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# Development of an Individual Tree Growth Model for Natural Teak (*Tectona grandis* Linn.)

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# သဘာဝကျွန်းအတွက် သစ်ပင်တစ်ပင်ချင်း ကြီးထွားမှုပုံစံဖော်ထုတ်ခြင်း

## စာတမ်းအကျဉ်းချုပ်

ကျွန်းသစ်သည် ကမ္ဘာပေါ်တွင် တန်ဘိုးအရှိဆုံး သစ်မျိုးတစ်မျိုးဖြစ်သော်လည်း မြန်မာနိုင်ငံအပါအဝင် အာရှတိုက်ရှိ နိုင်ငံ (၄)နိုင်ငံတွင်သာ သဘာဝအလျောက် ပေါက်ရောက်ပါသည်။ ဤစာတမ်းတွင် မြန်မာနိုင်ငံရှိ သဘာဝကျွန်းအတွက် သစ်ပင်တစ်ပင်ချင်း ကြီးထွားမှုပုံစံကို ဖော်ထုတ်လေ့လာတင်ပြထားပါသည်။ ဤလေ့လာမှုအတွက် ပဲခူးရိုးမရှိ သဘာဝကျွန်းတောများအတွင်း တည်ထောင်ထားသည့် အမြဲတမ်း နမူနာကွက်များမှ စုဆောင်းရရှိသည့် သတင်းအချက်အလက်များကို အသုံးပြုထားပါသည်။ ဖော်ထုတ်တင်ပြထားသည့် ကြီးထွားမှုပုံစံသည် အယူအဆနှင့် တည်ဆောက်ပုံ ရိုးစင်းသော်လည်း၊ သဘာဝတောများရှိ ကျွန်းတစ်ပင်ချင်း၏ ကြီးထွားမှုကို တိကျမှုမြင့်မားစွာဖြင့် ခန့်မှန်းနိုင်မည်ဖြစ်ပါသည်။

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# Development of an individual Tree Growth Model for Natural Teak ( *Tectona grandis* Linn.)

## Abstract

**Teak is one of the most valuable species in the world, but indigenous only to four Asian countries including Myanmar. An individual tree diameter growth model was developed for natural teak in Myanmar. The data used in this study were collected in permanent inventory plots located in the Bago mountain ranges. The concept and structure of the model is believed to be simple, but it can be used to estimate the growth of individual Teak trees in the natural forest with a high accuracy.**

# Contents

## 1. Introduction

**Teak is one of the most valuable timber species in the world. The species is indigenous only to four countries, including Myanmar (Kaosa-ard, 1981;Gyi and Tint, 1998). However, dense natural forests with large and good quality Teak have degraded and shrunk so rapidly that at present they are confined only to Myanmar and to some parts of India. Natural Teak has now become an endangered species (Gyi and Tint, 1998). Today, in Myanmar the remnants of the natural Teak forests cover approximately 16.5 million ha (Gyi and Tint, 1998; Forest Department, 2000).**

**Growth studies in naturally grown Teak in Myanmar were conducted by Brandis (1896), Tint and Schneider (1980); Vanclay (1992a, 1992b) and Nyi Nyi Kyaw (2003). Tint and Schneider (1980) and Nyi Nyi Kyaw (2003) developed individual tree growth models. Teak bearing forests, like other tropical forests, are characterized by multiple species, indeterminate tree ages, and a wide range of growth habits and stem sizes. Although Teak shows annual growth rings, this cannot be used in a growth model because it would be impractical to establish an age for each tree in the field. Furthermore, most of the other species have no distinct annual rings. Thus, modeling concepts based on age and site index are not applicable in these forests. The use of age as an independent variable in a growth model for Teak will not be consistent with the requirements of other species. It will therefore not be possible to use an age-based model in a stand projection system supporting the size-limit-based forest management practice and inventory data structure of Myanmar. In this context, an age-independent individual tree model is considered to be the only suitable option for modelling growth under the specific conditions in Myanmar, featuring a large variation in species composition and stand structure. Accordingly, the study was conducted with the following objectives:**

**(1) To develop an age-independent, distance-independent, individual tree growth model for natural Teak, based on data from a continuous forest inventory system of Myanmar**

