Government of the Union of Myanmar

Ministry of Forestry

Forest Department

Yield Tables for Plantations of *Xylia xylocarpa* (Pyinkado) in Myanmar

Thant Shin

Range Officer

Forest Research Institute

May 2006

Contents

ပျဉ်းကတိုးစိုက်ခင်းများ၏ ကြီးထွားမှုနှင့်အထွက်နှုန်း ပုံသေဇယားများ ခန့်မှန်းတွက်ချက်ခြင်း

သန့်ရှင်း (M.Sc, Forest.Trop, Technical University Dresden)
တောအုပ်ကြီး
သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်းချုပ်

ပျဉ်းကတိုးသည် မြန်မာနိုင်ငံတွင်အသုံးအများဆုံး သစ်မျိုး တစ်မျိုး ဖြစ်ပါသည်။ ကမ္ဘာ့ဈေးကွက်တွင် Myanmar iron wood ဟုထင်ရှားကျော်ကြားသောသစ်မျိုး ဖြစ်ပါသည်။ စီးပွားရေးအရ အရေးပါသော သစ်မျိုးဖြစ်သော်လည်း ပျဉ်းကတိုးစိုက်ခင်းများ၏ ကြီးထွားမှု နှင့် အထွက်နှုန်းကို လေ့လာမှုအနည်းငယ်သာ ရှိခဲ့ပါသည်။ ဤလေ့လာမှုတွင် ယာယီစမ်းသပ်ကွက် ၆၅ခုမှ အချက်အလက်များကို အသုံးပြု၍ ပျဉ်းကတိုးစိုက်ခင်းများ၏ ကြီးထွားမှုကိုခန့်မှန်းတွက်ချက်ထားပါသည်။ ယခင်ကသတင်းအချက်အလက် မရရှိခဲ့ဘူးသော ကိစ္စရပ်များတွင်ယာယီစမ်းသပ်ကွက် များမှာ လျှင်မြန်သော အဖြေ တစ်ခု ရရှိနိုင်သော နည်းလမ်းတစ်ခု ဖြစ်ပါသည်။ သစ်တော ဖွံ့ဖြိုးမှုများကိုခန့်မှန်း တွက်ချက်ရာတွင် DYNAMOBEM ကွန်ပျူတာ ပရိုဂရမ်ကိုအသုံးပြု ခဲ့ပါသည်။၎င်း ကွန်ပျူတာပရိုဂရမ်ကို ဥရောပ သစ်မျိုးများ သာမက အာဖရိကနှင့် အာရှသစ်မျိုးများစွာ အတွက်ပါ အောင်မြင်စွာ စမ်းသပ်အသုံးပြုခဲ့ပြီးဖြစ်ပါသည်။ ဤလေ့လာမှု၏ ရလာဒ်အနေဖြင့် ပျဉ်းကတိုးစိုက်ခင်းများအတွက် အထွက်နှုန်းပုံသေဇယားများအား အတန်းအစား ၄မျိုး ခွဲ၍တင်ပြထားပါသည်။ Technical University , Dresden, Germany တွင် မဟာသိပ္ပံဘွဲ့ အတွက် ပြုစုသောကျမ်းကို အခြေခံပြီး ဤစာတမ်းကို ပြုစုတင်ပြရခြင်းဖြစ်ပါသည်။

Abstract

Pyinkado (*Xylia xylocarpa*) is one of the most demanding species for house and bridge construction and for railway sleepers in Myanmar. It is a popular species owing to its strength, durability and relatively abundance. It is also well known as Myanmar iron wood at the international market. In spite of the economic importance of Pyinkado, little knowledge exists about its growth and yield in the plantations. This study is to render a contribution to improve this situation. Data from 65 temporary sample plots were used for modelling the stand development of Pyinkado plantations. There are 44 plots from the Bamaw-Katha region and 21 plots from the Bago Yoma region. Temporary plots provide quick solution in a situation where nothing is known about forest development. Temporary plots are still being used today for constructing growth models in situation where permanent plot data are not available. The program DYNAMOBEM was used for the simulation of growth and thinning process. The model is based on the extrapolation of stand volume by growth multipliers. It has been examined successfully for various European as well as for African and Asian tree species. At first, the development of important yield parameters over age was analysed. As the results of this analysis, 4 site classes were identified based on mean height. Stand Volume, stand density, mean stand height at the age of 20 years were taken as initial condition. Based on these initial conditions, further stand development is simulated using program DYNAMOBEM. Different parameters were used for each site class. As a result, yield tables for Pyinkado plantations were obtained.

Yield Table for Plantations of *Xylia dolabriformis* (Pyinkado) in Myanmar

1. Introduction

Yield tables (and growth models) are important planning aids in forestry. Yield tables contain detailed information about the development of important growth parameters of pure stands in relation to age. Growth models assist forest researchers and managers in many ways. Some important uses include the ability to predict future yields and to explore silvicultural options. Model provides an efficient way to prepare resource forecasts, but the more important role may be their ability to explore management options and silvicultural alternatives (VANCLAY, 1994).

Growth models are of limited use on their own, and require ancillary data to provide useful information. With suitable inventory and other resource data, growth models provide reliable ways to examine silvicultural and harvesting options to determine the sustainable timber yield, and the impacts of forest management and harvesting on other values of forests.

Forest managers may require information on the present status of the resource, forecast of the nature and timing of future harvests, and estimates of maximum sustainable harvests. This information can be compiled from three sources.

- area estimate of the existing forest,
- stand level inventory of present forest and
- growth and harvesting models based on dynamic inventory

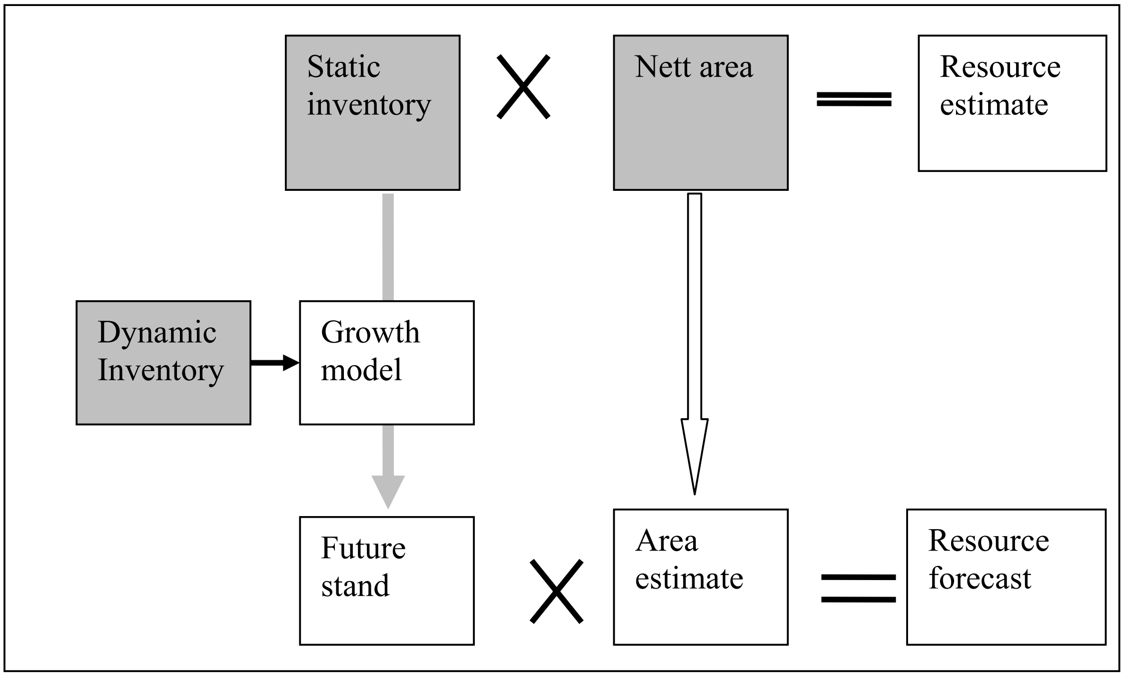

Figure (1) the role of growth models and complementary data in providing forest management information (VANCLAY, 1994)

There is a global concern over increasing rate of deforestation and forest degradation in tropics. According to the latest FAO studies, the estimated annual rate of tropical deforestation was 1. 55 million ha during 1981-90. To certain extent, deforestation is counter balanced by creation of plantations (FAO, 1990).

Teak (*Tectona grandis*) and Pyinkado (*Xylia xylocarpa*) used to be major species both for export and domestic use. In Myanmar, large areas of Pyinkado plantations are being established since 1980. Up to 2003, the total area of 789031 ha forest plantations were established by Forest Department of which 57004 ha (7.22%) were Pyinkado (FOREST DEPARTMENT, 2003).

Although teak is an excellent timber, it is a bad forester, it does not improve the soil and its leaves do not readily form the humus. (KEH et.al, 1994)

Pyinkado is a natural associate of teak and is the favoured and demanding construction timber in Myanmar due to its strength, durability and relative abundance.

1.1. Problem Statement

Pyinkado is one of the most important timber species in Myanmar. Because of over exploitation of natural forests, natural forest resources have declined rapidly. Plantations of Pyinkado have become an alternative option for domestic use and also for export. Unfortunately, there is a lack of systematic studies on growth and yield of Pyinkado plantations.

In Myanmar, forest plantations fall into four categories namely commercial, industrial, watershed and village supply plantations. The felling age or rotation of commercial plantations is 60 years. Thinning is conducted four times during rotation age, namely first mechanical thinning (1M), second mechanical thinning (2M), first silvicultural thinning and second silvicultural thinning. Yield tables for plantations of *Xylia dolarformis* have not yet been constructed.

Due to the absence of yield tables, the expected yield for Pyinkado plantations in different thinning operations and final felling cannot be provided.

1.2. Objectives

The purpose of this study is to examine the productivity of *Xylia xylocarpa* over ages and different site conditions.

The specific objectives of the study are –

- To determine basic growth and yield parameters of *Xylia xylocarpa* plantations based on measurements of selected stands which represent different age classes and site conditions.
- To describe the development of important growth and yield parameters of *Xylia xylocarpa* plantations with suitable models and to derive yield tables based on these models.

2. General characteristics of Pyinkado

Pyinkado is one of the most important timbers in Myanmar. It is a very large deciduous tree. Leaf is bipinate with one pair of pinnae, each pinna with two to six pairs of leaflets. The bark of Pyinkado is thin, yellowish or radish grey, fairly smooth exfoliating in irregular rounded plates. The heartwood of Pyinkado is reddish brown, very hard, extensively used for house and bridge construction and for railway sleepers. Under favourable conditions, the tree reaches a height of 36,58m and a girth of 3,66m or more, but on poor ground it is stunted (TROUP, 1921).

2.1. Silvicultural Characteristics

Pyinkado is a shade-tolerant, particularly in young stage, although in this respect, it cannot compete with more shade-bearing evergreens. It is sensitive to drought in youth. For best development, it requires a moist, deep, well-drained soil. It is also sometime found on dry shallow soils. However, it cannot reach large dimensions. The bark is thin and is readily injured by fire. Therefore, large wounds are frequently found at the base of the tree. The coppicing power is moderate.

2.2 Establishment of Pyinkado Plantations in Myanmar

Pyinkado plantations are established by Taungya System. Taungya plantations were started in Myanmar in 1869 (KERMODE, 1964). Taungya literally means hill cultivation.

According to KYAW (1995) and MYINT et al. (1999), the establishment of a of Pyinkado plantation by the Taungya system involves the following stages.

(a) Site selection
(b) Plot allocation
(c) Site preparation
(d) Staking
(e) Seed collection
(f) Field planting / direct sowing

(g) Patching

(h) Maintenance and protection

(i) Periodical thinning, and

(j) Final harvesting

- **Spacing**

Different spacings are used in the establishment of commercial plantations in Myanmar. Initial spacing of 2.6m x 2.6m has been the common spacing in commercial plantation after 1980 (MYINT et al., 1999). It is also observed that initial spacing of 1.8m x 1.8m was also common before 1980.

Spacing and rotation determine the timing, intensity and frequency of thinning. A wider spacing can provide an opportunity for longer cultivation of food crops to farmers and low cost planting (MYINT et al., 1999).

- **Planting Methods**

Methods of planting include direct seed sowing, transplanting of seedlings and stump planting. The transplanting of seedlings gives better results than direct seed sowing. However, the former requires more favourable conditions at the time of planting and intensive care and management in later stages (MYINT et al., 1999).

In the Taungya method of Pyinkado plantation establishment, direct sowing method is used in field planting. Cleaned and selected Pyinkado seeds are provided to the Taungya farmers after staking. The beginning of the raining season, first week of June, is the suitable time to sow the Pyinkado seeds. Early sowing is risky as a few showers may cause the seed to germinate and the following period of intense heat may cause the seedlings to wither. Planting should occur as soon as the soil is moist enough when annual rains occur regularly (KYAW, 1995).

