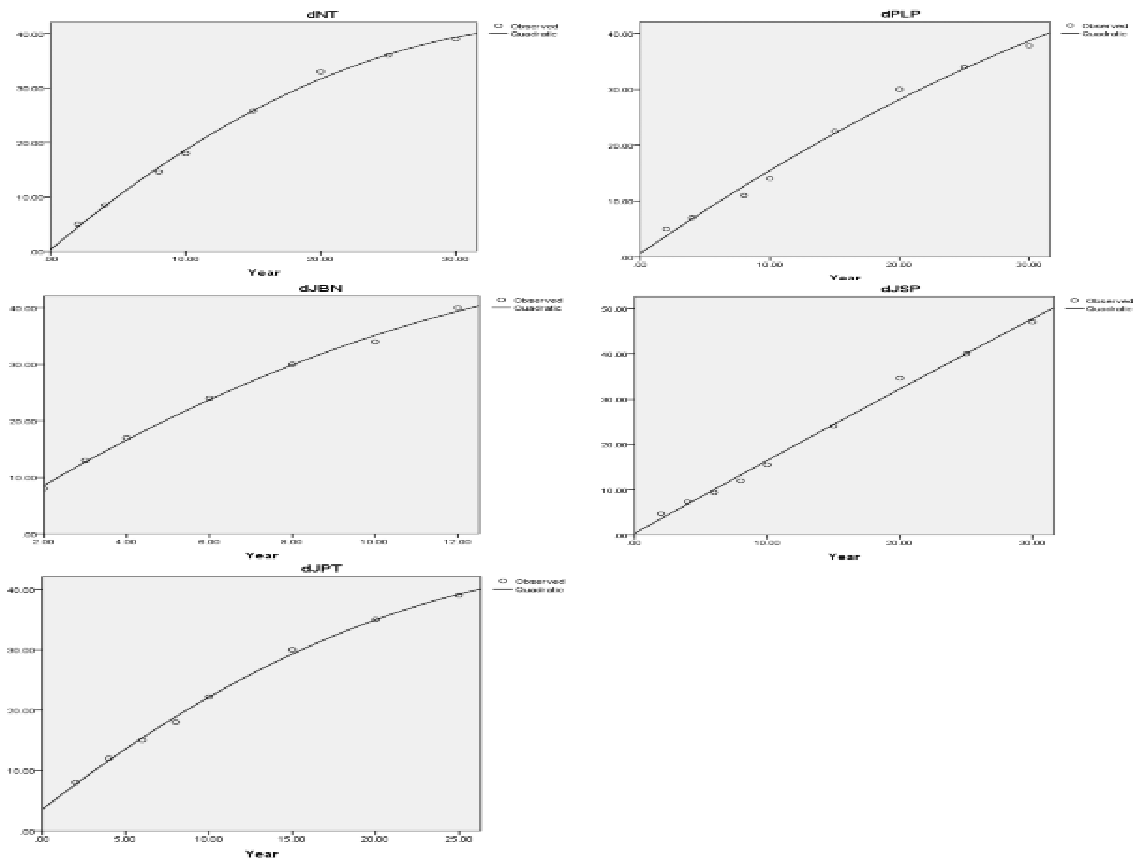


Figure 1. The increase in diameter among various community forest stands. Description: Nantu: $Y = 0.346 + 2.1X^{**} - 0.027X^{2**}$, adjusted $R^2 = 0.996$. Palapi: $Y = 0.593 + 1.598X^{**} - 0.011X^{2**}$, adjusted $R^2 = 0.986$. Jabon: $Y = -0.452 + 4.741X^{**} - 0.118X^{2*}$, adjusted $R^2 = 0.996$. Super Teak: $Y = 0.351 + 1.623X^{**} - 0.001X^{2*}$, adjusted $R^2 = 0.993$. White Teak: $Y = 3.513 + 2.153X^{**} - 0.029X^{2**}$, adjusted $R^2 = 0.997$. ** = significant at α = 1%, * = significant at α = 5%. X = Plant age (Year); Y = Tree diameter (cm).

Table 2. Research plot data for community forest product stands.

