# Modelling Teak Forest Growth and Scenario Analyses

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## Summary

*Based on three experimental plots in Teak stands from the Mae Moh plantation in Northern Thailand the distance dependent single tree model SILVA is parameterized. This parameterization shall serve for educational, teaching and training purposes in the context of a training course on system analysis and modelling in Chiang Mai in 1997. The parameterization included a model for crown diameter and crown intersection, potential height and potential diameter growth, real height and real diameter growth and mortality. Local values for timber sales prices and harvesting costs are included.*

*With the parameterized model a scenario analysis was performed. The reference scenario was characterized by real site conditions and a planting pattern like in Mae Moh plantation and no thinning impact over the total simulation period. The simulation period reached from the starting age 11 up to 120 years stand age. For two scenarios the site conditions were variied (one better site and one worse site), two further scenarios showed a thinning from above and a thinning from below. The two last scenarios modified the initial stand structure at the starting age, and instead of a planting pattern one structure was randomized, another was determined by a broad logging trail.*

*The results of the scenario analysis revealed that on medium site conditions the mean annual increment in timber volume culminates at a stand age of about 60 years. The mean net value increment culminates about 10 to 20 years later, depending on the sales prices for log wood. A regular planting pattern seems to maximize volume production and the net financial turn out. Heavy thinning does not seem to be an advantage because of expected losses in volume production. Because of a lot of modelling, especially data restrictions the results have a limite d reliability.*

## 1. Preface

In the year 1997, from Febr. 25th to March 25, the German Foundation for International Development (DSE) conducted a training course on Computer Aided System Analysis for the Sustainable Management of Tropical Forest Resources. The course took place at Chiang Mai University in Thailand in cooperation with the Faculty of Agriculture and with Dr. Apichart from the Department of Forest Resources as counterpart. 20 participants from Southeast Asia attended the course which had a special focus on system analysis and modelling of socio-economic issues and on forest growth and yield. During the training course three experimental plots in Teak stands were established by the participants, the data were analyzed and used for parameterizing a distance dependent single tree growth model. This model was applied for scenario analyses in Teak management, for structure analysis in a natural forest reserve and for agroforest modelling and analyses. The presentation in the next chapters gives an overview of the chosen modelling and analysis approach and the most important results.

## 2. Introductionary remarks

There are a lot of different approaches for modelling forest growth. They can generally be categorized into 3 different classes: stand models, single tree models and ecophysiological or process models (for more details see for example PRETZSCH, 1998). Stand models have proven to be easy in modelling, but in general they are suitable for even aged and pure species stands only. In tropical and subtropical regions they can surely be applied very effectively to Teak, Eucalyptus or Pine plantations. The most famous realizations of stand models are the yield tables. The great disadvantage of these models is that the approach can not be applied for modelling uneven aged and mixed species stands. So they shall not be considered here.

Process models are very sophisticated from a methodical point of view and they may help in biological understanding. Yet they are not suitable for management purposes, because the results of a growth prognosis from a process model is more reliable in a qualitative than in a quantitative sense. Process models are at present not recommendable for management purposes, i.e. as decision support tools for forest management.

The most favourable approach for modelling forest growth is actually based on single tree models. They can be classified into distance dependent and distance independent models. The latter do not consider the treeís position for a growth prognosis. But the treeís position in a stand is decisive for its growth, because it determines the competitive situation of a single tree. Distance dependent growth models seem to be at present the most powerful tools to model forest growth, they are reliable and most suitable for management purposes, for supporting in ecological understanding and for educational, teaching and learning purposes. The single tree and distance dependent growth model SILVA 2 shall be the basis for the following modelling. The data for this modelling have been assessed on experimental plots in Teak stands in the Mae Moh plantation near Lampang (KAHN, 1998). After the model has been parameterized scenario analyses are performed.

## 3. Parameterizing SILVA 2 for Teak stands in Northern Thailand

In the following chapters a scetch of parameterizing the single tree model SILVA 2 (PRETZSCH, 1992) for Teak stands (Tectona grandis L.) in Northern Thailand is given. Of course not all the details can be presented, but it will give a rough idea how the model works and which steps are of decisive importance. Which steps are necessary? A single tree growth model consists of modules to estimate diameter and height growth, it needs a site model, a model to generate stand structure, a crown model including crown intersection and crown diameter and a mortality model. Because only one site in Mae Moh plantation is analyzed here we get only a simple approach to site modelling. The module of SILVA to generate stand structure will not be modified. So the following passages concentrate on height and diameter growth and on crown intersection and crown diameter.

### 3.1 Modelling Crown Diameter

The crown diameter is modelled by a simple allometric equation:

$$CDiam = a_0 * DBH^{a_1}$$

The parameters are fitted with a non linear regression (although a linearization is possible after a logarithmic transformation). Before that the crown diameter as dependent variable is calculated from the 4 crown radii by the quadratic mean as

$$CDiam = \sqrt{\frac{\sum_{i=1}^{n} crad^2}{n}}$$

where

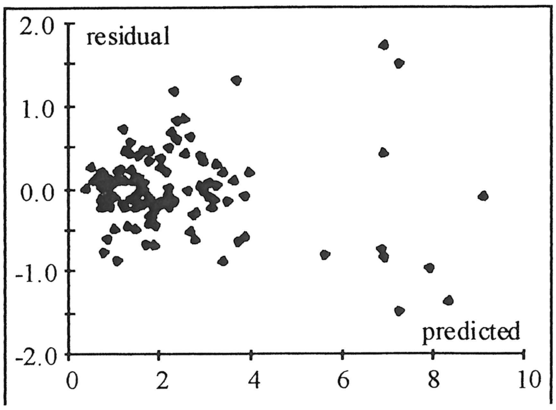
crad = crown radius in m
n = 1 to 4 (radius from north, east, south and west).

The parameters for Teak are summarized in table 1.

Table 1: Parameters of the model to estimate crown diameter for Teak trees:

| Parameter | Parameter estimate | Asymptotic standard error of the parameter | $R^2$ | N |
|---|---|---|---|---|
| $a_0$ | 0.186440936 | 0.018399093 | 0.89760 | 123 |
| $a_1$ | 0.905931009 | 0.027468236 | | |

The standard errors of the parameter estimates are small, the model is stable. Figure 1 shows the crown diameters as they were assessed on the experimental plots and the curve fit. In addition the residuals are plotted over the predicted values, and although the residuals are heteroscedastic the model seems to be unbiased.



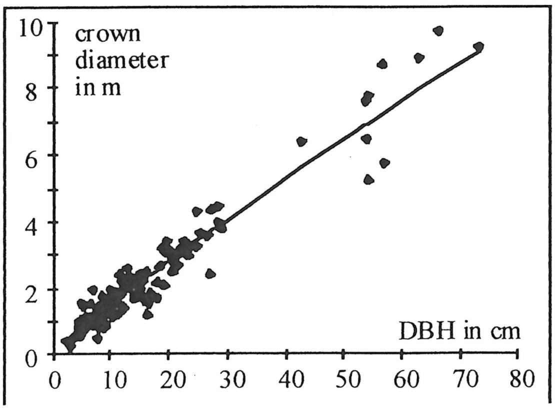


Figure 1: Residuals over predicted values and crown diameter over DBH of data from the Teak experimental plots in Mae Moh plantation.

### 3.3 Modelling Crown Intersection

The crown intersection is modelled using the following equation:

$$CInt = height * (1 - e^{a_0 + a_1 * DBH + a_2 * height/DBH})$$

The parameters are fitted with a non linear regression, although also here a linearization is possible. The parameters for Teak are summarized in table 2.