**(2) To explore an appropriate and consistent modelling strategy to develop a tree-list model for Teak-bearing forests of the country**

## 2. Materials and Methods

### 2.1. Data

**The present growth study uses the re-measurement data of permanent sample plots (PSPs) installed on the Bago mountain ranges, which is situated in the central region of the country and which is renowned for its Teak forests. These PSPs were established systematically in a grid of approximately 6 x 6 km over the forest areas under the National Forest Inventory Project. The individual plots consist of an L-shaped strip with a horizontal dimension of 30 m by 175 m in both west-easterly and north-southerly directions. Each plot was subdivided into seven record units (RU), each comprising 0.15 ha (30 m x 50 m except RU 4 which was L shaped). The total area of a PSP covers 1.05 ha. All trees with a breast height diameter of at least 20 cm were enumerated on the whole plot and these trees were labeled with aluminum tags and the position of them was marked for future measurement. A more detailed description may be found in Forest Department (1985).**

**The permanent plots were marked so that they could be relocated for remeasurement, but kept inconspicuous in order to eliminate research plot bias and ensure that forest inventory was representative of the growing conditions and forest management throughout the country. The plots were established in 1982 and remeasured in 1987 and 1992. Field crews had no access to previous records in the field at the second measurement, so that some plots could unfortunately not be recognized properly. Therefore, these plots were reinstalled. The present study covers 46 PSPs, some of which have two measurement records and some have three. Then pairs of remeasurements, 5-year growth intervals, were selected from the database.**

**Exploratory data analysis found that some diameter increments had negative values and some comparatively high positive values. The measurement data with negative increments have not been used in calculating increment, but only in calculating stand basal areas. Comparatively high positive values of increment were classified as outliers. Outliers on increment data were identified by using a modified form of a boxplot suggested by NIST/SEMATECH (2004). The increment values outside the upper outer-fence which was defined by the upper quartile plus 3 times the interquartile range were labeled as extreme outliers and these data were omitted in the analysis. A data file was then created to use as an input to the statistical package STATISTICA for further analysis and contained 297 observations of diameter increment derived from 272 individual trees. The data file also holds records of the diameter at breast height (dbh*)* and stand variables such as stand basal area. Two indices of competition, the BAL index (Basal-Area-of-Larger trees) and the GD index (Basal area-Diameter) are also available for each tree.**

### 2.2. Model Development

**A preliminary analysis indicated that there was no imaginable relationship between the breast height diameter (dbh) at the beginning of the growth period and the annual diameter increment, which appears to be the case in tropical forests (e.g. Alder, 1995; Gourlet-Fleury and Houllier, 2000)(see Figure 1). After a thorough review of various modeling approaches, the potential * modifier concept was adopted as the basic structure for the individual-tree diameter growth model. The model has two components: a potential growth function and a modifier function. The potential function represents an upper bound for the growth rate that may be attained by a tree of a given species based on some inherent characteristics. The potential growth represents the maximum growth attainable for a given tree with certain attributes. The modifier component reduces the potential growth by taking into account various environmental conditions such as, inter-tree competition. As a result, the modifier function represents deviations from the potential due to limiting factors. The modifier thus gives greater accuracy and precision to the growth model by allowing the predicted values to**

**decrease from those given by the potential model. The expected growth is estimated as follows:**

$$\text{Expected growth} = (\text{potential growth}) * (\text{modifier function}) \qquad (1)$$

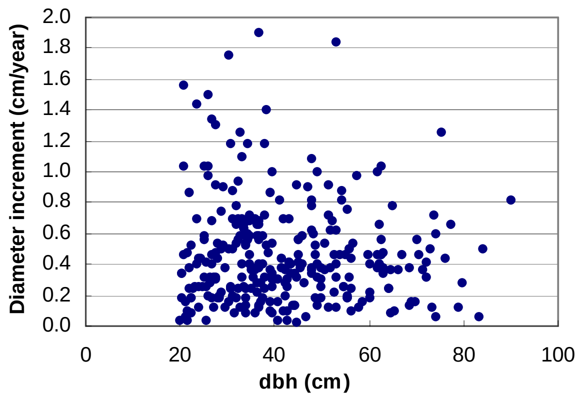



**Figure 1 The relationship between the breast height diameter (dbh) at the beginning of the growth period and the annual diameter increment**

