Growth Model of Pine (*Pinus merkusii* Jungh. Et de Vriese) Stand on Community Forest in Tana Toraja Regency

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Abstract

Growth modeling and yield simulation of forest is a very important aspect in forest management including community forests. Stand growth model is an abstraction of the dynamic nature of a forest stand, including growth, ingrowths, mortality, and other changes in the structure and composition of the stand. In forest management, growth estimation plays an important role in supporting the sustainability of the benefits value of the community forests. The objectives of the research were to find out the stand growth model and the potential of community's pine forest. The study was conducted at the location of the community pine forests in District Mengkendek Tana Toraja Regency. Sample location, as representative of stand age classes that distribute on some villages in Mengkendek District, were selected by purposive sampling. The study results indicate that the most suitable model for upper trees mean height (H) is Weibull Model, for growth diameter and growth volume is Logistic Model. The stand mean height (h) can be presented as a function of H and Relative Spacing Ratio (Sr) on the basis of function $\log Sr = 0.197 - 0.653 \log H$, then the tree volume, can be estimated on the basis of function $\log V = -1.70 + 0.94 \log d + 1.50 \log h$, and then the growth function of volume on the basis of function $V = 1.008 / [1 + 251.322 \exp(-0.373t)]$. Further, the maximum value of stand Annual Increment was $18\ m^3 ha^{-1} year^{-1}$, attained at the age of 20 years.

Keywords: community's pine forest, stand growth, tree volume, annual increment

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Introduction

Community forest is a forest located on a land not owned by the government, thus it is owned by public (Hendarto 2003). According to Act No. 5/1967 on Forestry Principal Provisions, community forest is considered as private forest growing or planted on alienated land, usually called community forest and can be owned by an individual or shared by some people or corporations. Forests planted with own initiative on land charged by other right, are also considered as the forests owned by the respective people/corporations. Whereas, according to Act No. 41/1999 on Forestry (the substitute for Act No. 5/1967) Section 5 Article 1(b), the term private forest is replaced by right forest which is in its explanation section called community forest.

In Tana Toraja, pine trees have been planted since the late 1960s. The big scale planting of this tree has been commenced since 1976 either by community enterprises or through green assistance program. In attempt to utilize the pine trees in Tana Toraja Regency, the governor of South Sulawesi in 1994 had issued a Decree No. 71/II/1994 dated

October 12, 1994, about the technical guidance of timbers and resins maintenance activity from community forest of Tana Toraja Regency. The intended maintenance activity are spacing and tapping, but no further explanation about how the spacing and tapping should be implemented. The development of community pine forest, particularly in Tana Toraja has been re-proclaimed since 2002 (Patabang *et al.* 2008). This was due to the fact that community forest is a timber source alternative that can be expected to compensate the lack of woods industry raw materials. Furthermore, Patabang *et al.* (2008) suggested that the strategy that can be used in community forest development included the formation and improvement of farmer group/institutional role, development of agroforestry pattern for the improvement of productivity and economic value of land, areal management to manage the production/felling and planting in order to regulate the production continuity and warrant the certainty of community forest utilization. In order to achieve these community forest development goals, particularly the yield sustainability, every community forest

management has to be always oriented to yield sustainability. However, this community forest management is never free from obstacles.

According to Andayani (2003), one of the obstacles faced in the community forest management is technological one, particularly the availability of information about its potential development. In order to overcome this problem, Malamassam (2006) suggested that community forest management should be classified into Community Forest Management Units, in order to get the sustainable yield. Sustainable yield that has been the goal of forest management as woods producer, can be achieved through forest cover and growth maintenance, and guarantee the availability of adequate and fixed reserve stand to supply or as wood material source that can support woods industry stability sustainably, in addition to be fixed income source for its owner (Prudham 2005). In order to support the management planning, particularly the plant maintenance in the community forest, information is needed regarding the increment or the trees growth or stand. According to Patabang *et al.* (2011a) the models to predict plant growth increment accurately were the Weibull, Logistic, and Gompertz models. In addition, Herault *et al.* (2010) suggested that the growth modeling is done with the aim to predict trees response in the implementation of felling system. Trees growth modeling and forest yield can also be used to predict change in forest resource due to natural resources management system and environmental changes (Ikonen *et al.* 2008).

