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MODELING OF TREE GROWTH AFTER FOREST FIRE IN MOUNT CIREMAI NATIONAL PARK, INDONESIA

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ABSTRACT

Forest fire is a massive threat towards tropical forest causing various negative impacts to nature and human being. Forest fire often leads to alteration of forest structure and its functions. This study of tree growth after forest fire was conducted using a model simulation. The model was performed at the individual level of plant community and built to analyze the potential of tree growth and its scenario for post-fire recovery. Five important tree species from montane forest of Mount Ciremai were chosen to build the model based on four main parameters i.e. plant growth rate, diameter at breast height (DBH), tree-to-grass competition and tree-to-tree competition. The scenario of post-fire recovery was performed by replanting similar species with 5 cm DBH seedling. Prediction from our model showed that most of the chosen species would recover to its pre-fire condition after 37 - 50 years. Considering the limitation of competition after re-planting, it was suggested to minimize tree to tree competition and applied silvicultural treatments to maximize tree growth and tree community recovery.

Keywords: Forest fire, Mount Ciremai National Park, tree growth model, tropical montane forest

INTRODUCTION

Nowadays, forest fire is a serious threat towards tropical land including tropical forest, plantation and other forestry land. Fire used to be extremely rare in tropical forests, leaving ample time for forests to regenerate to pre-fire conditions. Moreover, undisturbed old-grown forests were difficult to burn due to their air humidity and high moisture content in soil and litter, even after prolonged droughts (Slik *et al.* 2010; Knox & Clarke 2012). However, nowadays, tropical forest fires occur more frequently and at larger spatial scales than in the previous decades (van Nieustadt & Sheil 2005; Laurance 2007; Slik *et al.* 2008). In recent years, forest fire occurs every year in dry season and had become the characteristic of disturbed tropical forest ecosystem (Stolle *et al.* 2003).

Several reasons can be identified as main causes of *catastrophic* fire i.e. population growth, changes in land-use practices and short-term climatic oscillations commonly known as *El Nino* (Kinnaird & O'Brien 1998; Le Page *et al.* 2008). Forest fire causes several negative impacts to nature and human being. It affects public health as the net forest emissions may have released carbon which equivalent to 41% of worldwide fossil fuel used in 1997- 1998 (Cochrane 2003). The fire itself led to local extinctions of some plants and animals. Furthermore, a country may suffer economic losses in forestry, non-timber forest products and agriculture. Fire is able to deteriorate forest structure, tree species diversity, tree species composition, aboveground biomass and forest soil (Flannigan *et al.* 2000; McIntosh *et al.* 2005; Knox & Clarke 2012).

Several studies related to forest fire and its recovery had been conducted in tropical forest of Indonesia. Slik *et al.* (2002) recorded that tree density (diameter >10 cm) and canopy closure in Borneo were able to recover within 10 to 15 years. Other studies had also been conducted focusing on recovery of the habitat and species diversity after forest fire in Borneo (Slik 2004; Watanabe *et al.* 2009; Slik *et al.* 2010). However, tree ingrowths during this initial phase of regeneration consist mostly of early successional, fast-growing tree

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species with low wood densities. Successful recovery of forest aboveground biomass, therefore, depends strongly on the regeneration of the pre-fire species composition (Slik *et al.* 2008). In addition, tree community recovery after forest fire was also determined by several conditions i.e. growth rate, resprouting rate, competition and survival rate.

Study on post-fire recovery using ecological modeling as a prediction tool has never been applied in Indonesian forest, specifically in tropical montane forest. In this study, we have modeled the recovery of five dominant trees in Mount Ciremai National Park (MCNP) after forest fire. The model was developed using the growth model of Menaut *et al.* (1990). However, tree biomass calculation was modified by replacing the estimation of volume from diameter and height function (Botkin's equation; Botkin *et al.* 1972) to allometric equation of biomass calculation (Basuki *et al.* 2009). The biomass equation was applied due to the importance of biomass re-growth rate in post-fire forest recovery (Minchella *et al.* 2009).

The potential growth of the selected trees was predicted for fifty-year projection. The selection of tree species was based on plant community data in MCNP by Rozak (2007). Recent publication showed that MCNP experienced at least four forest fire events in 2011, especially in long dry season (Syachera 2011). Therefore, this study was aimed to: predict the potential growth of selected trees before forest fire event (normal growth) and predict the best scenario for replantation based on tree to tree competition. The results of the study were expected to provide information related to post-fire forest recovery which is important for MCNP management.

