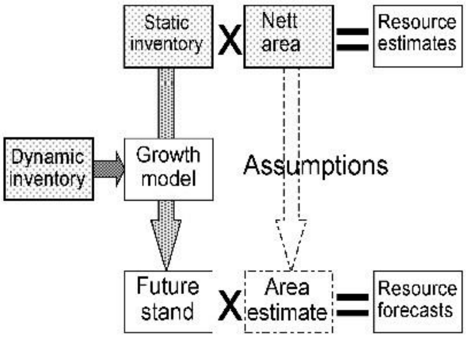
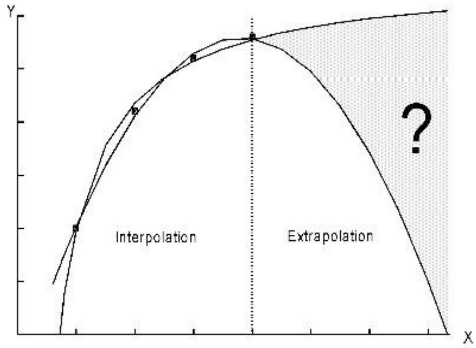
Final Report

Modelling of forest growth and yield in Uganda

Pinus caribaea and Eucalyptus grandis





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Client: Sawlog Production Grant Scheme

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Content

1 Introduction 4
2 Terms and definitions 5
3 Designing a forest inventory system 7
3.1 Introduction to modelling of forest growth and yield prediction 7
3.2 Objectives of forest inventories in Uganda 8
3.3 Considerations when designing a forest inventory 9
4 Data for modelling of growth and yield in Uganda 13
4.1 Data requirements 13
4.2 Review of available data sets 14
4.2.1 *Pinus caribaea* 14
4.2.2 *Eucalyptus grandis* 14
4.3 Data gaps 14
5 Recommendations and way forward 16
Literature 18
Annex 19

Figures

Figure 1: Work flow of a forest inventory 7
Figure 2: The role of growth models in decision making, forest 8
Figure 3: The influence of plot location on quality of growth modelling 10

Tables

Table 1: Parameters measured in forest inventories 13

Abbreviations

SPGS	Sawlog Production Grant Scheme
SI	Site Index
MAI	Mean Annual Increment
CAI	Current Annual Increment
PSP	permanent sample plot
R^2	Coefficient of determination
N	number
DBH	Diameter at breast height
H	Height
UFD	Uganda Forest Department
PhD	Doctor of Philosophy
FAO	Food and Agriculture Organisation
FRP	Forest Rehabilitation Project

1 Introduction

Forest managers, planners and policy makers worldwide use forecasts predicting growth and yield of forest. The models used in these forecasts assist in the management of forest stands, i.e. deciding which silvicultural options will be applied throughout the live of a forest stand and when best to harvest.

Prediction of future yields is also important for the wood processing industry. Decisions such as what kind of processing plant is needed, where to place a plant and what products to expect should be based to a large extend on information provided by yield models. Where industries are already established operations of growers and the depended plants can be streamlined to avoid large fluctuations in wood/ timber supply. Such fluctuations can lead to declining/rising prices for timber and timber products and the possible standstill of processing plants causing significant losses.

When yield models are linked to economic modelling they will also serve to predict future costs and revenues as well as permit the valuation of a plantation at a given point in time.

The Ugandan commercial plantation sector is still at the beginning of its development, although significant improvements have been made during the last few years, largely due to the efforts of the Sawlog Production Grant Scheme (SPGS). The SPGS recognised the need for a better scientific base for commercial forestry in Uganda, in particular where silvicultural practises are concerned. Growers need simple tools to understand the need for timely and appropriate interventions and for planning their businesses. However such tools are not available in Uganda, while models from other countries cannot be transferred easily due to the fact that each region has unique growth conditions.

Therefore UNIQUE forestry consultants was contracted to

- Review the available data on growth and yield in Uganda,
- Give guidance on how to develop an appropriate database for future modelling,
- Develop yield models and tables at SPGS cluster level,
- Develop an economic modelling tool and
- To train SPGS staff in using these tools.

This report provides some of the basic knowledge needed when looking at forest growth. To that end chapter 2 will explain some important terms used throughout the document. In chapter 3 the principles of forest inventory systems and modelling of forest growth will be explained. Chapter 4 provides detailed information on the data needed and available in Uganda. Recommendations and way forward are given in the last chapter.

The yield and economic models as well as the training are provided separately.

2 Terms and definitions

In order to understand the following chapters some terms often used in forestry, in particular when it comes to monitoring of forest growth and yield need to be explained. Unfortunately terms are often not used in a consistent manner in the international forest literature. Definitions provided here can therefore not be taken to be the **one** definition. Terms are explained in the context of commercial plantation forestry.

The list is not meant to be exhaustive; but refers only to the more complicated or ambiguous terms.