Growth is the backbone of forest management science with the aim to produce woods. Without information on growth, a forest management plan is no more than a guide to handle field tasks, and not a plan to implement to achieve the management goal (Simon 2010). Plant growth, particularly the height growth is highly influenced by stand density structure (Patabang *et al.* 2011a). A forest structure that guarantees forest yield sustainability can be viewed from 2 aspects: age distribution (diameter) of trees and stand increment. Diameter of trees in a specific time and location can reflect the sustainability aspect of community forest management (Widayanti 2004). Further, Pukkala *et al.* (2009) suggested that equation model that can be used to calculate diameter increment is logarithmic model in which the diameter can be a logarithmic function of trees height.

Growth modeling and forest yield are 2 fundamental things in forest management (Corona & Scotty 1998). Stand growth model is a source for abstraction of nature dynamic condition of a forest stand including growth, decay, and other changes in stand structure and composition. The general use of growth model term refers to an equation system that can predict the growth and forest product of a wide forest stand and based on covering condition and its environment (Vanclay 1994). Growth in forestry term is highly related to dimensions addition of one or more individual trees in forest stand until specific time. This growth definition is usually differentiated from increment that can be used to state dimensional addition or stand per specific time unit, but in daily use both of these terms are frequently interchangeable. In forest management, growth estimation plays an important role in supporting the sustainability, management

alternatives development, and optimized management strategy (Rodriguez *et al.* 2010).

The comprehensive description of trees growth can be obtained by using trees growth data of various age classes, from the 1 year or 2 year old trees to aged trees or trees without more growth due to aging factor. However, in many researches, complete data is generally not available, while the growth description is highly required for planning purpose.

Considering the brief description above, growth description is usually performed with several assumptions for simplification. Growth (total increment), tree components (height, diameter, basic area, and volume) are frequently assumed as the function from time to age. In other aspect, increment or dimensional addition/change of trees at specific age, is assumed as the function of age and/or growth achieved at the respective age.

This study was aimed to establish a model for pine (*Pinus merkusii* Jungh. et de Vriese) stand growth in community forest of the Tana Toraja Regency. This stand growth model consists of height, diameter, and volume growth models. The obtained growth models in this study are expected to be useful in the formulation of stand table which is a basic reference to determine the measures need to be taken in forest management, from planting, maintenance, to felling.

Methods

Data were collected in community pine forest area of Mengkendek Subdistrict, Tana Toraja. The used measuring sample plots are 20×20 m squares at each of the sampling location. The selection of measuring sample plots location for every age class in each location was performed randomly, where each of the age class was represented by 10 measuring plots. The measured trees were 5, 10, 15, 20, 25, and 30 old trees. The measured or observed variables were the diameter at breast height and trees height.

The growth shape of community pine forest stand was analyzed with the following growth modeling steps:
1 Height growth (h) was determined from the best model from Patabang *et al*. (2011a) with the Equation *[1]*:

$$h = 34.58 - [28.04 \exp(0.001 t^{2.647})] \qquad [1]$$

note:
t = stand age (years)
h = height growth achieved at t age (m)