MATERIALS AND METHODS

Study Site and Tree Community Data

Mount Ciremai National Park (MCNP) is located in West Java Province *ca.* 270 km eastward from Jakarta, the capital of Indonesia. Geographically, the MCNP is situated at 108º20' – 108º40' E and 6º40' – 6º58' S. The highest elevation reaches 3,078 m asl. making this mountain to be the highest mountain in West Java. Topographically, around 26.52% of the area has 0º - 8º slope. The rest of the area has slope more than 8º or equal to 73.48% of the area (Rozak & Gunawan 2015). The annual mean of precipitation is 2,000 mm and the annual temperature is 22 ºC (Kuningan Government 2011). The tree community data were collected in 2007 from Cigugur-Darma Resort located at the eastern part of the MCNP. Tree community data were collected from twenty quadrat plots (10 x 10 m) which were placed in parallel to mountain topography. Within each plot, all live trees taller than 1.3 m were identified and DBH greater than 10 cm were measured.

Five tree species with the highest Important Value Index (IVI) were chosen for model development and the name of those tree species were standardized through The Plant List website (www.theplantlist.org). The Important Value Index were generated from three parameters i.e. dominance index, abundance index and frequency index. We selected the DBH from *Engelhardtia spicata* Blume, *Ficus ribes* Reinw. ex Blume, *Trema orientalis* (L) Blume, *Saurauria pendula* Blume and *Lithocarpus pallidus* (Blume) Rehder in the study site, as the reference size of initial DBH before forest fire event (Table 1).

Table 1 The Important Value Index (IVI) of five dominated tree species in Mount Ciremai National Park (MCNP)

Species	IVI	DBH	H	D_{max}	H_{max}
Engelhardtia spicata Lechen ex Blume	32,482	35	22	60	25
Ficus ribes Reinw. ex Blume	28,469	15	8	30	15
Trema orientalis (L.) Blume	21,582	34	16	60	25
Saurauia pendula Blume	19,891	17	7	30	17
*Lithocarpus pallidus (*Blume) Rehder	18,041	12	9	35	21

Notes: IVI = Important Value Index; DBH = Diameter at Breast Height (cm); H = actual height of tree (m) measured by hagameter; D_{max} = maximum diameter (cm); H_{max} = maximum height (m). Value of D_{max} and H_{max} were derived from Hanum and van der Maesen (1997) as well as van der Vossen and Wessel (2000)

Modeling Process

A model to explore the growth trend of tree structure which suffered from forest fire in the tropical mountain forest was developed. The model follows a Gleasonian approach, integrating the biology and the fate of all individuals throughout their life cycle (Menaut *et al.* 1990). The model was based on two conditions of selected tree growth and estimated size of each tree. These conditions were:

1. normal growth which means that there was no forest fire. In this condition, the biomass of the tree at initial condition (year 0), at the next 25 years and at the next 50 years were counted;
2. plant growth after plantation which means that there was forest fire occurred; the selected trees were planted accordingly. Therefore, the model was based on the growth and estimated biomass of the replanted trees.

The time of each tree species reaching the same tree size at normal condition (without fire) was recorded. The modeling was focused on the components of replanted tree competition with its potential competitors i.e. grass (especially for the early stage of the growth) and other tree species. The model of tree growth was developed in "R software". The inputs of the model were:

1. An initial tree community structure from field data survey;
2. Allometric equation consisted of diameter, height and biomass;
3. Plant growth rate;
4. Parameter of competition, both tree to grass and tree to tree competitions.

Modeling the normal tree growth

The used approach in this study was developed by Menaut *et al.* (1990) who expressed potential tree growth as a function of growth rate (G) multiplied by volume (V, m^3) of tree:

$$\frac{dV}{dt} = G * V \quad (1)$$

Menaut *et al.* (1990) adopted volume equation from Botkin *et al.* (1972) which is:

$$V = D^2 * \frac{1 - D*H}{D_{max} * H_{max}} \quad (2)$$

where:

D = diameter at breast height in cm;
D_{max} = maximum diameter at breast height in cm;
H = height in m;
H_{max} = maximum height in m.

Parameters D and H were collected from field data. Parameters D_{max} and H_{max} were according to Hanum and van der Maesen (1997) as well as van der Vossen and Wessel (2000).