Table 2: Parameters of the model to estimate crown intersection for Teak trees:

| Parameter | Parameter estimate | Asymptotic standard error of the parameter | $R^2$ | N |
|---|---|---|---|---|
| $a_0$ | -0.270089717 | 0.056514090 | 0.86237 | 123 |
| $a_1$ | -0.007463189 | 0.001050255 | | |
| $a_2$ | -0.022321619 | 0.039698033 | | |

The standard errors of the parameter estimates are small, the model is stable. Figure 2 shows the residuals over the predicted values, and there appears to be a small bias. The crown intersection model for different height/DBH-ratios reveals that trees with the same diameter at breast height have a crown intersection that is the higher the larger the height/DBH-ratio is. This is in general a well known biological fact, so the crown intersection model seems to be biologically reliable.

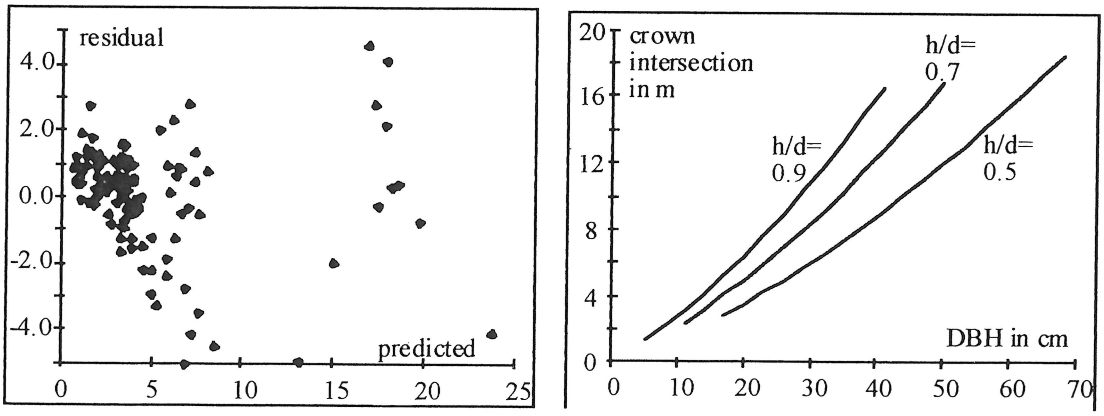


Figure 2: Residuals over predicted values and crown intersection over DBH for different height/DBH-ratios (h/d) of data from the Teak experimental plots in Mae Moh plantation.

## 3.4 Potential Modifier Approach

There are a lot of successful concepts of modelling height and diameter growth. Often multiple linear regression models of the form

$$\text{increment}_{\text{real}} = a_0+a_1*x_1+\text{Ö}+a_n*x_n$$

are applied, with $x_i$ as any mathematical transformation of suitable or unsuitable variables one can imagine. Yet these formulars do not show any acceptable chance of switching from description to explanation, i.e. from correlation to causality. Although this is true also for non linear regression models, especially the potential modifier approach shows a close formal relationship to system analytic modelling as it is used for example in the context of socio-economic analyses. The potential modifier approach can be scetched as follows:

$$\text{increment}_{\text{real}} = \text{increment}_{\text{potential}}*\text{increment}_{\text{modifier}}$$

The real increment is estimated as the product of a potential increment with a modifier, the so called potential modifier. The potential increment is site dependent, and it is assumed to be free from any inter- and intraspecific competition. The concept of a potential modifier is applied for estimating the height increment and for estimating the diameter increment. So the next chapters concentrate at first on the derivation of a potential height and a potential diameter increment. Then the respective modifier functions are presented.

## 3.5 Potential Height Increment

The potential height increment is derived from a site dependent height curve over time. A monomolecular growth function is applied to estimate the potential top height $h_{pot}$ over stand age:

$$h_{pot} = const + A*(1-e^{-k*age})$$

where

$h_{dom}$ = top height
age = stand age
const = an additive constant
k = slope parameter

This function has shown to be the best for modelling height growth of Teak, given the data from the experimental plots at Mae Moh Teak plantation. This tree species has obviously no inflexion point in its height development. The parameters are const=8, A=40.74 and k=0.012. It makes no sense here to give values for the $R^2$ or the standard errors of the parameters because only 3 values were available (the top heights of the three experimental plots). The inclusion of the constant was statistically necessary, so the model must not be extrapolated below stand ages of about 10 years. Of course extrapolations beyond 100 years are also problematic. Figure 3 shows the potential stand height growth as it was assessed on the 3 plots of Mae Moh plantation.

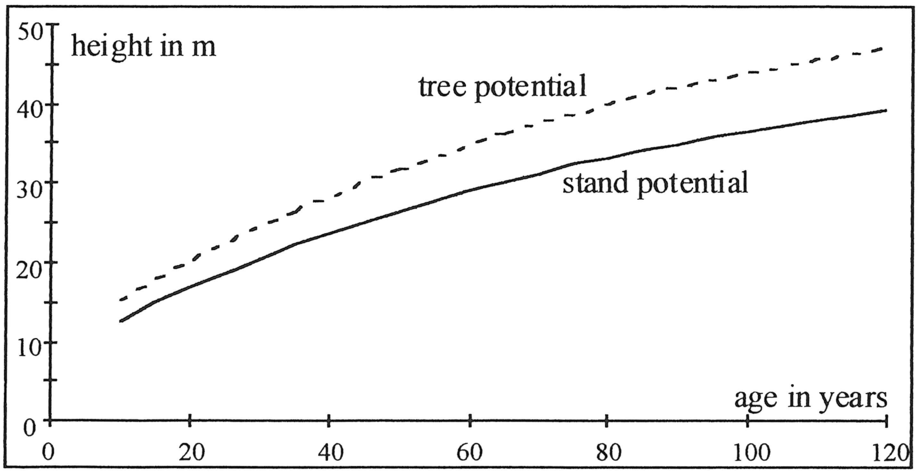


Figure 3: Site dependent height growth over age on the Teak experimental plots in Mae Moh plantation.

From figure 3 it is easy to see that the measured plots had a site index of about 20, that is the height at age 30 amounts to about 20 m (see for example ROYAL FOREST DEPARTMENT, 1992). Because we need a potential height growth of single trees, the $h_{pot}$ is enlarged by a factor of 1.2 which is derived from the plot data, i.e. the highest tree on a plot is in no case more than 20% higher as $h_{pot}$. To assess an age independent potential height increment the inverse $h_{pot}$-function is applied. Let a tree have the height $h_t$, then its theoretical age is given with

$$age_{theoretical} = \frac{-\ln(1-{}^{(h_t-const)}/_{A})}{k}.$$

After a period of say 5 years the example tree would have a height of

$$h_{t+5} = const + A*(1-e^{-k*(age_{theoretical}+5)}),$$

so that the potential height increment is given with

$$ih_{pot} = h_{t+5} - h_t$$

The parameters A and k of the monomolecular height growth function are assumed to be dependent on site variables. Because of a lack of data only the parameter A as the asymptotic value of the height growth is (normatively) implemented into SILVA to be site dependent.

### 3.6 Potential Diameter Increment

The development of height over DBH can be described with a S-shaped function, for example a 3-parametric Chapman-Richards function. To derive a potential diameter increment this relationship is used by applying an inverse Chapman-Richards function for the relationship diameter over height:

$$DBH_{height} = \frac{-\ln\left(1 - \sqrt[p]{{(height-1.3)}/{A}}\right)}{k}$$

In this function the parameter A is fixed, because it is the same as in the model height over age multiplied by 1.2, so it results in A=48.888. Because of this the potential diameter is theoretically site dependent. The parameters k and p have to estimated by a non linear regression (table 3).

Table 3: Parameters of the model to estimate a potential tree diameter for Teak trees:

| Parameter | Parameter estimate | Asymptotic standard error of the parameter | $R^2$ | N |
|---|---|---|---|---|
| k | 0.024776006 | 0.001009484 | 0.92418 | 119 |
| p | 1.223538866 | 0.050705382 | | |

The standard errors of the parameter estimates are low, the estimation gives good results. The function is depicted in figure 4.