This model is based on Weibull equation, which is the best among pine growth models according to Patabang *et al*. (2011a) study. In this Weibull equation, the modeling of stand growth is established by substituting the *Weibull* random variables with age and stand growth variables. Through this substitution, it can be seen that the growth or increment level of an organism at specific age is equal to its age, whereas its total growth is equal to the difference between maximum size that can be achieved and growth that can be achieved at given age. This Weibull model can be analyzed for its reliability by calculating the relationship between upper height standard deviation and plant age. This model is tested by calculating standard deviation with the Equation *[2]*:

$$Sd = a t^{b} \qquad [2]$$

note:
Sd = upper height standard deviation
t = stand age
a, b = constant

According to analysis result of this plant height increment, a further analysis was performed for relative spacing ratio of trees to know the ideal stand density level that can support the optimal growth. The used allometric Equation *[3]* to determine the relative spacing ratio was:

$$\log Sr = a - b \log H \qquad [3]$$

note:
Sr = relative spacing ratio
H = upper height growth (m)
a, b = constant

2 Diameter growth was analyzed by using growth equations of Gompertz and Logistics equations as shown in Equation *[4]* and Equation *[5]* respectively (Yosimoto 2001; Carona *et al.* 2002; Malamassam 2012).

$$d = A.exp-B.exp(-kt); \qquad [4]$$

$$d = A/1 + B.exp(-kt) \qquad [5]$$

note:
d = diameter (m)
t = tree age (years)
A, B, k = constant

3 Volume was analyzed by using Schumacher equation (Simon 2010). The used diameter and height value to formulate and analyze the volume equation was the calculated diameter from the values obtained from Equation *[2]* and *[4]* with the following model in Equation *[6]*:

$$\log V = a + b \log d + c \log h \qquad [6]$$

note:
V = volume of tree (m³)
d = diameter (m)
h = height (m)

Analysis on these models were carried out to obtain model coefficients by using Demming Least Square Method. Height and diameter growths obtained based on modeling results were then substituted into the volume equation as shown in Equation *[7]*:

$$V = f(\text{trees height, bonita, age, relative spacing ratio}) \qquad [7]$$

The volume increment was modeled by using a model that state relationship between volume (v) growth and tree age (t) was analyzed by using growth equation was Gompertz equation and Logistics equation. as shown in Equation *[8]* and Equation *[9]* respectively:

$$v = A.exp-B.exp(-kt) \qquad [8]$$

$$v = A/1 + B.exp(-kt); \text{ Logistics} \qquad [9]$$

note:
v = volume (m³)
t = stand age (years)
A, B, k = constants

The steps of stand volume modeling can be presented diagrammatically in Figure 1.

Results and Discussion

Height growth and stand density level Height growth modeling is based on Patabang *et al.* (2011a) in Equation *[1]*. Analysis results indicated that this model is reliable enough to estimate the pine upper-height increment growth because this model has a relatively small standard error (0.867) and correlation coefficient (0.999). Diversity change analysis was in parallel to time change based on analysis result on the above height equation, as shown in Equation *[10]*:

$$Sd = 0.039 \, t^{1.047} \qquad [10]$$

Variance analysis based on Equation *[10]* it was obtained that this model was reliable enough to estimate the upper height standard deviation change along with time change because this model has a significance level smaller than 0.05 and correlation coefficient of 0.97. This value indicates that plant age (t) has a strong correlation to plant diversity, in other words, high plant diversity will increases with the plant aging. To calculate the estimated height growth in different growing place conditions, the following equation was used as shown in Equation *[11]*
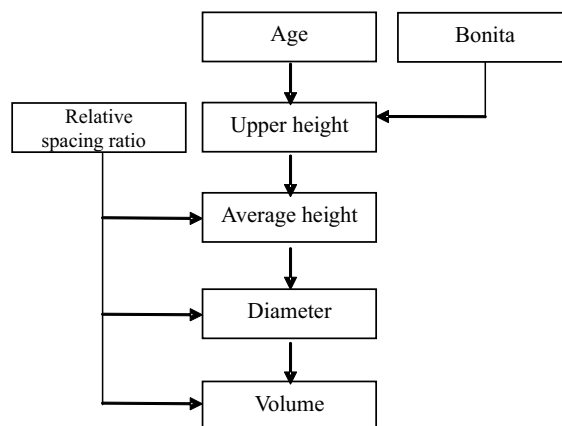