**The potential * modifier function for Teak was developed in two stages. First, the potential growth of a tree growing free from competition was estimated. Secondly, an adjustment was applied to reduce the potential growth to that which was actually observed. Different strategies were reviewed and tested for developing the potential function. Finally, the Potential Relative Increment (PRI) approach suggested by Bragg (2001, 2003) was adopted. The PRI approach balances the use of empirical data to predict the growth based on an ecologically robust assumption. The calculations are relatively simple and the model is independent of age. The method can be combined with appropriate environmental modifiers into a comprehensive diameter growth model capable of predicting diameter growth under a variety of scenarios. The Actual Relative Increment (ARI) was then calculated for all individual trees using equation (2) which represents the proportional change in diameter (Bragg, 2001).**

$$ARI = \frac{dbh_2 - dbh_1}{dbh_1} * p \qquad \textbf{(2)}$$

**where,**

**$ARI$ = the Actual Relative Increment (dimensionless)**
**$dbh_1$ = the diameter at breast height at previous inventory (cm)**
**$dbh_2$ = the diameter at breast height at current inventory (cm)**
**$p$ = the measurement interval standardization factor**

**The ARI values were classified by 2 cm initial dbh-classes (Figure 2) and the highest values for each class were selected. It was assumed that the highest ARI values represented trees growing at near-optimal conditions. The following power function was then fitted to the maximum ARI data for obtaining PRI.**

$$PRI = b_1 * (dbh_{\max})^{b_2} * b_3^{(dbh_{\max})} \qquad \textbf{(3)}$$

**where,**

**$PRI$ = the Potential Relative Increment (dimensionless)**
**$dbh_{max}$ = the dbh for the trees with maximum ARI within each 2 cm diameter class (cm)**
**$b_1$, $b_2$, $b_3$ = species-specific regression coefficients**

**The parameters of equation (3) were estimated with the STATISTICA software using a non-linear ordinary least square estimation procedure (see Figure 2). The PRI represents the maximum possible growth rate for naturally grown Teak for a given dbh.**

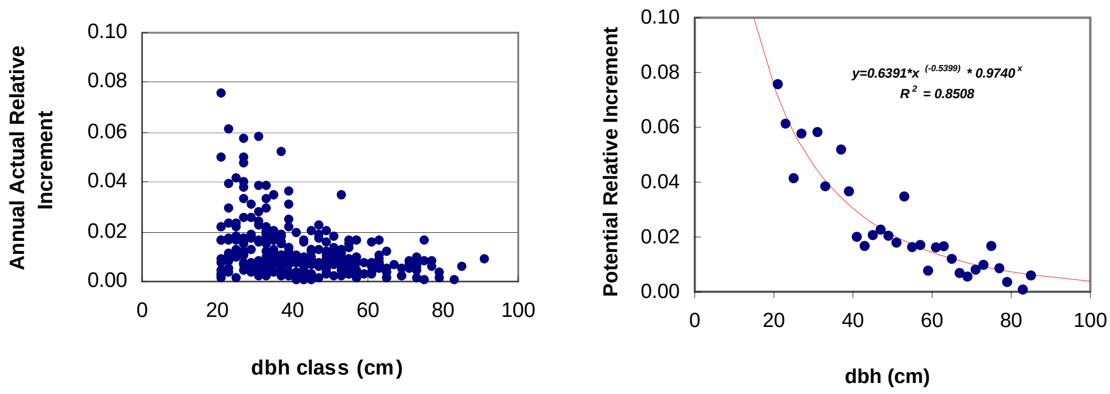



**Figure 2. Observed Annual Actual Relative Increments by diameter (left) and fitted curve for the Potential Relative Increment of natural Teak trees (right).**

**The estimated parameters and the coefficient of determination ($R^2$) are presented in table 1.Once the model parameters were obtained, the predicted maximum diameter increment ($ID_{max}$) was calculated by equation (4). The maximum growth for different dbh values of Teak trees is presented in figure 3.**