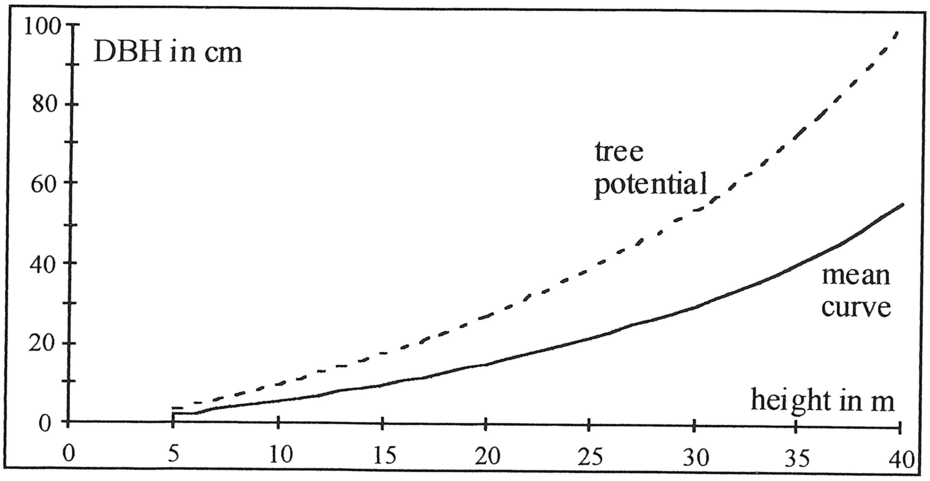


Figure 4: Potential diameter at breast height in dependence on height on the Teak experimental plots in Mae Moh plantation.

The estimation of $DBH_{height}$ is not yet a potential diameter, because the regression fits the curve by minimizing the sum of squared residuals. Starting from this, the residuals are transformed to be relative to $DBH_{height}$, then the mean value $mean_{res}$ (should be 0) and the standard deviation of the relative residuals $std_{res}$ are calculated, and the potential diameter results from a factor 3 extension of $std_{res}$, which is 0.27 here, as

$$DBH_{pot} = DBH_{height} + (mean_{res} + 3*std_{res})*DBH_{height}$$

To get now a potential diameter increment $DBH_{pot}$ for a tree with a given height at first its $DBH_{pot}$ at the height ëheightí is calculated. From this results a $DBH_{pot}(height)$. At second the $DBH_{pot}$ at the height ëheight+$ih_{pot}$í is calculated. Then the potential diameter increment is defined as

$$iDBH_{pot} = DBH_{pot}(height+ih_{pot}) - DBH_{pot}(height).$$

With this $iDBH_{pot}$ and $ih_{pot}$ the potential diameter and height increments are given, so that the potential modifier concept can be applied. Both $iDBH_{pot}$ and $ih_{pot}$ are site dependent.

### 3.7 Modelling Height Increment

In the context of modelling Teak growth with only few data given a simple non linear model shall be sufficient for explaining most of the variance found. With the functions

$$r\_height = (1+height/A)$$

and

$$mod_{ci} = a_0*e^{-a1*CI*r\_height}$$

and

$$ih_{real} = ih_{pot} * mod_{ci}$$

the real height increment can be estimated as the product of the potential height increment $ih_{pot}$ and modifier $mod_{ci}$. The modifier $mod_{ci}$ is negative exponentially dependent on the competition index CI, and this modifier itself is dependent on the relative height of the considered tree. The height is relative to the site dependent asymptotic height growth value A. The parameters of the models are summarized in table 4.

Table 4: Parameters of the model to estimate tree height increment of Teak trees:

| Parameter | Parameter estimate | Asymptotic standard error of the parameter | $R^2$ | N |
|---|---|---|---|---|
| $a_0$ | 0.1389923 | 0.0118 | 0.86 | 124 |
| $a_1$ | 0.6631353 | 0.0117 | | |

The standard errors of the parameter estimates are very small, the $R^2$ is quite high. The standard deviation of the residuals relative to the predicted values is 0.45, the mean of these relative residuals amounts to -0.08. These data are important because during a prognosis run of SILVA the estimated height increments are additionally modified with a N(-0.08,0.45) distributed random variable.

## 3.8 Modelling Diameter Increment

The model for estimating diameter increment is similar to the height increment model. There is only one more additional parameter that modifies the factor r_height. The model functions are

$$r\_height = (1+height/A)^{a2}$$

and

$$mod_{ci} = a_0 * e^{-a1*CI*r\_height}$$

and

$$iDBH_{real} = iDBH_{pot} * mod_{ci}$$

Table 5 includes the parameters of this model.

Table 5: Parameters of the model to estimate tree DBH increment of Teak trees:

| Parameter | Parameter estimate | Asymptotic standard error of the parameter | $R^2$ | N |
|---|---|---|---|---|
| $a_0$ | 0.4681010 | 0.0112 | 0.63 | 108 |
| $a_1$ | 0.1135231 | 0.0190 | | |
| $a_2$ | 4.0562134 | 0.5402 | | |

The standard errors of the parameter estimates are relatively small, the $R^2$ is considerable high. As described for the height increment relative residuals are calculated to modify the estimated DBH increment with a normal distributed random variable. The mean value of the relative residuals is here 0.06 and the standard deviation reaches 0.32 only.

## 3.9 Modelling Mortality

Getting data about natural mortality in an ad hoc assessment as it was in Mae Moh plantation is difficult. Because a mortality function is necessary for model runs without thinning, a competition based mortality is assumed. Therefore the competition indices over tree height are plotted and a covering function is designed that lies above all occuring competition index values at a given height. During a prognosis run all trees that show a competition index higher than this covering function are assumed to die. This process of natural mortality is supported by a random choice process.

## 3.10 Critical remarks

The modelling has to be accompanied with some critical remarks that are special in the context of the training course. The first critics brings again the small sampling size into mind. We investigated only three plots, so we estimate the growth dynamics on the basis of only three points (concerning stand level). Because of the small plots the tree numbers are very low too, so that the sampling size is small. In addition the edge effects at the borders of the plots may be considerably high in comparison to the number of trees that have no edge effects. These disadvantages have to be skipped when planning a research for an absolutely reliable forest growth and yield modelling.

The second critics refers to the site dependency of the model functions, for example potential height growth and potential diameter growth. Only one site was investigated, so changing site conditions in the model is an extrapolation. In addition the site conditions of the 100 year old plot seem to be better than on the younger plots. But it is important to recognize that with data from different sites for example with site indices from 10 to 30 (top height at the age 30) site effects can be very effectively included because of the flexible model structure.

A third critical remark concerning only little knowledge about processes in natural mortality has already been done, but it seems to be important to mention it here again. For the following scenario analyses with the SILVA 2 model based on the proceeding modelling steps these weak points should be kept in mind, but it is also important to see that the critics are no weak point of the modelling structure or research concept but mainly result from the small data base because of limited time that has been available.

# 4. Scenario Analysis with the forest growth simulator SILVA 2

## 4.1. Concept of Scenarios

A scenario analysis shall provide results and solutions on a problem that is otherwise difficult to solve. Such problems are widespread in forestry, because working on an ecosystem in combination with socio-economics is really a hard task. In the following we assume that we do not know much about Teak management, but that we want to learn about growth dynamics in Teak stands with the help of the growth model SILVA 2, that is parameterized for Teak stands in Lampang province. The factors we want to analyze are site, thinning and stand structure and their effects on Teak growth and the economic turn out.

