Evaluation of a stand simulator and implementation of the Plantation Planner, a Large – Scale scenario model for forest management

Validering av en tilvekstmodell og implementering av Plantation Planner, et prognoseverktøy for beslutningsstøtte i storskala skogforvaltning

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MASTER THESIS 30 + 30 CREDITS 2008

PREFACE

This master thesis has been written at the Norwegian University of Life Sciences, at the Department of Ecology and Natural Resource Management, in the special field of forest economics and planning. The thesis was initialized by Green Resources that needed a validation of the current growth and yield tables used at some of their plantations in Tanzania.

Firstly, great thanks to our tutor, Professor Dr. Scient Tron Eid at the Norwegian University of Life Sciences. Also a special thanks to Endre Hofstad Hansen and Green Resources.

Ås, June 2008

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Abstract

Forest management planning relies on information from present and predicted future conditions of the forest. The aim of the present work was to develop a tool to test the existing growth and yield tables at Sao Hill Tanzania, and then implement this in the forest scenario model Plantation Planner. A previously developed growth and yield simulator for *Pinus patula* at the Sao Hill area was recreated and validated by means of SAS-software. The theoretical examinations and tests were based on independent data from both continuous forest inventories and temporary sample plots from three different sites. The results showed significant difference between predicted and observed values for basal area growth and volume. The mean deviations were respectively 25% and 30%. A theoretical study of the equations revealed lack of documentation on three equations and also possible irregular behaviour of volume after thinning. Because of lack of data, absent of systematic inventory data and large differences in error between sites, we conclude; that we cannot do any adjustments of the equations in the Stand Simulator.

From this basis a decision support system, Plantation Planner, was developed to describe different alternatives for forest management and forest conditions. The core in this tool is the Stand Simulator. A plantation area close to Sao Hill was used in a case study. Different scenarios were run and compared to a basic scenario where the stocking was 1600 trees/ha, rotation age was 19 years and no thinning was performed. All adjustments to the basic scenario resulted in NPV losses, but the most severe was thinning fraction of 40% which resulted in a NPV of 46% compared to the basic scenario. In general the different scenarios showed that the model responds logically to adjustments. Small errors in both basal area growth and site index had a large impact on standing volume and NPV. A sensitivity analysis showed that a 25% reduction in basal area resulted in a negative NPV. We conclude that the Plantation Planner is a useful tool for forest management predictions on plantation level. However, the product should not be considered as “finished”, and because of uncertainty connected to the Stand Simulator, calibrations of the input variables are recommended.

Sammendrag

Skogplanlegging er basert på informasjon om nåværende status og antakelser om fremtidig utvikling av skogen. Målsetningen med dette arbeidet har vært å utvikle verktøy for å teste eksisterende tilvekstmodeller på Sao Hill Tanzania, og videre implementere dette inn i Plantation Planner, et prognoseverktøy for beslutningsstøtte i skogbehandling. En eksisterende tilvekstmodell for *Pinus patula* på Sao Hill ble gjenskapt ved bruk av SAS-software. Teoretiske undersøkelser og tester basert på uavhengige data fra både permanente og midlertidige prøveflater fra tre ulike områder ble gjennomført. Resultatene viste signifikante avvik mellom fremskrevet og observerte verdier av grunnflatetilvekst og volum for alle områder, det gjennomsnittlige avviket var henholdsvis 25 % og 30 %. En teoretisk gjennomgang av funksjonene i modellen avdekket en mulig logisk feil i volumfunksjonen, og manglende dokumentasjon på tre av funksjonene i modellen. Grunnet manglende data, ikke systematiske takstdata og store forskjeller mellom de tre områdene konkluderer vi med at det ikke er grunnlag for en justering av tilvekstmodellen.

På dette grunnlaget ble et prognoseverktøy Plantation Planner utviklet med den målsetning å beskrive ulike alternativer for skogforvaltning og utvikling av plantasjen. Kjernen i dette verktøyet er tilvekstmodellen fra Sao Hill. En plantasje nær Sao Hill ble brukt som case studie. Ulike scenarioer på plantasjenivå ble kjørt og sammenliknet med et basisalternativ der plantetetthet 1600 tre/ha, omløpstid 19 år og ingen tynning var faste verdier. Alle justeringer i forhold til basis scenarioet medførte redusert nåverdi. Den største reduksjonen var alternativet med 40 % tynning, som resulterte i en nåverdi tilsvarende 46 % av basis scenarioet. Ellers viste de ulike scenarioene at modellen responderte logisk på ulike skogskjøtselstiltak. Videre viste den at selv små feil i grunnflatetilvekstfunksjonen og bonitet kunne gi store endringer i stående volum og nåverdi. En sensitivitetsanalyse basert på dokumenterte avvik viste at en reduksjon på 25 % i grunnflatetilvekst resulterte i negativ nåverdi. Vi konkluderer med at Plantation Planner er et brukbart verktøy for beslutningsstøtte i skogforvaltning på plantasjer. På den annen side kan ikke modellen ansees som et ”ferdig” produkt. Vi anbefaler også en ny kalibrering og oppfølging av inputvariablene som brukes grunnet usikkerheten knyttet til kvaliteten av tilvekstmodellen.

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1. **Introduction**

1.1 Plantation forestry

The developments of plantations in the tropics are growing in an accelerating pace to satisfy the ever growing global demands for wood products as well as to improve the environment and livelihoods of poor people (Evans & Turnbull 2004). During the last decades awareness of the importance of plantations has grown and the plantation area has increased. A large number of donors from the developed world, including international agencies, private investors and banks have also extended their financial support to the plantation activity (Pandey 1995). With 13 million ha of plantations Africa has approximately 10 % of the world's cover of plantation area and the plantation area is increasing, particularly in the South and West (FAO 2007).

Most forest plantations in Africa are established to produce industrial wood for sawmills and the pulp industry. Approximately 18 %, however, are also planted for protective purposes. South Africa, Algeria, Nigeria, Sudan and Morocco alone hold 52 % of the plantation area in Africa. The east coast and central Africa is less represented, probably because of plantation activities are negligible in countries where there are still large tracts of natural forests (FAO 2003). At the same time the report from FAO (2003) lifts up Mozambique, Tanzania and Zambia as countries with potential for expanding their plantation forestry, mainly because of good ecological conditions, political stability and appropriate markets.

Along with a growing population as well as growing economy there will be an ever increasing demand of supply of fuel wood, charcoal, sawn and pulp wood. The forests in Tanzania are under high pressure, and because of a growing demand for scarce recourses the government has lately encouraged private investments in plantation forestry (FAO 2000). There were in year 2000 about 80,000 ha of forest plantations in Tanzania, consisting mainly of *P.patula* and *Cupressus lusitanica*, and it is predicted that plantations in future will be a major source for industrial purposes, fuel wood and charcoal production. Knowing that bioenergy is responsible for about 90 % of the total energy consumption in the country and that forest in general is a scarce recourse (FAO 2000), the importance and potential of commercial plantations is quite obvious.

From 1950 plantations were established in the Sao Hill area consisting mainly of *Pinus spp*. and *Eucalyptus spp.* species. This founded a basis for different forest industry in the area. The Sao Hill Saw Mill Ltd. was established in 1973 as a subsidiary of the Tanzania Wood Industries Corporation (TWICO), and commenced production in 1976, its overall objective was to provide the Tanzanian market with more home-produced timber and thus reduce imports (NORAD 1980). During 1996 the Uchindile forest project was initiated by Green Resources Ltd. This is an afforestation activity in the area of Uchindile, close to Sao Hill with a total land claim of 12000 ha. The project will convert low yielding grass and degraded forest land to grow yielding crops suitable for saw mill industry, pulp and paper as well as carbon offset business (Green Resources 2006).

1.2 Growth and Yield models

Forecasting forest growth is important when predicting how a forest develops through different regimes of climatic, as well as management regimes. Growth and yield modelling is the models of tree growth and yield that forest managers use for forest planning. Such models are traditionally used to predict future harvest potentials, how different management regimes affect forest growth and finally reflect the economic potential of a forest stand or area.

Present yield tables for *P.patula* at Sao Hill Forest plantations are based on Malimbwi et al. (1998). Today these yield tables are also used at the Uchindile forest project in order to facilitate yield and hence allowable cut. Before 1998 there were some published works of growth and yield for *P.patula* in the area (Valkonen 1999), but few of them are specific for Sao Hill. With the report of Malimbwi et al. (1998), yield tables were constructed for the Sao Hill Forest Plantations. The yield tables have now been in use for about ten years but have not yet been validated. A perfect situation for an empirical evaluation of the totality of these tables would be to apply a wide range of forest conditions over a large area where forest developments and treatments were described continuously over a long period (Eid 2004). Such data does not exist, however, permanent sample plots were established in 1998 at the Uchindile Forest Project. Annually these permanent sample plots are measured by the Green resources inventory team. Based on this there has lately been a suspicion that the predicted volume from present yield tables is overestimated (Personal communication. Endre H. Hansen). However, the stands are still young and the data material small.

Erroneous forest data and/or incorrect assumptions may have different consequences. Errors in the input variables can affect calculation results and decisions, and possibly lead to net present value (NPV) losses because the resources are not efficiently utilized (Eid 2004; Hauglin 2007). A good evaluation of a forest model (e.g. yield tables) should include qualitative as well as quantitative examinations (Soares et al. 1995). Qualitative and quantitative evaluations should be seen in a consistence relationship, since model evaluation is an ongoing process that consists of a number of interrelated steps that should not be separated from each other, or from model construction (Vanclay & Skovsgaard 1997).

In addition to model errors, a large number of other factors could contribute to misleading figures concerning forest plantations. Important factors may be the lack of inventory or survey data of established plantations, or that existing yield tables prepared for fully stocked stands have been indiscriminately applied to estimate growth or yield of plantations which do not grow under such conditions (Pandey 1995; Malimbwi et al. 1998). The Uchindile forest project was established at an altitude and a location that can possibly lead to other climatic conditions than the model fitted for the Sao Hill forest plantations by Malimbwi et al. (1998). Unreliable predictions may lead to suboptimal decisions (Soares et al. 1995; Eid 2000). This means that each model should be evaluated and its limitations should be determined before it is used. A challenge in this respect is that forestry scenario models are complex and a question is how to choose appropriate biological sub models. Such models and the interactions between them also have to be considered with respect to logical biological behaviour (Eid 2000).

1.3 Forest level planning

By simulating future growth and development of a forest it is possible to obtain an objective foundation for different alternative decisions. In forest level planning it is important to survey how the forest will develop to get an overview of future resources and to come in a position where you can evaluate different treatment alternatives. Appropriate information about growth and yield is essential to predict future harvesting levels and to give accurate and solid budgets for a plantation (Eid 2000). In such a setting a tool for analysing potential and limits with respect to harvests within a geographical unit is required, i.e. a forest scenario model for analysis of future harvests and yield. It is therefore important to develop a tool for biological and economic projections and a suitable tool for strategic decisions on stand and forest level. The importance of an instrument that can illustrate responses to different management regimes is quite obvious when different strategic decision is to be made. At a strategic level the knowledge of trends and thresholds of broad indicators such as timber flow, growing stock, habitat, and patterns is important. Still forest-level models are just one component of the overall decision support system that is needed to address multiple objective forest management planning (Nelson 2003).

1.4 Problem Statement

The main objective of the thesis is to develop tools that can be applied for planning in *P.patula* plantations at the Sao Hill area.

Sub-objective 1: Development of a Stand Simulator for *P.patula.*
Based on biological sub-models describing dynamics for *P.patula* plantations (Malimbwi et al. 1998) develop a Stand Simulator by means of SAS-software that enables simulations according to different forest conditions and treatments.

Sub-Objective 2: Evaluation of the performance of the Stand Simulator.
Evaluate the biological model basis applied in the Stand Simulator by means of independent data, and, if necessary, make suggestions for calibrations.

Sub-Objective 3: Forest level planning tool.
Develop a Plantation Planner, where the Stand Simulator constitutes the core, which can be used for predictions of future growth, harvests and NPV at the forest level.

Sub-objective 4: Scenarios at forest level.
Produce scenarios for future growth, harvests and NPV according to different treatment assumptions at the Uchindile forest project.

2. Materials & Methods

2.1 Area description

Sao Hill and the surrounding areas belong to the central highlands of Tanzania and represent a typical tropical highland climate. The data is collected from three different sites around Sao Hill, i.e. the Sao Hill forest plantations Division 1 is around the Saw Mill at Latitude -8.41649° Longitude 35.2129°, while Division 4 forest plantation and the Uchindile forest project is located at Lat -8.72056° Long 35.4554°. This is illustrated in Figure 1 in proportion to some main cities in Tanzania.