Table 1 Parameter estimates for PRI equation of Teak

| Scientific Name | $b_1$ | $b_2$ | $b_3$ | $R^2$ |
|---|---|---|---|---|
| ***Tectona grandis*** | **0.6391** | **-0.5399** | **0.9470** | **0.8508** |

$$ID_{max} = dbh * PRI \qquad (4)$$

**where,**

- $ID_{max}$ **= the predicted maximum diameter increment (cm/year)**
- ***dbh*** **= the diameter at breast height(cm)**
- ***PRI*** **= the potential relative increment (dimensionless)**

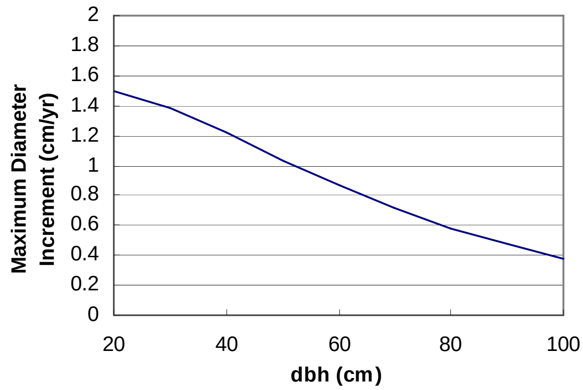



**Figure 3 Maximum diameter increment in relation to initial dbh**

**There are numerous environmental factors that can influence the growth of a tree. However, only a small number of variables is actually available in practice. An obvious choice is a suitable competition index that can be used in the modifier function for adjusting the potential growth of a tree (c.f. Holdaway, 1984). A competition index is a mathematical formulation describing competition from adjacent trees that could be affecting the growth of any considered tree (Daniels, 1976; Schreuder and Williams, 1995: Woodall et al., 2003). In the present study, two distance-independent competition indices are used: the basal-area-of-larger-tree (BAL) index and the basal area-diameter (GD) index (Gadow, 2003). The BAL index is a linear function of the stand basal area:**

$$BAL_{ij} = BA_i\ (1-p_j) \quad (5)$$

**where,**

| | |
|---|---|
| $BAL_{ij}$ | **= the sum of the basal areas of all trees larger than the subject tree** |
| $BA_i$ | **= the basal area of the stand i** |
| $p_j$ | **= the basal area percentile of the subject tree** |

**The basal area-diameter (GD) index simultaneously takes into account stand density as a relative stand basal area and relative tree size**

$$GD_i = \left( \frac{G_J}{G_{\max}} \right)^{\left(d_i / \overline{d_j}\right)} \quad \textbf{(6)}$$

**where,**

**$GD_i$ = basal area-diameter index for tree $i$ (dimensionless)**
**$G_j$ = the basal area of the stand $j$ ($m^2$)**
**$G_{max}$ = observed maximum stand basal area ($m^2$)**
**$d_i$ = the diameter of tree $i$ (cm)**
**$\tilde{d}j$ = the average diameter of the stand $j$ (cm)**

**Modifier values were obtained by dividing the observed increments by the associated maximum growths estimated using equation (4). Preliminary analyses showed a negative exponential relationship between these modifier values and the two competition indices. Finally, the following two modifier functions were developed assuming values between one and zero in order to proportionally reduce the potential growth to an expected growth depending on the intensity of the competition.**

$$Modifier = e^{-b \,*\, BAL} \quad \textbf{(7)}$$

$$Modifier = e^{-b \,*\, GD} \quad \textbf{(8)}$$

**where,**

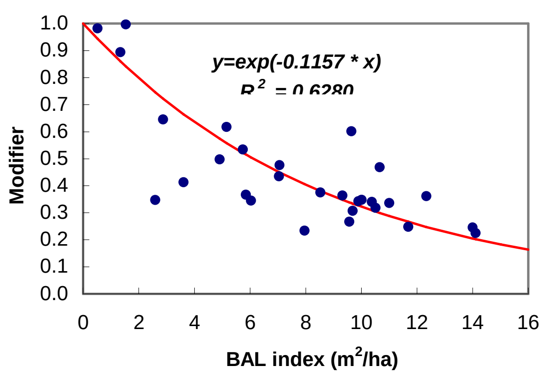
**$BAL$ = BAL index ($m^2$/ha)**
**$GD$ = GD index (dimensionless)**
**$b$ = parameter to be estimated**