- **Thinning**

Thinning operations in young Pyinkado plantations are carried out to remove trees of poor form and vigour which are competing with the trees to be retained for light, available soil nutrient and moisture. The first thinning should be done when the average height of the tree is 5 to 7.5 metres and the second when the average height is 9 to 11 metres. Normally, thinning commences at the age of 7 to 8 years. The first two thinning should be mechanical or modified mechanical where full stocking has not been obtained, removing fifty percent of the trees each time.

The third thinning (silvicultural) is governed by average diametre of the crops. Low or ordinary thinning is the common silvicultural thinning in Myanmar. Basically, geographical range, site, weather condition and planting intensity influence the method, grade and timing of thinning. Heavier grade (D-grade) becomes a standard practice in Myanmar, and in some instances even heavier extreme grade (E. grade) is applied as the final thinning (MYINT et al, 1999).

- **Final felling**

Final felling is done by clear-felling. It is carried out at the age of rotation which is fixed at 60 years for all commercial plantation in Myanmar. The total yield includes final yields obtained from harvesting at the rotation age and intermediate yields obtained during different thinning operations.

3. Literature Review

3.1. Growth and Yield tables

Yield tables are summaries of expected yields tabulated by stand age, site index etc. Growth tables are a variation more suited to uneven-aged stands, and tabulate expected growth according to various stand characteristics (VANCLAY, 1994).

A yield table anticipated yields from an even-aged stand and is one of the oldest approaches to yield estimation. The concept was apparently first applied in the Chinese ``Lung Ch´uan codes´´ some 350 years ago (VUOKILA, 1965, cited in VANCLAY, 1994).

Modern yield tables often include not only yield, but also stand height, mean diameter, number of stems, stand basal area and current and mean annual volume increment. Normal yield tables provide estimates of expected yields tabulated by stand age and site index for ideal, fully stocked or normal forest stands. These were usually based on data derived from stem analyses and temporary plots, analysed using graphical techniques.

3.2. Growth and Yield Equations

It is important to understand the relationship between growth and yield. Growth refers to the increase in size of a population or an individual over a given period of time (e.g. growth in volume of a stand, in $m^3ha^{-1}yr^{-1}$). Yield refers to the final size of a population or individual at the end of a certain period (e.g. total volume produced by a stand, in m^3ha^{-1}) and usually includes any removal (e.g. thinning). A growth equation for even-aged stands predicts the growth of diameter, basal area or volume in units per annum, whilst a yield equation predicts the diameter, stand basal area or total volume production attained at a specified time (i.e. age). Thus, a growth function may indicate that, at age'‘t’, a stand is growing at (dy/dt) units per annum, whereas an equivalent yield function indicates that a stand at age‘t’ has produced ‘y’ units. The notation (dy/dt) simply means the change in ‘y’ observed during a very short period of ‘t’ so that if (t_2-t_1) spans a very short time, ▲t becomes very small, and

$$dy/dt = \blacktriangle y/\blacktriangle t = (y_2-y_1)/(t_2-t_1)$$

For growth and yield prediction models to be efficient, it needs to be flexible. Apart from being flexible, the growth function should be as simple as possible. It should also be able to predict both growth and yield either by integrating or by differentiating the yield function (SARAMÄKI, 1992).

BERTALANFFY (1968) hypothesized that a growth of an organism could be represented as the difference between the synthesis and degradation of its building materials (VANCLAY, 1994). He assumed that the processes of anabolism and catabolism could be expressed as allometric functions of mass (Y) and thus growth (dy/dt) would be approximated as follows.

$$dy/dt = \beta_1 Y^{\alpha} - \beta_2 Y^{\gamma}$$

where,

Y= mass of organism

t = time

γ, β , α are constants.

The Bertalanffy equation is a number of a family of asymptotic, nonlinear growth equations including the:

1. Monomolecular Growth equation where $\alpha = 0$

$Y= Y_{max} (1- e^{-\gamma t})$ $dY/dt = \gamma (Y_{max} - Y)$

2. Gompertz Growth equation when $\alpha = 1$

$Y = Y_{max} (e^{-\beta e) -\gamma t}$ $dY/dt = \gamma Y \ln(Y_{max} - Y^{-1})$

3. Autocatalytic growth equation where $\alpha = 2$

$Y = Y_{max} (1+ \beta e^{-\gamma t})^{-1}$ $dY/dt = \gamma (Y_{max} - Y) A^{-1}$

4. Bertlanffy equation ($2/3 \leq \alpha \geq 1$)

$Y = Y_{max} (1-\beta e^{-\gamma t})$ $dY/dt = \beta Y^{\alpha} - \beta Y$

Where,

Y = the size of organism,

Y_{max} = asymptotic maximum size

t = time

γ, β , α are constants.

3.3. Types of Forest Models

Forest models represent average experience of how trees grow and of how forest structures are modified. The level of these models differs greatly. *Tree Models* deal with morphological details of branching, stem form and root growth. *Regional production models* and *stand growth models* produce aggregate information about the development of a population of trees with a given set of environmental conditions and given intermittent modifications of stand attributes through human interference and other disturbances. According to GADOW and HUT (1999), four types of growth models are identified.

- **Regional yield models**

Regional yield models are represented by highly aggregated yield-over-age equations. They are used in resource forecasting, specifically for predicting the development of a given age-class distribution in response to a series of periodic harvest levels.

- **Stand growth Model**

Stand growth models require more information and, in turn, provide a greater degree of detail, including estimates of dominant height, basal area and stems per hectare. The development of an even-aged forest stand could be predicted using a stand model. Important variables are average or dominant stand height, the basal area and stems per ha. These basic quantities are used to derive secondary values, such as the quadratic mean diameter or stand volume.

- **Size class models**

The basic modelling unit in size class models is a representative tree impersonating a number of trees within a size class or cohort. Size class models, requiring even more information than stand models, are probably the most common type for simulating alternative silvicultural programs.

- **Individual tree models**

Individual tree models utilize information about the position and size of specific trees and of the trees in their immediate neighbourhood. The spatial information may be available in two or three dimensions. Three dimensional spatial models are used to quantify the amount of shading and constriction of growing space caused by neighbouring trees.

3.4. Data requirement for Growth Modelling

Forest development is in direct response to various types and intensities of thinnings, and is influenced by the environmental factors existing on the site. In sequence, two different kinds of empirical data are required for modelling. Firstly, data describing the change of state variables through thinning and secondly, data describing the change of state variables through natural growth. Growth data may be obtained from a variety of field experiments (GADOW and HUT, 1999). The following types, which differ with regard to the dominant objective, are most common.

1. Provenance trials for evaluating the suitability of exotic species and/or specific provenance on particular sites
2. Fertilizer trials for investigating possible growth improvements in response to fertilizer application
3. Spacing and thinning trials, for evaluating the effects of different planting espacements and thinning treatments on tree growth

Three types of Growth trials may be distinguished with regard to the time horizon. Permanent plots are established for collecting yield table data for a particular silvicultural program. The plots are re-measured, usually at regular intervals, until harvesting. Temporary plots, measured only once, provide age-based information about relevant state variable, which is used to construct a yield table, again assuming normal or representative silviculture. Interval plots are re-measured once, thus providing an average rate of change in response to a given set of initial conditions. They may be abandoned after one measurement interval.

3.4.1 Permanent sample plots

The observation from long-term growth plots represents a very important database for developing growth models. During long periods of time, the change of qualitative tree attributes is assessed reiteratively in the same plot. Observations are thus obtained, permitting the construction of a growth model for a given set of conditions. Many yield tables were constructed using such a long-term database.

One of the advantages of a database derived from the permanent plots is the potential to describe polymorphic growth patterns by evaluating the data of each plot separately and by expressing the parameters of the height model as a function of site index or as a function of specific site variables. In this way, it is possible to develop non-disjoint polymorphic height models (CLUSTER., 1983; KNHN, 1994, cited in GADOW and HUT, 1999).

Disadvantages of the permanent sample plot are the high maintenance cost of the research infrastructure and it is also necessary to wait for a long time to get data. The object of the trial is not always achieved, as plots may be destroyed prematurely by wind or fire, or by unauthorized cutting.

3.4.2 Temporary Sample Plots

Temporary plots may provide quick solution in a situation where nothing is known about forest development. They are measured only once, but cover a wide range of ages and growing sites. Thus, the sequence of re-measurements in time is substituted by simultaneous point measurements in space. This method has been used extensively during the 19th century (ASSMANN, 1953, cited in GADOW and HUT, 1999)

Yield tables were developed in a number of European countries after World War II using data from temporary plots. These tables are static in nature. They represent the development of a standard silvicultural treatment and cannot be used to predict forest development for alternative thinning regimes (ALDER, 1980, cited in GADOW and HUT, 1999). The main limitation of temporary plots is that they cannot provide information about the rate of change of a known initial state. Thus, some of the more effective contemporary techniques of growth modelling using a system of differential equations cannot be used (GARICIA, 1988, cited in GADOW and HUT, 1999).

3.5 Site Evaluation

The evaluation of forest site productivity is one of the main tasks in growth and yield studies. Being biological in nature, site is difficult to be quantified (TINT *et al*., 1993). There are several different approaches to access the site productivity. SAMRAMAKI (1992) distinguished three different types of expressions.

- Site index. Height of stand at a predetermined age
- Mean annual increment, either at a fixed age or at the age when mean annual increment culminates
- Other stand characteristics

In even-aged plantations, site index is the most commonly used expression. Also in naturally regenerated stands, site index is used as long as the stands are even-aged (SARAMAKI, 1992).

VANCLAY (1994) distinguished the site classification into two methods:

- Phytocentric methods and
- Geocentric methods

Phytocentric methods are based on assumptions that total stand volume production or phytomass production is the ultimate measure of site productivity. Geocentric methods are based on assumption that site productivity depends upon the soil and climatic factors.

- **Phytocentric Methods**

Phytocentric measures such as site index are widely used as the measure of the site productivity of plantation because they are easy to measure. Under this method, different techniques can be used. The measurements such as basal area, the height at nominated index diameter, total volume productions are commonly used as the measure of site productivity.

- **Geocentric Methods**

Phytocentric methods of site assessment are based on forest measurements, and thus, cannot be used where suitable forest stands are not present. In Europe, Scandinavia, Canada and elsewhere, the Patterson-Weck's CVP index has been used to define homo-climates or areas of similar climate; these are useful when searching for species to introduce in order to raise the useful yield from the forest (PHILLIP, 1994).

'CVP index' is defined as follows.

I = (Tu/Ta) (p) (G/12) (E)

where,

I = CVP Index ranging from 0 to 30,000 with forest growth possible in areas with an index greater than 25

Tu = mean monthly temperature of the hottest month in °C

Ta = difference between the mean monthly temperature temperatures in °C, of the hottest and coldest months

P = mean annual precipitation

G = length of growing season in months

E = Rp/Rs

Rp = radiation at the pole, 10^3 g cal cm^{-2} min^{-1}

Rs = radiation at the site 10^3 g cal cm^{-2} min^{-1}

Most investigations of the relationship between topography and site productivity have used simple variables such as elevation, aspect and slope (VANCLAY, 1994).

Soil conditions can also be used in geocentric estimate of site productivity. Soil depth, colour, and texture can easily be determined, but soil moisture and nutrient status are difficult to quantify and may vary with time and space.

4. Methodology

Yield tables are conventionally based on long-term measurements of experimental series, which should be distributed over the whole area to which the yield tables are to be applied. These long-term experimental series are ideally kept under continuous observation from the time the stand is established and contain many single plots for examinations of different treatment programmes. Comprehensive and uninterrupted data allow the formulation of goal-oriented treatment programmes (ROEHLE, Undated).

However, there is no long-term measurement for Pyinkado plantation in Myanmar. Data were collected only from the temporary sample plots. Following the review of available data, different alternatives for collection of data were discussed. Finally, it was decided to use the method which will be described in detail below. The objective was to transform the spatial sequence into time sequence similar to the procedure of compiling growth series (ASSMANN, 1970, cited in ROEHLE, Undated). Therefore, the sequence of remeasurements in time was substituted by the simultaneous measurements in space.

4.1. Survey Design and Instruments

Survey and inventory in forestry is one of the basic steps to other forestry branches in putting the silvicultural and management plan. For large areas, sampling could provide all necessary information at much lower costs with reliable result than total enumeration (ADAM, 1989)

A field survey was carried out with subjective sampling. Temporary sample plots were selected only in places where stocking was full.

Each selected plantation was divided into 3 or 4 equal parts based on the shape of the plantation. One of the corners of the sample plot was located as accurately as possible by measuring from a reference point identifiable on map and ground; the plot was then established from this point. The sample plots are all square with 60m x 60 m in size.

Reference point may be on the boundary of forest reserve or compartment, at the intersection of roads and confluence of streams or similar significant land marks. The distance from the reference point to the sample plot was read from the 1 inch: 1 mile map.

- Instruments

The following materials were used for the fieldwork.

(a) Distance tape

(b) 30 cm transparent ruler

(c) Metal clipper

(d) Blume-Leiss altimeter

(e) A compass and topographic maps

(f) Writing materials and clipboards

The bole length of the tree is obtained by measuring the height between the stump height and the Crown Point. The instrument for measuring diameter was a metal caliper. To measure the diameter of a point, two diameter readings, perpendicular to each other of the corresponding points, were taken. Arithmetic mean was used for the required diameter.