A scenario analysis should have a statistical background, i.e. we do not want to perform one prognosis run and to draw far reaching conclusions. More recommendable is a systematic approach: a scenario analysis shall cover the best, the worst and the most probable scenario. In addition every scenario that is analyzed with the model shall be repeated many times, so that a statistical analysis of the results gets possible and a sensitivity analysis can be conducted. The latter is not possible in the context of a time limited training course. Therefore we perform only 1 simulation run for the worst, best and most probable scenario. And in respect of classifying best, worst and average scenarios this is just what we want to find out: what is the best thinning regime, which is the most profitable planting pattern and which effect has site on the yield? The following scenarios are analyzed:

(1) reference scenario with
  - real site conditions of the 11 year old plot in Lampang
  - no thinning
  - real structure of the 11 year old plot

(2) Site scenarios with
  a) - site is better than in the reference scenario
  - no thinning
  - real structure of the 11 year old plot

  b) - site is worse than in the reference scenario
  - no thinning
  - real structure of the 11 year old plot

(3) Thinning scenarios with
  a) - thinning from below, basal area control curve for strength of thinning
  - site conditions of the 11 year old plot
  - real structure of the 11 year old plot

  b) - thinning from above, basal area control curve for strength of thinning
  - site conditions of the 11 year old plot
  - real structure of the 11 year old plot

(4) Structure scenarios with
  a) - random tree distribution
  - site conditions of the 11 year old plot
  - no thinning

  b) - a broad logging trail through the plot, beside this trail the trees are randomly distributed
  - site conditions of the 11 year old plot
  - no thinning

So there are in total 7 scenarios, starting in age 11 with a simulation up to age 120. Scenario 1 is the reference, to which all other scenarios are compared. The second scenario changes site conditions a little bit, so that the extrapolation in respect to the real site conditions is quite small. On the one hand side the site is assumed to be better, on the other hand side it is assumed to be worse. Better means that at a stand age of 100 years the top height is 6 m higher than on the reference plot, and worse means it is 6 m lower. The thinning scenarios consider a thinning from below and one from above. The strength of the thinning is controlled by a basal area curve, which origins from a yield research from local Teak researchers (ROYAL FOREST DEPARTMENT, 1992). A third group of scenarios considers different starting conditions concerning stand structure. The reference scenario has a structure resulting from a 4m x 2m-planting pattern. The first structure scenario starts with a random pattern, i.e. the distances between a tree and itís nearest neighbour are Poisson distributed. The second structure scenario has also random distributed tree distances, but along the mid of the plot a broad logging trail is established. The main effect of this trail is that the trees must be positioned on the remaining plot area, so that there is much higher competition. But in advance we do not yet know if this higher competition can be compensated by the trees that stand along the logging trail, because they have more space to grow.

### 4.2. Results of the simulation runs: sales prices and harvesting costs

The results of the scenario analysis are so complex that the presentation is restricted to the key variables mean annual volume increment and mean annual net value increment. These key variables indicate the natural production on growth and yield and the economic turn out in respect to log wood sales and harvesting costs. For the calculation of the financial turn the data from table 6 are used.

Table 6: Girth-dependent sales prices for Teak timber and harvesting costs.

| Girth | sales price | harvesting costs | net value |
|---|---|---|---|
| □ 30 cm | $188\ \mathrm{US\$/m^3}$ | $92\ \mathrm{US\$/m^3}$ | $96\ \mathrm{US\$/m^3}$ |
| 31cm - 50 cm | $250\ \mathrm{US\$/m^3}$ | $92\ \mathrm{US\$/m^3}$ | $158\ \mathrm{US\$/m^3}$ |
| 51 cm - 70 cm | $292\ \mathrm{US\$/m^3}$ | $92\ \mathrm{US\$/m^3}$ | $200\ \mathrm{US\$/m^3}$ |
| 71 cm - 90 cm | $333\ \mathrm{US\$/m^3}$ | $92\ \mathrm{US\$/m^3}$ | $241\ \mathrm{US\$/m^3}$ |
| > 90 cm | $833\ \mathrm{US\$/m^3}$ | $92\ \mathrm{US\$/m^3}$ | $741\ \mathrm{US\$/m^3}$ |

Ttable 6 shows that the harvesting costs are assumed to be constant, although they might decrease with increasing girth. It is also a quite rough assumption that the sales prices remain constant when the girth is larger than 90 cm. But these data are more or less related to local average costs and sales prices for Mae Moh plantation and they are assumed to be constant also during the time periods in the prognosis runs. Because the sales prices keep constant for girth > 90 cm and because the harvesting costs do not decrease with increasing girth the scenarios are more pessimistic than optimistic and so there probably will be no over estimation of the financial turn out.

Figure 5 shows an aspect of the stands at the starting age of 11 years, after 50 years (age 61) and in the end of the simulation (stand age about 120 years) for the reference scenario, that is characterized by real site conditions, no thinning impact and the real stand structure from experimental plot no. 1.

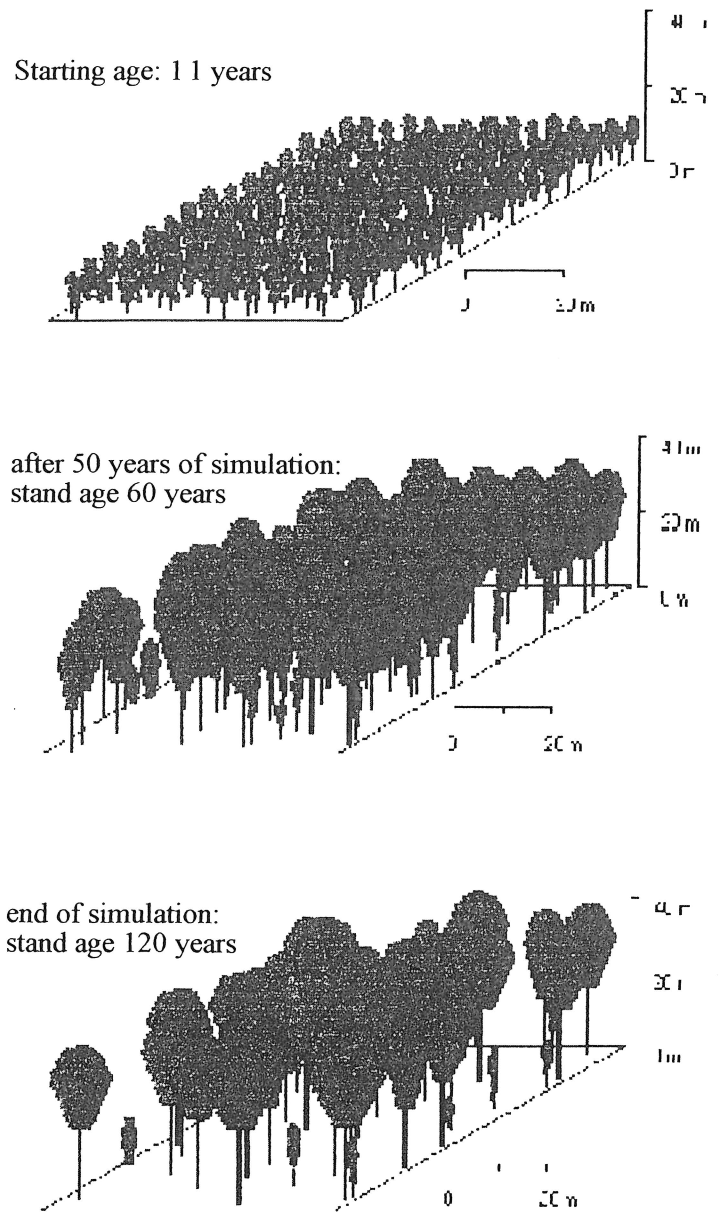


Figure 5: Aspect of the Teak stands for the reference scenario (real site conditions, no thinning, real structure), simulation results from SILVA 2.

## 4.3. Results of the simulation runs: mean annual volume increment

Concerning the results on growth and yield, indicated by the mean annual increment MAI of merchandable volume, figure 6 shows for changes in site conditions that the best site of course has the highest MAI, the worst site has the lowest. It can be seen that the MAI culminates at a stand age of about 60 years on the real site, so this may be the optimum rotation period concerning the production of Teak timber. During the culmination time the MAI amounts to about 11.4 m$^3$ merchandable timber volume per ha and year. On the worse site the MAI reaches only about 8 m$^3$ per ha and year, and on the best site it is remarkable 18 m$^3$ per ha and year. Of course these values for the best and the worst site are not very reliable because the extrapolations on site conditions are not based on real data (KAHN,1998).