Figure 1 The steps of stand growth modeling of study area.

$$ht = Ht + Sd_r(SI - H_{20}) / Sd_{20} \qquad [11]$$

note:

ht = upper height (for stand with specific growing place index (SI) at t age, namely 27, 30, and 33 years old. Ht and Sd_r is upper height (m) and upper height standard deviation (m) for average value condition ($SI = 30$) at t age), namely upper height for average condition (medium bonita). H_{20} and Sd_{20} is upper height and upper height standard deviation (m) at 20 years, which is used as standard age

Calculation of upper height growth by using Equation *[11]* indicated that the pine stand in study area with growing place index (SI) of 27 will achieve maximum upper height growth at 23 years, whereas at the same age the stand with growing place index (SI) of 30, the upper height still adds average 9 cm per year. Likewise, the upper height of stand with growing place index (SI) of 33, the upper height between age 23 to 30 years still underwent significant growth. The result of this equation was then distributed to calculate the relative growing space. According to upper height growth result (H), the relative spacing ratio (Sr) can be analyzed by using the Equation *[12]*:

$$\log Sr = 0.197 - 0.653 \log H \qquad [12]$$

The analysis result of this Equation *[12]* was reliable enough to estimate the relative spacing (Sr) because it analysis significant level was smaller than 0.05. This value indicated that stand height has significant effect on relative spacing of the plant. The older the plant the wider the growing space used until the stand reaches optimum growth. After analyzing the upper height (H) and relative spacing (Sr), the next step in the growth modeling is the height calculation (h) by using the Equation *[13]*:

$$\text{Log } h = -0.982 + 1.44 \log H - 0.166 / \log Sr \qquad [13]$$

Analysis results of this community pine forest height growth indicated that the equation coefficient of correlation was 0.93 with significance level higher than 0.05. This value indicates that there was a strong relationship between height (h) and upper height (H) and relative density (Sr). The relationship between height and upper height at various spacing level according to equation 10 can be seen from Figure 2. The height growth in Figure 2 indicates that the height growth will continue to occur until the maximum height is reached with specific Sr value. In order to obtain upper height growth, the Sr value need to be added that the density become smaller, which in turn reduce the growth competition between trees . This density/spacing reduction can be achieved by implementing spacing practice according to ideal trees number for specific age level. The height values obtained from Equation *[12]* and Equation *[13]* were then taken as basic in calculating the diameter growth presented in Table 3.

The controlling of stand density is based on the fact that each individual tree in stand will need wider space to grow, in parallel to its age. In this case, one thing to note is that higher spacing allocation until specific density and age will result in the increase of diameter growth of individual trees that form the stand. However, the excessive space allocation that exceeds the growing requirement will produce useless land, in addition to no effect to growth. In other words, each of the individual trees of every species at specific age will require a specific growing space to support its optimum growth for the entire stand, in which this density can be considered as optimum density. If the management goal is to produce maximum wood volume, the forest should be managed in optimum density condition. The optimum density value obtained here can also be used as a basic to determine the number of spacing level that can be done at each age class.

Diameter growth The diameter increment was modeled by using a model that state relationship between diameter (d) growth and tree age (t). Analysis result of diameter growth model in relation to age was as presented in Table 1.