4.2. Data analysis

Methods of data analysis include volume computations and regression functions by using 'Microsoft Excel 2002' and also by the use of 'SPSS' software. Stand height curves were also constructed. For data analysis, a database was constructed in Excel. The main purpose of the database is to give information on each tree.

4.3. Calculation of basic Parameters

4.3.1. Calculation of basal area (g)

The total basal area of all trees or of specified classes of trees per unit area is a useful characteristic of a forest stand. Basal area is related to stand volume and is a good measure of stand density and competition. Stand basal area is calculated from the measurements of diameter at breast height (dbh).

Stem basal area (g) is the cross-sectional area of a tree at breast height and it is calculated as follows.

$g = d^2 * \pi / 4$

where d = diameter at breast height

4.3.2. Calculation of mean basal area (gm)

Mean basal area of a stand (g_m) is derived from basal area as follows.

$g_m = \sum g_i / n$

where g_i = basal area of tree 'i', n = total number of trees, and i = 1,…, n

4.3.3. Calculation of mean diameter (dm)

Diameter is the most widely used descriptor of the stand structure. The average diameter of a stand may be expressed as arithmetic mean or quadratic mean. If the primary interest is to obtain an average for the calculation of stand basal area and volume, the quadratic mean diameter is more appropriate (HUSCH et al., 2003).

Mean diameter (d_m) of trees is the diameter of the tree having mean basal area (g_m) and, is derived from the mean basal area as follows

$d_m = (g_m * 4 / \pi)^{1/2}$

where,

dm = mean diameter

gm = mean basal area

4.3.4. Calculation of top diameter (d100)

Top diameter (d_{100}) is the diameter of mean basal area tree derived from 100 largest trees per hectare. It is calculated as follows.

$d_{100} = (g_{100} * 4 / \pi)^{1/2}$

where,

d100 = top diameter

g_{100} = mean basal area of hundred largest trees / ha

In even-aged stands, 'd_m' is influenced by thinning regime. Thinning from below (cutting of small tree from stand) causes an increase in 'd_m'. However, 'd_{100}' is not influenced by thinning regime.

4.3.5. Calculation of mean height (hm)

Height is another widely used stand parameter. Height is an important factor in determining individual and total stand volumes. Height is widely used as a measure of site quality and stand productivity (HUSCH et al., 2003).

Mean height (h_m) is the height of the tree with diameter 'dm'. The heights of these mean trees are derived from the stand height curves constructed for each plot by using MICHAILOV function.

$h\,m = 1.3 + a_0 * \exp(a_1/dm)$

dm= mean diameter at breast height

hm = mean height

exp = 2.71828 (base of natural logarithm)

a0, a1 are coefficients from stand height curve of corresponding plot.

4.3.6. Calculation of top height (h100)

Top height (h_{100}) is the height of the tree with diameter of 'd_{100}' and calculated using the same procedures as mean height.

In even-aged stands, mean height 'h_m' is influenced by thinning. Thinning from below causes an increase in 'h_m'. However, 'h_{100}' is not influenced by thinning regime. It is a very good parameter for comparison of different yield classes of different stands.

4.3.7. Calculation of tree volume

An estimate of total volume of trees in a stand is an important parameter for providing information necessary for making decisions on the management of a forest (HUSCH. *et al*., 2003)

For volume estimation of Pyinkado trees, the following polynomial model which was developed by Leech et al., (1990) was used. The estimated parameters of this model were calculated for most of the forest region in Myanmar, including Bago Yoma region and Bamaw-Katha region.

$V = b0+b1\ D+b2\ D^2$

where,

V = volume over bark

D = Diameter at breast height in cm

b0, b1, b2 = regression coefficients

The estimated parameters of this polynomial function for the study areas are as follows. The standard error of each parameter is shown beneath the respective parameter estimated.

Study area	bo	b1	b2
Bago	0.01857	-0.008331	0.0007699
	(0.06742)	(0.003309)	(0.0000378)
Katha	0.24220	-0.022316	0.0010968
	(0.09206)	(0.005420)	(0.0000751)

4.3.8. Stand Height Curve

Stand height curve is the best to fit a series of points representing the plots of height against diameter for all trees in the sample plot. The stand height curves were constructed by using an exponential function (Michailov). Nonlinear regression was used to estimate the parameters of this function by using ‘Solver tool’ in the computer program of ‘Excel 2002’.The regression was based on the statistical concept of least squares method proposed by ZAR (1999) No constraints were put on the parameters when they were estimated.

$h = 1,3 + a_0 * \exp(a_1/dbh)$

where,

dbh = diameter at breast height

h = height

exp = 2,71828 (base of natural logarithm)

a_0, a_1 = regression coefficients

The results of the coefficients of this function for each plot are given in Appendix 3 and 4

4.4. Calculation of Yields from Thinning

The yields from thinnings were estimated by measuring the diameter of stump. Time of thinning were known from forest records or estimated from the rate of decay of stump.

To calculate the volume of thinnings, the above volume equations for the standing tree were used again. In these equations, the volume was estimated from diameters at breast height (dbh).So, it was necessary to estimate the dbh of stumps.

For the estimation of diameter at breast height (dbh) from the diameter of stump, the diameters at stump height of standing trees(d.sth) were measured. Regression analysis was made between d-sth and dbh. Both linear and polynomial regression gave high R^2.

4.6. Determination of mean height site classes

Among different methods for site evaluation, mean height site class system was used. For this purpose, the graphs of mean height and age were constructed with program DYNAMOBEM.

4.5. Program DYNAMOBEM for construction of Yield Tables

Program DYNAMOBEM is a model for growth and yield of pure and mixed stands, in which stand development is derived from a description of increment in relation to age. The initial condition for model is derived by stand volume, stocking density, and stand height at a certain age. Height development is related to volume increment through an allometric relationship;

thinning volume depends on the degree of thinning, as well as on the production level as expressed in the relationship between increment and stand age (WENK, 1994).

Volume increment

The central element of the model is the algorithm for describing stem volume increment in relation to age. Stem volume at any age is taken as the initial condition at the beginning of the simulation. The annual increment is derived from actual stand volume through multiplication by a growth multiplier.

$M_{t+6t} = V_{b,t+6t} / V_{a,t}$

where,

M_{t+6t} = the growth multiplier at t +6t (t in years)

$V_{b,t+6t}$ = stand volume before thinning at time t +6t (m^3ha^{-1})

$V_{a,t}$ = stand volume after thinning (m^3ha^{-1})

Therefore, total volume at t +6t can be calculated as follow.

$V_{b,t+6t} = M_{t+6t} * V_t$

This algorithm is repeated in the model up to the end of the simulation.

The multiplier can now be expressed as an apparent growth rate.

$M_{t+6t} = 1/(1-P_{t+6t})$

With

$P_{t+6t} = (V_{b,t+6t} - V_{a,t}) / V_{b,t+6t}$

Where,

P_{t+6t} = relative growth rate

Relative Volume Increment function

The volume increment percent plays important role in modelling the volume development. According to WENK (1994) , it can be described as 3 steps exponential function.

$Pv = \exp(-c_1t'(1-\exp(-c_2t'(1-\exp(0.4t')))))$

With $t' = (t-5)/5$

where,

Pv = relative volume increment percent of trees and stand

c_1, c_2 are regression coefficients

Height development

As in the case of stem development, height development is calculated from an initial condition using a multiplier that depends on stand age.

$H_{t+6t} = M_{h,t+6t} * H_t$

Where,

H_{t+6t} = stand height at time t +6t

$M_{h,t+6t}$ =height multiplier at time t +6t

H_t = stand height at time t

As the same in volume growth multiplier, height growth multiplier can be expressed as follow.

$M_{h,t} = 1/(1-P_{h,t})$

Where, $P_{h,t}$ relative height growth rate.

Multiplier for volume increment and height growth is related to an allometric equation (WENK, 1978).

$P_h = 1- e^{(1/x * \ln(1-Pv))}$

Using above equation, height development can now be calculated if the coefficient x is known.

Thinning

For the calculation of the amount of stem volume removed by thinning ($V_{th} = V_{b,t} - V_{a,t}$), thinning intensity is linked to the relative volume increment (Pv) through the following differential equation.

$d(P_{v,t} - P_{th,t})/dt = -k_v C_1(P_{v,t} - P_{th,t})$

where,

$P_{v,t}$ = relative volume increment at time t

$P_{th,t}$ = thinning intensity at time t expressed as ($V_{a,t}/V_{b,t}$)

t = age in years

k_v = thinning intensity factor determining the thinning intensity

C_1= species dependent growth parameter from above equation.

The integrated form of above equation is simply given by

$P_{th,t'} = P_{v,t'} - \exp(-C_1 t')$

The above thinning model was also extended by ZIMMERMANN (1974)

$P_{th,t'} = P_{v,t'} - \exp(-C_1 t' k_v (1+a\exp(-bt')))$

where, the parameters a and b define the deviations of the thinning intensity with age.

Stocking density

Stocking intensity changes concurrently with thinning. Here, it is described as the same way as thinning, starting from an initial stand density in trees per hectare. To calculate the effect of thinning on the stocking density, an additional thinning intensity expressed as the ratio between stocking density before and after thinning is applied.

$P_{th\text{-}N,t} = N_{th,t}/N_{b,t}$

where,

$P_{th\text{-}N,t}$ = thinning intensity, expressed in terms of number of trees at time t

$N_{th,t}$ = number of trees removed at time t (ha^{-1})

$N_{b,t}$ = number of trees before thinning at time t (ha^{-1})

According to ZIMMERMANN (1974), the thinning intensity expressed in number of trees can be related to thinning intensity expressed as stem volume from the ratio between the volume of the average tree of thinning ($v_{th,}$) and the volume of the average tree before thinning ($v_{b,}$).

$P_{th} / P_{th\text{-}N} = v_{th}/v_b = k_N$

where,

k_N = thinning intensity factor determined by the type of thinning.

When thinning intensity is known in terms of relative stem volume removed, then the number of stems removed in thinning can be derived from above equation, provided the type of thinning is specified using the thinning density factor k_N.

Additional stand Variables

Additional stand variables such as basal area (G) and average diameter at breast height (dm in cm) can be derived from total stand volume using an empirical stand form factor that depends on stand height and on the site class.

Basal area is calculated as follows.

$G_t = V_t / F_H$

where,

G_t = basal area in m^2h^{-1}

F_H = form factor for stand height

The average diameter is calculated as follows.

$dm = (4.G_t / \pi N))^{1/2}$

Schematic presentation of the Model DYNAMOBEM

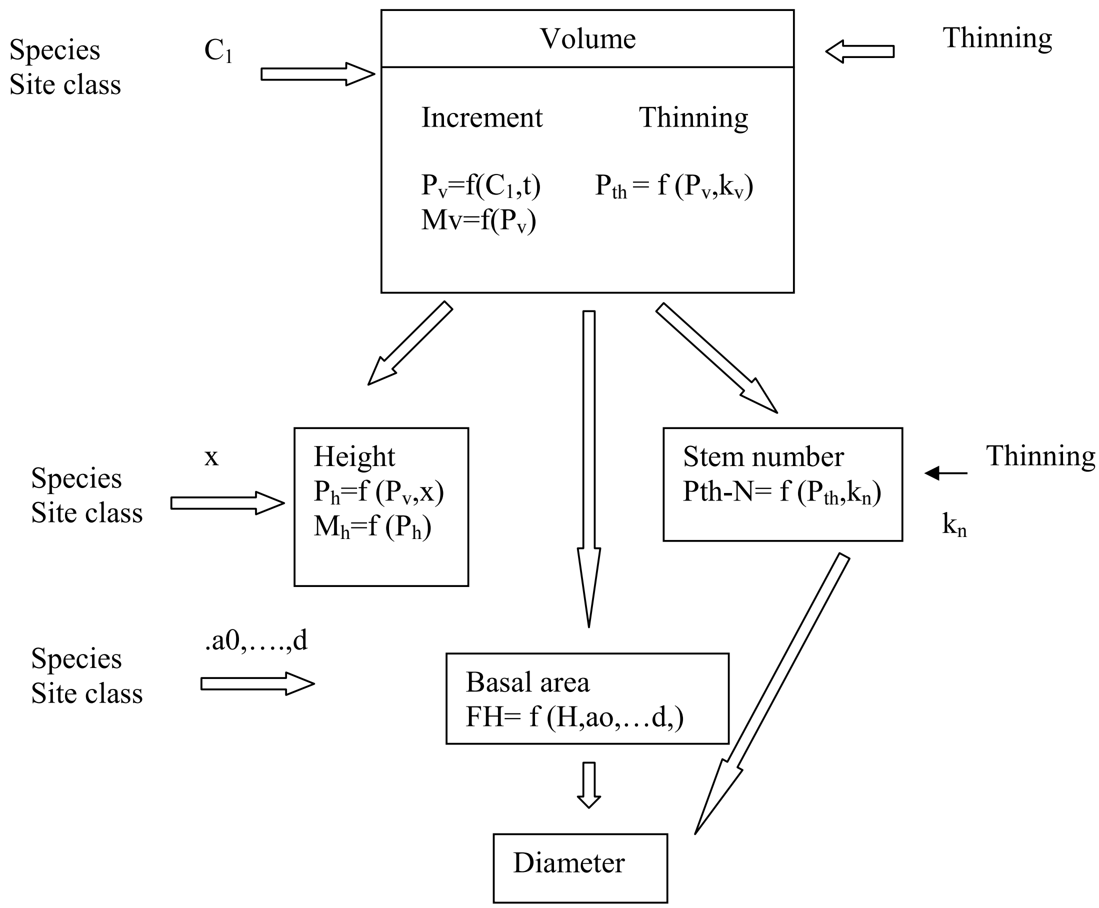

Figure (2) schematic representation of DYNAMOBEM (HAUFE, 2001)

5. Results and Discussions

5.1. Basic Parameters for Modelling Stand Development

The results for the calculation of basal area (g), mean basal area g (m), mean diameter (dm), top diameter (d100), mean height (hm), top height (100), volume of stand are given in Appendix 1 and 2.