The results obtained based on equation 2 were negative and therefore, unrealistic. Subsequently, the original equation from Botkin *et al.* (1972) was applied as in Equation 3.

$$V = D^2 * \left(1 - \frac{D*H}{D_{max} * H_{max}}\right) \quad (3)$$

Combining equations (1) and (3) to become equation (4):

$$\frac{dV}{dt} = G * D^2 * \left(1 - \frac{D*H}{D_{max} * H_{max}}\right) \quad (4)$$

The following equation was developed using equation (1) and (3) to combine normal growth rate of tree community and to take into account the tree-to-tree competition (C_{tt}):

$$V[t+1] = V[t] + G * D^2 * \left(1 - \frac{D*H}{D_{max} * H_{max}}\right) * C_{tt} \quad (5)$$

Basuki *et al.* (2009) had developed more accurate equations to predict tree biomass (B, kg/tree) using allometric model (with r^2 = 0.963) of the tree species found in mixed tropical forest based on diameter at breast height (DBH). The equation is expressed by:

$$\ln(B) = c + \alpha * \ln(DBH) \quad (6)$$

which means:

$$B = e^c * (DBH)^{\alpha} \quad (7)$$

where:

c = the intercept (= -1.201)
α = the slope coefficient (= 2.196) of Basuki *et al.* (2009) equations.

Plant growth is considered as the changing of biomass over time (replacing the volume equation (5) to biomass equation (7)). Therefore, formula to measure the next year biomass is:

$$B[t+1] = B[t] + G * e^{-1.201} * (DBH)^{2.196} * C_{tt} \quad (8)$$

Modeling tree growth after replantation

Forest fire caused all tree community perished in the study area and the replanting was done using selected tree species which is important for the area. The importance of these tree species was represented by the high important value indices shown for these tree species.

After forest fire, in the succession process of the community, there were interactions and competitions from the pioneer species, such as competition within pioneer species to get light, nutrition, etc. According to Menaut *et al.* (1990), the competition component encompassed two kinds of competitive interactions i.e. tree-to-grass competition (C_{tg}) and tree-to-tree competition (C_{tt}). Based on Menaut *et al.* (1990), the C_{tg} value used was 0.99 for a tree reaching 2 m high and C_{tt} value used were 0.3, 0.5 and 0.7.

The change of biomass from one year to the next year based on its potential growth (equations 7 & 8) limited by competitions (C_{tt} and C_{tg}) would be:

$$\text{Bnew}[t+1] = \text{Bnew}[t] + G * e^{-1.201} * (\text{DBH})^{2.196} * C_{tg} * C_{tt} \cdots (9)$$

Data Interpretation

The projection of tree community in Mount Ciremai National Park (MCNP) for 50 years was examined. Tree growth was modeled to get the pre-fire condition, represented by the value of total aboveground biomass between the normal growth projection (equation 8) and after replantation (equation 9). One important parameter to determine the speed of tree species growth is the value of tree to tree competition. The results of low, medium and high C_{tt} were compared, i.e. $C_{tt} = 0.3$ (three other tree canopies overlapped with replanted tree canopies), $C_{tt} = 0.5$ (two other tree canopies overlapped with replanted tree canopies) and $C_{tt} = 0.7$ (only one tree canopy overlapped with replanted tree canopies). Overlapped tree canopies were used to characterize the tree-to-tree competition. Other important coefficient is C_{tg} which reflected the intensity of competition from grass (and other herbaceous layer) towards the newly planted trees.

RESULTS AND DISCUSSION

Plant growth model provided the projection of future size of the plant. In this study, the model was developed based on several parameters i.e. plant growth rate, competition and initial biometric of the measured tree. Furthermore, the model tried to predict the future state of tree community after being suffered from forest fire and had been replanted. The replantation was an effort to accelerate the succession of the tree community in order to shorten the recovery period. Previous publications mentioned that tropical forest regeneration to pre-fire condition took a long time (Viedma *et al.* 1997; Kinnaird & O'Brien 1998).

Four of five replanted species reached the pre-fire condition within 37 - 50 years (Fig. 1 to 5). Based on the comparison among three after-fire models and pre-fire model, the fastest model to reach the pre-fire condition/initial biomass (Table 2) was the model with lower value of tree-to-tree competition (C_{tt}). The value of C_{tt} was generated from the total number of possible overlapped canopies among neighboring trees (Menaut *et al.* 1990). In general, model having one overlapped tree canopy provided the fastest period to reach the pre-fire condition. Exceptionally, *S. pendula* did not reach the expected value within the 50 years period.