Tree Type	Location	Planting Distance (m)	Age (years)	Plot Area (m^2)
Nantu	Bolano Lambunu Sub-district Parigi Moutong Regency	3 x 4	4, 8, 10, 15, 20, 25	10
Palapi	South Dampal Sub-district Donggala Regency	3 x 4	4, 8, 10, 15, 20, 25	10
Jabon	Lampasio Sub-district Toli-Toli Regency	3 x 3	3, 4, 6, 8, 10	10
White Teak	Lampasio Sub-district Toli-Toli Regency	3 x 4	4, 6, 8, 10, 15, 20	10
Super Teak	Lampasio Sub-district Toli-Toli Regency	3 x 4	4, 8, 10, 15, 20, 25, 30	10

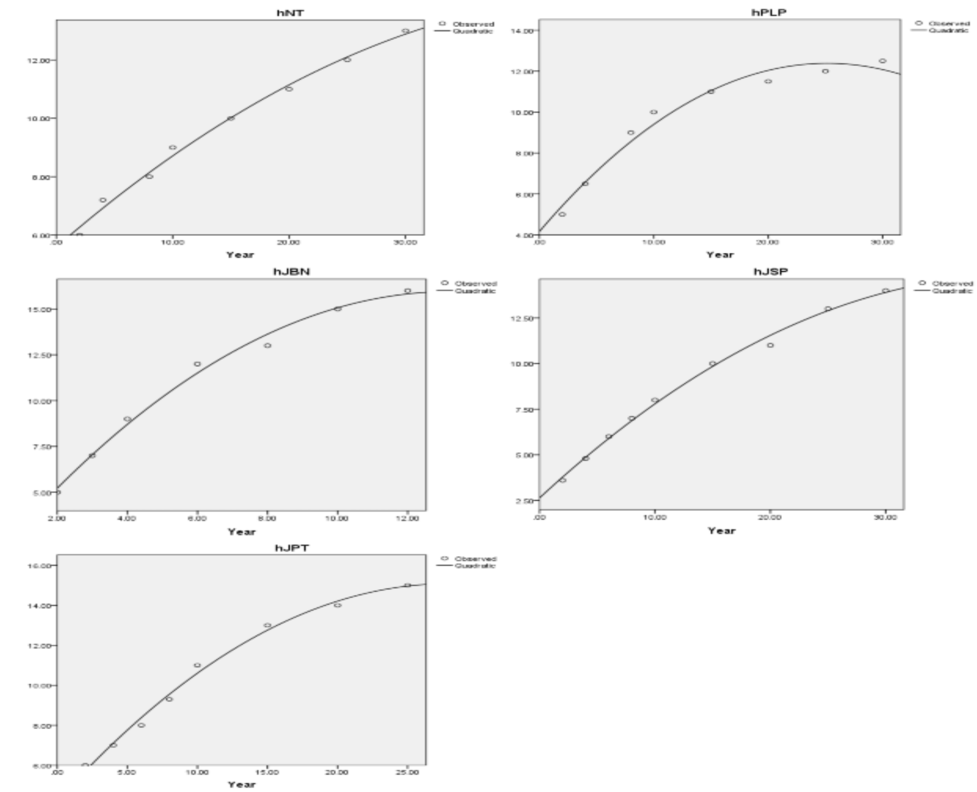


Figure 2. The increase rate of total height in various community forest stands. Description: Nantu: $Y = 0.346 + 2.1X^{**} - 0.027X^{2**}$, adjusted $R^2 = 0.996$. Palapi: $Y = 0.593 + 1.598X^{**} - 0.011X^{2**}$, adjusted $R^2 = 0.986$. Jabon: $Y = -0.452 + 4.741X^{**} - 0.118X^{2*}$, adjusted $R^2 = 0.996$.Super Teak: $Y = 0.351 + 1.623X^{**} - 0.001X^{2*}$, adjusted $R^2 = 0.993$. White Teak: $Y = 3.513 + 2.153X^{**} - 0.029X^{2**}$, adjusted $R^2 = 0.997$. ** = significant at α = 1%, * = significant at α = 5%. X = Plant age (Year); Y = Branch free height (m).