There are some problems in the calculation of volume with the polynomial model developed by Leech et al., (1990).The minimum diameter range of this model is 20.5 cm for Bago Yoma region and 20 cm for Bamaw-Katha region. This model gives abnormal results for the smaller diameters.

To avoid this problem, the linear relationship was assumed between the volume of dbh 20 cm and origin. This meant that a straight line was drawn from the volume of dbh 20cm to origin. The following linear relationships were used to estimate the volume for the trees having dbh smaller than 20 cm.

For Bago Yoma region; where, V= volume of tree

V = 0.008 dbh + 2E-17 dbh = diameter at breast height

For Bamaw-Katha region;

V = 0.0117 dbh

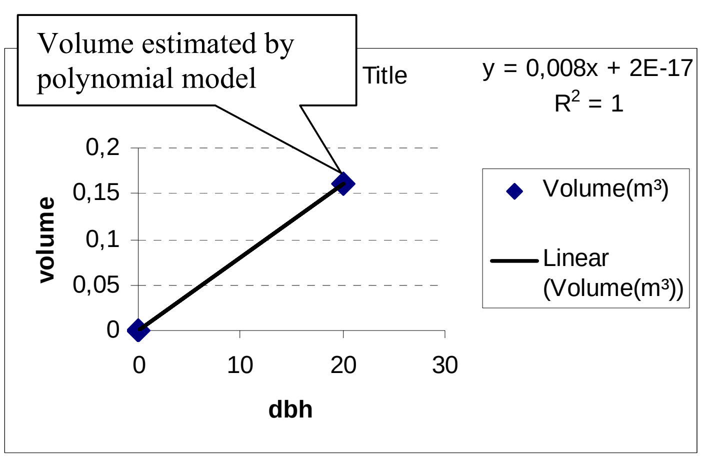

Figure (3) Linear relationship between and Volume and dbh for Bago Yoma region

5.2. Yields from Thinnings

Both polynomial and linear regression give high R^2 to estimate diameter at breast height of felled trees (DBH) from its diameter of stump (D-STH). Only the linear relationship was used for this purpose.Volume of felled trees were calculated from their DBH

The mean diameter (dm) and basal area are again derived from volume of thinning stand.

Relationships between DBH and D-STH

For Bamaw-Katha region;

DBH = 0, 7718 (D_STH) +1,913 R^2 = 0,9411

For Bago Yoma region;

DBH = 0, 8211(D_STH) + 0, 4439 R^2 =0, 9433

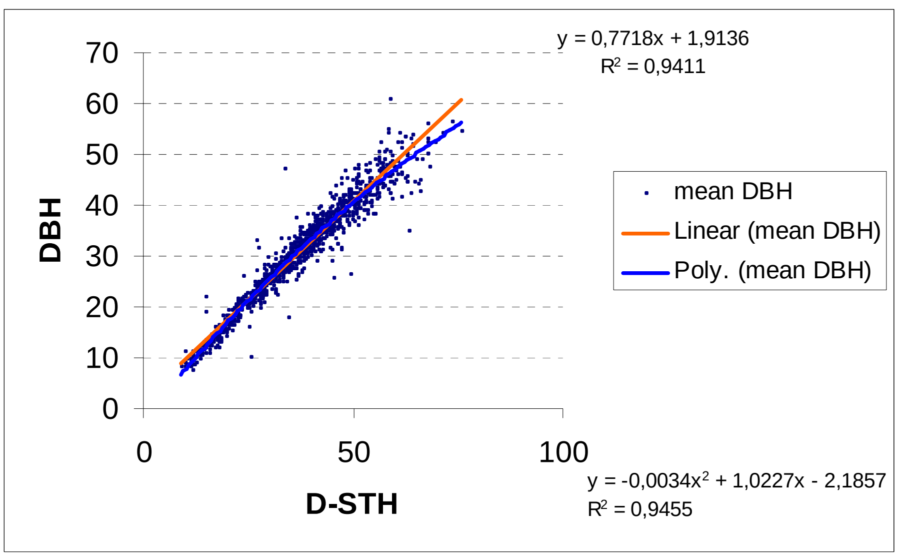

Figure (4) the relationship between dbh and d-sth for Bamaw-Katha region.

5.3. Height Diameter Relationship

For this purpose, the stand height curves were constructed for each sample plot using MICHAILOV function. The parameters of this function are given in Appendix 3 and 4.These relationships between height and diameter were used to derive mean stand height (hm) and top height (h100).

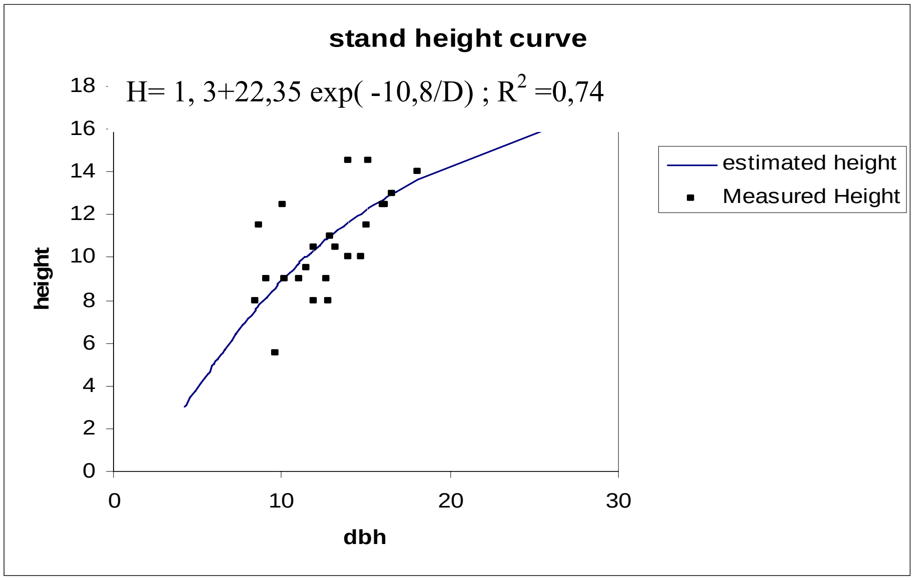

Figure (5) Stand height curve for sample plot 13 of Bamaw-Katha region

5.4 Development of Important Yield Parameters over Age

The sequence of the measurement of variables from different temporary plots is plotted against ages. The objective is to change the simultaneous point measurements in space to the sequence of measurement in time. This is the main concept of this research. The following graphs show the development of yield parameters over age.