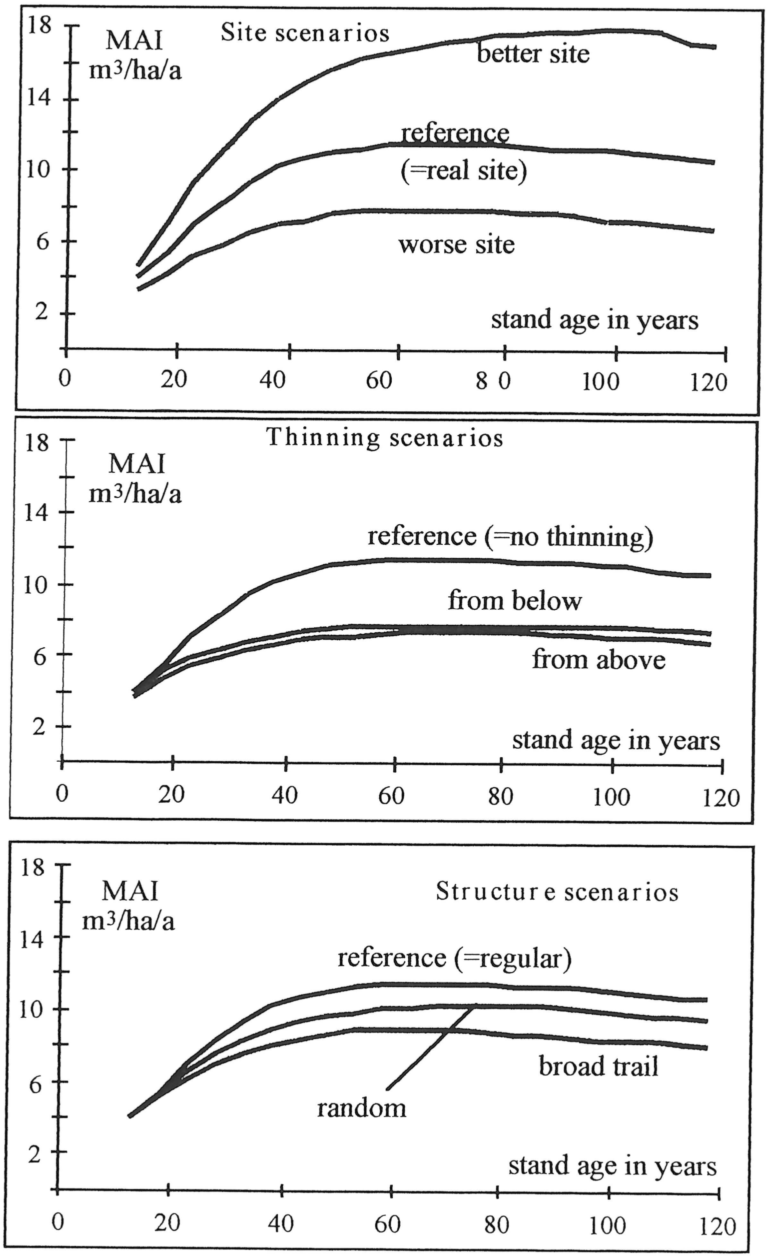


Figure 6: Mean annual merchandable timber volume increment (MAI) in the scenarios.

The scenarios on thinning strategies show that the concept ‚no thinning‘ is superior to ‚thinning from below‘ and ‚thinning from above‘ in respect to timber volume production. The strength of the thinning impact is controlled by stand basal area curves from the local yield table. So, if the basal area of the stand is forced to develop along the basal area control curve from the local Mae Moh yield table, the stand cannot fully use its productive capacity. Of course this is true only if the mortality model is reliable, and the respective problems were already mentioned. Another interesting observation is the higher production of the ‘thinning from below scenario’ in comparison to the 'thinning from above scenario'. This seems to be quite reasonable because a thinning from above removes often the most productive tree individuals (but which should have a worse stem quality).

The scenarios on modifications of the inital stand structures show impressively the effect of structure on stand growth. The more regular the stand structure is the higher is the volume increment (fig. 6). If the tree distribution is randomized, the productivity goes down. This underlines that the 4m x 2m planting pattern of the stands from Mae Moh plantation is superior to the analyzed alternatives. The broad logging trail led to the highest losses in timber volume production.

### 4.4 Results of the simulation runs: mean annual net value increment

Timber volume production is important, but the search for the best solution often focuses on monetary parameters. So the next paragraphs will concentrate on the mean annual net value increment MAI in US $ per ha and year. It seems that in the reference scenario the financial MAI culminates afew years later than the MAI on timber volume, so the optimum rotation time may ly at an each of about 80 years (fig. 7). This appears to be reasonable under considering the increasing timber sales prices with increasing tree diameter.

Because the financial MAI remains nearly constant above a stand age of about 70 years it could be more profitable under considerations in respect to liquidity and interest rates to cut Teak better to early than to late.

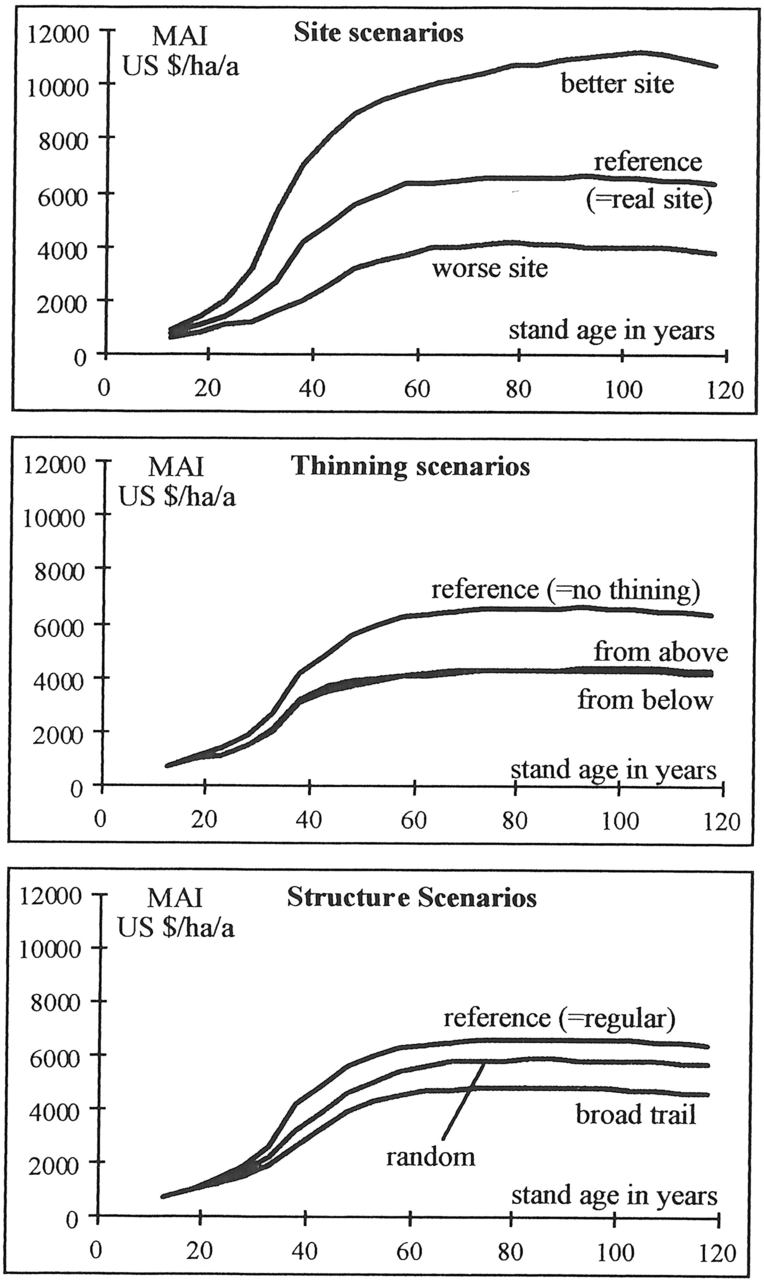


Figure 7: Mean annual net value increment (MAI in US $ per ha and year) in the scenarios.