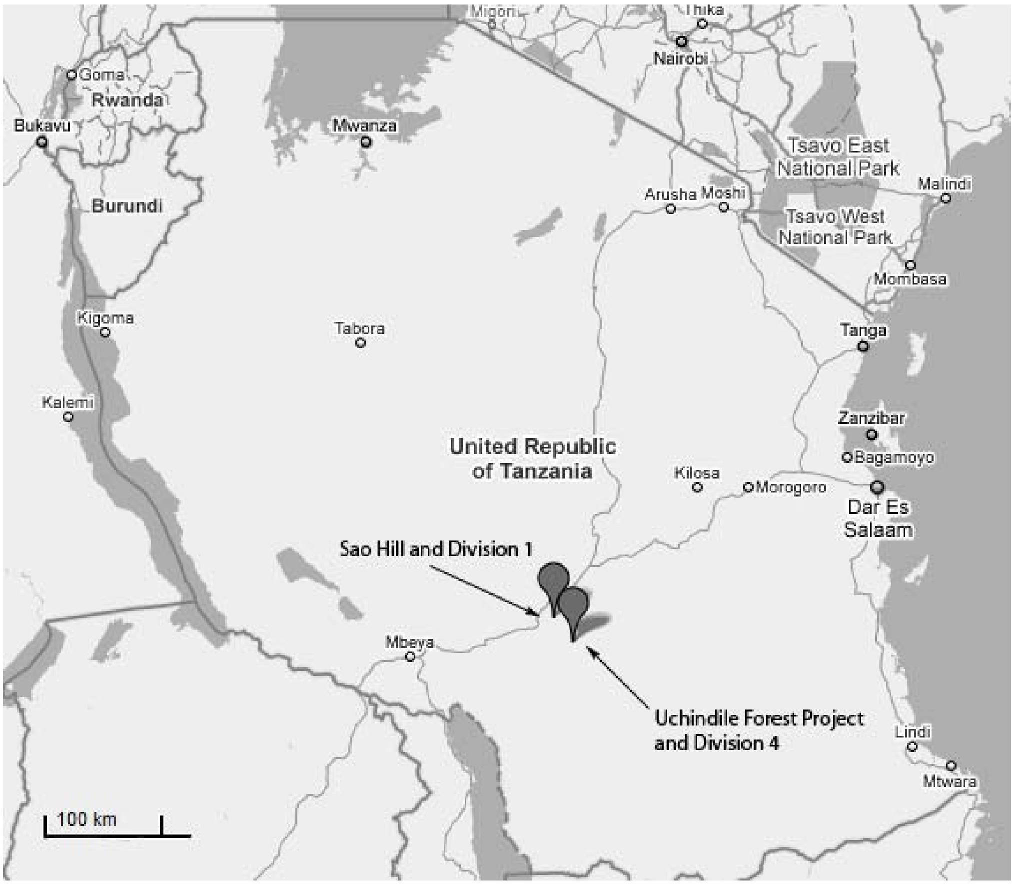

Figure 1. Sao Hill and Uchindile area in Tanzania, source: (Google 2008a).

The Division 1 forest plantation is located at an average altitude of approximately 1900 meter and temperatures are ranging from a monthly average of 3.3^{O}C in August to 29.6^{O}C in November. Mean annual temperature is 16 degrees Celsius. Mean annual rainfall is 935 mm with greatest precipitation occurring from December to March (NORAD 1980; Mugasha et al. 1996). This makes the area very suitable for plantation production.

Table 1. Some characteristic of the three different sites.

Site	Number of observations	Mean Site index	Standard Deviation m	%	Altitude	Annual Rainfall	Mean Temperature
Division 1 (Sao Hill)	17	22.5	3.0	14%	1900	935 mm	16.0 ^{O}C
Division 4 (Uchindile)	55	22.6	2.2	10%	1200	1135 mm	15.8 ^{O}C
Uchindile	46	18.4	3.0	16%	1200	1135 mm	15.8 ^{O}C
All	118	21.0	3.4	16%			

The Division 4 forest plantation and the Uchindile forest project are located quite close to each other at an altitude of approximately 1200 meter, and 50 km South-East of Sao Hill. The landscape of the Uchindile forest project rises from an elevation of 1080 meter in the South East to a peak of 1439 meter in the North West. Local data from the Green Resources weather station at Uchindile shows a mean annual rainfall of 1035 mm, and a mean temperature of 15.8 ^{O}C (Table 1).

2.2 Stand level simulations

2.2.1 Model basis

To develop a variable density yield table, a number of functions must be present. Such models were constructed by Malimbwi et al. (1998) in the Sao Hill *P.patula* plantations, based on 185 circular sample plots. Based on these sample plots, site index curves, a basal area growth equation, a stand volume equation and a mortality function were developed. When comparing site index curves and the basal area equation with earlier studies conducted by (Malimbwi 1987), some of the old equations performed better than the developed functions (Malimbwi et al. 1998). The Stand Simulator is therefore a mix of new and old equations. This is presented in Table 2. Since there were no data on thinning, there was used a thinning equation from a former study conducted by Malimbwi (1984). Regarding basal area there was developed a new equation BA1 to get initial basal area in young stands by Malimbwi et al. (1998).

Table 2. Biological model basis of functions and equations used in the model of Malimbwi et al. (1998).[a]

Initial Basal Area (BA1)	*m^2/ha*	*= Exp(-0.3618 + 0.14365 * Hdom+0.00119 * N)*	*Malimbwi et al. (1998)*
Basal Area Growth (BA2)	*m^2/ha*	*= Exp(-0.02 + 3.94 * (1-A1/A2) + 0.02844 * (1-A1/A2) * SI + (A1/A2) *ln(BA1))*	*Malimbwi (1987)*
Stand Volume Equation (Vol)	*m^3/ha*	*= Exp(0.06192 + 0.73434 * Ln(BA1)+1.0786 * Ln(BA2))*	*Malimbwi et al. (1998)*
Initial Volume Equation (Vol 1)	*m^3/ha*	*= Exp(-0.0476 + 1.00679 * ln(BA1) - (1.4379 / Age) + 0.88471 * Log (Hdom))*	*Malimbwi et al. (1998)*
Dominant height (hdom)	*m*	*= 1.32 * SI * (1-Exp(-0.13 * Age)$^{1.83}$)*	*Malimbwi (1987)*
Mortality Function (N)	*stocking/ha*	*= 1408 * Exp(- 0.0341 * Age)*	*Malimbwi (1987)*
Thinning Simulation (Y)	*%*	*= Exp(4.143 * X – 2.8)*	*Malimbwi (1984)*

[a] *Where N = Stocking, A1 = Age last year, A2 = Age present year, Hdom = Dominating height from the 100 tallest trees pr. Hectare, Y = Basal area fraction removed relative to basal area before, and X = Fraction of number of stems removed.*

The purpose of the initial basal area function is to initiate basal area for younger stands (5 Years). The input is stocking (number of trees/ha) and site index, and output is m^2/ha. Observed basal area was tested against predicted basal area using predicted stocking. Validation was done at age four, five and six.

From stand age 5 years the basal area growth equation (BA2) is using initial basal area (BA1) as foundation for further development combined by age today (A1) and next year (A2) and site index. This gives an annual growth in basal area. Growth decreases with age, and the input variable that leads to a flattening of stand basal area growth over time comes from the relationship between A1 and A2 in the formula. Output is in m^2/ha.

Two volume equations were used. An initial volume equation (VOL1) is used at age five, but is not presented in the report (Malimbwi et al. 1998), instead it is attached in the BASIC code. The inputs to the initial volume equation are dominant height and basal area and age, output is volume in m^3/ha. Stand volume equation (VOL) is used from age six, and inputs are site index, age and basal area, and gives volume in m^3/ha.

The mortality function gives stocking at a given age, and the only variable which affects mortality is age. The mortality function is used at age five to give the stocking when calculating initial basal area. This is also the only time the mortality equation is used and even though the mortality is visualised in the yield tables of Malimbwi et al. (1998), the function is actually not used. Still, the function is tested for all observations due to the way it impacts stocking and mean diameter in the prize table used in the Plantation Planner. The mortality equation premises no thinning.

Thinning intensity is determined by the thinning equation as given in Malimbwi (1984). The thinning equation (Y) gives removed basal area, and is a function of removed stocking (X). In the Stand Simulator separate yield tables were developed for thinned stands. There has not been done any validation of the thinning equation due to lack of data. Since the removed trees gives a lower removed basal area than a possible average tree would have done this is a low-thinning (Børset 1986).

Site index is the dominant height at reference age of 15 years. Dominating height (Hdom) is average height of the 100 tallest trees/ha. No independent data were available for testing the site index equation. Since this equation is the foundation for all calculations, and therefore is very important for the end results, the equation was compared with existing equations in order to check the performance (Valkonen 1999). This was done to get an indication of the usability of the site index.

Figure 2 shows dominant height from sample plots plotted against age combined with the site class curves from Malimbwi et al. (1998). Collected data is mainly below site class 2 which represent class middle for site indexes 21-27 (Malimbwi et al. 1998). Scatter plots show that most of the observations are close or inside the site class curves. Site index was divided into three classes of <21, 21 – 27 and 27<. When comparing predicted and observed values of volume and basal area growth, the performance was tested within the tree classes to discover possible deviations.

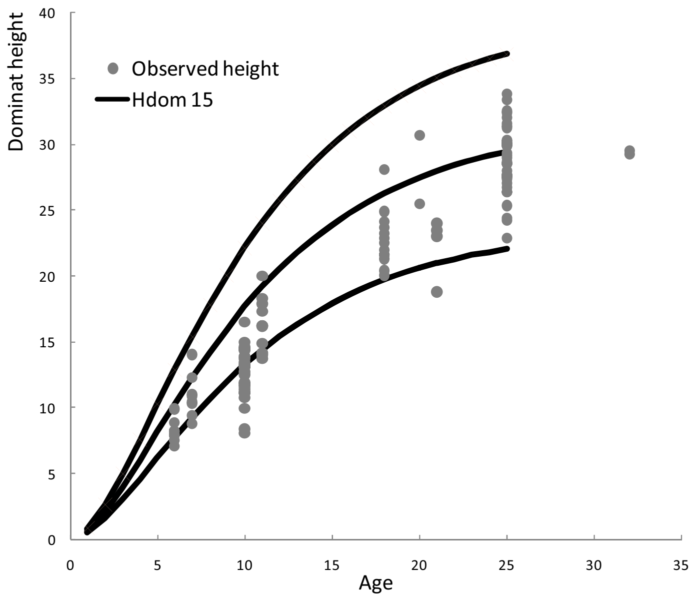

Figure 2. Site index; Solid lines show the site classes used by Malimbwi et al. (1998) at the age of 15 years. Three site classes of 18, 24 and 30 are drawn and illustrated with class middle. The dots show observations from different permanent and temporary sample plots.

2.2.2 Development of the Stand Simulator

The Stand Simulator applied in this thesis is a 'copy' of the Stand Simulator developed by Malimbwi et al. (1998), except that now it is programmed by means of SAS-software instead of BASIC programming. The Stand Simulator is developed as an area model based on stand characteristics. Figure 3 shows a flow chart over the Stand Simulator and how it works. Below is a stepwise description on how the Stand Simulator is working.

The user defines the initial number of planted trees per hectare and site index, and then initial basal area at the stand age of 5 years is calculated automatically.

If thinning is present the user has to define the following; number of thinnings, thinning age and thinning intensity (thinning fraction).

Initialising of basal area (BA1) at age 5 are using predicted stocking (trees/ha) and site index, initial basal area is also used to calculate volume at age five.

For every year up to a user defined age (e.g. 25 years) the following steps are performed;

1) Basal area growth sub-model: basal area growth (BA2) for the coming year is predicted with present age (A1), next year age (A2), present basal area (BA1) and site index. New basal area is updated for annual predicted growth.
2) Height development sub-model: dominant height according to the actual new age and site index is determined.
3) Volume equation: new volume per hectare is determined by means of a volume equation with the new basal area per hectare and the new dominant height as independent variables.

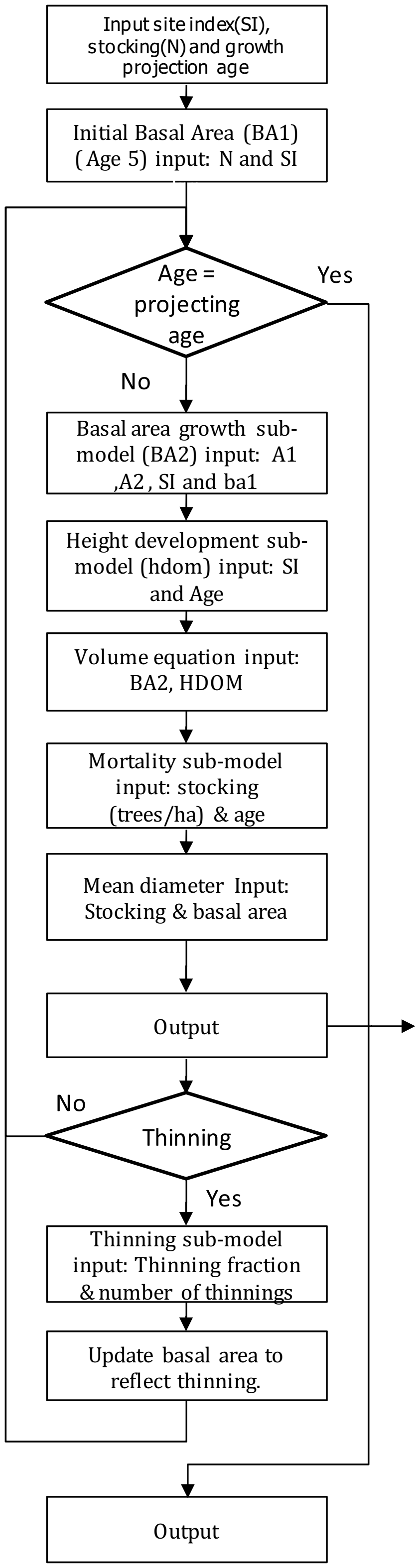

Figure 3. Flow chart over the Stand Simulator

4) Mortality sub-model: number of trees dying in natural mortality predicted based on age. The new number of trees per hectare in the stand is updated according to mortality.
5) Mean diameter: the new basal area mean diameter is calculated from the new basal area per hectare and the new number of trees per hectare.
6) Thinning sub-model: Thinned basal area is calculated from thinning fraction, and thinned basal area is used to calculate removed volume from thinning. In addition volume removed from thinning is calculated.