Table 2 Biomass projection from five tree species without fire event in Mount Ciremai National Park (MCNP)

Species	DBH	Initial Biomass (kg)	Biomass-25 (kg)	Biomass-50 (kg)
Engelhardtia spicata	35	742	1,060	1,538
Ficus ribes	15	115	186	304
Trema orientalis	34	696	949	1,311
Saurauia pendula	17	152	222	331
Lithocarpus pallidus	12	115	296	788

Notes: Biomass - 25 = expected biomass after 25 years
Biomass - 50 = expected biomass after 50 years

Biomass Growth after Replantation for Each Tree

Engelhardtia spicata Lechen ex Blume

Biomass growth model for single tree species *E. spicata* (Fig. 1) predicted that in the next 50 years the tree would reach 1,315 kg (with C_{tt} = 0.7), 345 kg (with C_{tt} = 0.5) and 87 kg (with C_{tt} = 0.3). The model also predicted that *E. spicata* would reach the same biomass as initial/pre-fire biomass after 44 years of planting when based on C_{tt} = 0.7. However, for C_{tt} = 0.5 and C_{tt} = 0.3, the model predicted that the biomass would not reach the initial/pre-fire biomass after 50 years of planting.

Ficus ribes Reinw. ex Blume

Based on the normal growth model, total biomass for *F. ribes* would be 304 kg in 50 years. Meanwhile, the initial/pre-fire total biomass based on this model was 115 kg (Table 2). Based on the results generated from the application of three different values of tree-to-tree competition on the model for plant recovery, it was predicted that the initial/pre-fire biomass would be achieved by C_{tt} = 0.7 in 37 years after replantation. This prediction was the fastest period compared to the C_{tt} = 0.5 and C_{tt} = 0.3, which provided prediction of above 50 years after planting to reach the initial/pre-fire biomass (Fig. 2).