Analysis results in Table 1 indicates that the logistic equation showed better than gompertz equation to estimate growth diameter because Logistic equation has a standard
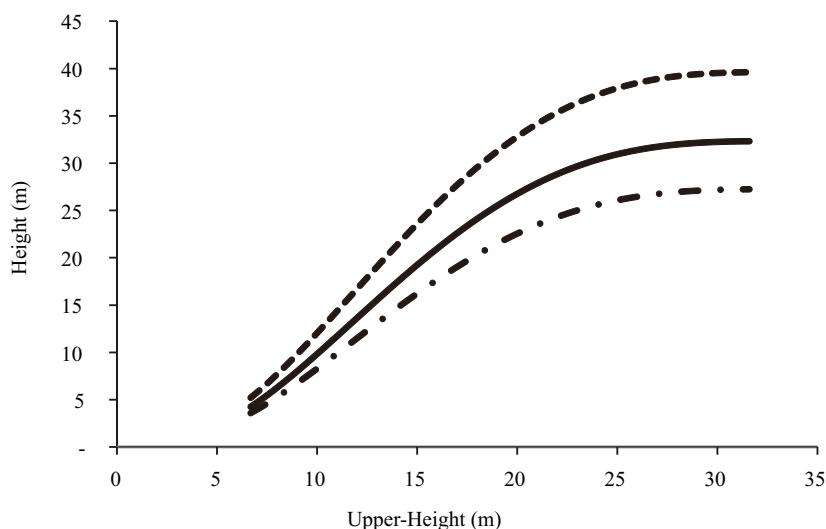

Figure 2 Relationship between height and upper-height at various density level. Sr1 = 0.15 (−··−), Sr2 = 0.25 (——), Sr3= 0.35 (---).

error level smaller (0.193) than Gompertz equation (0.335), besides Logistic equation has a correlation coefficient a higher level than Gompertz equation. This also indicates that this equation is feasible to be used as estimation base for growth diameter because the tree age significantly influences the diameter growth.

This analysis of results of height and diameter growth in Equation *[1]*, Equation *[10]*, and Table 1 were obtained from pine age class obtained from study location in which the measuring swath used was not permanent measuring plots, but measuring plots that were created for each plant age class. This may influences the produced model but its influence was not considered in this case because it was assumed that pine with same age will reach the same and equal height and diameter growth.

Volume growth Volume increment was measured using diameter and height variables as factors that affect the volume calculation of trees. The equation used to calculate volume was the general equation used in trees volume calculation as depicted in Equation *[5]*. Analysis results on height and volume based on Schumacher equation was as shown in Equation *[14]*:

$$\log V = -1.70 + 0.94 \log d + 1.50 \log h \qquad [14]$$

Statistic test on this volume equation indicated that standard error of this equation was small (0.19) and its coefficient of correlation was high (0.95). Both of these values indicated that this model was reliable enough to be used in estimating volume due to the relationship between both of independent variables (diameter and height) its dependent variable (volume) was very strong. According to Putranto (2010), the diameter distribution can be used to estimate the stand volume distribution according to diameter class because volume significantly correlates to diameter. According stand structure dynamic, regeneration potential and appropriate measures on regeneration and volume potential distribution in turn can establish the most appropriate silviculture to guarantee the forest sustainability.

This equation was modeled by using form factor ranging from 0.56 to 0.89 and average 0.73 and average standard deviation of 0.10 according to volume table-based analysis result. When Equation *[13]* was substituted into Equation *[14]*, a new equation obtained expressing the relationship between volume, diameter, upper height, and density as shown in Equation *[15]*:

$$\log V = -3.08 + 0.94 \log d + 2.16 \log H + 0.249/\log Sr \qquad [15]$$

The volume increment was modeled by using a model that state relationship between volume (v) growth and tree age (t). Analysis result of volume growth model in relation to age was as presented in Table 2.

Analysis results in Table 2 indicates that the Logistic equation showed better than Gompertz equation to estimate growth volume because Logistic equation has a standard error level smaller (0.006) than Gompertz equation (0.019), besides Logistic equation has a correlation coefficient a higher level than Gompertz equation. This also indicates that this equation is feasible to be used as estimation base for growth volume because the tree age significantly influences the volume growth.

According to this equation (Weibull equation and Logistic equation), a stand table can be obtained indicating community pine trees increment in study area is shown in Figure 3 and presented in Table 3.