Steps 1 - 5 are repeated until the user defined age is reached.
If thinning is present step 6 is done until thinning frequency is reached.

2.2.3 Data collection

One of the best methods to test basal area growth is to monitor diameter growth on permanent sample plots (Vanclay 1994; Malimbwi et al. 1998; Avery & Burkhart 2002). Since existing permanent sample plots only were found in stands younger than 11 years, the data material was supplemented with temporary sample plots from older stands.

In total it has been measured 118 plots of whom 26 plots were permanent sample plots at the Uchindile forest project, 20 from temporary sample plots at the Uchindile forest project, 55 from temporary sample plots in Division 4 of the Governmental forest, and finally 17 temporary sample plots from Division 1.

The permanent sample plots at the Uchindile forest project cover age classes between 4 and 11 years. In Division 1 and Division 4 the age classes stretches from 11 to 32 years. Initial stocking is 1600 trees/ha at the Uchindile forest project and Division 4 respectively, in the Division 1 initial stocking is 1370 trees/ha.

Stand selection, measurements and field work was conducted in the Sao Hill and Uchindile area from January to March 2008. Most important for selection of stands is to know planting year and planted spacing because these input values are essential in running the Stand Simulator (Vanclay et al. 1995). Maps in scale of 1:10 000 with information about compartment, stand – size, species and planting year were used to locate usable stands for measurement. The maps are prepared and published by the Forest and Beekeeping Division/SAPU, Ministry of Tourism and Natural Recourses Dar Es Salam and are produced by aerial photographs taken in 1997, supported by Swedish International Development Aid (ORGUT-Consulting 1998). The sample plots were only chosen if it was possible to be 100 % sure of the age and spacing of the stand (Vanclay et al. 1995).

The following parameters were recorded on the sample plots: species, slope, aspect, vegetation, litter fall, diameter at breast height (DBH) and determination of site index. The positions of each permanent sample plot were predetermined, but in the case of temporary sample plots there had to be a design of sampling the forest. In each stand there was established a grid system of sample plots. The direction of each line was decided in each individual case from how it was most handy to cover up the stand. If nothing else was prepared the first plot was established 50 meter into the stand at a right angle from the stand boarder. The next plot was established 50 meter north of the first plot, and then the direction was given. If this second point was outside the stand the sample plot should be 50 meter south of the first plot. When the stand edge was reached on the other side, the next line was moved to be 100 meter parallel to the first line. The sample plot was a circle of 200 m^2 (radius = 7.98 meter). For an overview of how the Green Resources inventory team do their inventory, see Appendix 1.

2.2.4 Comparing predicted and observed values

Advised by Soares et al. (1995), qualitative analyses of the model were done by splitting it up in its individual functions and then examine these separately. To verify the logic of the model it is examined from a theoretical as well as a biological point of view (Vanclay & Skovsgaard 1997). Handling of data material was done in Excel, and the verification was done by means of SAS for projection and analysis, finally SAS was used to make the same volume tables as in Malimbwi et al. (1998).

Calculation of observed and predicted values can be summarized down to; observed initial basal area was calculated by summarizing basal area from all trees at a sample plot. Predicted initial basal area was calculated using the initial basal area equation (BA1). Observed basal area was directly calculated by summarizing basal area from all trees at each sample plot. Predicted basal area was predicted using Stand Simulator, input index and initial stocking.

Observed volume was calculated from observed basal area and observed site index using stand volume equation (VOL) for stands older than six years and initial volume equation (VOL1) was used for stands at age five. Predicted volume was calculated using the Stand Simulator, using initial stocking and site index from the sample plot. Mortality was directly calculated by observed stocking at the sample plots compared with predicted stocking.

The models for initial basal area, basal area, mortality and volume were tested by comparing predicted and observed values. The difference is given in m^3, m^2 and % as:

$$Predicted - Observed = Difference$$

Average differences between predicted and observed values were used as an indication of bias:

$$\overline{D} = (\sum_{i=0}^{n} D_i)/n$$

The standard deviation to the difference between observed values and values calculated from the model was used as an index for random error:

$$s = \sqrt{\frac{\sum_{i=0}^{n}(D_i - \overline{D})^2}{(n-1)}}$$

Where:

n	=	*number of observations*
D_i	=	*Difference between observed and predicted values of observation no. (i=1,2 ,…n)*
$\overline{D}$	=	*mean difference of all observations*
s	=	*standard deviation*

When comparing predicted and observed values paired t-tests were applied to determine whether the differences were significantly different from zero. When the predicted volume was calculated, it was used a scatter plot in combination with t-test to see the performance. Vanclay (1994) point out that one of the most efficient ways to test model performance is to plot residuals for all possible combinations of tree and stand variables. The common practice is to plot observed (y) values against predicted (ŷ) values, but in many cases it will be more revelling to plot residuals (e = ŷ – y) (Gonick & Smith 1993; Tabachnick & Fidell 2007). R-square is also possible to use but this does not necessarily tell how good the model is, since it doesn't tell the difference between "pure error" and natural variation (Vanclay 1994). Instead another tool analogous to R-square was used as an indicator of quality of the different equations, i.e. model efficiency.

Model efficiency was tested for volume, initial basal area, basal area growth and mortality. This is a test that provides a simple index of performance on a relative scale, where the value 1 indicates a "perfect" fit, while zero reveals that the model is no better than a simple average, and negative values indicate a poor model (Vanclay 1994; Soares et al. 1995; Vanclay & Skovsgaard 1997). The equation for calculating the model efficiency-index (E_m) is given as:

$$E_m = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

Where:

$\hat{y}_i$	=	*Predicted values of each observation*
$\bar{y}$	=	*Average observed values*
y_i	=	*Observed values*
E_m	=	*Model efficiency*

2.3 Forest level planning

2.3.1 Description of the Plantation Planner

The Plantation Planner is a decision support system for forest management, based on area-based biological models. The decision support system was developed to describe different alternatives for forest management. The core in this tool is the Stand Simulator.

Operational planning and decision processes in forest management are complex and extensive procedures. The Plantation Planner is strongly heuristic and user defined and are different from models where an object function is determined on forest level and the program calculate optimal settings (i.e. linear programming). The Plantation Planner is simpler and based on a repeated process where the user defines different forest management treatments until "satisfaction". The tool focuses on long-term planning on forest level with focus on harvest and forest management, and is hence a typical tool for strategic analysis (Eid 2007). There are no elements of optimisation built into the Plantation Planner.

Figure 4 shows main features of Plantation Planner and how it works. Below follows a stepwise description of how the Plantation Planner is working.

First, the user defines the plantation characteristics; compartment identification, compartment area, site class, planted year, future planting and spacing of planting. Then the user define different treatment assumptions; rotation age, number of thinnings, thinning age and thinning intensity (thinning fraction).

For every year up to a user defined year (e.g. year 2038) the following steps are performed for each compartment;

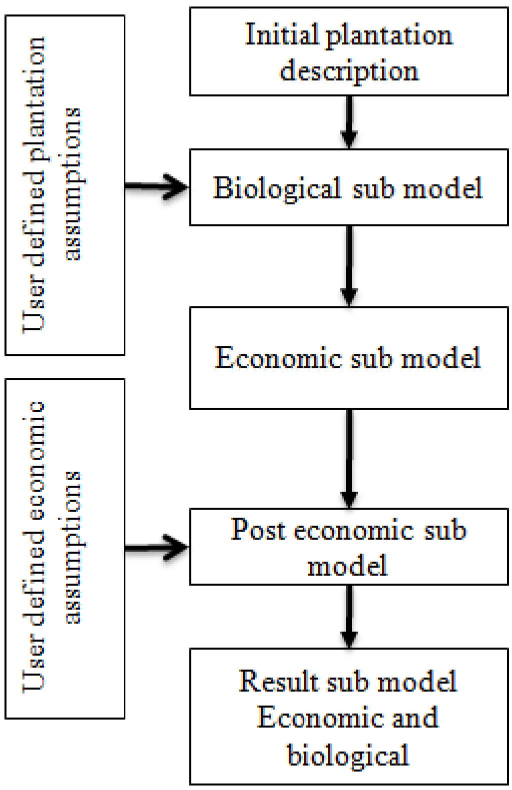

Figure 4. Main features and data flow of Plantation Planner.

1) Biological sub models; The Stand Simulator makes the foundation of biologically calculations. Annually, each compartment gives the following output; Volume, average DBH, and if thinning, volume removed in thinning. When rotation age is reached clear cutting is done, and then simulations starts again and planted area is given as output for future calculation of costs.
2) Economic sub models; Uses DBH, area and volume from the Stand Simulator to calculate expected yearly income for each compartment. This is done in combination with a defined price list which awards higher DBH (Table 3).

Steps 1-2 are repeated until the user defined year is reached. After simulation, the following steps are done.

1) Post economic sub model; Uses information from the Economical sub model in combination with economical assumptions to calculate NPV and IRR.
2) Presentation sub model; present the different economical and biological results.

Excel was used as foundation for the Plantation Planner where the core component was the Stand Simulator. The Stand Simulator was added into Excel using Visual Basic. Functionality was added so it can handle many stands, different rotation age and different thinning regimes. In addition a module for economical calculation was added.

A database was constructed in Excel as an administration module, as distinct from some Scandinavian models (i.e. AVVIRK 2000 (Eid & Hobbelstad 2000) and GAYA-JLP (Gobakken 2003)) the Plantation Planner directly integrates the file of data into the model. The outputs are given in the same sheet.

Biological outputs are standing volume, volume growth, thinning volume, harvested volume, and average DBH per tree per stand. To get total volume, all stands are summarized every year. An approach to find standing volume for year 1-5 was done because the function doesn't cover age classes below 5 years. Volume calculation for year 1-5 is a linear distribution of predicted volume in year five.

In addition, assumptions can be done for economical variables like interest rate, gross costs and changes in price tables. The economical aspect of the model will be revealed through annual net income, NPV and internal rate of return (IRR). Predictions of NPV was done by calculating cash flow of all future income and operating expenses, and discount of all values to the time reference of today. Mathematically the IRR is defined as any discount rate that results in a NPV of zero of a series of cash flows:

$$NPV = \sum_{i=0}^{n} \frac{C_t}{(1+r)^t} \qquad\qquad NPV = \sum_{i=0}^{n} \frac{C_t}{(1+r)^t} = 0$$

Where:

t	=	*the time of the cash flow*
N	=	*the total time of the project*
r	=	*the discount rate*
C_t	=	*the net cash flow (the amount of cash) at time t*
NPV	=	*net present value*

2.3.2 Scenarios

2.3.3 Assumptions for input data

All the areas were based on compartments from the Uchindile forest project. It was also assumed that the whole area connected to each compartment can be used for timber production.

Site class on each compartment was determined subjectively during field work. All compartments were classified into three site classes, 1, 2 and 3 which represent the three class middles H15=18m, 24m and 30m. In the areas where permanent sample plots are present, site class was determined as combination of several factors with the determinant of measurements from the sample plots as the most important. In addition the visual impression of the stand, satellite photos from Google Earth (Google 2008b) and slope were used as basis for the decisions of site class. It was assumed that the growth was better in the valley-bottoms than on the ridge-tops and that moderate slope improve growth in preference to flat land. Most of the Uchindile Forest Project is still not planted, and open land were not looked up to check a possible site index. In this situation the site index was determined as a combination of satellite photos from Google Earth to see vegetation cover (Google 2008b), maps, slope and an expectation about how the growth would be in the area; it was assumed that the distribution of site classes would be the same as in the areas of the permanent sample plots. This gave a distribution of 10% in site class 1, 40% in site class 2 and 50% in site class 3.

Economical assumptions were based on Tanzanian governmental prizes and approximate costs from known forest plantations in Tanzania, with reservations of local variations and changes in the economic premises (Personal communication Endre H. Hansen). Table 3 shows that high average DBH are rewarded with higher prizes.