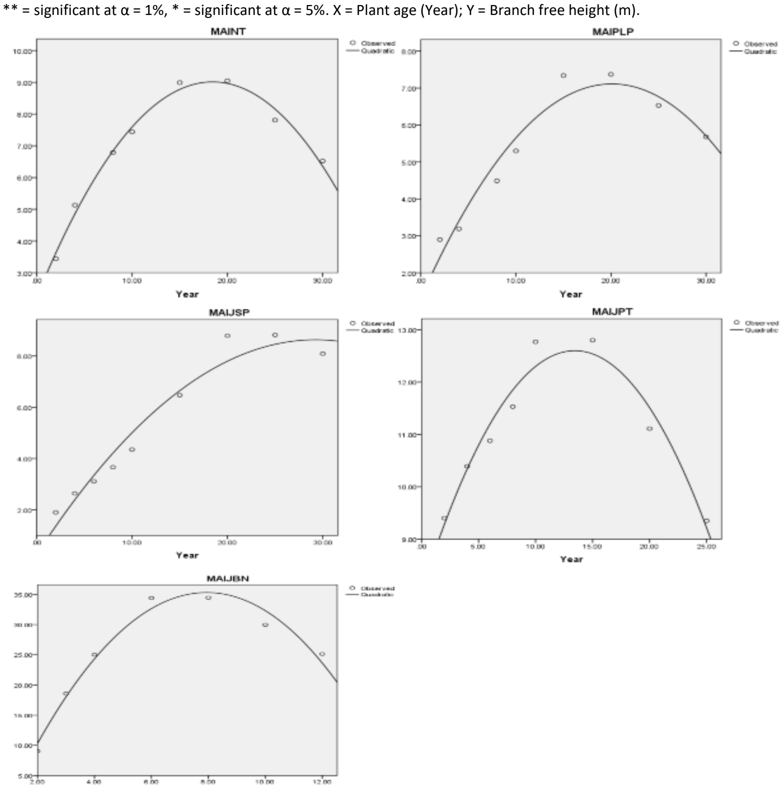
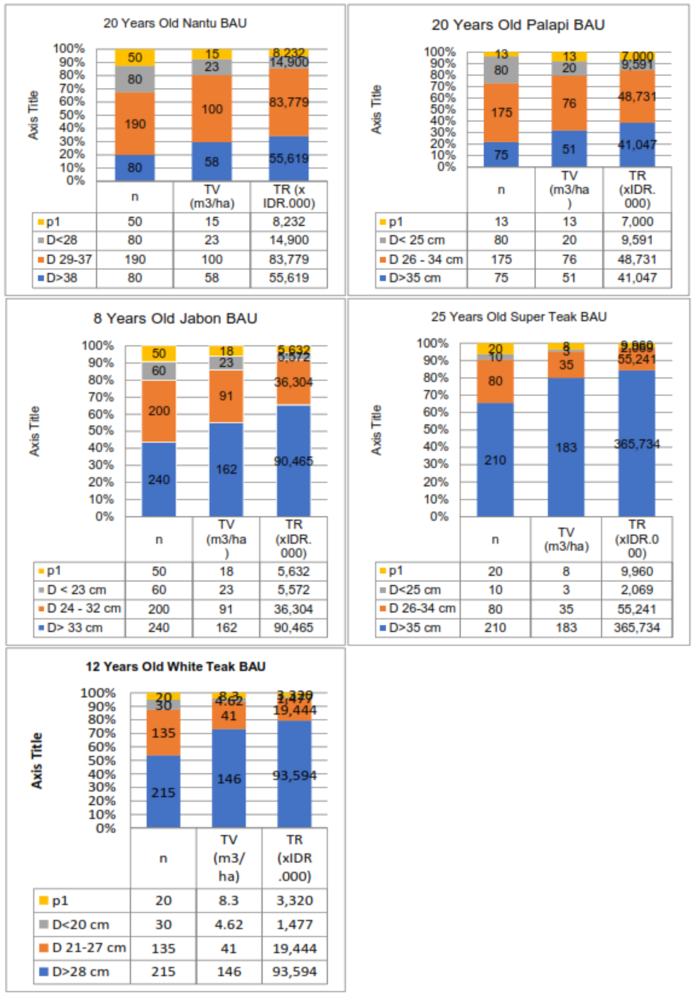