Concerning the effect of thinning on the financial MAI there occurs now a little variation in comparison to the timber volume MAI, because financially the thinning from above seems to be more profitable than the thinning from below. Probably the removal of productive competitors lead to an over compensation of the net value production by the remaining trees, which experienced an improved competitive situation (enlarged growing space). The scenarios an modifying the inital stand structures lead to similar results for the financial MAI as could be observed for the volume MAI.

## 4.5 Discussion and critical remarks

The conclusions from the scenario analyses are:

Site conditions are the most important productivity and profit determining factors. Nevertheless, they are not that easy to change, maybe they should not be changed.

Thinning impact can lead to heavy losses in productivity and profit, if the control curve for the strength of thinning is to low. With the given timber prices the concept 'no thinning' reaches the best results, because it has the highest productivity, and in addition the sales prices for low dimensioned log wood are considerable high. It must be recognized that aspects of timber quality are not considered here too, but especially stem quality is heavily dependent on thinning impact.

The results from structure analysis show very clear that for Teak production a regular pattern seems to be the best. Teak is a light demanding species, and a regular pattern can minimize competition between trees. Obviously Teak reacts immediately on too high competition, and the increment goes down (fig. 8).

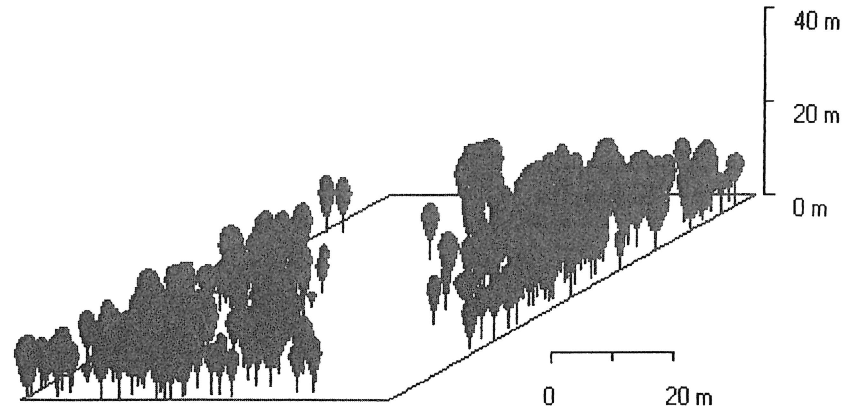


Figure 8: Starting conditions with a logging trail (scenario 4b) lead to increment losses.

Based on this result and in combination with the results from the thinning scenarios the best Teak management may be a careful control of the competition between trees without harvesting to much, so that the site productivity reaches its optimum. If in dependence on the situation on the timber market high quality log wood is demanded, this low impact strategy should be combined with a selective thinning, that is here a weak thinning from above which removes all those trees, that are big but of bad quality.

Finally it shall again be emphasized that the presented results are derived from simulations. These simulations base on a single tree model which is parameterized with data that were assessed on three small experimental plots on a Teak plantation in Northern Thailand. Therefor the results should be seen as what they are: examples for the benefits of a careful modelling.

## 5. Literature

KAHN, M., 1998: Data assessment on experimental plots in Teak stands, in MIES, E. (Ed.): Natural and Socioeconomic Analysis and Modelling of Forest and Agroforestry Systems in Southeast Asia, Publication by the German Foundation for International Development, Zschortau, Germany.

PRETZSCH, H., 1992: Konzeption und Konstruktion von Wuchsmodellen für Rein- und Mischbestände, Forstliche Forschungsberichte München, Nr. 115, 358 S.

PRETZSCH, H. 1998: Models for Pure and Mixed Forests, in MIES, E. (Ed.): Natural and Socioeconomic Analysis and Modelling of Forest and Agroforestry Systems in Southeast Asia, Publication by the German Foundation for International Development, Zschortau, Germany.

ROYAL FOREST DEPARTMENT, 1992: Proceedings Teak Conference, 50th Year Anniversary of Mae Huad Teak Plantation, Ngao Lampang, Thailand, 414 p.

# Appendix

Table A1: Remaining stand, simulation results from the reference scenario: real site condititons, no thinning and real stand structure (experimental plot no. 1, Mae Moh Teak plantation)

Age = stand age in years, N = tree number pe ha, $h_{dom}$ = top height in m, $d_{dom}$ = diameter of the $h_{dom}$-tree in cm, hg = mean height in m, dg = mean diameter in cm, BA = stand basal area in m$^2$ per ha, Vol = stand timber volume with bark in m$^3$ per ha

| Age | N | $h_{dom}$ | $d_{dom}$ | hg | dg | BA | Vol |
|---|---|---|---|---|---|---|---|
| 11 | 856 | 12.8 | 18.1 | 11.0 | 11.9 | 9.5 | 47 |
| 16 | 800 | 15.4 | 21.4 | 13.5 | 14.9 | 14.0 | 89 |
| 21 | 753 | 17.9 | 24.6 | 15.7 | 17.8 | 18.6 | 142 |
| 26 | 708 | 20.0 | 27.6 | 17.8 | 20.4 | 23.1 | 202 |
| 31 | 658 | 22.0 | 30.4 | 19.7 | 22.8 | 26.8 | 259 |
| 36 | 606 | 23.8 | 33.4 | 21.4 | 24.9 | 29.5 | 311 |
| 41 | 539 | 25.4 | 35.7 | 22.9 | 26.8 | 30.3 | 342 |
| 46 | 503 | 26.8 | 37.4 | 24.2 | 28.1 | 31.3 | 371 |
| 51 | 472 | 28.0 | 39.6 | 25.5 | 29.9 | 33.1 | 412 |
| 56 | 444 | 29.3 | 41.7 | 26.7 | 31.1 | 33.8 | 439 |
| 61 | 414 | 30.5 | 43.8 | 28.0 | 33.0 | 35.5 | 478 |
| 66 | 389 | 31.7 | 46.0 | 29.0 | 34.5 | 36.3 | 506 |
| 71 | 375 | 32.7 | 47.7 | 30.0 | 35.7 | 37.5 | 536 |
| 76 | 356 | 33.8 | 49.4 | 30.9 | 36.8 | 37.9 | 555 |
| 81 | 331 | 34.7 | 50.9 | 31.8 | 37.9 | 37.3 | 558 |
| 86 | 317 | 35.6 | 52.7 | 32.7 | 39.4 | 38.7 | 591 |
| 91 | 292 | 36.3 | 54.0 | 33.6 | 40.7 | 37.9 | 589 |
| 96 | 272 | 37.0 | 55.4 | 34.3 | 41.9 | 37.6 | 593 |
| 101 | 253 | 37.6 | 56.5 | 35.1 | 43.4 | 37.4 | 598 |
| 106 | 228 | 38.2 | 57.6 | 35.8 | 44.7 | 35.8 | 580 |
| 111 | 217 | 38.8 | 59.3 | 36.4 | 46.2 | 36.3 | 594 |
| 116 | 194 | 39.2 | 59.4 | 36.9 | 46.6 | 33.1 | 546 |
| 121 | 169 | 39.5 | 59.3 | 37.4 | 47.9 | 30.6 | 508 |
| 126 | 167 | 40.0 | 60.6 | 38.0 | 49.1 | 31.6 | 529 |
| 131 | 167 | 40.6 | 62.4 | 38.6 | 50.6 | 33.5 | 564 |
| 136 | 164 | 41.0 | 64.2 | 39.0 | 52.2 | 35.1 | 594 |
| 141 | 153 | 41.3 | 63.6 | 39.5 | 53.2 | 33.9 | 576 |
| 146 | 142 | 41.4 | 63.1 | 39.9 | 54.4 | 32.9 | 560 |
| 151 | 133 | 41.6 | 64.5 | 40.5 | 57.1 | 34.2 | 584 |
| 156 | 133 | 42.0 | 66.1 | 40.9 | 58.6 | 36.0 | 615 |