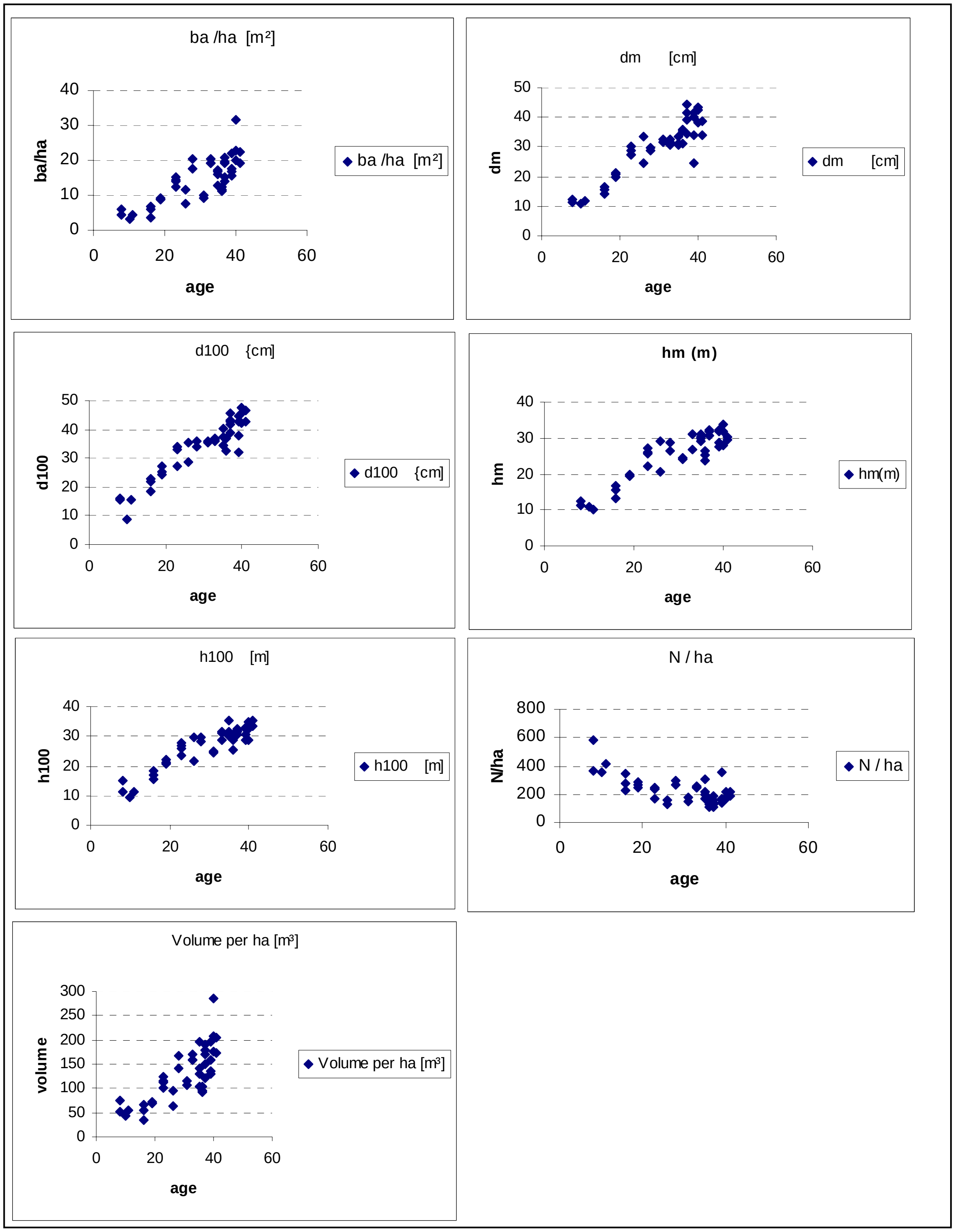

Figure (6) development of Yield parameters over age for Bamaw-Katha region

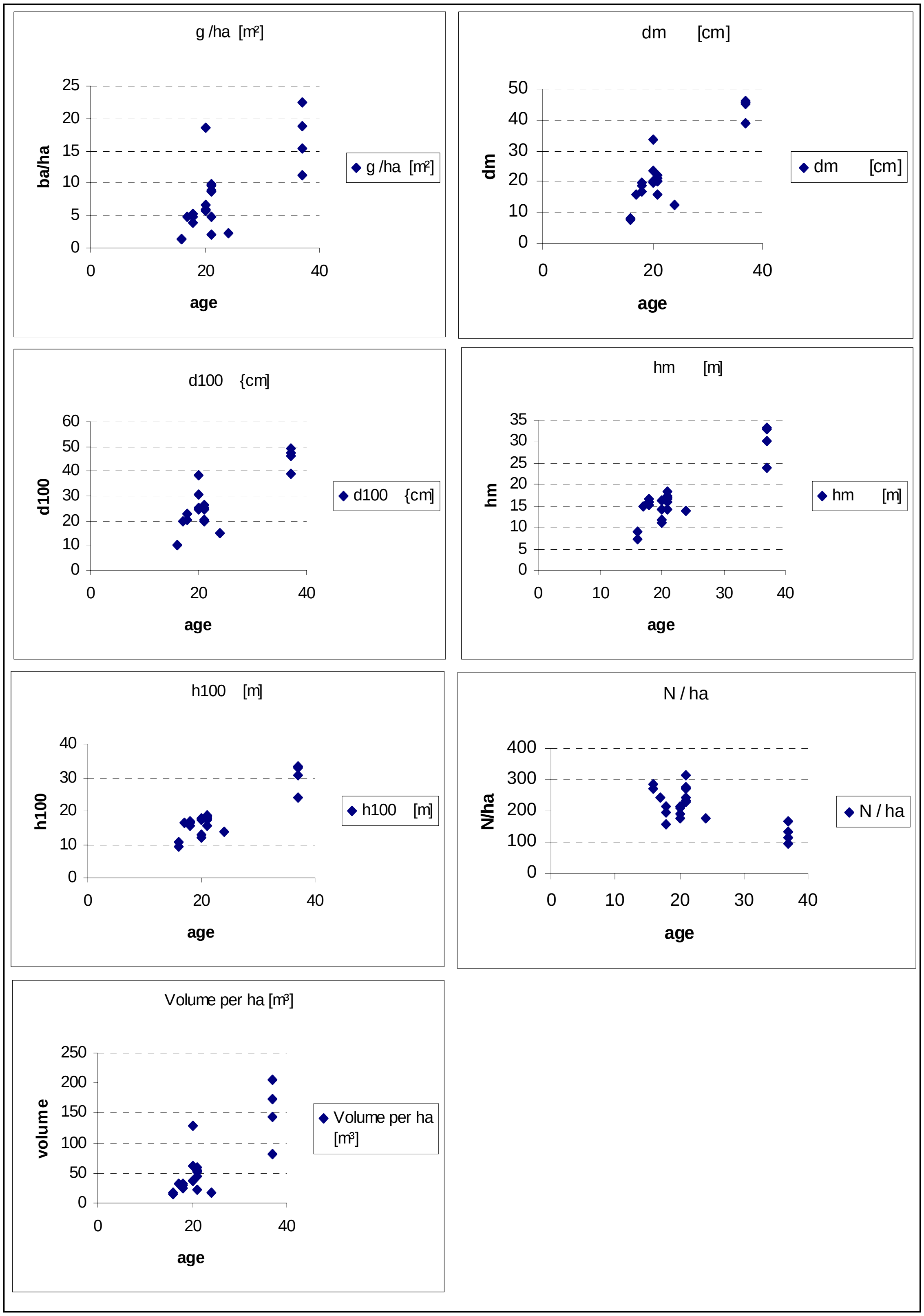

Figure (7) development of Yield parameters over age for Bago Yoma region

5.5. Simulation of stand development with the help of Program DYNAMOBEM

5.5.1. Height Development

Height increment in principle depends upon the volume and is controlled by the parameters c_1 and c_3. It is also influenced by the parameter x. For the construction of yield tables for Pyinkado, the value of parameter x for all site classes is 3,3. This relationship between mean height and age was used as mean height site classes in terms of site index. The mean height of the plantation at age 40 years was designated as site index.

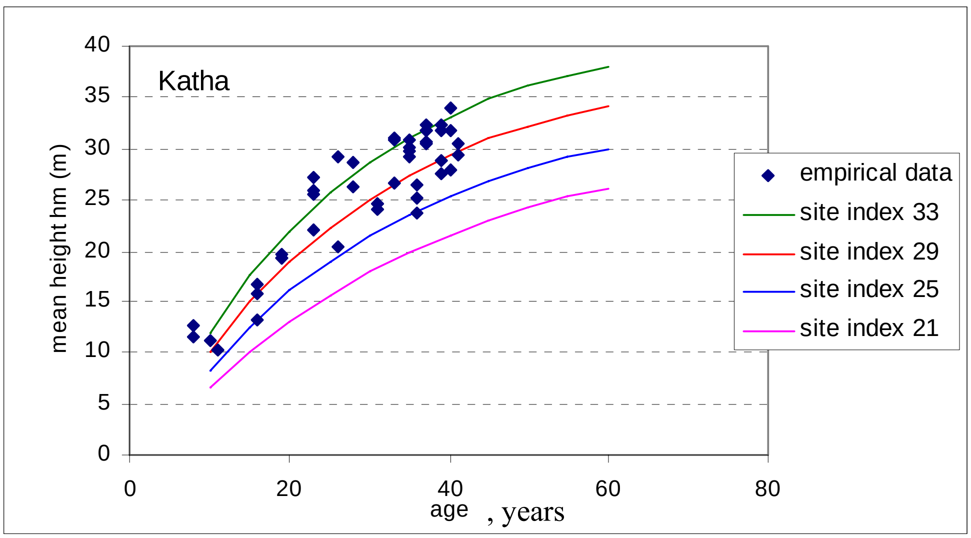

Figure (8) Mean height site index curves for Bamaw-Katha region

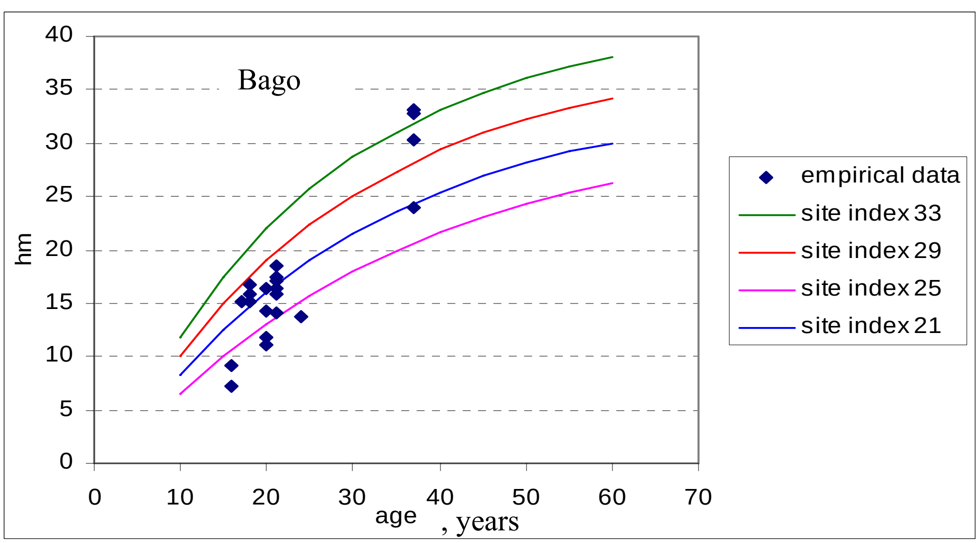

Figure (9) Mean height site index curves for Bago Yoma region.

5.5.2. Mean diameter development

The mean diameter of the stand is derived from the stand basal area per hectare and the number of stems per hectare in the model. The graphs below show the empirical data and the results of DYNAMOBEM models.

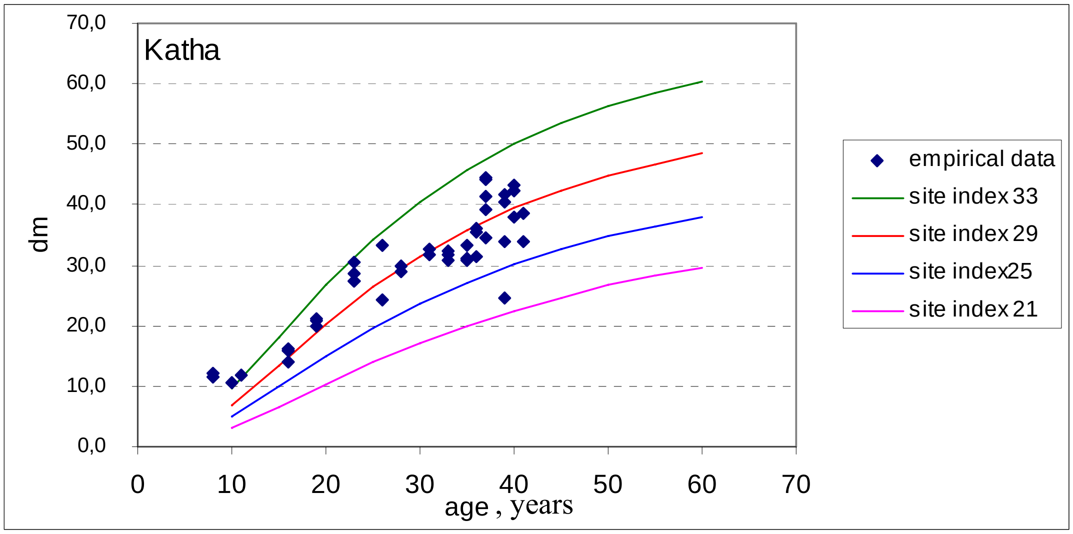

Figure (10) Mean diameter development over age for Bamaw.Katha region.

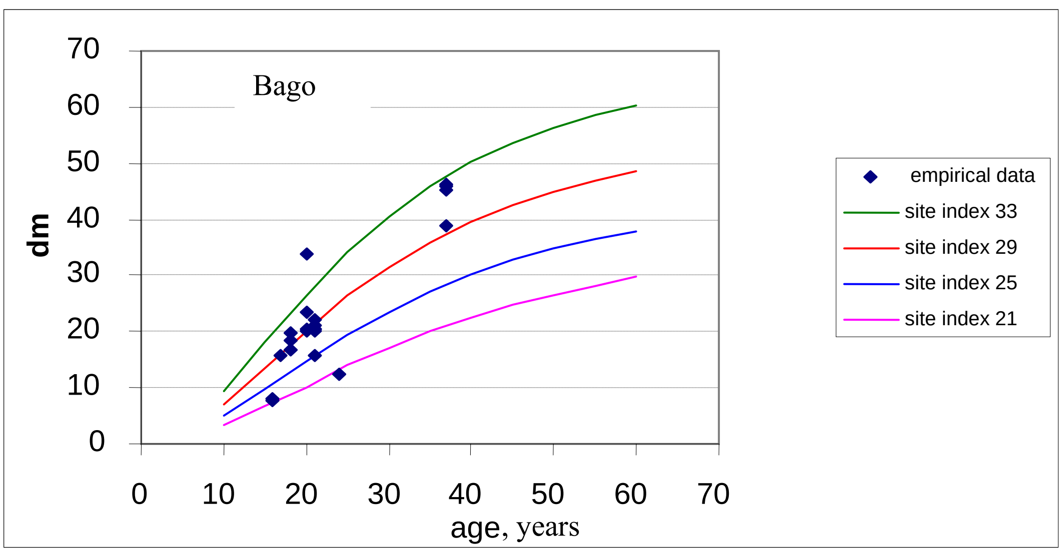

Figure (11) Mean diameter development over age for Bago Yoma region.

5.5.3 Stem number development

Stem number is controlled by basal area increment and also by the thinning intensity in the model.. The thinning density factor (k_n) is used as an input variable in the model to project stem number development. The thinning intensity also changes with the type of thinning and the age of the stand.

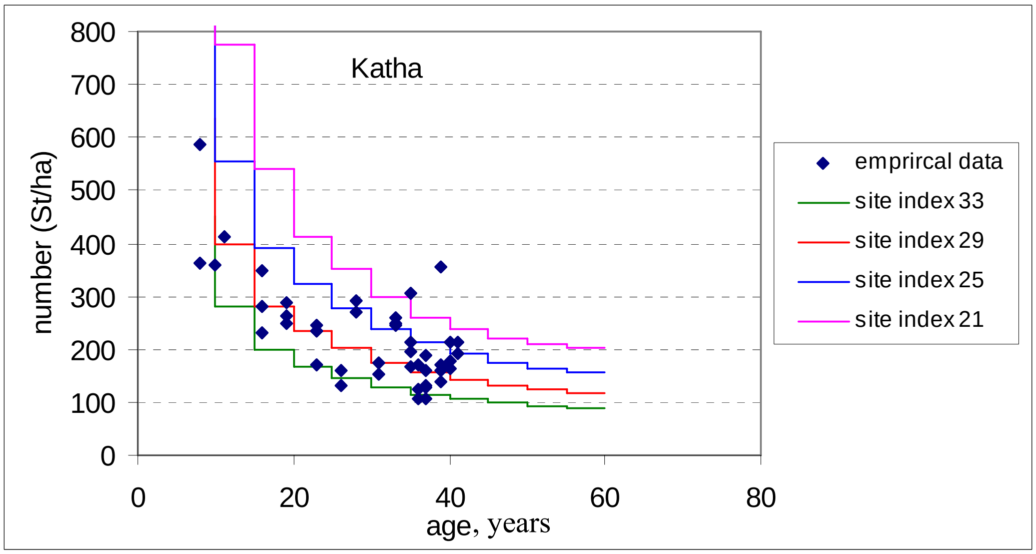

Figure (12) Stem number development in relation to stand age for Bamaw-Katha region

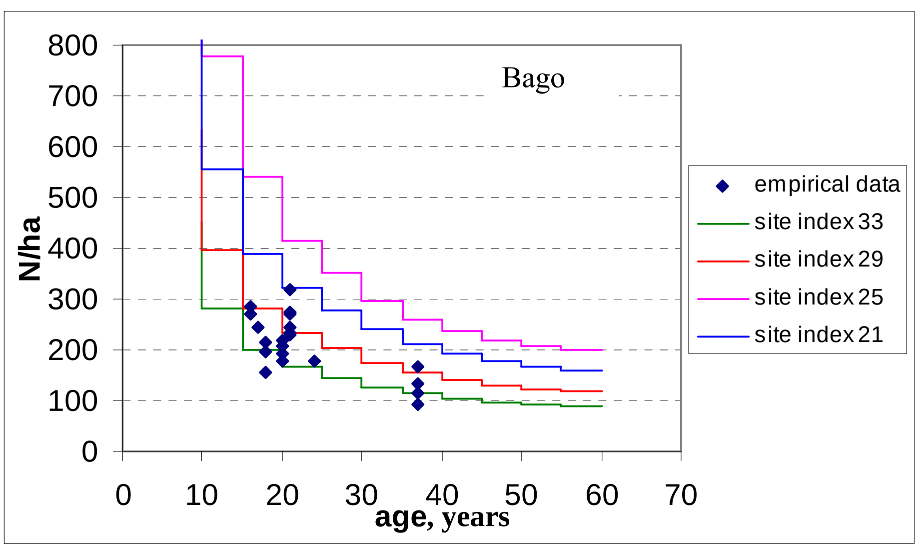

Figure (13) Stem number development in relation to age for Bago Yoma region

5.5.4 Basal area development

The basal area development is also derived from the volume increment in the model as an output. The form factor of stand height (FH) is kept constant at 9m for Pyinkado. The form factor of stand height is calculated from basal area (m^2 ha^{-1}) and volume ($m^3 ha^{-1}$). The graphs below show the empirical basal area and the results of DYNAMOBEM model.