**The modifier values and the associated BAL and GD values were classified into classes of 2 cm dbh. Then the mean modifier values for each class were used as the dependent variable for both equations while the mean values of BAL and GD were used as independent variables in the respective equations. The parameters were estimated using the Levenberg-Marquardt algorithm in**

**STATISTICA. For each model, the mean residual (MRES) and coefficient of determination (*$R^2$*) were calculated to examine the differences in terms of bias and precision. A weighted regression analysis was tried with a hope to improve the fit and reduce bias in the models. However, the added improvement was only marginal. The parameter estimates and associated statistics are given in table 2. Figures 4 and 5 provide a visual impression of the performances of the BAL index and the GD index equations.**

Table 2 Parameter estimates and associated statistics for different modifier functions

| Function | b | Asymptotic standard deviation | Mean residuals | $R^2$ |
|---|---|---|---|---|
| **BAL index** | **-0.1157** | **0.0083** | **-0.0024** | **0.6280** |
| **GD index** | **-1.8512** | **0.1460** | **0.0106** | **0.4693** |



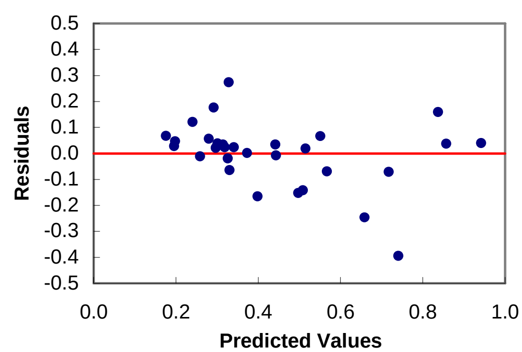



**Figure 4 Modifier function for BAL index (Left) and predicted values versus residuals (Right)**

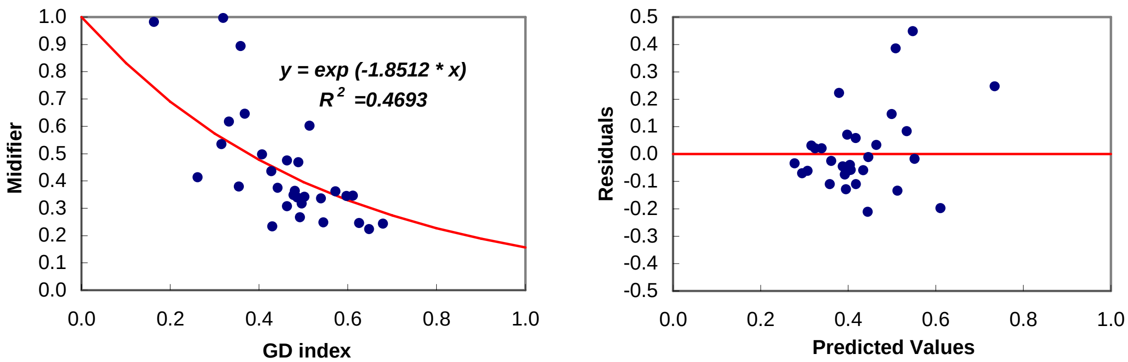



**Figure 5 Modifier function for GD index (Left) and predicted values versus residuals (Right)**

**Finally, actual growth of the individual Teak tree can be expressed as a product of potential function and modifier function. Annual growth response at given dbh to different intensity of competition are demonstrated in figure 6.**