Stand yield table Stand yield table is a table containing information about stand potential data completely from growth, density level, and volume. Stand yield table plays a very important role in forest management. In addition to determine the time and the felling, stand yield table can also be used as a base to formulate silviculture plan in forest management. This stand yield table contains normal stand growth data, which are estimated values based on analysis and modeling of stand growth previously performed. Stand yield table includes: age, trees number and gap percent ($S\%$), upper height, average height, average diameter, basic area per hectare, volume per hectare, and Mean Annual Increment (MAI) as well the Current Annual Increment (CAI), for various bonita class.

The obtained stand yield table in this study was made based on community pine trees growth models in study area. Stand yield table stating community pine trees increment growth in study area based on the previously mentioned growth model equation is presented in Table 3. Analysis results in Table 3 indicate that community pine trees in study area are 30 years old with 24.57 m upper height and average height of 27.5 m. When these values are compared to the most

Table 1 The growth function of diameter

Model	Equation	Standard error	Correlation coefficient
Gompertz	$d = 33.295 \ \exp[-\exp(1.820 - 0.225\,t)]$	0.335	0.9993
Logistic	$d = 32.669/[1 + 23.206\exp(-0.318\,t)]$	0.193	0.9997

Table 2 The growth function of volume

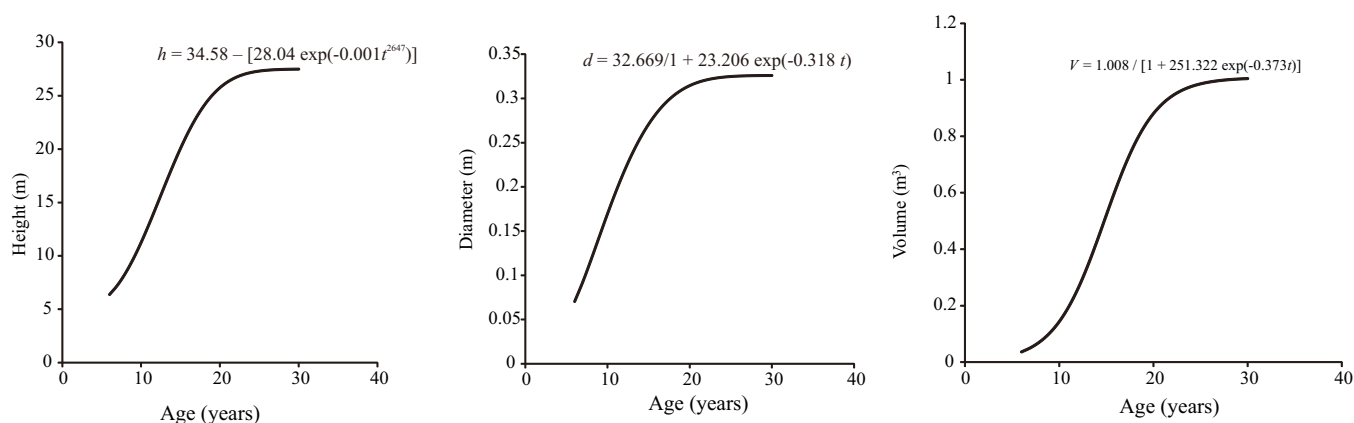| Model	Growth function	Standard error	Correlation coefficient
Gompertz	$V = 1.048 \ \exp[-\exp(3.112 - 0236\,t)]$	0.019	0.9988
Logistic	$V = 1.008/[1 + 251.322 \ \exp(-0.373\,t)]$	0.006	0.9999

Figure 3 Growth individual tree curve of height, diameter and volume.