Table 3. Stumpage fees P.patula by different diameter classes

Diameter Class (cm)	Tshs/m^3	USD/m^3
11-20	8,000	6.7
21-25	12,600	10.5
26-30	22,050	18.4
31-35	31,560	26.3
35+	34,000	28.3

Prices and costs are based on the following assumptions: All cost and prices are in US dollars (USD), exchange rate between USD and Tanzanian shilling (TZS) is 1 USD=1200 TZS. Planting cost is 600 USD pr hectare, pruning cost is 20 USD per hectare, thinning cost is 6 USD pr. m^3 and harvest cost is 5 USD pr. m^3. Planting and pruning cost before 2008 is sunk cost and all prices and cost are the same today as in the future. The assumption is also that planting follows immediately after harvest and that pruning is done at age 4 and age 7. Thinning income is 50 % of thinning volume, and the price is from the lowest diameter class. All the costs and incomes were fixed due to the complexity of cost (e.g. an increase in planted spacing will most likely reduce planting cost, but will increase weeding costs). One of the intentions is see how the Plantation Planner performance under different silvicultural regimes.

2.3.4 The scenarios run through the Plantation Planner

A basic scenario was run with defined rotation age of 19 years, initial stocking 1600 trees/ha and no thinning. This is the reference alternative that all other alternatives are compared with and the aim was to see how growth and standing volume develop over time. For an evaluation process of long term timber production it is essential to gain knowledge of different input variables used in the scenario model (Eid 2000). 8 different scenarios were run according to different assumptions for initial stocking, thinning and rotation age. Sensitivity analyses were done by testing the impact of change in rotation age, spacing and thinning regimes. Alternatives for rotation age were done for 16 and 22 years. Thinning was tested with alternatives for no thinning, thinning 20%, 30% and 40%. Different spacing was tested for 1300 trees/ha and 1900 trees/ha. All adjustments were done with the other factors fixed as for the basic scenario. Results from the scenarios are presented in terms of volume development and potential harvest over time.

The basis alternative premises a discount rate of 12%. Using the information from the basic scenario and the different adjusted scenarios, a sensitivity analysis was done for discount rate. It was tested with adjustments of 10% and 14%. This was done mainly to make visible how changes in discount rate will affect NPV.

12 % is chosen as the internal rate of return in the base scenarios because it reflects the uncertainty and risk around plantation industry in East Africa. In the single value of discount rate several factors are submitted; rate of return, the economical climate, future prospects and risk. The inflation in Tanzania was predicted to be 7% in 2007(CIA 2008) and the 12 % discount rate is chosen as an example, based on suggestions of plantation industry in the area (Green Resources 2006).

3. Results

3.1 Evaluation of the Stand Simulator

3.1.1 Initial basal area

Table 4 shows predicted and observed initial basal area from permanent sample plots, where the mortality function is used to give the expected stocking at a given age. The performance of initial basal area is illustrated at three different ages; four, five and six. Initial basal area is in the Stand Simulator calculated from site index and stocking at year five. The table show no significant bias at year five and six for the initial basal area, still, only initial basal area at year five show a positive model efficiency of 0.51. Model efficiency is in some way analogous to R^2 and as mentioned before the scale goes from 1 which indicates a perfect fit, to negative values which indicates a poor model. A positive value of 0.51 therefore indicates a model over average fit (Vanclay 1994; Soares 1995; Vanclay & Skovsgaard 1997). At age four there is a significant difference at 1% level. The overestimation of predicted initial basal area at age four is 68%.

Table 4. Predicted and observed initial basal area (m^2/ha) at three different age classes.

Age	Number of	Basal area (m^2/ha)		Difference		Level of	Standard Deviation		Model
	observations	Predicted	Observed	m^2 /ha	%	significance	m^2 /ha	%	efficiency
Age 4	17	7.30	4.34	3.0	68%	<.0001*	1.17	27%	-6.60
Age 5	13	8.83	8.74	0.08	1%	0.81	1.22	14%	0.51
Age 6	18	10.62	11.38	-0.76	-7%	0.44	4.11	36%	-0.77

* Significant on a level of 1%

3.1.2 Observed and predicted basal area

Table 5 shows a significant difference at 1% level between predicted and observed basal area pr. hectare for all the observations. The model predicts a mean basal area of 36.2 m^2/ha while observed basal area is 29.0 m^2/ha. This is corresponding to a mean overestimation of basal area by 25%. All the three sites show the same trends. However, Division 4 has the largest overestimation. The site of Division 1 and Division 4 show negative model efficiency which indicates a poor model, but the Uchindile forest project has model efficiency of 0.50. Merged together all areas have a model efficiency of 0.15 which is slightly over a simple average.

Table 5. Difference and standard deviation to difference in basal area (m^2/ha) between observed and predicted value sorted by the areas.

Site	Number of observations	Basal Area (m^2/ha)		Difference		Level of significance	Standard Deviation		Model efficiency
		Predicted	Observed	m^2/ha	%		m^2 /ha	%	
Division 1	17	45.5	41.8	3.7	9%	0.0037*	4.5	11%	-0.35
Division 4	55	46.2	33.9	12.4	36%	<.0001*	5.6	16%	-4.61
Uchindile Forest Project	46	20.9	18.4	2.5	13%	0.0006*	4.5	24%	0.50
All	118	36.2	29.0	7.3	25%	<.0001*	6.9	24%	0.15

* Significant on a level of 1%

3.1.3 Observed and predicted volume

Table 6 shows that there is significant difference at 1% level between predicted and observed volume (m^3/ha) for all the observations. The Stand Simulator predicts a mean volume of 521 m^3/ha while mean observed volume is 400 m^3/ha. This is corresponding to a mean overestimation of the volume by 30%. Both Division 1 and the Uchindile Forest Project have a significant difference in volume, although Division 4 has the largest overestimation with a difference of 215 m^3/ha between predicted and observed volume. There is a negative trend for model efficiency on the area of Division 4. Division 1 and the Uchindile Forest Project show positive values, and merged together there is a positive trend of 0.49 for model efficiency.

Figure 5a shows the difference between observed and predicted values of volume/ha for all observations. The figure shows overestimations of volume for nearly all observations. Figure 5b shows the difference between observed and predicted values of volume/ha at the Uchindile forest project. The residual plot illustrates the deviation from observed volume/ha. There is a trend of overestimate volume of stand with low true volume and a small trend of underestimation for stands with high true volume. Figure 5c shows a clear overestimation of volume, the random error around the mean value tends to be wider for younger stands. Also in Division 1 there is an overestimation of volume, but Figure 5d shows that the deviation is not as clear as for the other sites. Table 6 shows that the deviation is significant for all the sites.

Table 6. Difference and standard deviation to difference in volume (m^3/ha) between observed and predicted values sorted by the areas.

Site	Number of observations	Volume (m^3/ha)		Difference		Level of significance	Standard Deviation		Model efficiency
		Predicted	Observed	m^3 /ha	%		m^3 /ha	%	
Division 1	17	739	671	68	10%	0.0047*	85	13%	0.39
Division 4	55	743	528	215	41%	<.0001*	111	21%	-1.91
Uchindile Forest Project	46	176	147	29	20%	<.0001*	38	26%	0.65
All	118	521	400	121	30%	<.0001*	123	31%	0.49

* Significant on a level of 1%

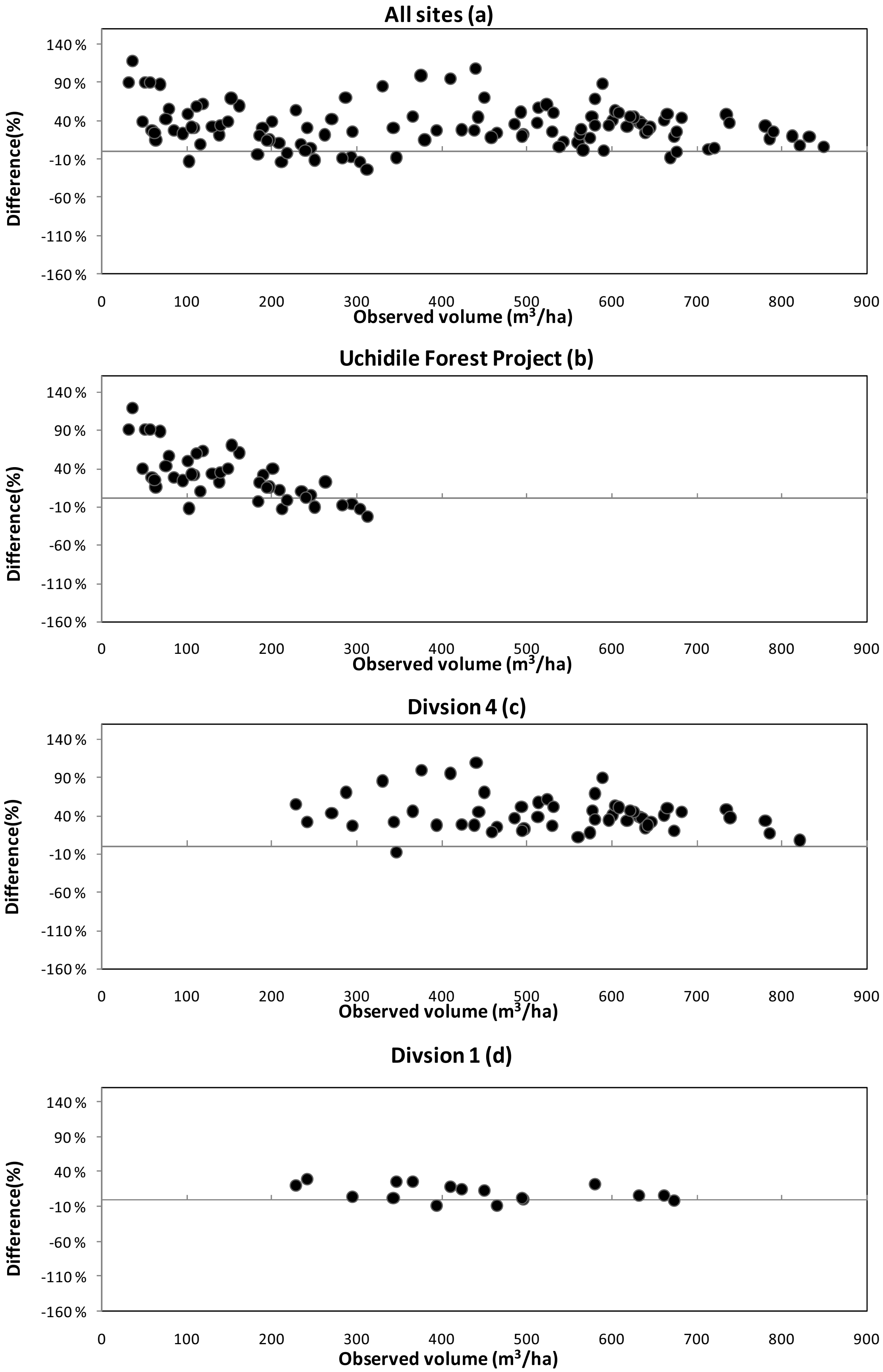

Figure 5. The residual plots show the difference between predicted and observed basal area and volume for tree different sites, and all sites merged. The deviation is expressed in terms of %.

3.1.4 Observed and predicted mortality

Table 7. Difference and standard deviation to difference in stocking (trees/ha) between observed and predicted values sorted by the areas.

Site	Number of obser-vations	Mean stocking/ha		Difference		Level of significance	Standard Deviation		Model efficiency
		Predicted	Observed	n	%		n	%	
Division 1	17	741.3	955.9	-214.6	-22%	<.0.001*	384.9	40%	-0.24
Division 4	55	771.2	765.5	5.7	1%	0.824	188.8	25%	0.67
Uchindile Forest Project	46	1191.8	1307.1	-115.2	-9%	0.048	393.7	30%	0.35
All	118	930.9	1004.0	-73.2	-7%	<.0.001*	301.7	30%	0.40

* Significant on a level of 1%

The predicted stocking (i.e. number of trees/ha) was tested against observed stocking. Table 7 shows significant underestimation of stocking in Division 1, but not for Division 4 and the Uchindile forest project. However, all areas merged together show significant underestimation of 73 trees/ha which is corresponding to a mean underestimation of 7%, even though Division 4 and the Uchindile forest project represent 101 of the 118 observations. When testing model efficiency the Division 1 have a negative value of -0.24 which indeed indicates a poor model. Division 4 and the Uchindile forest project show model efficiency of 0.67 and 0.35. When testing the predicted values from the function against observed basal area for all the sites, the model efficiency was 0.40. A test was also done for initial stocking at year five based on information from the permanent sample plots. This showed that there were no significant bias for the function, the random error was 1 %. Figure 6 shows observed stocking plotted against age and stocking, where the lines are predicted stocking from the mortality function with two different initial stockings. Division 4 and the Uchindile forest project have initial stocking of 1600 trees/ha, and the Division 1 has initial stocking of 1370 trees/ha. The figure shows that there is considerably variation between observed and predicted stocking.