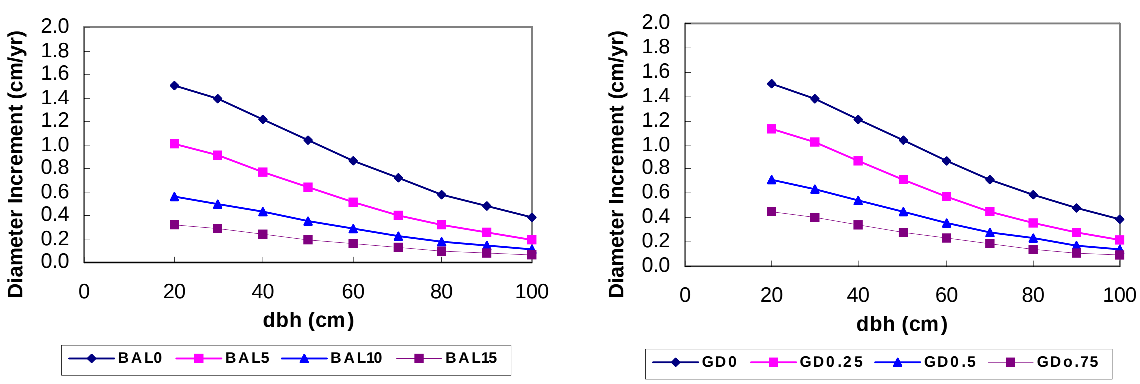



**Figure 6 Annual diameter growth response to different competition intensity at different dbh**

## 3. Results and Discussion

**The concept and structure of the diameter growth model for Teak is rather simple. However, defining a best subset of growth data for developing the potential function was a partially subjective process. Since the goal was to fit an idealized response curve to a biologically intuitive relationship between tree size and growth potential, some bias was unavoidable. The potential relative**

**increment responses of naturally grown Teak formed a declining monotonic curve, reaching a maximum PRI value at the smallest diameters. The rapid decline in PRI value with diameter of Teak indicates that the relative growth rate drops appreciably with increasing tree size. This reflects the fact that large trees experience disproportionately lower rates of diameter change than smaller and thus younger trees. An important feature of the PRI method is the fact that while PRI approaches zero, it never actually reaches this asymptote. However, it is advisable that projecting the increments over the range of the data is strictly an artifact. When the modifier function was incorporated into the model, both indices- BAL and GD could sensibly explain the growth reductions from the potentials due to competition. The BAL index function can explain the observed growth marginally more effectively than the GD index. However, the BAL index model with the mean residual value of –0.0024 will generally overestimate, whereas the GD index model with the mean residuals value of 0.0106 underestimates the modifier values. The magnitude of the bias in the BAL index is smaller.**

**Although some of the variability in the annual diameter growth of the individual Teak trees can be explained by the stand and tree variables contained in this model, the remaining variability is due to other factors such as the spatial distribution of radiation, and micro site conditions. Model predictions in a complex biological system like a forest will never be perfect, because the environmental conditions within which that system resides continue to change and cannot be predicted with certainty. The ultimate aim of the modeling presented in this paper is not to imitate the system, but to predict the system performance with a reasonable accuracy. It is concerned with how well the model predicts change relative to alternative models. The model presented in this paper is based on some inherent assumptions: (1) the growth of an individual tree cannot exceed its potential growth- it equals the potential growth only when the competition indices assume the value zero; (2) as competition increases, individual-tree diameter growth rate for a given dbh asymptotically approaches zero. The modeling approach presented here offers a good potential for use in**

**similar conditions. A crucial aspect in future modeling endeavors is the improvement of the data base.**

**Teak is one of the most valuable timber species in the world, but is indigenous only to four Asian countries including Myanmar. Teak therefore plays a key role in preserving ecological integrity and ensuring a sustainable national economy of Myanmar. Sustainable management of the naturally grown Teak is essential for sustainable development of the country. Individual growth models are crucial for updating forest inventory data and regulating yields for sustainable management of timber resources. Even though the present model was developed exclusively for Teak, it could contribute to a large extent for the Teak-based forest management system which is currently applied in the country. At the present time, this model is the only regionally calibrated, individual tree, age-independent, distance-independent diameter growth model for naturally grown Teak for typical Teak bearing forests of Myanmar. Teak bearing forests cover vast areas and usually consist of hundreds of different tree species. A concerted effort should be made to develop a tree list model for whole forest using a consistent modeling strategy, like the one presented in this paper, for improving the accuracy of growth estimation for better yield regulation in these forests.**

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