Figure 3. Relationship between age and MAI in various community forest stands. The regression analysis shows that the age and MAI of various community forest stands had a quadratic relationship, as seen in the following equations: Nantu: $Y = 2.237 + 0.735X^{**} - 0.02X^{2**}$, adjusted $R^2 = 0.981$. Palapi: $Y = 1.320 + 0.577X^{**} - 0.014X^{2**}$, adjusted $R^2 = 0.923$. Jabon: $Y = -9.328 + 11.242X^{**} - 0.708X^{2**}$, adjusted $R^2 = 0.958$. Super Teak: $Y = 0.254 + 0.573X^{**} - 0.010X^{2*}$, adjusted $R^2 = 0.943$. White Teak: $Y = 8.021 + 0.681X^{**} - 0.025X^{2**}$, adjusted $R^2 = 0.922$. Note: ** = significant at α = 1%, * = significant at α = 5%. X = Plant age (Year); Y = Mean annual increment *(*m^3/ha/year).



20 Years Old Nantu BAU

	n	TV (m3/ha)	TR (x IDR.000)
p1	50	15	8,232
D<28	80	23	14,900
D 29-37	190	100	83,779
D>38	80	58	55,619

20 Years Old Palapi BAU

	n	TV (m3/ha)	TR (xIDR. 000)
p1	13	13	7,000
D< 25 cm	80	20	9,591
D 26 - 34 cm	175	76	48,731
D>35 cm	75	51	41,047

8 Years Old Jabon BAU

	n	TV (m3/ha)	TR (xIDR. 000)
p1	50	18	5,632
D < 23 cm	60	23	5,572
D 24 - 32 cm	200	91	36,304
D> 33 cm	240	162	90,465

25 Years Old Super Teak BAU

	n	TV (m3/ha)	TR (xIDR.000)
p1	20	8	9,960
D<25 cm	10	3	2,069
D 26-34 cm	80	35	55,241
D>35 cm	210	183	365,734

12 Years Old White Teak BAU

	n	TV (m3/ha)	TR (xIDR .000)
p1	20	8.3	3,320
D<20 cm	30	4.62	1,477
D 21-27 cm	135	41	19,444
D>28 cm	215	146	93,594

Figure 4. Business feasibility of various community forest stands.

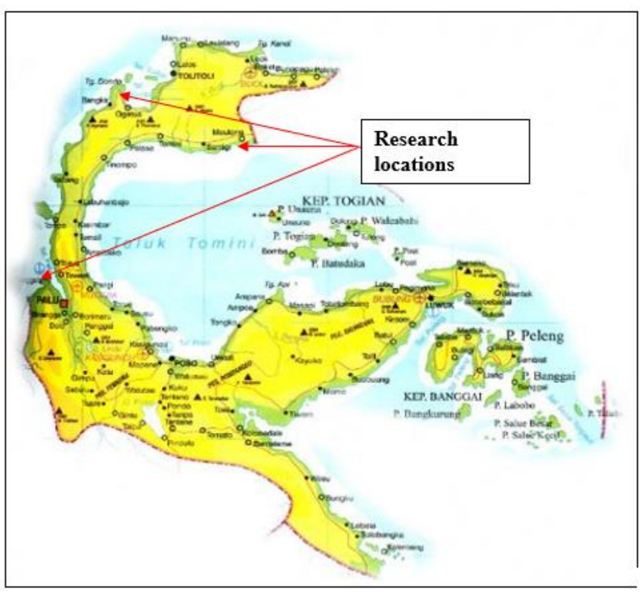


Figure 5. Research location map.

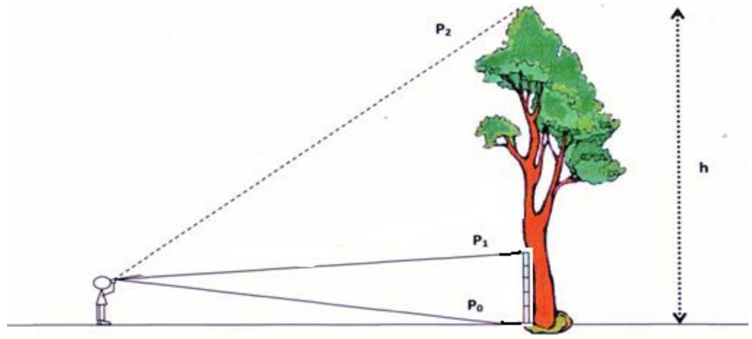


Figure 6. Determination of tree height using a clinometer.