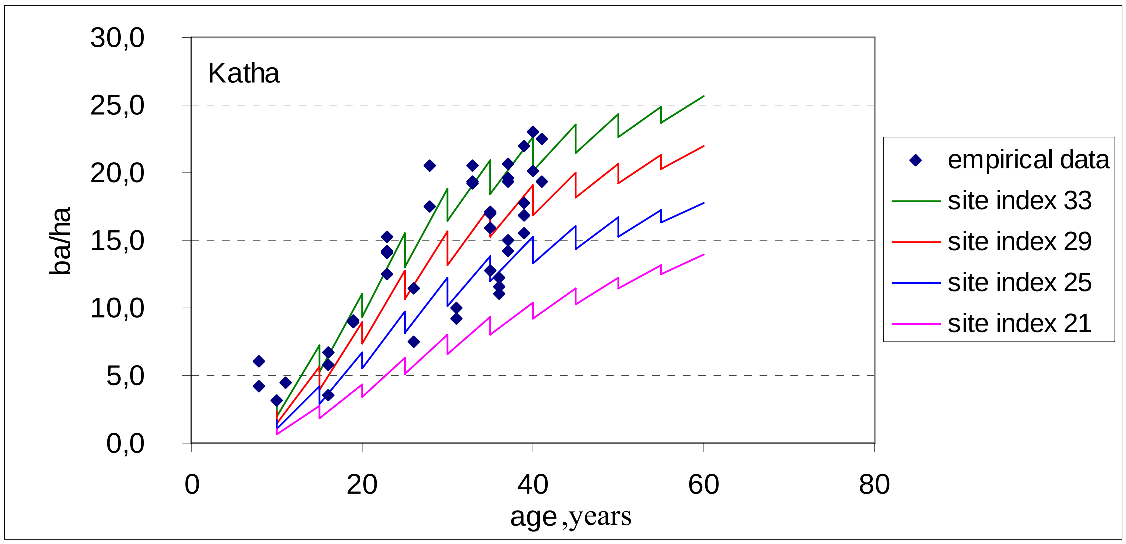

Figure (14) Basal area development in relation to age for Bamaw-Katha region.

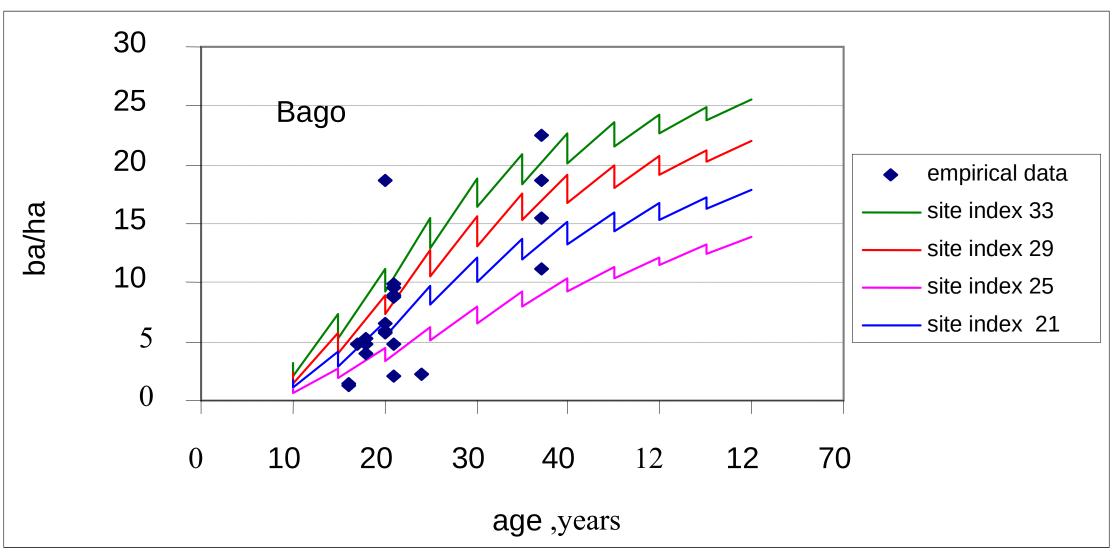

Figure (15) Basal area development in relation to age for Bago Yoma region

5.5.5 Volume Development

The volume development of a stand is derived from the initial volume at age `t ´ and volume increment percent P_v. P_v is controlled by the parameter c_1, c_2. The parameter c_1 defines the shapes of the growth curve, and depend on the tree species, site quality and silvicultural treatment. Parameter c_2 accounts for variability of juvenile growth and gradually lossea its influence beyond age 40-50 (WENK,1994).The results of the parameter c_1 and c_2 from the model are give in the table below

Table 1: Parameters for the Volume increment percent function

Parameter	Site index 33	Site index 29	Site index 25	Site index 21
c_1	0,24	0,23	0,22	0,205
c_2	1	1	1	1

In the case of the volume removed in different the thinnings, the thinning factor k_v is used as input parameters. The parameter k_v and c_1 influences the thinning intensity.

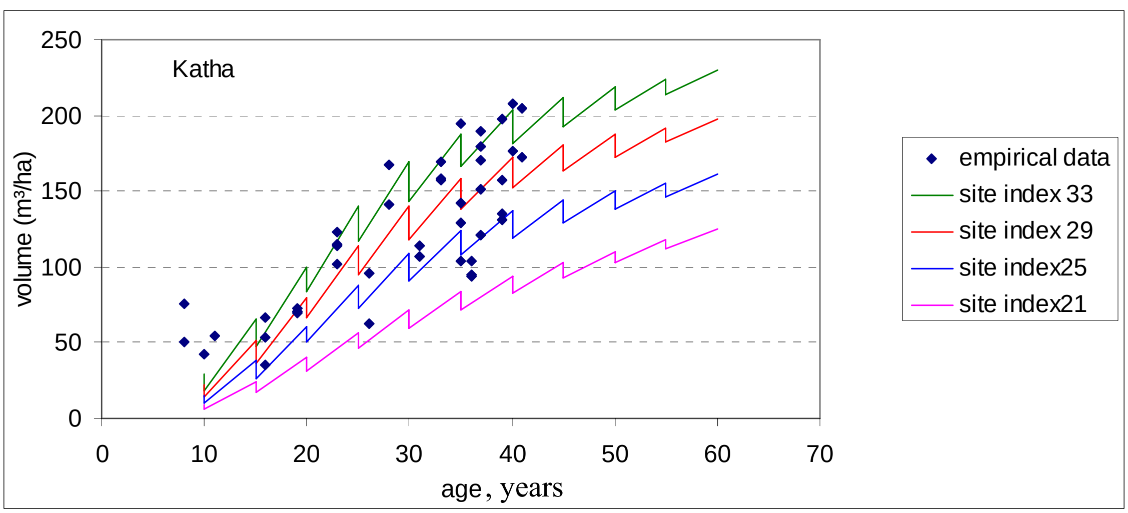

Figure (16) Standing Volume development in relation to age for Bamaw- Katha region

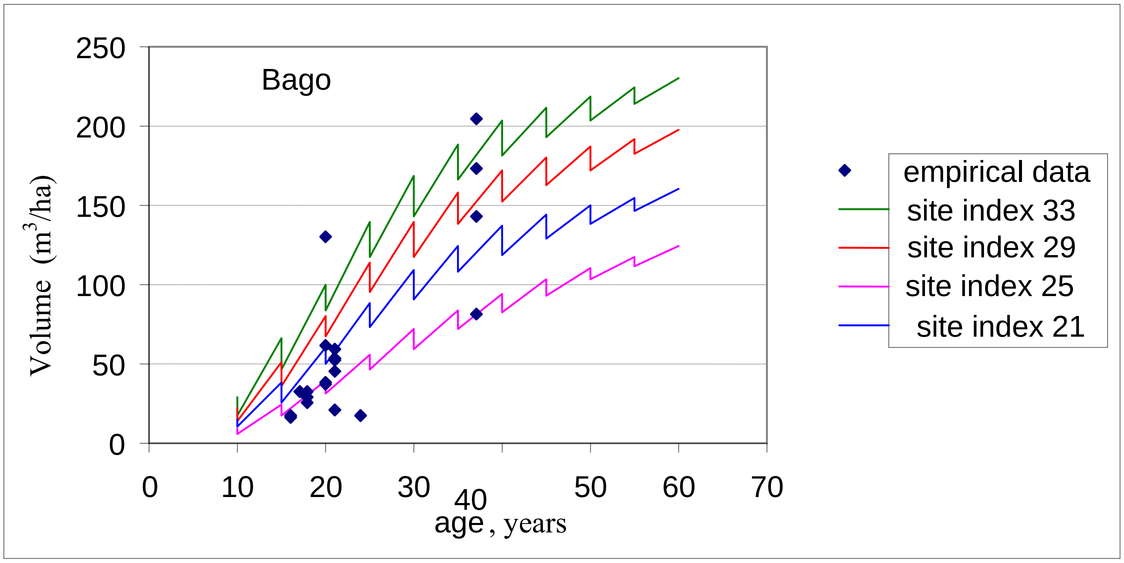

Figure (17) Standing Volume development in relation to age for Bago Yoma region

5.6 Comparison with the results of another research

MYINT et al., (1999) also constructed a yield table for Pyinkado. These tables provide two parameters of the stand, namely bole volume and mean annual increment (MAI). They used site indices for site classification.

MYINT et al., (1999) estimated 497 m^3/ha at the age of 60 for site index of 35 of Pyinkado plantation. This estimation is slightly higher than that of site class 33 from this study. Estimated volume at age of 60 years for site class 33 in this study is about 413 m^3/ha. However, the estimations of volume form this study is higher than that of MYINT et al., (1999) if the comparisons are made between the other nearest site indices, i.e. between site class 29 and 30, site class 25 and 25, site class 21 and 20(See Figure 18).

MYINT et al., (1999) estimated MAI of 8,28 m^3/ha/yr at the age of 60 year for the site class 35. This estimation is higher than that of site class 33. However, at the age of 43 years, both MAI curves show the same results as shown in figure (19).