Table 3 Increment growth by community pine trees age class in study area

Age (year)	Upper height (m)	Number of trees ha^{-1}	Height (m)	Diameter (cm)	S%	Spacing stand potential		Remaining stand potential/final felling		Volume (m^3)		Mean Annual Inc. (MAI) (m^{3}ha^{-1}year^{-1})	Current Annual Inc. (CAI) (m^3 ha^{-1} year^{-1})
						Trees number ha^{-1}	Volume (m^3 ha^{-1})	Trees number ha^{-1}	Volume (m^3 ha^{-1})	per tree	per ha		
5	8.46	1,050	5.75	5.2	39.0	410	(*)	640	(*)	0.02	17.95	3.59	-
10	16.58	658	11.25	17.0	25.1	166	(*)	493	(*)	0.14	93.53	9.35	15.12
15	26.92	470	20.07	27.1	18.3	86	45.30	384	201.84	0.53	247.14	16.48	30.72
20	32.84	410	25.75	31.5	16.1	66	57.98	344	302.14	0.88	360.12	18.01	22.60
25	34.39	397	27.31	32.5	15.6	62	61.33	335	331.28	0.99	392.61	15.70	6.50
30	34.57	395	27.49	32.6	15.6	62	61.71	334	334.68	1.00	396.39	13.21	0.76

MAI (Mean Annual Inc); CAI (Current Annual Inc)
$h = 34.58 - [28.04 \exp(-0,001t^{2.647})]$; $d = 32.669 / [1 + 23.206 \exp(-0.318t)]$; $v = 1.008 / [1 + 251.322 \exp(-0,373t)]$;
$MAI_t = V_t/t$; $CAI_t = V_t - V_{t-1}$
h = height (m); d = diameter (cm); v = volume (m^3); t = tree age (years)

commonly used pine stand yield table in pine forest management in Indonesia, the community pine trees in study area can be categorized as medium bonita (bonita III) because the maximum height that can be achieved by a 30-years old pine in medium bonita for normal stand is 34.8 meter.

In addition to upper height, Table 3 also indicates the increment values that are the interaction results of various factors that can be differentiated into internal factor (trees type) and environmental factor. Furthermore, environmental factor can be classified into growing place and density. Stand increment modeling can be started by describing the influence of growing place factors and density factor as explained previously. Increment types displayed in Table 3 are Mean Annual Increment (MAI) and Current Annual Increment (CAI). MAI is an average increment per year of trees or stand until specific age or trees increment or stand until specific age. CAI is a tree growth or stand from year to year.

The highest MAI value shown in Table 3 was observed in age range of 19–20 years old (18.16 m^{3}ha^{-1}years^{-1}), whereas the highest CAI was obseved in 14-years-old age (32.61 m^{3}ha^{-1}years^{-1}. Graphic showing the relationship between MAI, CAI, and time increment is shown in Figure 4. The

graphic in Figure 4 indicates that when current increment begins to decrease, the average increment still keep increasing, that both of them intersects at the point when average increment reaches maximum. The intersection between current increment and average increment has a great importance to forest industry, because it is at this period the maximum wood production can be achieved. Cycle or harvest age of stand that is predetermined coinciding with the intersection between CAI and MAI is called maximum production cycle. Maximum production cycle is stand age in which the annual wood product reaches the highest volume. Basically, this cycle is counted not only from felling wood but also includes the whole spacing yield ever implemented at that age. This cycle type is the most important cycle concept with practical value (Simon 2010).

Figure 4 indicates that intersection point between MAI and CAI graphic occurs at a period when the plant age reaches 19–20 years old with increment value of 18 m^{3}ha^{-1}years^{-1}, meaning that the maximum production cycle of community pine trees in study area was when the plants reaches 19–20 years old age. This value indicates that in order to obtain maximum economic value sustainably from community pine forest wood potential in study area 20–year cycle or rotation is suggested in its management.

As a comparison to verify the estimated values presented in Table 4 the analysis results of community pine forest by Patabang *et al.* (2011b) was used. The analysis was the estimation of potential by using median estimation method analyzing all 20−30 years old trees data for the same trees types and at same location in the present study. The analysis results of potential estimation by using median value estimation method by Patabang et al (2011b) is presented in Table 4.