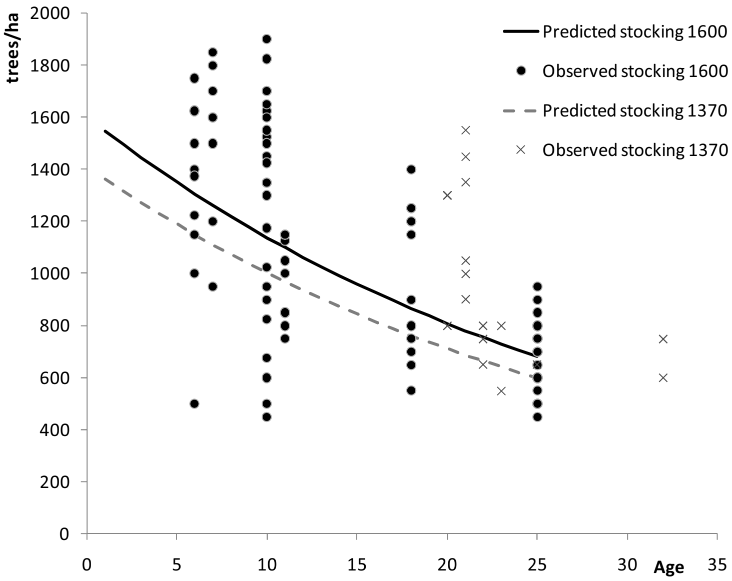

Figure 6. Observed stocking and predicted stocking.

3.1.5 Thinning equation

The thinning equation is not tested against observed data. Figure 7 illustrates how the volume growth will develop after thinning as run through the Stand Simulator. The tree lines show no thinning, thinning as presented in the model and thinning as presented in the BASIC-code, all using site class 2.

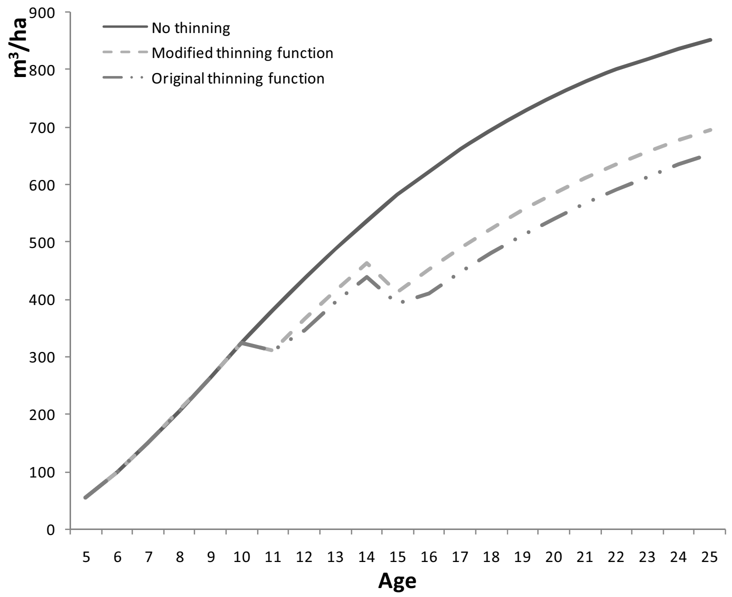

Figure 7. The thinning equation in the report differs slightly. The figures show how volume growth will develop using the thinning equation from the formulas.

3.1.6 Volume and basal sorted according to Site Index

When examine differences between predicted and observed basal area according to different site indexes, Table 8 shows a significant overestimation of basal area on 1% level for site indexes below 27, and for all sites merged together. Site indexes over 27 tend to overestimate basal area, however, the results are not significant on 1% level. There is a tendency of less overestimation for the lowest site indexes.

Significant overestimation of volume was observed at site indexes below 27 and for all areas merged together. A trace of overestimation of volume could be suggested for site indexes higher than 27, but these values are not significant on a 1% level. There is a tendency of less overestimation for the lowest site indexes. It is noticeable that site indexes over 21 gives negative values for model efficiency for both volume and basal area.

Table 8. Difference and standard deviation to difference between predicted and observed volume (m^3/ha) and basal area (m^2/ha) according to site index.

Site Index	Number of observations	Basal Area (m^2/ha) Predicted	Observed	Difference m^2/ha	%	Level of significance	Standard Deviation m^3/ha	%	Model efficiency
>27	5	48.7	35.8	12.8	36%	0.0311**	8.8	25%	-0.80
21-27	54	44.7	34.2	10.5	31%	<.0001*	6.3	19%	-0.17
<21	59	27.4	23.7	3.8	16%	<.0001*	5.4	23%	0.75
All	118	36.2	29.0	7.3	25%	<.0001*	6.9	24%	0.15
Site Index	**Number of observations**	**Volume (m^3/ha) Predicted**	**Observed**	**Difference m^3/ha**	**%**	**Level of significance**	**Standard Deviation m^2/ha**	**%**	**Model efficiency**
>27	5	879	624	255	41%	0.0397**	190	30%	-1.97
21-27	54	726	541	185	34%	<.0001*	121	22%	-0.78
<21	59	304	248	55	22%	<.0001*	67	27%	0.54
All	118	521	400	121	30%	<.0001*	123	31%	0.49

* Significant on a level of 1% ** Significant on a level of 5%

3.2 Scenarios

3.2.1 Sensitivity analysis

In the following passage results from different scenarios from the Plantation Planner are presented using the same formula set as in the report without any adjustments (Malimbwi et al. 1998). A basic scenario was run as a reference alternative with initial stocking 1600 trees/ha, no thinning and rotation age 19 years. Standing volume development and potential harvest from this scenario are illustrated in Figure 8, all other scenarios are compared to this basic scenario.

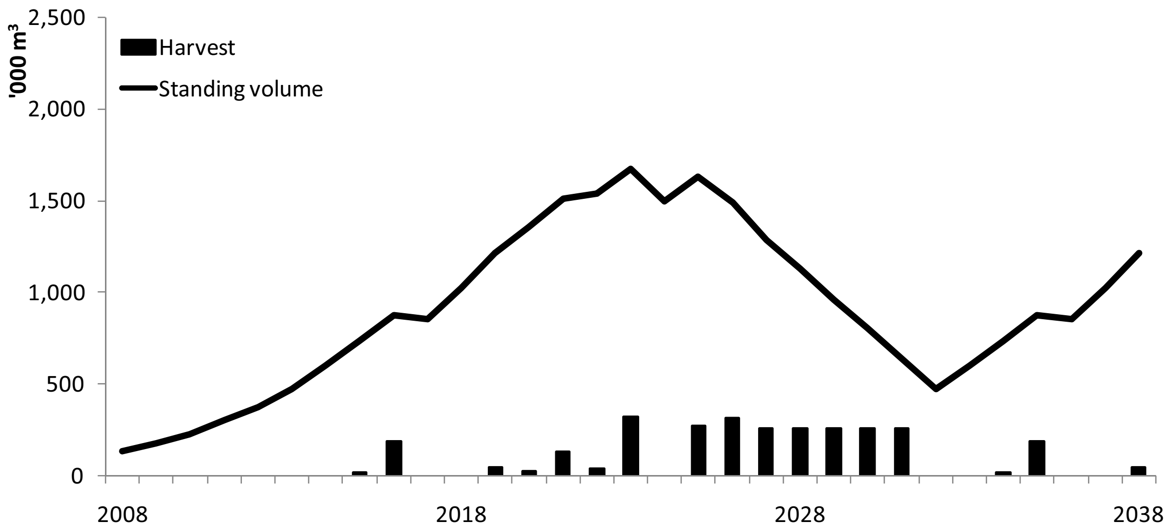

Figure 8. The figure shows how standing and harvested volume over time2008-2038, from the basis scenario with no thinning, initial stocking 1600 trees/ha and rotation age 19 years.

The predicted standing volume potential in Figure 9 shows that the deviations between seven different scenarios is relative small the first 10-year period, but larger in later periods. From 2023 and onwards massive harvest reduces standing volume and after 2032 the difference is not so large. Over the entire period (30 years) there is a large difference between the scenarios. Among the different scenarios the most important factor affecting standing volume is an adjustment of rotation age from 16 to 22 years which gives over 1 mill m^3 difference in standing volume in 2027. All experiments with thinning show a reduction of standing volume compared to the basic scenario. On the other hand an initial stocking of 1900 trees/ha tends to increase standing volume. Compared to the basic scenario also an extension of rotation age tends to increase standing volume up to year 2034.

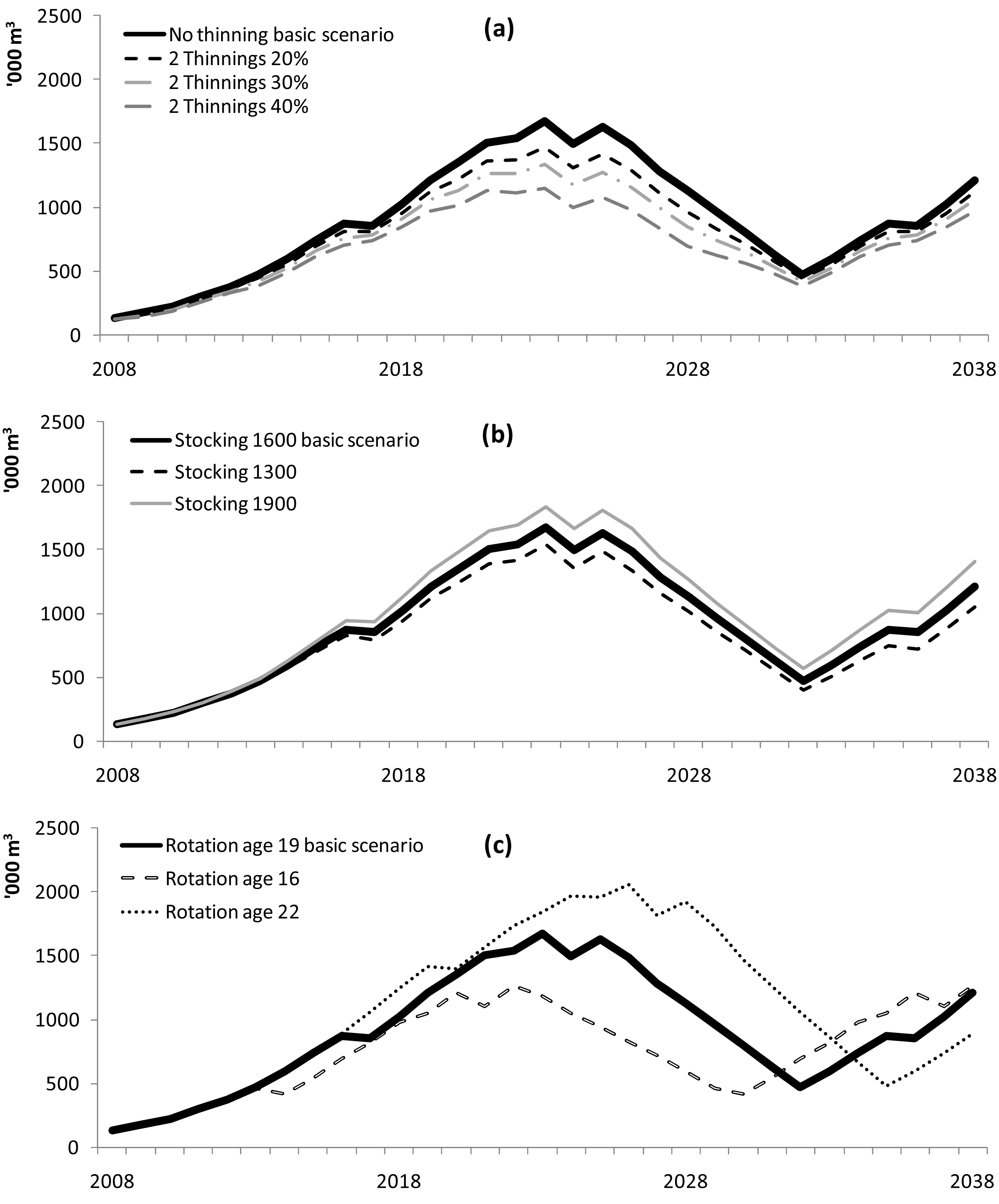

Figure 9. Standing volume development 2008-2038. The figure shows 7 different scenarios compared to the basic scenario with rotation age 19 years, no thinning and initial stocking of 1600 tree/ha.

Figure 10 shows how harvest occurs with different scenarios. Harvested volume was affected by thinning. The basic scenario gives over time the largest harvested volume compared to all thinning scenarios. Figure 10a shows that a thinning fraction of 40% gives some more harvested (removed from thinning) volume early in the time cycle, but lower harvested volume later.