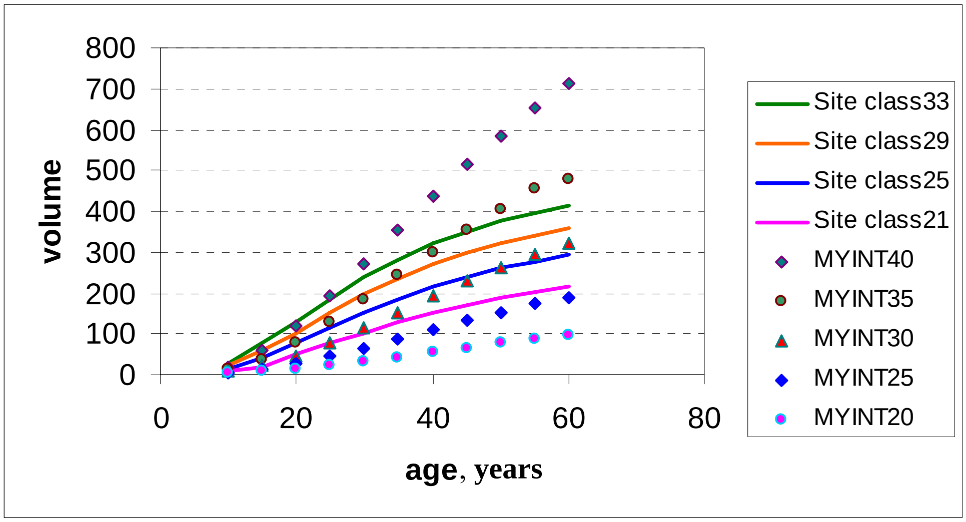

Figure (18)Total volume development of Pyinkado from the present study and MYINT et al., (1999)

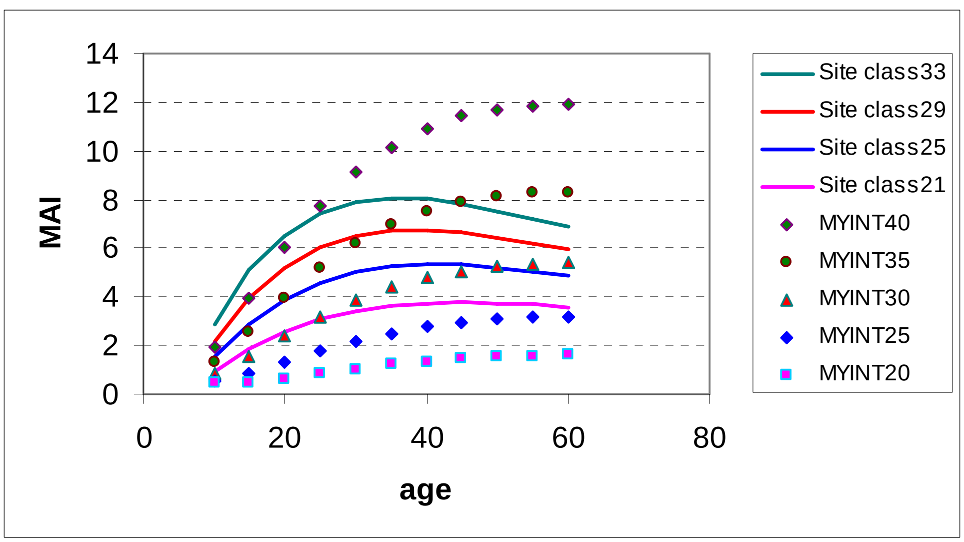

Figure (19) MAI development of Pyinkado from the present study and MYINT et al., (1999)

6. Conclusions and Recommendations

6.1. Conclusions

The simulation program, DYNAMOBEM, produces growth and yield forecasts for the plantations of *Xylia xylocarpa* (Pyinkado) in Myanmar. The outputs are Yield tables for different site classes. The yield tables are described with 3 separate tables for each site class, namely (a) main crop after thinning, (b) yield from thinning and (c) total crop.

Final yield, accumulated yield of thinnings, mean annual increment, current annual increments are illustrated at the age interval of five years in these tables (see in Appendix 7). Therefore, decisions on the optimal rotation of Pyinkado plantations, in terms of productivity and profitability, could be made based on these tables.

6.2. Recommendations

- The yield table are constructed based on the temporary plot data collected from the Bago Yoma region and Bamaw-Katha region. Therefore, the applicability of these tables outside the range of these study areas need verification.
- Pyinkado is economically the most important species in Myanmar. To be able to estimate the actual rate of change of growth, permanent sample plots should be established in different locations throughout the country.
- The estimated maximum basal area of the remaining stand at the end of the rotation by these yield tables is only 25, 4 m^2/ha. This indicates that the productivity of Pyinkado plantations could be increased with alternative silvicultural systems.
- This research was carried out using temporary sample plots. It was not possible to compare different silvicultural systems. In this context, the further researches are recommended in order to be able to better forecast the growth and yield of Pyinkado and compare different silvicultural treatments.

References

Adam, H.A. (2000) MSc thesis, Developing sample method for assessment of growing stock, composition and distribution of trees in Abu Haraz natural reserve forests in N.Kordofan State, Sudan..

Creswell, J.W. (1994) Research Design, Qualitative and Quantitative Approaches, SAGE Publications, International Educational and Professional Publisher, Thousand Oaks, London, New Delhi .

Forest Department, (undated) Register of artificially regenerated area. Appendix XIV-A, Yangon . Myanmar

Gadow, K.V., and Hui, G., (1999) Modelling Forest Development, Dordrech.

Haufe, J.U, (2001) Modellierung Von Wachstum Und Ertrag in *Pinus oocarpa*- reinbestaenden in Honduras, Tharandt, Germany.

Husch, B., Beers, T.W., Kershaw, J.A. (2003) Forest Mensuration, John Wiley & Sons, Inc., Hoboken, New Jersey.

Keh, S.K., and Aung, M. (1994) Critical review of the silvicultural treatments of teak bearing forest of Bago Yoma with some remedial treatments

Kermode, C.W.D. (1964). Some Aspects of Silviculture in Burma , Central Press, Yangon, Myanmar.

Kyaw, N.N (1995). M.Sc thesis, Plantation Establishment with Xylia dolarformis (Pyinkado) by the Taungya method in Myanmar.

Leech, J.W., Myint, A.K., Kyaw, S. and Lynn, H. (1990), Tree Volume Equations for Myanmar, Forest Department, Myanmar.

Ministry of forestry (1993); Forestry facts sheet 1993 ,Myanmar

Ministry of Forestry,. (1999). Forestry in Myanmar. Forest Department, Yangon, Myanmar.

Myint, S., Tun, K and Hlaing, C. (1999), Evaluation of Commercial plantations in Myanmar, study 2 (GCP/RAS/158 JPN), Yangon, Myanmar.

Pambundhi, F. (1989) Contruction of volume table for Merchantable Shorea species in Danni, East Kalkantan, Indonesia.

Pendey, D. (1995) Forest resource assessment (1990) FAO Forestry paper 128

Phillip, M.S.(1994) Measuring Trees and Forests, Second Edition, CAB INTERNATIONAL, Wallingford, Oxon OX108DE, UK.

Roehle, H. (undated) Yield Table for Alppo Pine (Pinus halepensis) in Israel. Chair of Forest Yield science, University of Munich,

Saramaki, J.(1992) A Growth and Yield Prediction Models of *Pinus kesiya* (Royle Ex Gordon) in Zambia. The Society of Forestry in Finland. The Finnish Forest Research Institute

Shin, T (2004) MSc Thesis, Yield tables for the plantations of *Xylia dolarbriformis* (Pyinkado) in Myanmar, TU Dresden, Germany.

Tint, K, Kyaw, S, Bo, S, Myint, A.K, and Win, S (1993) Growth and Yield Tables for Plantation teak in Myanmar, Forest Department, Myanmar.

Troop, R.S., (1921) The silviculture of Indian Trees, Volume II ,Leguminosae (Caesalpiniae) to Verbenaceae, Oxford At The Clarendon press.

Tun, K. and Hlaing, C. (2000) Analysis of productivity and profitably of commercial plantation in Myanmar, Forest Department, Ministry of Forestry, The Union of Myanmar.

Vanclay, J.K. (1994) Modelling Forest Growth Yield .CAB International, Wallingford Oxon OX10 8DE.UK

Wenk, G. (1994) A yield prediction model for pure and mixed stands. Technical University of Dresden, Faculty of Forest-,Geo-,and Hydro-Sciences, Water Management and Forestry, Institute of Wood Growth and Forest Informatics, Dresden, Germany.

Zar, J.H. (1996) Biostatistical Analysis, Fourth Edition, Prentice-Hall, Inc, New Jersey.

Zin, A.T. (2000) Potentialities and Constraints of teak bearing forest for sustainable forest management under current management system in Oattwin township forest, Bago Yoma region, Myanmar. M.Sc.Thesis, Technical University of Dresden, Germany

Appendix 1

Results of basic parameters (Bamaw-Katha region)

Plot No.	age	gm [cm²]/plot	g100 [cm²]	dm [cm]	hm [m]	d100 {cm]	h100 [m]	ba /ha [m²]	N / ha	Volume per ha [m³]
1	37	1531,168	1652,146	44,15364	31,86941	45,86477	32,21122	19,56493	128	179,1352
2	36	982,8862	1074,299	35,37583	26,43919	36,98433	30,15327	12,28608	125	104,1976
3	36	769,2094	828,9363	31,29517	23,73829	32,48745	28,76659	11,6337	169	93,28658
4	36	1019,441	1056,792	36,02767	25,26773	36,68173	25,43437	11,04395	108	94,35161
5	37	1344,312	1364,788	41,37186	30,69156	41,68575	30,73948	14,18996	106	121,0775
6	37	1550,756	1453,61	44,43516	32,2666	43,02086	31,90899	20,67674	133	189,6478
7	31	792,0543	974,0778	31,75649	24,16533	35,21696	24,61644	9,217152	175	114,2409
8	31	835,2622	1013,746	32,61118	24,61992	35,92689	24,82681	10,01974	153	106,6389
9	23	647,7857	865,3814	28,71909	25,84956	33,19394	26,61359	15,29494	236	122,6615
10	23	593,542	918,902	27,49038	22,15598	34,20501	23,76381	14,01419	236	115,3098
11	23	724,2828	917,5165	30,36751	27,18948	34,17921	27,58996	12,47376	172	102,0901
12	23	582,179	589,2369	27,22597	25,61049	27,3905	25,69113	14,23104	244	113,6517
13	10	88,58129	57,80369	10,62004	11,05914	8,578925	9,312932	3,174163	358	42,6787
14	16	152,4373	265,2559	13,93159	13,18164	18,37755	15,403	3,514526	231	35,37537
15	16	208,2959	373,7586	16,28529	15,70618	21,81477	16,77785	5,843856	281	53,394
16	16	195,0007	400,978	15,75698	16,56503	22,59516	18,17353	6,770856	347	66,49451
17	19	313,1253	576,6375	19,96706	19,42024	27,09608	21,99961	9,045841	289	72,73044
18	19	340,6913	466,0458	20,82743	19,44494	24,35955	20,84823	8,990465	264	70,51184
19	19	356,3897	493,4146	21,30186	19,65375	25,06462	21,09127	8,909741	250	69,91427
20	35	757,4962	1261,885	31,05598	30,91445	40,08344	35,09048	16,97714	306	194,7671
21	35	762,5234	921,4888	31,15887	29,86184	34,25312	30,2333	12,70872	167	103,8718
22	35	878,171	1091,649	33,43833	30,19572	37,28178	31,51194	17,07555	194	142,3169
23	35	746,1691	931,0767	30,82291	29,20387	34,43085	30,23364	15,95973	214	129,3736
24	39	903,182	1137,978	33,91116	28,82965	38,06466	30,76559	15,5548	172	131,026
25	37	943,9377	1189,228	34,66783	30,5085	38,91237	31,53107	15,02287	189	151,3673
26	37	1198,188	1432,488	39,05868	31,78209	42,70715	32,4628	19,30414	161	170,1433
27	26	873,7416	992,5642	33,3539	29,23923	35,54957	29,69883	11,40718	131	95,53784
28	26	467,2086	644,5495	24,38993	20,43195	28,64727	21,82769	7,52725	161	62,94137
29	28	651,5169	898,7489	28,80169	26,24111	33,82784	28,41781	17,55476	269	141,0164
30	28	704,1813	1021,386	29,94314	28,64319	36,06202	29,42996	20,53862	292	167,5375
31	41	1176,222	1697,429	38,69901	29,41471	46,48907	33,36109	22,54426	192	204,452
32	41	905,0057	1426,898	33,94538	30,4476	42,62373	35,19524	19,35707	214	172,7805
33	40	1468,054	1760,5	43,23407	33,93704	47,34489	34,89612	31,40005	214	285,4901
34	40	1133,468	1405,19	37,98916	27,86726	42,29826	28,50226	20,15055	178	175,9947
35	40	1402,748	1637,109	42,2615	31,72348	45,65559	32,36693	22,98949	164	208,0582
36	39	1276,18	1425,106	40,30984	32,2844	42,59697	32,57723	17,72473	139	157,4841
37	39	1362,569	1580,972	41,65185	31,80962	44,86598	32,86523	21,9525	161	197,2775
38	39	475,0524	801,1882	24,59381	27,64291	31,93908	28,61694	16,89075	356	134,9556
39	33	823,6044	1082,172	32,3828	30,97325	37,11959	31,74245	20,59011	250	169,8181
40	33	788,5253	1005,756	31,68567	30,93012	35,78502	30,93012	19,27506	244	157,3204
41	33	740,0081	1046,946	30,6954	26,6173	36,51044	28,6097	19,32243	261	158,1416
42	11	108,6574	194,7341	11,7621	10,14754	15,74621	11,33281	4,497209	414	54,82588
43	8	102,9514	202,7771	11,4491	12,58486	16,0681	15,11702	6,034099	586	75,76365
44	8	117,2408	192,3503	12,21784	11,4527	15,64954	11,4527	4,266261	364	50,51397

Appendix 2

Results of basic parameters (Bago Yoma region)