more potential to be developed than the slow-growing trees. According to Dieterle and Karsenty (2020), Phuc et al. (2018), and the World Bank (2017), there are great opportunities for the forestry and wood products sector due to increasing domestic and export demand. Highlighting this allowed for greater participation by smallholders. This will promote rural development, reduce poverty, and help mitigate climate change (Nambiar, 2019). Community forests are very helpful in the production of wood for industrial and household purposes because logging wood from natural forests is no longer legal. Therefore, community forests must be managed to be more productive by promoting and ensuring sustainable management.

Materials and Methods

Location of experiment

This research was performed from August to December 2019, which included field orientation, preparation of research plans, research implementation, data collection, data analysis of research results, and preparation of manuscripts. The research was done in community forests located in Bolano Lambunu Sub-district Parigi Moutong Regency, South Dampal Sub-district Donggala Regency, and Lampasio Sub-district Toli-Toli Regency, Central Sulawesi Province. The research locations is depicted in Figure 5.

Sample location

The approach used in determining the research location was to use the field observation method by purposive sampling (deliberately) with consideration of the feasibility of the location of community forests and the existence of these types of commodities, which are located in Bolano Lambunu Sub-district Parigi Moutong Regency, South Dampal Sub-district Donggala Regency, and Lampasio Sub-district Toli-Toli Regency, Central Sulawesi Province.

Respondent sample

Respondents in this research were farmers who own community forests and carry out community forest cultivation and officials from related institutions.

The objects of research were farmers or communities that cultivate community forest products from various types of stands, as shown in Table 2.

Data analysis

To determine the volume of the stand, the tree height was measured using clinometers (Figure 6) with the help of a measuring stick (4 meters long), which was placed vertically on the tree trunk (Ruchaemi, 2006). Tree height was calculated using the following formula:

$$h = \frac{P_2 - P_0}{P_1 - P_0} x\ P_t$$

Description:

h : Tree height

P_2 : Scale readings in percent for treetops.

P_1 : Scale readings in percent for the tip of the stick.

P_0 : Scale readings in percent for tree base.

P_t : Stick long of 4 meters.

Diameter measurement

The diameter was measured with a measuring tape at a height of 1.30 m. To obtain the diameter value, we used the following formula:

$$d = \frac{K}{\pi}$$

Description:

d : Tree diameter (cm)

K : Tree perimeter (cm)

π : 3.141592654

Volume calculation

The tree volume was calculated using the following general formula:

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

Description:

V : Volume (m^3)

π : 3.141592654

d : Diameter of the tree at chest height (cm)

h : Branch free height (m)

f : Tree form factor

Mean Annual Increment (MAI)

Following Ruchaemi (1988), the following formula was used to calculate the volume of mean annual increment (MAI):

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

Description:

MAI = Mean annual increment (m^3/ha/year)

V_t = Total volume in t-th age (m^3)

t = Tree age (year)

In this research, the total volume was the standing volume. The standing stands were calculated as the total volume.

Conclusion

Nantu could be harvested at the age of 20 years, had a total volume of 181.02 m^3/ha/year and an increment of 9.05 m^3/ha/year, while the average diameter was 33 cm. Palapi could be harvested at the age of 20 years and had a total volume of 147.46 m^3/ha and an increment of 7.37 m^3/ha/year, while the average diameter was 30 cm. Jabon could be harvested at the age of 8 years with a total volume of 330.64 m^3/ha, an increment of 41.33 m^3/ha/year, and an average diameter of 30 cm. According to the economic cycle of super teak, it could be harvested at the age of 25 years with a total volume of 220 m^3/ha, an increment of 8.82 m^3/ha/year, and an average diameter of 40 cm. White teak could be harvested at the age of 15 years, had a total volume of 191.96 m^3/ha, an increment of 12.80 m^3/ha/year, and an average diameter of 30 cm. The results of this research show that investment in growing resources was different between each type of community forest stand, and jabon provided the best community forest stand. The optimal growth of jabon was achieved at the age of 8 years, so the policy of harvesting at the age of 8 years was the right silvicultural choice.

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