Table A2: Removal stand, simulation results from the reference scenario: real site condititons, no thinning and real stand structure (experimental plot no. 1, Mae Moh Teak plantation)

Age = stand age in years, N = tree number pe ha, $h_{dom}$ = top height in m, $d_{dom}$ = diameter of the $h_{dom}$-tree in cm, hg = mean height in m, dg = mean diameter in cm, BA = stand basal area in m$^2$ per ha, Vol = stand timber volume with bark in m$^3$ per ha

| Age | N | $h_{dom}$ | $d_{dom}$ | hg | dg | BA | Vol |
|---|---|---|---|---|---|---|---|
| 11 | 61 | 11.0 | 11.8 | 11.0 | 11.8 | 0.7 | 3 |
| 16 | 56 | 12.5 | 13.7 | 12.5 | 13.7 | 0.8 | 5 |
| 21 | 47 | 15.4 | 17.2 | 15.4 | 17.2 | 1.1 | 8 |
| 26 | 44 | 18.0 | 20.0 | 18.0 | 20.0 | 1.4 | 12 |
| 31 | 50 | 19.7 | 22.4 | 19.7 | 22.4 | 2.0 | 19 |
| 36 | 53 | 21.6 | 25.0 | 21.6 | 25.0 | 2.6 | 27 |
| 41 | 67 | 23.0 | 27.3 | 23.0 | 27.3 | 3.9 | 44 |
| 46 | 36 | 25.9 | 33.3 | 25.9 | 33.3 | 3.2 | 39 |
| 51 | 31 | 25.9 | 28.4 | 25.9 | 28.4 | 1.9 | 24 |
| 56 | 28 | 27.8 | 35.8 | 27.8 | 35.8 | 2.8 | 37 |
| 61 | 31 | 25.7 | 25.7 | 25.7 | 25.7 | 1.6 | 20 |
| 66 | 25 | 29.3 | 33.7 | 29.3 | 33.7 | 2.2 | 31 |
| 71 | 14 | 31.7 | 39.4 | 31.7 | 39.4 | 1.7 | 25 |
| 76 | 19 | 32.1 | 39.6 | 32.1 | 39.6 | 2.4 | 36 |
| 81 | 25 | 33.0 | 40.6 | 33.0 | 40.6 | 3.2 | 49 |
| 86 | 14 | 32.0 | 32.0 | 32.0 | 32.0 | 1.1 | 17 |
| 91 | 25 | 34.0 | 41.0 | 34.0 | 41.0 | 3.3 | 51 |
| 96 | 19 | 35.1 | 41.8 | 35.1 | 41.8 | 2.7 | 42 |
| 101 | 19 | 36.6 | 40.8 | 36.6 | 40.8 | 2.5 | 41 |
| 106 | 25 | 36.3 | 43.4 | 36.3 | 43.4 | 3.7 | 60 |
| 111 | 11 | 36.7 | 42.2 | 36.7 | 42.2 | 1.6 | 26 |
| 116 | 22 | 38.1 | 55.4 | 38.1 | 55.4 | 5.4 | 88 |
| 121 | 25 | 37.9 | 47.1 | 37.9 | 47.1 | 4.3 | 72 |
| 126 | 3 | 38.3 | 62.7 | 38.3 | 62.7 | 0.9 | 14 |
| 131 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 |
| 136 | 3 | 35.7 | 31.3 | 35.7 | 31.3 | 0.2 | 4 |
| 141 | 11 | 41.0 | 59.4 | 41.0 | 59.4 | 3.1 | 52 |
| 146 | 11 | 40.7 | 57.0 | 40.7 | 57.0 | 2.8 | 49 |
| 151 | 8 | 35.3 | 24.8 | 35.3 | 24.8 | 0.4 | 7 |
| 156 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 |

Table A3: Total stand, simulation results from the reference scenario: real site condititons, no thinning and real stand structure (experimental plot no. 1, Mae Moh Teak plantation)

Age = stand age in years, iBA = increment in stand basal area in m$^2$ per ha and year, iVol = increment in stand timber volume with bark in m$^3$ per ha and year, TVP = total timber volume production in m$^3$ per ha, MAI = mean annual increment in timber volume in m$^3$ per ha and year

| Age | iBA | iVol | TVP | MAI |
|---|---|---|---|---|
| 11 | 0.0 | 0.0 | 51 | 3.9 |
| 16 | 1.1 | 9.3 | 97 | 5.4 |
| 21 | 1.1 | 12.2 | 158 | 6.9 |
| 26 | 1.2 | 14.5 | 231 | 8.2 |
| 31 | 1.1 | 15.3 | 307 | 9.3 |
| 36 | 1.1 | 15.9 | 386 | 10.2 |
| 41 | 0.9 | 14.9 | 461 | 10.7 |
| 46 | 0.8 | 13.8 | 530 | 11.0 |
| 51 | 0.8 | 13.1 | 595 | 11.2 |
| 56 | 0.7 | 12.7 | 659 | 11.4 |
| 61 | 0.6 | 11.9 | 718 | 11.4 |
| 66 | 0.6 | 11.7 | 777 | 11.4 |
| 71 | 0.6 | 11.1 | 832 | 11.4 |
| 76 | 0.6 | 10.9 | 887 | 11.4 |
| 81 | 0.5 | 10.5 | 939 | 11.3 |
| 86 | 0.5 | 9.8 | 988 | 11.2 |
| 91 | 0.5 | 9.9 | 1037 | 11.2 |
| 96 | 0.5 | 9.2 | 1083 | 11.1 |
| 101 | 0.5 | 9.1 | 1128 | 11.0 |
| 106 | 0.4 | 8.4 | 1170 | 10.8 |
| 111 | 0.4 | 8.0 | 1211 | 10.7 |
| 116 | 0.4 | 8.1 | 1251 | 10.6 |
| 121 | 0.4 | 6.8 | 1285 | 10.5 |
| 126 | 0.4 | 6.9 | 1320 | 10.3 |
| 131 | 0.4 | 6.9 | 1355 | 10.2 |
| 136 | 0.4 | 6.8 | 1389 | 10.1 |
| 141 | 0.4 | 6.9 | 1423 | 10.0 |
| 146 | 0.4 | 6.6 | 1456 | 9.8 |
| 151 | 0.3 | 6.0 | 1486 | 9.7 |
| 156 | 0.4 | 6.2 | 1517 | 9.6 |

Table A4: Total stand, simulation results from the reference scenario: real site condititons, no thinning and real stand structure (experimental plot no. 1, Mae Moh Teak plantation)