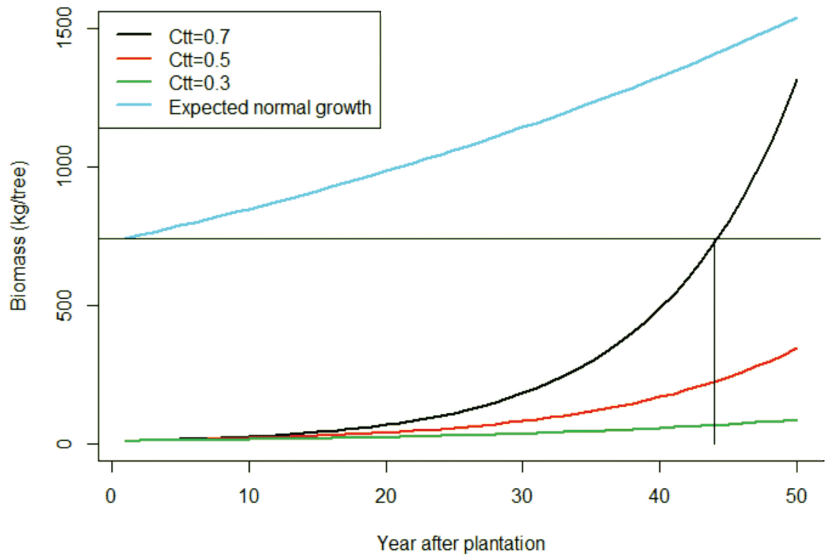

Figure 1 Biomass growth projection for *Engelhardtia spicata*

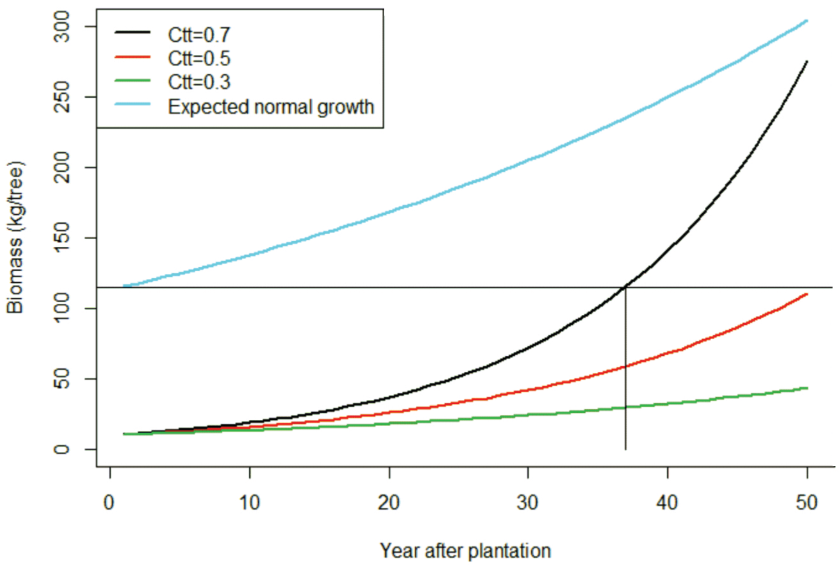

Figure 2 Biomass growth projection for *Ficus ribes*

Trema orientalis (L.) Blume

Based on the normal growth model, the initial/pre-fire biomass for *T. orientalis* was 696 kg. In 50 years projection, the total biomass would reach 1,311 kg (Table 2). Subsequently, C_{tt} = 0.7 was predicted to reach the initial/pre-fire condition within 50 years after planting (Fig. 3). Meanwhile, the C_{tt} = 0.5 and C_{tt} = 0.3 were predicted to provide lower biomass at all projection periods.

Saurauia pendula Blume

The initial biomass of *S. pendula* predicted by the normal growth model was 152 kg. Within 50 years after planting, the total biomass of *S. pendula* was predicted to reach 331 kg (Table 2). However, the given value within 50 years period from the post-fire model did not reach the initial biomass value obtained from the normal growth model. Moreover, all results of the post-fire model considering three different values of tree-to-tree competition were lower than the results from the normal growth model. For instance, in the next 50 years, tree biomass would be 145 kg (for C_{tt} = 0.7), 69 kg (for C_{tt} = 0.5) and 33 kg (for C_{tt} = 0.3) (Fig. 4).