Plot No.	age (years)	gm[cm²]	g100[cm²]	number of trees per plot	dm [cm]	hm [m]	d100 {cm]	h100 [m]	g /ha [m²]	N/ ha	Volume per ha [m³]
1	21	324,88	473,94	84,00	20,34	16,47	24,57	17,81	2,15	233	45,55
2	21	324,15	498,79	99,00	20,32	17,06	25,20	18,60	8,91	275	53,46
3	21	353,27	325,19	98,00	21,21	17,41	20,35	17,22	9,62	272	53,29
4	21	386,90	541,11	82,00	22,19	18,44	26,25	18,33	8,81	228	52,72
5	21	314,85	487,60	114,00	20,02	15,95	24,92	18,12	9,97	317	58,96
6	21	197,73	305,25	88,00	15,87	14,04	19,71	15,77	4,83	244	21,09
7	18	269,88	397,65	71,00	18,54	15,88	22,50	16,36	5,32	197	32,97
8	18	218,75	331,40	77,00	16,69	15,15	20,54	15,74	3,92	214	25,23
9	18	307,18	407,27	56,00	19,78	16,70	22,77	16,99	4,78	156	29,55
10	20	323,27	491,37	64,00	20,29	11,12	25,01	11,91	5,75	178	37,98
11	20	892,37	1143,81	75,00	33,71	16,41	38,16	17,54	18,59	208	129,82
12	20	311,98	470,74	69,00	19,93	11,86	24,48	12,70	5,98	192	37,34
13	20	428,11	729,82	78,00	23,35	14,29	30,48	17,64	6,57	217	61,53
14	16	47,21	80,72	97,00	7,75	7,31	10,14	9,41	1,27	269	15,84
15	16	51,26	78,04	102,00	8,08	9,15	9,97	10,66	1,45	283	17,84
16	17	197,73	305,25	88,00	15,87	15,07	19,71	16,66	4,83	244	32,22
17	24	123,23	169,84	64,00	12,53	13,78	14,71	13,61	2,19	178	17,14
18	37	1642,36	1761,71	41,00	45,73	33,16	47,36	33,42	18,70	114	142,77
19	37	1617,34	1904,00	60,00	45,38	30,25	49,24	30,80	15,42	167	205,12
20	37	1184,55	1184,55	34,00	38,84	23,90	38,84	23,90	11,19	94	81,20
21	37	1686,38	1686,38	48,00	46,34	32,79	46,34	32,79	22,49	133	172,68

Appendix-3

The parameters for Stand Height Curves for each plot in Bamaw.Katha region

$h = 1.3 + a_0 * \exp(a_1/d)$

Plot no.	a0	a1
1	44.14417574	-17.5333
2	30.45044779	-6.85378
3	38.86092212	-17.1879
4	35.35401104	-13.9925
5	36.48662296	-8.9505
6	44.08564372	-15.7336
7	27.89461285	-6.3138
8	25.66174564	-3.12113
9	30.81602869	-6.52877
10	30.44582608	-10.401
11	29.70872407	-4.17516
12	42.19008794	-15.0087
13	22.35495129	-10.7626
14	24.13349059	-9.87216
15	19.11660882	-4.6382
16	21.25534545	-5.81622
17	30.04753018	-10.1267
18	30.33140581	-10.6548
19	19.67146053	-1.45184
20	53.19662473	-18.1905
21	32.45433934	-4.45657
22	44.5126224	-14.9479
23	39.4327857	-10.6597
24	51.31974149	-21.1203
25	40.04175779	-10.9364
26	39.4747832	-10.0975
27	36.38676263	-8.81122
28	30.72798598	-11.5563
29	43.80152838	-16.2147
30	32.31896693	-5.0061
31	61.56856084	-30.3348
32	61.16214984	-25.1588
33	45.55935096	-14.4215
34	33.14997537	-8.80811
35	40.31576302	-11.8978
36	36.91708931	-7.06191
37	49.05022234	-19.7642
38	30.84810832	-3.88278
39	36.26295102	-6.49439
40	42.30221125	-11.2816
41	40.73620648	-14.5996
42	14.54171704	-5.84437
43	22.82113833	-8.06274
44	15.89029548	-5.49321

Appendix 4

The parameters for Stand Height Curves for each plot in Bago Yoma region

$$h = 1.3 + a_0 * \exp(a_1/d)$$

Plot no	a0	a1
1	24.73420185	-9.936265346
2	25.50224192	-9.777840066
3	21.40567868	-6.121538444
4	37.90303976	-17.61611293
5	33.06169582	-16.30332885
6	24.47150654	-10.35889996
7	17.57015473	-3.463637403
8	17.28764136	-3.697470832
9	17.74440349	-2.80881712
10	14.77788748	-8.288228157
11	28.01666411	-20.80579535
12	15.91000791	-8.161492513
13	34.5409635	-22.82622286
14	21.50214249	-9.881168185
15	19.79425348	-7.468893168
16	24.07483503	-8.86503759
17	11.35652716	1.18288221
18	40.42858955	-10.89535284
19	36.91304401	-11.03271366
20	37.4881129	-19.66001257
21	46.59541444	-18.15098143

Appendix 5
Yield Tables for Pyinkado (*Xylia dolarbriformis*)

Table1: Yield Tables for Mean Height Site Class 33 **Appendix 5**

(a) Main Crop after Thinning

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)
10	282	11.8	9.5	2.0	18
15	200	17.5	18.2	5.2	47
20	168	22.0	26.6	9.3	84
25	146	25.7	33.8	13.0	117
30	127	28.7	39.9	15.9	143
35	115	31.1	45.2	18.4	166
40	105	33.1	49.5	20.1	181
45	98	34.8	53.0	21.5	193
50	92	36.1	55.8	22.6	204
55	89	37.1	58.2	23.7	214
60	89	38.0	60.4	25.4	229

(b)Yield from Thinning

Age (years)	Number of stems	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Accumulated Volume (m^3/ha)	Thinning intensity (%)
10	168	9.5	1.2	11	0	37.39
15	82	18.2	2.1	19	11	29.03
20	32	26.6	1.8	16	30	15.95
25	22	37.6	2.5	22	46	15.93
30	19	44.4	2.9	26	68	15.30
35	13	50.1	2.5	22	94	11.92
40	10	57.2	2.5	23	116	11.21
45	7	61.0	2.1	19	139	8.80
50	5	64.2	1.7	15	158	6.92
55	3	66.7	1.1	10	173	4.54
60	0	0.0	0.1	1	183	0.54

(c)Total Crop

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	Basal area (m^2/ha)	Volume (m^3/ha)	Total Volume (m^3/ha)	MAI	CAI
10	450	11.8	9.5	3.2	29	29	2.89	5.40
15	282	17.5	18.2	7.3	66	77	5.12	9.58
20	200	22.0	26.6	11.1	100	130	6.50	10.64
25	168	25.7	34.3	15.5	140	186	7.42	11.13
30	146	28.7	40.5	18.8	165	237	7.91	10.36
35	127	31.1	45.8	20.9	188	282	8.06	8.97
40	115	33.1	50.2	22.6	204	320	8.01	7.62
45	105	34.8	53.5	23.6	212	351	7.81	6.22
50	98	36.1	56.3	24.3	219	377	7.53	5.04
55	92	37.1	58.5	24.9	224	397	7.22	4.06
60	89	38.0	60.4	25.6	230	413	6.85	3.28

Table 2: Yield Tables for Mean height site class 29 (continued) **Appendix 5**

(a) Main Crop after Thinning

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)
10	397	10.0	7.0	1.5	14
15	280	15.0	13.5	4.0	36
20	234	19.0	20.1	7.4	67
25	202	22.3	25.8	10.6	95
30	175	25.1	30.9	13.1	118
35	156	27.4	35.3	15.3	138
40	142	29.4	38.9	16.8	152
45	131	31.0	41.9	18.1	163
50	124	32.2	44.4	19.2	172
55	119	33.3	46.5	20.2	182
60	118	34.1	48.5	21.9	197

(b) Yield From Thinning

Age (years)	Number of stems	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Accumulated Volume (m^3/ha)	Thinning intensity (%)
10	238	7.0	0.9	8	0	37.50
15	117	13.5	1.7	15	8	29.42
20	46	20.1	1.5	13	23	16.38
25	32	28.8	2.1	19	36	16.55
30	27	34.4	2.5	23	55	16.08
35	18	39.1	2.2	20	78	12.65
40	14	45.0	2.3	21	98	12.02
45	10	48.3	1.9	17	119	9.54
50	8	51.1	1.6	14	136	7.57
55	5	53.4	1.1	10	150	5.01
60	1	48.5	0.1	1	159	0.58

(c) Total Crop

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Total Volume (m^3/ha)	MAI	CAI
10	635	10.0	7.0	2.4	22	22	2.18	4.08
15	397	15.0	13.5	5.7	51	60	3.98	7.57
20	280	19.0	20.1	8.9	80	103	5.17	8.74
25	234	22.3	26.3	12.7	114	151	6.02	9.45
30	202	25.1	31.4	15.6	140	196	6.52	9.03
35	175	27.4	35.7	17.5	158	236	6.73	7.98
40	156	29.4	39.5	19.1	172	270	6.75	6.90
45	142	31.0	42.4	20.0	180	299	6.64	5.73
50	131	32.2	44.8	20.7	187	322	6.45	4.71
55	124	33.3	46.8	21.3	192	342	6.21	3.84
60	119	34.1	48.5	22.0	198	357	5.95	3.15

Table 3: Yield Tables for Mean height site class 25 **(**continued) **Appendix 5**

(a) Main Crop after Thinning

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)
10	556	8.2	4.9	1.1	10
15	390	12.5	9.8	2.9	26
20	324	16.0	14.8	5.5	50
25	278	19.0	19.2	8.1	73
30	239	21.5	23.2	10.1	91
35	212	23.6	26.8	12.0	108
40	191	25.4	29.7	13.3	119
45	176	26.9	32.3	14.4	129
50	165	28.2	34.4	15.3	138
55	158	29.2	36.2	16.3	146
60	157	30.0	38.0	17.7	160

(b) Yield From Thinning

Age (years)	Number of stems	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Accumulated Volume (m^3/ha)	Thinning intensity (%)
10	335	4.9	0.6	6	0	37.60
15	166	9.8	1.2	11	6	29.82
20	66	14.8	1.1	10	17	16.82
25	47	21.4	1.7	15	27	17.20
30	39	25.9	2.1	18	42	16.89
35	27	29.7	1.9	17	61	13.43
40	21	34.5	2.0	18	77	12.89
45	15	37.3	1.7	15	95	10.33
50	11	39.6	1.0	12	110	8.29
55	7	41.6	0.1	9	122	5.54
60	1	38.0		1	131	0.62

(c) Total Crop

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Total Volume (m^3/ha)	MAI	CAI
10	891	8.2	4.9	1.7	15	15	1.53	2.88
15	556	12.5	9.8	4.2	38	43	2.89	5.60
20	390	16.0	14.8	6.7	60	77	3.85	6.73
25	324	19.0	19.5	9.7	88	115	4.59	7.53
30	278	21.5	23.6	12.2	109	152	5.05	7.40
35	239	23.6	27.1	13.8	124	185	5.29	6.69
40	212	25.4	30.3	15.2	137	215	5.36	5.89
45	191	26.9	32.7	16.0	144	239	5.32	4.97
50	176	28.2	34.8	16.7	150	260	5.20	4.15
55	165	29.2	36.5	17.2	155	277	5.04	3.43
60	158	30.0	38.0	17.8	161	292	4.86	2.86

Table 4: Yield Tables for Mean height site class 21 (continued) **Appendix 5**

(a) Main Crop after Thinning

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)
10	776	6.5	3.2	0.6	6
15	540	10.0	6.6	1.9	17
20	414	13.0	10.2	3.4	31
25	351	15.6	13.6	5.1	46
30	298	17.9	16.8	6.6	59
35	261	19.9	19.7	8.0	72
40	237	21.6	22.2	9.2	83
45	220	23.1	24.4	10.3	93
50	209	24.3	26.4	11.5	103
55	201	25.4	28.1	12.5	112
60	199	26.2	29.7	13.8	125

(b) Yield From Thinning

Age (years)	Number of stems	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Accumulated Volume (m^3/ha)	Thinning intensity (%)
10	471	3.2	0.4	3	0	37.76
15	236	6.6	0.8	7	3	30.42
20	126	10.2	1.0	9	11	23.32
25	63	15.2	1.1	10	20	18.22
30	53	18.7	1.5	13	30	18.19
35	36	21.9	1.4	12	44	14.69
40	24	25.7	1.2	11	56	11.93
45	18	28.2	1.1	10	67	9.71
50	11	30.4	0.8	7	77	6.32
55	8	32.3	0.7	6	84	5.15
60	1	29.7	0.1	1	90	0.69

(c) Total Crop

Age (years)	Number of stems	Mean height (m)	Mean diameter (cm)	basal area (m^2/ha)	Volume (m^3/ha)	Total Volume (m^3/ha)	MAI	CAI
10	1247	6.5	3.2	1.0	9	9	0.92	1.74
15	776	10.0	6.6	2.7	24	27	1.83	3.65
20	540	13.0	10.2	4.4	40	51	2.54	4.66
25	414	15.6	13.9	6.3	56	76	3.06	5.13
30	351	17.9	17.1	8.0	72	103	3.43	5.27
35	298	19.9	20.0	9.3	84	127	3.64	4.93
40	261	21.6	22.5	10.4	94	150	3.75	4.48
45	237	23.1	24.7	11.4	103	170	3.77	3.99
50	220	24.3	26.6	12.2	110	187	3.74	3.48
55	209	25.4	28.3	13.2	118	202	3.68	3.05
60	201	26.2	29.7	13.9	125	216	3.59	2.63