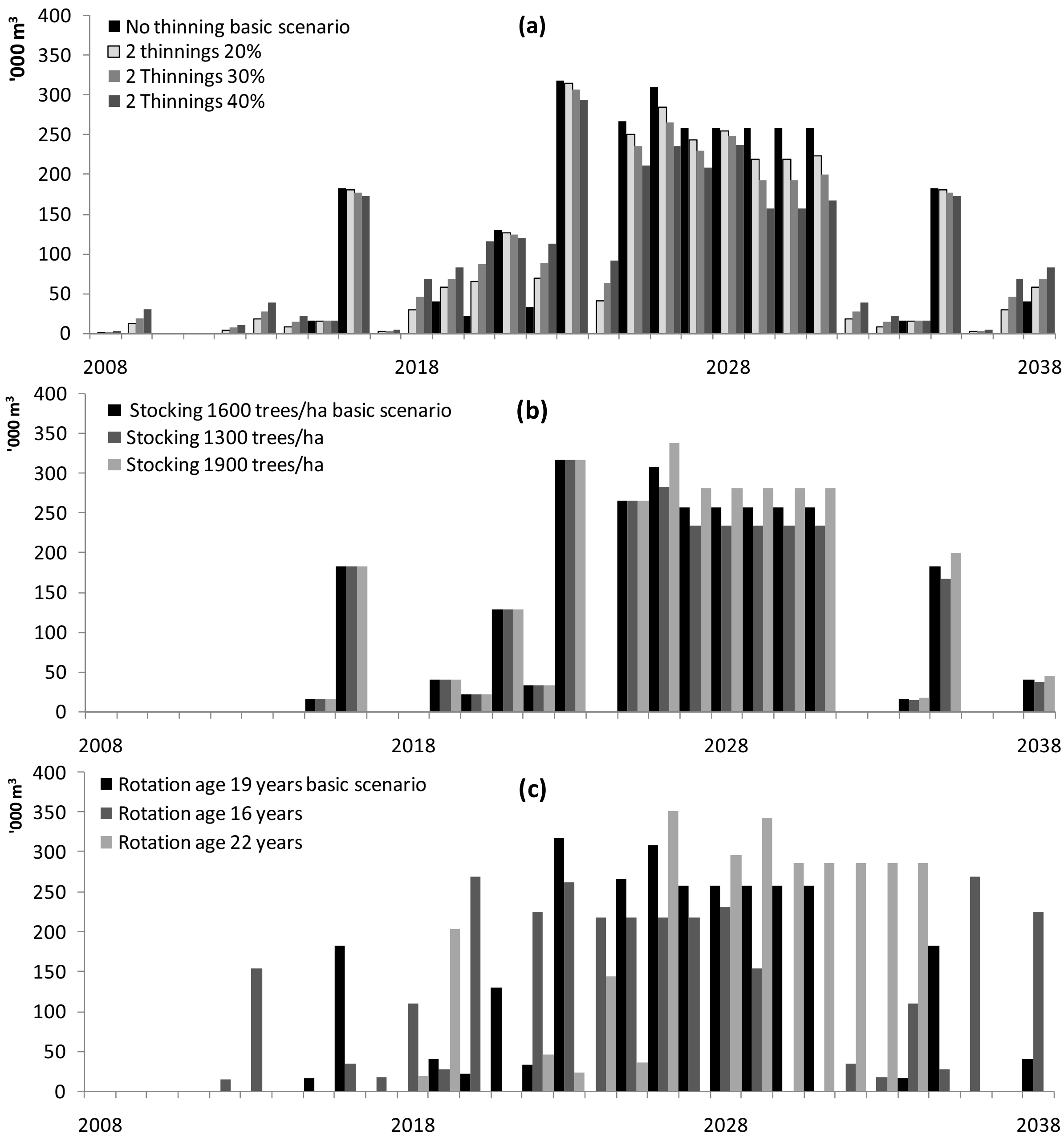

Figure 10. Harvested volume over time 2008-2038. The figure shows 7 different scenarios compared to the basic scenario. (a) shows three scenarios of thinning compared with the basic scenario, which has no thinning. (b) shows two scenarios of initial stocking compared with the basic scenario, which has initial stocking of 1600 trees/ha. (c) shows two scenarios of rotation age compared with the basic scenario, which has rotation age of 19 years.

Figure 10b illustrates how different initial stockings affect harvested volume over time (2008-2038). The figure shows that an adjustment of to different stockings has no influence on harvested volume until 2026. Looking at different initial stockings the harvested volume was slightly larger for stocking 1900 trees/ha, and slightly lower for 1300 trees/ha compared to the basic scenario. Different rotation age had a large influence on harvested volume. Figure 10c shows that different rotation age both affect the total harvested volume, and also the time where harvest is expected to occur. In the time period 2008 to 2038 a rotation age of 16 years gives slightly more harvested volume than the two other scenarios, by lead to 3,051,527 m^3 harvested compared to 2,887,708 m^3 for the alternative 22 years rotation age. The basic scenario gave at total harvest of 2,838,452 m^3 in the period. Alternative rotation age 16 years give harvest quite early in the period and rotation age 22 years leads to a major harvest later, between 2026 and 2034.

Table 9 shows the NPV from different scenarios, basic scenario with 19 years rotation age gives the highest NPV. A tough thinning fraction of 40% gives 54% reduction of NPV. Initial stocking of 1300 trees/ha had minor influence on NPV, and it was reduced by only 5%, there was no reduction of IRR. Test with different interest rates showed “normal” responses in NPV. In all cases the NPV increased with lower interest rate, and decreased with higher interest rate. On a relative scale higher interest rate results in larger NPV losses when thinning is carried out.

Table 9. Different forest scenarios and its impact on NPV and IRR

Discount rate	10%		12%		14%		IRR
Basic scenario	$ 3,956,881	100%	$ 2,684,573	100%	$ 1,794,501	100%	24%
Thinning 20%	$ 2,783,901	70%	$ 1,790,875	67%	$ 1,115,746	62%	21%
Thinning 30%	$ 3,337,940	84%	$ 2,179,987	81%	$ 1,398,920	78%	22%
Thinning 40%	$ 2,069,335	52%	$ 1,222,551	46%	$ 675,119	38%	18%
Stocking 1300	$ 3,741,373	95%	$ 2,538,053	95%	$ 1,694,018	94%	24%
Stocking 1900	$ 3,121,694	79%	$ 2,113,732	79%	$ 1,400,946	78%	23%
Rotation age 16	$ 2,410,671	61%	$ 1,639,998	61%	$ 1,094,116	61%	23%
Rotation age 22	$ 3,566,205	90%	$ 2,228,277	83%	$ 1,334,238	74%	20%

3.2.2 Impacts of potential errors

Figure 11a shows how a potential error in the basal area equations (BA1 & BA2) will impact standing volume. The basic scenario is using an unmodified growth equation, where the four other scenarios are adjusted down according to Table 5, which shows significant bias between predicted and observed values of basal area. Division 4 had the largest difference in basal area, which also gives the largest impact in volume. Division 1 and Uchindile Forest Project have a smaller overestimation of basal area, but still it has great effect on standing volume. The average difference for all areas is 25 %. Adjustment according to this value shows a large change in standing volume compared to the basic scenario, and the difference tends to be larger over time (2038). Figure 11b shows how standing volume will develop over time when the site index is adjusted. The figure shows that a small error in site index will lead to major differences in standing volume, which also impacts the NPV (Table 10).

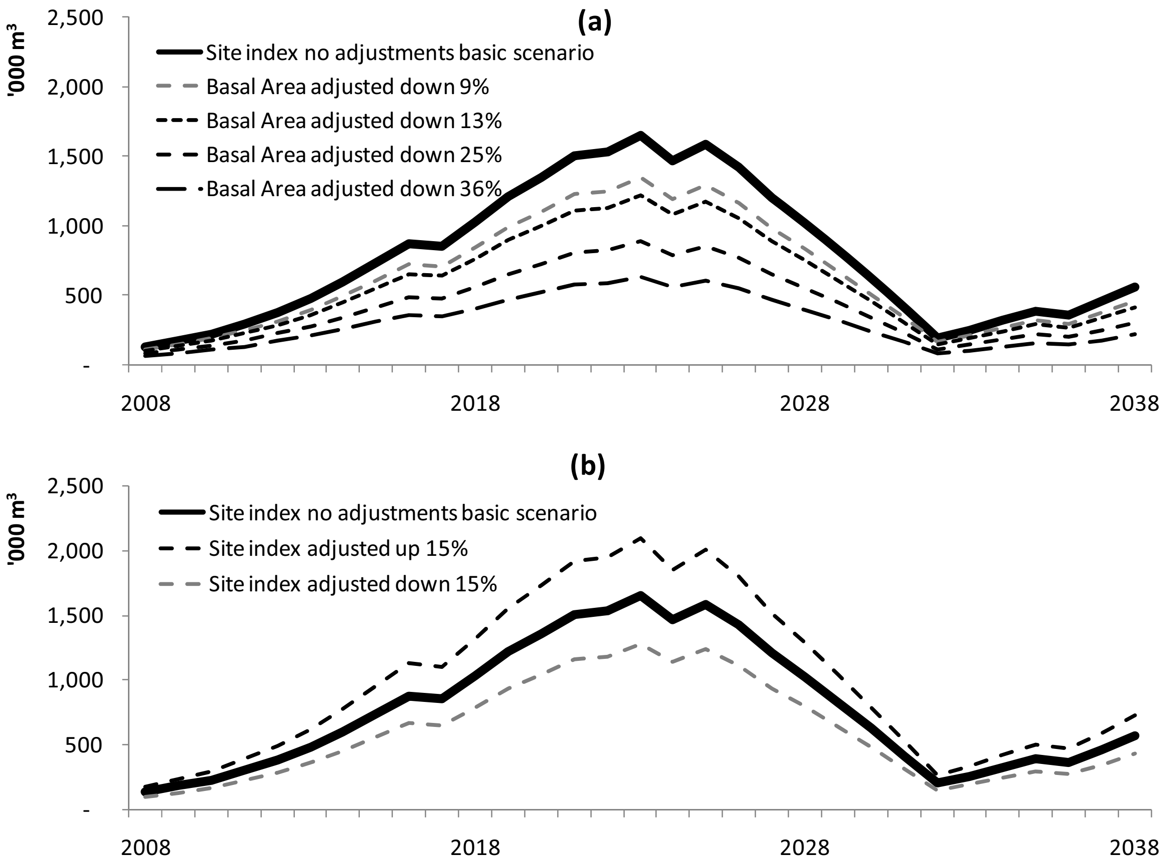

Figure 11. a) Standing volume development 2008-2038. Dotted lines are adjusted by a percentage in the basal area growth equation, according to the deviation illustrated in Table 5. b) Standing volume development for adjustments of site index. Dotted lines are standing volume adjusted by a percentage in the site index.

Table 10 shows how much NPV is influenced by a possible error in basal area and site index. The same trend occurs as in Figure 11. A relative small error results in large reductions of NPV.

Table 10. Adjustment of basal area and site index, and its impact on NPV and IRR.

Discount rate	**10%**		**12%**		**14%**		**IRR**
Basic scenario	$ 3,956,881	100%	$ 2,684,573	100%	$ 1,794,501	100%	24%
Basal Area adjusted down 25%	$ -104,253	-3%	$ -299,253	-11%	$ -426,317	-24%	9%
Basal Area adjusted down 9%	$ 1,167,860	30%	$ 635,044	24%	$ 268,452	15%	16%
Basal Area adjusted down 36%	$ -708,001	-18%	$ -744,855	-28%	$ -759,991	-42%	2%
Basal Area adjusted down 13%	$ 918,487	23%	$ 451,511	17%	$ 131,618	7%	15%
Site index adjusted down 15%	$ 1,030,379	26%	$ 534,085	20%	$ 193,418	11%	16%
Site index adjusted up 15%	$ 6,215,113	157%	$ 4,351,068	162%	$ 3,038,105	169%	28%

4. Discussion

4.1 Validation of the Stand Simulator

The random error for volume in this research is found to be 31% (Table 6). When examining the literature, similar investigations of growth and yield tables for *P. Patula* at Sao Hill were not found. Thus, there is some uncertainty if this is a high or low value. Still, a 31% random error indicates quite a lot of variance around predicted volume compared to some Scandinavian studies (Hauglin 2007). Looking at the different sites, the area of Division 1 has the lowest value with a random error of 13%, and the Uchindile forest project has the highest random error of 26%. It is interesting to note that the same trend exists for basal area growth (Table 5), it has the lowest random error at the Division 1 and highest random error at the Uchindile forest project. This might be explained by more variance around predicted stocking in younger stands. Figure 6 shows that younger stands, which are mainly represented in the Uchindile forest project have a significant variance around predicted stocking.

Bias was observed between predicted and observed volume, basal area growth and mortality. The volume and basal area growth equation had a mean overestimation of the predicted values by respectively 30% and 25%. Looking at Table 5 and 6 the bias for basal area growth and volume clearly follows each other, which is logic, since prediction of basal area growth lays the foundation for all estimations of volume (Table 2) (Philip 1979). On the other hand the mortality function underestimated stocking with 73 trees/ha, and the distribution of over and underestimation between the sites was opposite to the basal area growth and volume functions. There was a significant biased underestimation of stocking at Division 1, but no bias was found for Division 4 and the Uchindile forest project. Regarding the Stand Simulator 13 observations from permanent sample plots at year five was used to test initial stocking at year five, no significant bias was found.