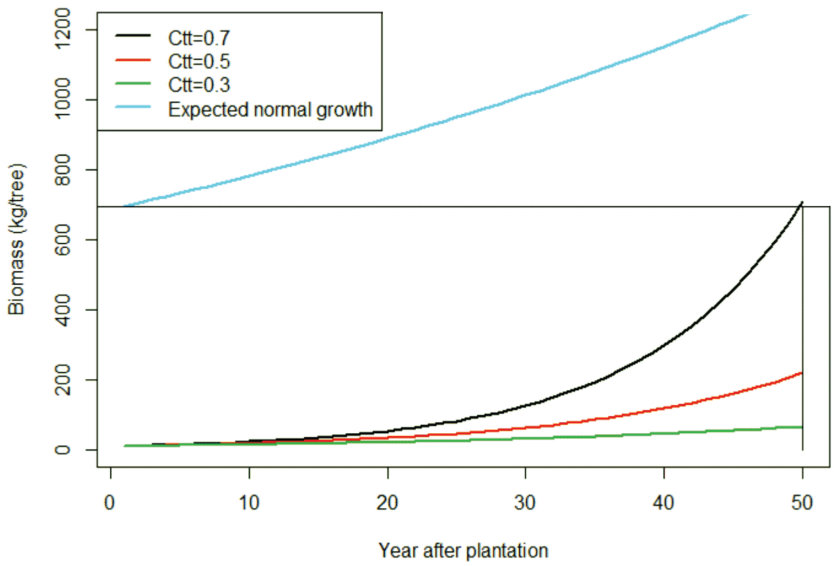

Figure 3 Biomass growth projection for *Trema orientalis*

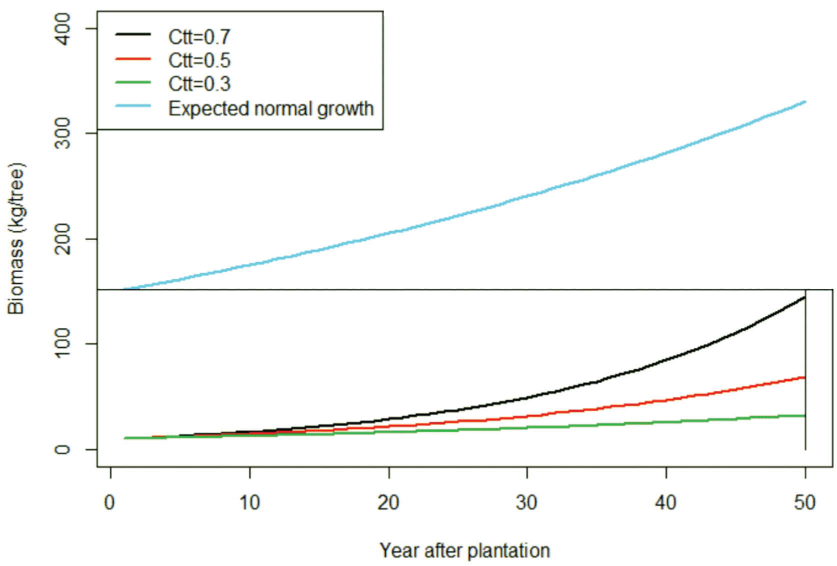

Figure 4 Biomass growth projection for *Saurauia pendula*

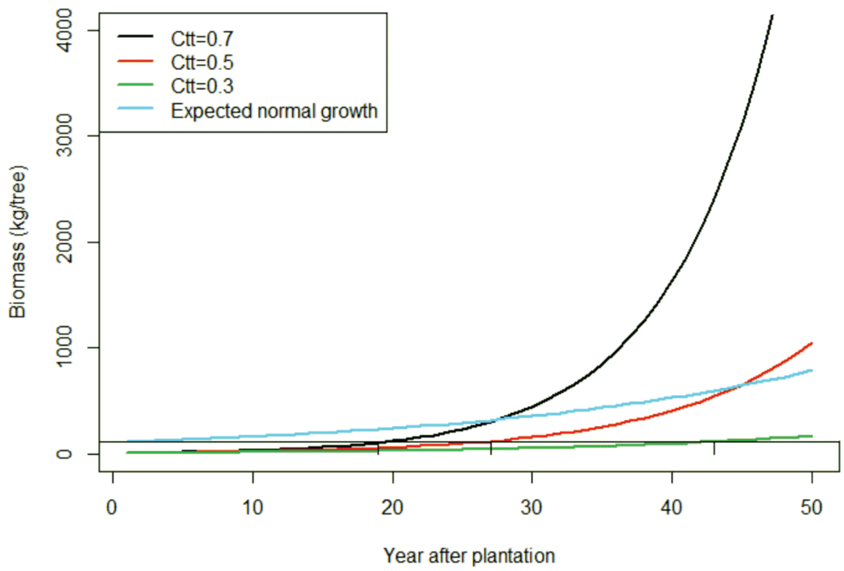

Figure 5 Biomass growth projection for *Lithocarpus pallidus*

Lithocarpus pallidus (Blume) Rehder

According to the pre-fire model, the initial biomass of *L. pallidus* was 115 kg and total biomass for 50 years after planting was predicted to be 788 kg (Table 2). Interesting results were shown on *L. pallidus* which had three possible values of tree-to-tree competition within 50 years after replanting. For $C_{tt} = 0.7$, the total initial/pre-fire biomass was predicted to be reached in 19 years after replanting. For $C_{tt} = 0.5$, the total initial/pre-fire biomass was predicted to be reached in 27 years after replanting, while $C_{tt} = 0.3$ was predicted to reach the total initial/pre-fire biomass in 43 years after replanting (Fig. 5). Consequently, the number of neighboring trees can be different to get expected plant growth within certain period. For instance, *L. pallidus* can grow with its canopy overlapped with the canopies of two other trees.

Factor Controlling Tree Growth

Other contributing factor to overall results was the initial biometric of tree species i.e. Diameter at Breast Height (DBH) and growth rate. The application of intensive silvicultural treatments is required to increase tree growth rate (Peña-Carlos *et al.* 2008). Among applicable silvicultural treatments to increase tree growth rate are: 1. reducing the amount of vegetations competing with tree seedlings (minimizing C_{tt} and C_{tg}); 2. early-fertilizing; 3. thinning; and 4. pruning (Gonzales-Ochoa & de las Heras 2002; Gonzales-Ochoa *et al.* 2004; Zald *et al.* 2008).

Model Improvement Consideration

Based on the results obtained from the developed models, it is important to redevelop the model because at some point (for example $C_{tt} = 0.7$, *Lithocarpus pallidus*, between year 30 - 50, Fig. 5) the biomass growth seemed to be unrealistic compared to the expected normal growth. The possibility is to develop allometric equation using logistic model. The tree-to-tree competition value should also be remeasured to include site specific factor, because the Menaut's data only included the savannah ecosystem.

CONCLUSIONS

The models developed in this study predicted normal and after-replantated tree growth. In general, this study provided further information regarding tree growth after replantation in tropical montane forests.

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