Analysis results in Table 4 indicates that mean volume potential of 20−30 yearsold community pine trees ranges 357.63–442.96 m^3 ha^{-1}. This value indicates that estimation error in this analysis was small enough (1.71%). Mean volume in Table 3 (387 m^3 ha^{-1}) is observed at average volume obtained in Table 4. Therefore, it can be said that the stand table obtained according to growth models produced in this study was adequate to be used to estimate potential and its addition in community pine forest in study area. The calculated potential yield to determine the scale of available

potential (standing stock) of community pine forest that regarded as comparator was the 20−30 years old pine trees because the diameter at this age have been adequate to be used as industrial raw material of wood processing at PT Nelly Jaya Pratama as the primary community pine woods consumer in study area. In addition, pines at this age have also reached the maximum production cycle to produce woods.

Conclusion

The findings of this study concluded that the community pine forest in study area with total area of 2,702 ha and trees age ranging 20−30 years, has volume ranging from 357.63–442.96 m^3 ha^{-1}, with average maximum annual increment (18 m^3 ha^{-1}) achieved at 20 years. These volumes and increments were estimated based on growth modeling, which the most suitable model for trees height growth is Weibull Model, for diameter growth and volume growth is Logistic Model.
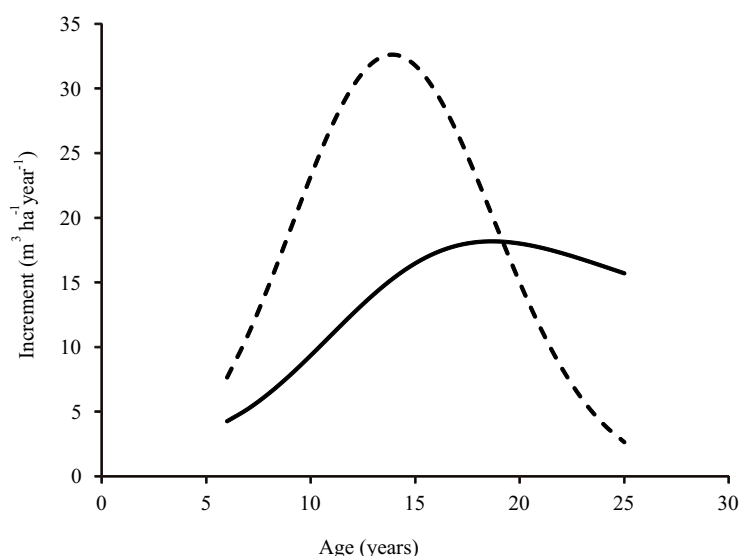

Figure 4 The graphic of increment growth of pine trees in study area. MAI (—), CAI (- - -).

Table 4 Estimated community pine trees potential in Tana Toraja

Age (year)	Mean volume (m^3 $plots^{-1}$)	SE	Estimated volume (m^3 $plots^{-1}$)		Estimated volume (m^3 ha^{-1})	
			Minimum	Maximum	Minimum	Maximum
20	12.19	1.04	11.15	13.24	278.67	330.89
25	17.23	1.67	15.56	18.91	388.97	472.67
30	18.61	2.40	16.21	21.01	405.26	525.32

Source: Patabang *et al*. (2011b)

Suggestion

In order to obtain a sustainable yield, the community pine forest management in Tana Toraja needs to consider the values shown in stand table that were formulated based on the described modeling. From these results the followings are suggested:

1 Community Forest management in Tana Toraja should be begun by areal arrangement and production regulation based on stand yield tables that were formulated according to growth models obtained in this study.

2 Pine forest management in Tana Toraja could achieve yield sustainability when the used cycle is 20 years, and the volume of annual felling 18 m^3 multiplied by area (total effective area divided by 20).

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