4.1.1 Possible causal relations leading to different deviations

The following statements describe some important factors that could possibly lead to differences between observed and predicted results from the Stand Simulator. However, other moments not considered here might have similar consequences.

Inventory for collecting data to do the evaluation of the Stand Simulator was conducted in three different areas, in forest ranging from young stands to mature stands. The data was partly based on a continuously, intensive and well-documented inventory design in the area of the Uchindile Forest Project, which improve the quality of the data (Eid 2004). However, the sample plots from Division 1 and 4 were not systematically distributed, and this means that it is impossible to state whether they are representative for the forest conditions of the area. In the selection of plots from the other areas it was emphasized to have plots with a large variability with respect to ages and productivity. Also for these plots it is impossible to say if they were representative. Uncertainty related to the basic data used for evaluation is therefore quite high, and this weakens the basis of evaluation.

Originally the yield tables were made for the Sao Hill area, which includes Division 1 but exclude the Division 4 and the Uchindile area. The majority of these studies observations are from Uchindile and Division 4, which lies on average 700 meter lower than the Sao Hill area, and this may give a different mean temperature and annual precipitation (Table 1). Even if the yield table is constructed for the entire Sao Hill forest project, which includes Division 4, there were no observations from Division 4. This is because the aim of Division 4 was to supply the locale paper mill with pulp (Malimbwi et al. 1998). The fact that Division 4 was excluded from the data material could possibly lead to other conclusions. Table 5 and 6 and Figure 5 support this statement since observations from Division 1 had a better fit than observations from Division 4 and the Uchindile forest project.

Forest management and different site preparation techniques can also have a great impact on volume production. Kalaghe & Mansy (1989) did a study on how different site preparation techniques impacts the volume growth potential of *P.patula.* Site preparation had a great impact and ploughing gave almost 40% better volume growth compared to pitting. During field work it was noted that at the Uchindile forest project all planting was done by pitting. On the other hand approximately half of the stands in Division 4 were ploughed, and in Division 1 almost all stands were prepared for planting by ploughing. Also Kariuki (1998) conducted a study on the impact of growth with seeds from different provenances of *P.patula* and *P.patula spp*. He found significant difference of volume, but not on height. However, the factor of seed sources on the different sites was not possible to check. Still it is not improbable that the provenances were different for the sites. Malimbwi et al. (1992) looked at the effect of different spacing on *P.patula* stands, and most interestingly found that higher initial stocking might lead to lower basal area and volume. Findings from Division 4, the Uchindile forest project and Division 1 support this report. Division 1 had an initial stocking of 1370 trees/ha and had 10% overestimation of volume. This is different from Division 4 and the Uchindile forest project which has an initial stocking of 1600 trees/ha and had an overestimation of respectively 41% and 20%. This leads to a trend that a higher stocking could give both lower basal area and volume (Table 5 and 6).

Two adjustments of the Stand Simulator and one use of an additional volume equation have been done without description in Malimbwi et al. (1998). The adjustment of the basal area growth function shows that there originally might have been an overestimation of basal area. Since adjustment is a complex and full of pits, one must be careful (Vanclay 1994). There has not been any opportunity to examine the original data-material, therefore it is hard to say how successful the adjustments have been. Further it is not described how and why adjustment is done, maybe this is a just a spelling error, or an intuition that basal area has been overestimated. However a spelling error seems unlikely due to the fact that there also were two other adjustments without any explanation. An intuition can be more likely, since the original growth equation gives a volume of almost 1300 m^3/ha at 25 years and site class 1, but in the adjusted version it is “only” 950 m^3/ha. However, other studies show that there is great variance in the volume growth of *P.patula* (Alder 1975; Malimbwi et al. 1998; Verzino et al. 1999; Gutiérrez et al. 2006) which indicates that such functions ought to be calibrated to local conditions before they are used. Thinning was adjusted to a lower removal than the original equation, which leads to a higher total standing volume (Figure 7).

4.1.2 Functions and equations in the report (Malimbwi et al. 1998)

According to Vanclay & Skovsgaard (1997) a model should be examined in terms of logic structure, and from theoretical and biological views to see if it among other factors is biologically realistic, consistent with existing theories of forest growth, and if it predicts sensible responses to management actions.

Regarding initial basal area the equation is sensible, but there is a clear trend of overestimating when the stand age reaches 6 years and a clear underestimation below five years. At year 5 the initial basal area showed no signs of bias, and the random error was 1 %.

What has to be held in mind is that there are very few observations of initial basal area, which might explain the large deviation from year four to six (Table 4). Still the data is based on permanent sample plots that are repeatedly measured every year, so the quality of the material should be good (Vanclay 1994; Eid 2004).

In the report from Malimbwi et al. (1998), some adjustments to the basal area growth model have been done. These are not described in the report, but are attached in the BASIC code. The original basal area equation (BA2, Table 2) uses 0.006 (Malimbwi 1987) and is adjusted to -0.02 in Malimbwi et al (1998). Figure 12 shows how the adjustment impacts basal area growth. After adjustment the basal area seems to have a more reasonable growth. Still, the predicted basal area tends to be overestimated compared to the observations. Most probably this has been discovered, and therefore the adjustment has been used when constructing the growth and yield tables. The curve of the adjusted basal area growth function looks more sensible, but the function does not respond to thinning. When describing biological phenomena (e.g. thinning) it is sensible that responses to management actions should be taken into account (Soares et al. 1995). The way the growth formula now works, a reduction of basal area just leads to less basal area on stand level. Figure 7 shows that no compensating growth occurs after thinning. Some studies from other conditions indicate that compensating growth can happen after thinning. This is logic because of more light, available nutrients and water access etc. (Børset 1986; Lesch & Scott 1997).

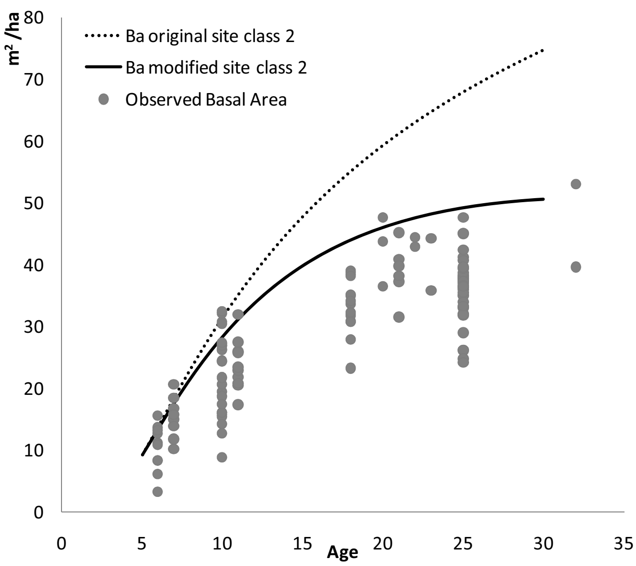

Figure 12. The figure shows the difference between the original basal area growth equation and the modified basal area growth equation given in the BASIC -code. Dots are observed basal area from the 118 sample plots.

One volume function is used to estimate volume at the age five (VOL1) and another volume function is used for prediction of volume from year five and above (VOL) (Table 2). This is not presented in the report, but was revealed when recreating the Stand Simulator. There has not been done any validation of the two volume equations, therefore there cannot be said anything about their performance. Still Malimbwi et al. (1998) point out that those volume equations had a superior fit and did perform adequately.

Valkonen (1999) states that site index from Malimbwi (1987) does not show any significant differences compared to other site index curves from East Africa. Figure 2 shows three site classes compared to observed dominate height, almost all observation are inside the three different site classes. However there is a trend that most of the observations are in the lower aspect. Table 8 support this observation, where only five sample plots are in the highest site class. Due to limited data and lack of decision basis no conclusions about the correctness of the site classes can be stated. Many factors impact on the growth and yield of *P.patula.* Site index is a single independent variable that tries to describe every aspect of soil nutrients, temperature regimes, available light, moisture, topography and so on (Avery & Burkhart 2002). The fact that all these independent variables are brought together in one single factor of site index leads to uncertainty around what variables that impact growth the most in each case.

The mortality function is used only once in the volume and basal area calculation, this is at year five, as a component to initialise basal area. During inventory it was discovered a great deal of self thinning when the stands passed ten to fifteen years. This is supported by the fact that trees actually die when the competition for light and water accelerate, and that this is a biological process that increases continuously up to a certain limit. As mentioned by Vanclay and Skovsgaard (1997), the logical behaviour of a model is essential for the quality of the product. In case of mortality, the function itself seems to work properly with a model efficiency of 0.40, but the way it is used in the Stand Simulator is strange. It is not directly described how to put stocking into the initial basal area equation. Even if the planted spacing is 1370 trees/ha, the mortality equation uses a stocking of 1408 trees/ha instead of a variable, for initial planted stocking instance N (Table 2). This can impact the result, since 101 of the observations used a different stocking of 1600 trees/ha.

The thinning equation presented in the report and Table 2 differs slightly from the one that is used in the BASIC programme. From the thinning equation (Y) the basal area is reduced by removing 1.5 m^2/ha after calculation. This reduced basal area from thinning, and therefore removed volume and basal area is less than the original thinning function (Figure 7). In addition, the equation for thinning is adopted for *Cupressus lusitanica*, and not for *P. patula*, because of "absence of suitable data" (Malimbwi et al. 1998). Still, the thinning equation just determines the percentage of removed basal area, and hence it might be accepted to implement another equation for the purpose. The fact that this is a low thinning seems reasonable, but has to be kept in mind when using the function. The main purpose of thinning is not always to remove the smallest trees. In some cases it might be more important to sort out defect trees then small tress (Personal communication Endre H. Hansen).

4.1.3 Possible Adjustments of the Stand Simulator

Simulation is a complex and difficult process. With help of a few easy measurable values, a model tries to describe the complexity of nature (Eid 2004). There are many components in the Stand Simulator, therefore any adjustment must be done with a great deal of caution (Vanclay 1994). Site index is the foundation of all observations and calculations in this study, so this cannot be adjusted. The easiest is to adjust down the finale product; e.g. adjustments of the volume function down 30%, which will make a better fit for this study's observation. On the other hand the volume function was encumbered with less uncertainty than other biological functions (Malimbwi et al. 1998). The volume function had an R-square value of 0.98 and it is mentioned as a superior fit, where both the initial basal area (0.94) and basal area growth (0.82) has a lower R-square. By adjusting volume the utterly consequence is that an error will be compensated by another error. In the end this might be a poor solution, and it could impact and make errors to other components (Vanclay 1994).

From Figure 12, it is clear that the basal area growth in some way follows observed data, but is overestimated. This leads to two possible adjustments, either initial basal area or basal area growth. The basis for initial basal area is 13 observations form the permanent sample plots which show no signs of bias, this does not lead in the direction of adjustment. Contradictory the data material is not especially large, so some uncertainty will be connected to the result because of limited data. However, correction of initial basal area would be unnatural.

There has already been an adjustment of basal area growth. If a correction of the Stand Simulator is of interest, an adjustment of basal area growth could be meaningful, how much is a matter of discussion. Figure 12 shows that an adjustment might lead to a better shape of the curve and better fit. However, as mentioned before there is uncertainty connected to the data material from Division 4 and 1. A correction should be fitted to the area where the function will be used (Malimbwi et al. 1998), which in this case is the Uchindile forest project. Some uncertainty is also connected to how representative the temporary sample plots are. In addition the age distributions of permanent sample plots at the Uchindile forest project are too small and narrow. Therefore any adjustment of basal area growth will associated with a great deal of uncertainty.

4.1.4 Conclusion Stand Simulator

A Stand Simulator was successfully developed by means of SAS-software that enables simulations according to different forest conditions and treatments. Validation of the yield tables showed that standing volume was significant different from zero on all sites. Although there is a significant difference between the observed and predicted volume and basal area, many aspects of the Stand Simulator still work in a good way; basal area and volume is following each other, and reacting logically according to stocking, age, and site index. Much of the deviations can most likely be explained by different sites and uncertainty concerning forest management at the different sites. However, the main objection is lack of proper documentation to every aspect of the Stand Simulator. The difference in volume indicates that an adjustment in a function could be adequate, but due to lack of proper data a correction of the Stand Simulator is not recommended this time. However, it is recommended to keep up the good system of permanent sample plots from the Uchindile forest project and utilise this data in the future. A continuously process of utilizing data from permanent sample plots to see possible trends in the future will give a better decision basis, and a new similar study will give some better indications to possible adjustments.