Age = stand age in years, TOver remain = turn over remaining stand in US $ per ha, Costs remain = harvesting costs remaining stand in US $ per ha, NetVal remain = net value remaining stand in US $ per ha, TOver remove = turn over removal stand in US $ per ha, Costs remove = harvesting costs removal stand in US $ per ha, NetVal remove = net value removal stand in US $ per ha, iNVal = annual increment of net value in US $ per ha and year, mNVal = mean annual increment of net value in US $ per ha and year, tNVal = total net value in US $ per ha (=NetVal reamain + sum of all preceeding NetVal remove)

| Age | TOver remain | Costs remain | NetVal remain | TOver remove | Costs remove | NetVal remove | iNVal | mNVal | tNVal |
|---|---|---|---|---|---|---|---|---|---|
| 11 | 13937 | 5051 | 8886 | 991 | 359 | 632 | 0 | 732 | 9518 |
| 16 | 25844 | 8635 | 17208 | 1429 | 485 | 944 | 1853 | 1044 | 18784 |
| 21 | 41528 | 12972 | 28556 | 2377 | 748 | 1629 | 2595 | 1381 | 31760 |
| 26 | 64001 | 17725 | 46276 | 4519 | 1087 | 3432 | 4230 | 1890 | 52912 |
| 31 | 97269 | 22140 | 75129 | 5668 | 1640 | 4029 | 6576 | 2600 | 85794 |
| 36 | 161354 | 26071 | 135283 | 13201 | 2293 | 10908 | 14212 | 4128 | 156855 |
| 41 | 192079 | 28226 | 163854 | 27176 | 3643 | 23533 | 10421 | 4860 | 208959 |
| 46 | 230186 | 30421 | 199765 | 25990 | 3157 | 22832 | 11749 | 5577 | 267703 |
| 51 | 269461 | 33523 | 235938 | 15515 | 1992 | 13523 | 9939 | 5989 | 317399 |
| 56 | 293509 | 35520 | 257989 | 25998 | 2962 | 23036 | 9018 | 6250 | 362486 |
| 61 | 325279 | 38478 | 286800 | 10959 | 1668 | 9291 | 7621 | 6359 | 400589 |
| 66 | 348329 | 40579 | 307750 | 21125 | 2498 | 18627 | 7915 | 6473 | 440165 |
| 71 | 370800 | 42962 | 327838 | 17193 | 1989 | 15204 | 7058 | 6513 | 475457 |
| 76 | 384233 | 44408 | 339825 | 25436 | 2833 | 22602 | 6918 | 6539 | 510047 |
| 81 | 388251 | 44633 | 343618 | 33644 | 3909 | 29735 | 6706 | 6549 | 543575 |
| 86 | 414725 | 47187 | 367539 | 10489 | 1336 | 9153 | 6615 | 6553 | 576649 |
| 91 | 416813 | 47071 | 369742 | 35535 | 4059 | 31476 | 6736 | 6563 | 610329 |
| 96 | 419453 | 47384 | 372069 | 30413 | 3366 | 27046 | 5875 | 6528 | 639702 |
| 101 | 423152 | 47772 | 375380 | 29161 | 3268 | 25893 | 5841 | 6494 | 668906 |
| 106 | 411871 | 46362 | 365509 | 42985 | 4801 | 38184 | 5663 | 6456 | 697219 |
| 111 | 423899 | 47589 | 376310 | 17555 | 2059 | 15497 | 5260 | 6403 | 723516 |
| 116 | 390668 | 43837 | 346831 | 63353 | 7091 | 56262 | 5357 | 6359 | 750300 |
| 121 | 364672 | 40866 | 323807 | 51455 | 5795 | 45660 | 4527 | 6284 | 772936 |
| 126 | 381711 | 42617 | 339094 | 10236 | 1130 | 9105 | 4879 | 6229 | 797329 |
| 131 | 407649 | 45486 | 362163 | 0 | 0 | 0 | 4614 | 6168 | 820398 |
| 136 | 430875 | 48055 | 382820 | 2635 | 291 | 2344 | 4600 | 6112 | 843399 |
| 141 | 418749 | 46705 | 372044 | 38452 | 4261 | 34191 | 4683 | 6062 | 866814 |
| 146 | 409563 | 45556 | 364007 | 34396 | 3937 | 30459 | 4484 | 6008 | 889236 |
| 151 | 428226 | 47599 | 380627 | 4604 | 529 | 4075 | 4139 | 5947 | 909931 |
| 156 | 452341 | 50264 | 402077 | 0 | 0 | 0 | 4290 | 5895 | 931381 |

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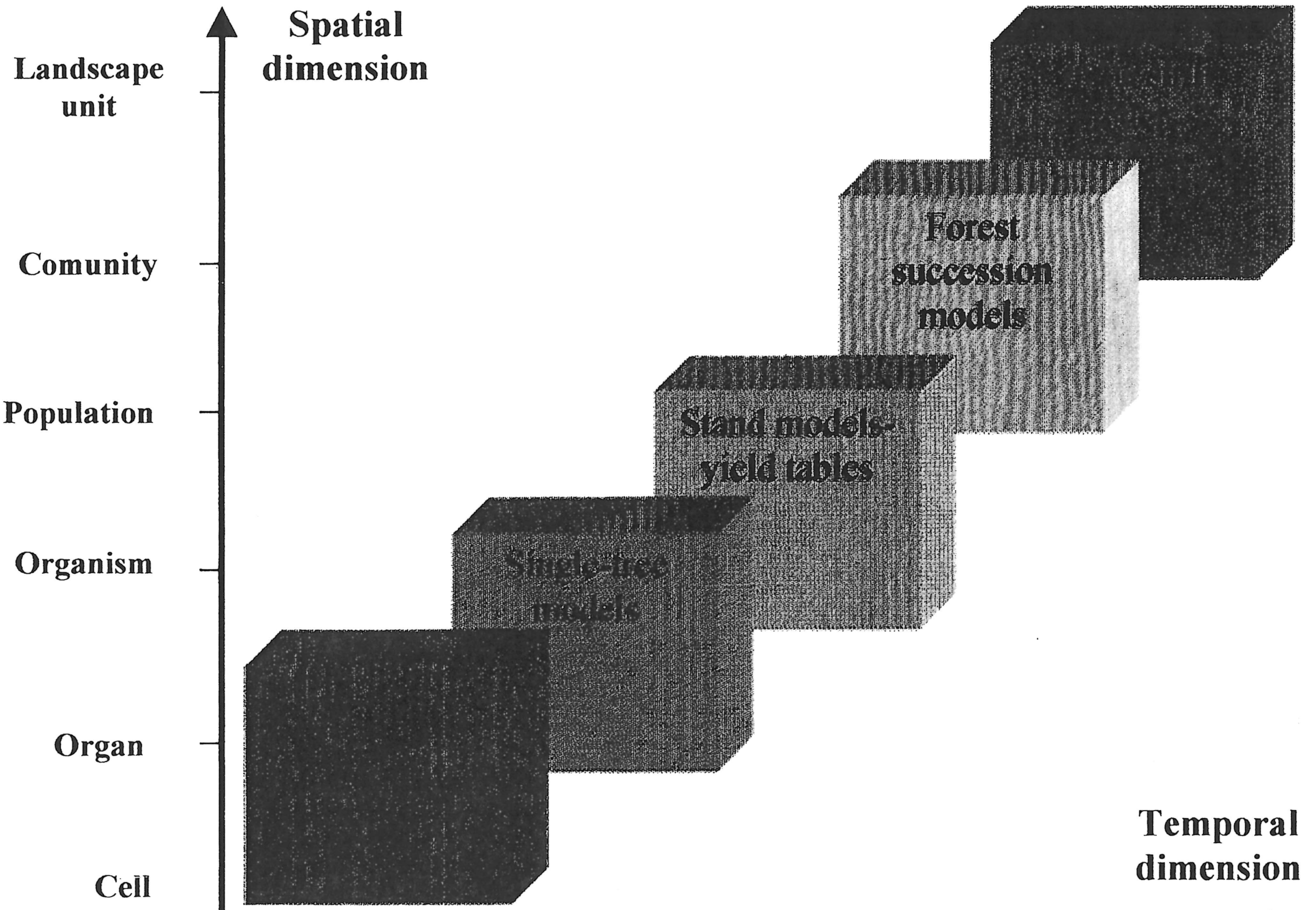

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# Table of Contents

Page

Preface

Addresses of Authors

DSE in Brief

DSE Addresses