4.2 Forest level planning

The Plantation Planner is a tool to help in the decision process of forest level planning. The intention is to give an indication of future potential of growth when using different kind of forest management. Predicting the future is complicated and full of uncertainty. Moments like fire, climatic changes, insect and beetle attacks etc. are stochastic variables that are difficult to model. Such elements are not implemented in the Plantation Planner. Other more pragmatic factors are important for assumptions of uncertainty; changes in the economic climate, future planting, area and wrong assumptions of site index are typical examples. All models and sub models are just reflections of reality (Soares et al. 1995) and hence some variables might be left out. Therefore interactions between sub-models can get a wrong perspective of ratio, which leads to the fact that results from the Plantation Planner never will achieve higher quality than the input variables. The core of the Plantation Planner is the Stand Simulator, and hence the quality of the Stand Simulator is essential for the product.

Scenarios were run over a 30 years period, this gives one rotation. For the basic scenario rotation age was set to the age of maximum mean annual increment (Avery & Burkhart 2002), which in this case is 19 years for site class 2. This was found using the Stand Simulator. The Basic scenario shows that the Plantation Planner is acting reasonably, volume is responding according to planting and rotation age, and volume is reduced according to harvest. Economical outputs respond to increased prices from the price table of different diameter classes and changes in interest rate (Table 3 and Table 9).

Before the different scenarios are commented, some notes about area size and planting have to be mentioned. The planted area between 1997 and 2008 are not evenly distributed. Following an early peak in planting in 1998, there were no planting during 1999-2002. New planting increased again from 2005, and after 2008 there is an assumption of evenly distributed planted area of hectare each year. This impact standing volume in such a way that there is a small reduction of standing volume in 2016 and 2023 before there comes a steady reduction until 2031. From 2032 standing volume is increasing again.

From Figure 9a one can see the impact thinning has on standing volume, this seems logic since each scenario is a yearly parallel reduction according to thinning, this corresponding to how basal area growth equation in the Stand Simulator are working. Figure 10a shows that thinning gives harvest earlier in the time cycle and therefore income a few years before the basic scenario. Another moment is that thinning gives more evenly distributed harvest, and the big peaks are flattened out. Table 9 shows that there is a lower NPV for thinning fraction 20% contra 30%. This might look like a remarkable observation, but the reason is how the Plantation Planner responds to a higher average DBH. A higher average DBH could lead to a leap from one diameter class to another. This gives a higher sales value, according to Table 3. When thinning fraction reach 40% the volume loss is too large to be compensated by a higher price class.

A reduction of planted stocking down to 1300 trees/ha, gives standing volume a reduction of almost 130,000 m^3 at age 2028 compared to the basis scenario. When planting 1900 trees/ha the standing volume gives an increase of almost 135,000 m^3 compared to the basic alternative. However, the NPV is higher for stocking 1300 trees/ha than with 1900 trees/ha. This is the same as for thinning, the average DBH will go up with lower stocking, and lead to a leap in price class. Figure 9b shows how standing volume over time is impacted by different stockings. It seems logical that higher stocking increase standing volume, at least some Scandinavian models confirm this (Børset 1986). This is contradictory to Malimbwi et al. (1992). He found that increased spacing up to 3.14 meter lead to higher survival, increased height and basal area growth, and finally higher volume. This might be explained by difference in climatic conditions between boreal and tropical conditions, this again favour different inputs. Further the specie of *P.patula* has quite extreme growth compared to most Scandinavian species, and hence it is difficult to compare. Still this finding from the Plantation Planner differs slightly from the findings when comparing Division 1 with Division 4 and the Uchindile forest project. The Stand Simulator revealed that the overestimation of volume was higher in Division 4 and at the Uchindile forest project than at Division 1 (Table 5 and 6). Why the Plantation Planner still gives a higher volume when the stocking is increased is explained by the initial basal area equation which rewards higher stocking with higher basal area. This is consistent to the Stand Simulator, and must be held distinct from the differences between areas like Division 1 vs. Division 4 and the Uchindile forest project.

Figure 9c shows how different rotation age impacts standing volume, a longer rotation age gives a higher standing volume and a shorter rotation age gives a lower standing volume, this is logic since the growth period is longer. Table 9 shows that NPV is lowest for rotation age of 16 years, this is also sensible since the average DBH is low and there is less standing volume. The 3 extra years of growth still gives a lower NPV compared to the basic scenario. This might be explained by the fact that the rotation age of the basic scenario is closer to the optimum age of mean annual growth, and therefore volume growth cannot compensate for economical expectations. This is according to Table 9 which shows that a rotation age of 22 years and an interest rate of 10% gives 90% of NPV compared to the basic scenario. Also when testing the same variables with an interest rate of 14%, it only gives 74% of NPV compared to basic scenario.

4.2.1 Impact of possible errors and adjustments

The Stand Simulator revealed an overestimation of basal area growth (Table 5), this will also lead to an overestimation of volume (Table 6). There was a significant mean overestimation of basal area of 25% for all areas. As illustrated in Figure 11 and Table 10, analyses were done to check how much an error in the code, function, or erroneous site index could affect volume and NPV. The error was adjusted to reflect the observations, and the adjustment had a great impact on both standing volume and NPV. The NPV loss was higher than expected. When adjusting down basal area 25% compared to the basic scenario, the NPV was reduced by almost 3 million USD (Table 10), and standing volume was reduced by roughly 800,000 m^3 in 2023 (Figure 11a). First, the most logic is that a reduction of standing volume leads to lower sale potential, and therefore a reduction of NPV. Secondly and not so clear is that average DBH is reduced by the adjustments in basal area. This might lead to a lower price class for each log, which again lower the timber value. The other adjustments of basal area were done according to local difference for each area, and gave similar reductions of standing volume and NPV.

How correct it is to make adjustments in basal area is a matter of discussion. One must be very careful when adjusting formulas. Even though an adjustment might give a more correct result, it does not necessarily mean that the error is revealed. Philip (1979) showed that there was close relationship between basal area and volume for *P.patula,* which is logic. Still Table 5 and 6 show that the difference is larger for volume than basal area. This indicates that there might be other explanatory variables not considered here that affects volume.

A similar experiment was done for site index. The site index at the Uchindile forest project is as mentioned for a great deal subjectively determined. Because of this a great deal of uncertainty is connected to site index, and a test was done to reflect how much impact a possible wrong site index impact standing volume and NPV. This is presented in Figure 11b and Table 10 which show how site index adjusted 15% up or down compared to the basic scenario influence on volume and NPV. Similar results as for adjustments in basal area were revealed, and a wrong site index have major influence on NPV. Figure 11b shows that 15%

increase in site index have more positive impact on standing volume than 15% reduction affect in negative direction. The NPV seems to be affected very similar to the case of basal area.

Summarized the basic scenario must be seen as the most realistic maximum alternative, this is due that the Stand Simulator shows clear signs of overestimation of volume, however site index can give a boost of standing volume if its overestimated, and from Figure 11b even a small change can have a great impact. However this will only be speculations.
A possible minimum scenario could be the basic scenario with an adjustment of basal area down 25%. Table 5 states that this is the mean overestimation of basal area, however, the Uchindile forest project has an overestimation of 13%, which is lower.
The most "realistic" alternative will most likely be an adjustment of basal area down somewhere between 9% and 13%. This is to reflect the difference. An adjustment of site index seems unreasonable since there is no data to support such a decision. In addition, the site index is encumbered with some uncertainty, since it for a great part is subjectively decided at the Uchindile forest project.

4.2.2 Conclusion Plantation Planner

Forest level planning is a complex process, and the Plantation Planner includes information from several disciplines within forestry. The different scenarios show that the model responds in a logical way to different inputs. Still, a model will seldom be "correct" and the modeller is seldom satisfied (Eid & Hobbelstad 2000). A huge amount of information has to be put into the model, and the modeller faces numerous challenges, especially connected to the quality of inputs and the methodology of the model, in this case some uncertainty is related to the Stand Simulator. Still the Plantation Planner is built mainly for use in practical planning and in this respect we conclude that the model is a suitable tool for use at plantations in Tanzania. However, even though the model seems to be a suitable tool it should not be considered as "finished". Further development is recommended, and we suggest a continuous calibration of the model, especially connected to the "core". In this study only *P.patula* is used, but it is possible to expand the tool with other species, economic assumptions and calculations. However, one has to consider that the Plantation Planner will not perform better than the biological models it is based on.

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6. Appendix

6.1 Appendix 1: Instructions for the Green Resources inventory team

INVENTORY AND MONITORING OF PERMANENT SAMPLE PLOTS (PSPs) IN CARBON FOREST BASED PROJECTS.

INTRODUCTION

In order to monitor and manage our forest plantations, special studies and research are in place. Monitoring of carbon, growth and forecast development and yield in future some data must be collected within our forest plantation. These data are collected in Permanent Sample plots laid out in the plantation of the same management regime. These receive the same treatment like any other tree plant in the field. Data collected from these plots are analyzed to produce results of the intended. To achieve this 22 Permanent Sample plots have been laid subjectively randomized and laid out in the forest plantation that covers planted area.

BASICS:

A. Representability

Plots justified for statistical analysis should be as much representatives as possible. 22 PSPs laid in the field are such that they represent more or less all-environmental attributes of the field.

B. Sampling design

Subjective randomized sampling is adopted, proceeded by the clear stratifications of sampling blocks/compartments. A block compartment is assigned a plot representing the environmental attributes of the field.

C. Sampling intensity and Sample size

Sampling intensity of 0.062 % is taken giving sample size of 0.88ha This is arrived at by multiplying the area planted during the first two years (1996/97 and 1997/98) by the sampling intensity (i.e. 0.062% x 1420ha. = 0.88ha.)
However, forestry is using a sampling intensity of 0.05%. We used a bigger intensity so that we may have a bigger area for taking measurements.

D. Plot sizes and number of plots

A plot size of 0.04 is to be selected as it gives adequate number of plants for measurements. This comes up with 22 PSPs for studies that is 0.88 ha/0.04 ha = 22 plots.

E. Plot shape and demarcations

A standard circular shape is laid out with radius of 11.2m giving plot size of 0.04 ha. These plots are dernarcated by putting poles around the plot while a pit 1 m x 1m with a depth of one meter is put at the center of the plot and Global Positioning System (GPS) coordinated are taken at this point, so that a plot can be mapped and located on the map. Screefing around the plot is abandoned to avoid age effect.

F. Planting Demarcation

Unique number marks are put on all trees inside the plot. These numbers are written by use of oily paint on aluminum covers keeping the information concerning the tree safe from weather effect e.g. rain. All trees are marked with white weather resistant paint at DHB i.e. at 1.3 m height so that the same point is measure d all the time during measurement.

WHAT TO MEASURE:

a. Parameters

Parameters of interest as far as an objective of monitoring is concerned are;
Carbon pools: live biomass; (Trees, Roots, Fine Litter and Course Woody debris) and dead biomass (soil and wood products). These parameters will be analyzed to give the actual results intended. However some more information will be recorded for other purpose eg species, altitudes, GPS reading, slope, vegetation cover etc. (see the attached PSP field form).

b. Measurements

All the trees in the plot will be measured for DBH,
Heights of the following trees will be measured:-
One fattest tree
One thinnest tree
Two trees whose diameters are most occurring.

One tree at each plot will be selected for litter measurement.
Tree near to each plot at age 3 years and above will be measured for above ground biomass i.e. separated into stem, branches, leaves and litter components, thereafter more than 50% of the plots will be measured.

All plots will be measured for soil carbon at depths of 0 – 30cm, 30 – 50cm, 50cm and above.

NOTE: Trained personnel under supervision of the crew leader will do the work.

ANALYSIS AND RESULTS

The data collected from these plots will be analyzed according to international laid out principles and the results obtained from the analyzed data will give the following information:

- Actual carbon benefits
- Actual stocking
- Actual growth trends, e.t.c

PERMANENT SAMPLE PLOTS FIELED FORM

A) VOLUME MEASUREMENT.

PSP NO	SPECIES	PLANTING YEAR	AGE
PLOT SHAPE	PLOT SIZE	ALTITUDE	VEG.COVER
SLOPE	SAMPLING INTENSITY	DATE OF MEASUREMENTS	ASPECTS
LOCALITY	COORDINATES	RAINFALL	SOIL TYPE

A) HEIGHT (m)	B) DBH (cm)		
1	1	28	55
2	2	29	56
3	3	30	57
4	4	31	58
5	5	32	59
	6	33	60
	7	34	61
	8	35	62
	9	36	63
	10	37	64
	11	38	65
	12	39	66
	13	40	67
	14	41	68
	15	42	69
	16	43	70
	17	44	71
	18	50	72
	19	46	73
	20	47	
	21	48	
	22	49	
	23	50	
	24	51	
	25	52	
	26	53	
	27	54	

B) BIOMASS MEASUREMENTS

TREE SELECTED	GREEN WEIGHT (kg)			
	STEM	BRANCHES	LEAVES	CONES

C) SOIL CARBON MEASUREMENT.

DEPTH (cm)	CARBON CONTENT (g/cm3)
0 - 30	
30-50	
50-80+	

REMARKS:……………………………………………………………………………………………