The **Site Index** (SI) describes certain regions in terms of capacity for forest growth. Underlying parameters are climatic conditions and soil, which can be split further. The SI is given as the height of a stand at a defined age. Here the SI is defined as dominant height at age ten.

Forest stands are unique entities within a forest defined by at least age, site index, location and area.

Forest inventories describe the status of the forest resource. Depending on its design it can provide information on location, extent, composition and structure of forests. Based on this standing volume can be calculated.

Single forest inventories provide information on the forest for one point in time only; **static forest inventory**. If the users need information on how forests are changing it must be a **continuous** or **dynamic forest inventory**; meaning repeated measurements of the same sample plots are necessary.

Growth models can reflect very different scales:

Single tree models → Size class models → Whole stand models

At the whole stand level they provide information on the development of a stand over time in terms of tree numbers, heights and diameters. From that other important parameter such as basal area and volume can be derived. Models at stand level ideally incorporate information on social aspect between trees, i.e. interdependencies between trees, structural changes and intervention effects.

Growth models are of limited use on their own, and require ancillary data to provide useful information.

Yield models are based on growth models. They predict different volumes at any given time throughout the rotation length. With the help of dimensionless factors (based on single tree models) and other limiting parameters (e.g. minimum saw log diameter) prediction of volumes such as standing volume, harvestable volume and round wood volume can be made.

The **Mean Annual Increment** (MAI) is the volume of wood growing on one hectare of forest during one year (m^3/ha/year) on average since the forest has been established. For a tree plantation, the MAI is the present total growing stock volume of one hectare divided by the total age.

Current annual increment (CAI) is the volume increment of wood growing on one hectare of forest (m^3/ha) for the reference year only.

Dominant height is the height of the thickest trees in a stand. On sample plot level the thickest two to three trees (depending on plot size) might be selected.

Mean height is the average height of trees of all sizes.

Permanent sample plots are necessary for continuous forest inventories. Each plot has a re-identifiable location and is re-measured every few years.

3 Designing a forest inventory system

3.1 Introduction to modelling of forest growth and yield prediction

As outlined above forest models have various purposes and uses. Unfortunately there is not the one-model-fits-them-all option. Models that reflect a lot of detail even on a small scale require more primary data parameters than less sophisticated models. Up scaling highly sophisticated models to cover large tracts of forest quickly becomes very expensive. Accordingly the forest inventory as well as the form of data storage and analysis need to be well adjusted to the purpose. Figure 1 outlines the general work flow when designing a forest inventory system for modelling purposes.

Figure 1: Work flow of a forest inventory

Define the objectives of the forest inventory
Plan the forest inventory
- Technical objectives
- Inventory design
- Inventory protocol

Collect data
- Field data
- Literature review

Store, manage and analyse data
- Data base development
- Data entry
- Data analysis/modelling
- Database maintenance

Report

Ideally, modelling and the definition of data to be collected should form an iterative process, commencing with the formulation of the technical objectives, i.e. data needed to feed the model itself.

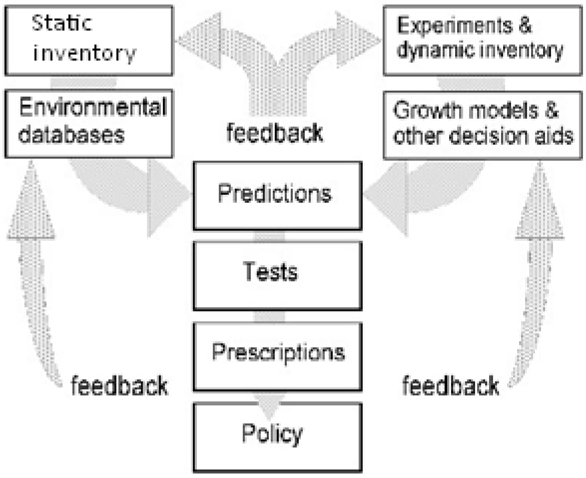
Definition, collection, validation, storage and analysis of data are equally important; an efficient data management system requires a healthy balance between them.

As soon as inventories deliver a sound database and have been analysed, two kinds of products are available.

- Growth equations: Growth of diameter, height and volume and development of stand density per annum as a function of age and site characteristics and silvicultural interventions.
- Yield equations: Volume at specified ages.

Figure 2 highlights feedback loops in such a system. It is apparent that different inventory types (here Resource inventory and dynamic inventory) can be linked. Models don't just serve as tools in decision making but also reflect past forest management decisions.

Figure 2: The role of growth models in decision making, forest management and the formulation of forest policy



Source: (after Nix and Gillison 1985).

3.2 Objectives of forest inventories in Uganda

The aim of forest inventories initiated under the SPGS is to build a reliable data base on commercial forest plantations in Uganda with the following objectives:

1. The information gathered will be used to feed into the provided “Cluster Yield Model” and “Economic Model” for pine and eucalypt. In the future this data will also be used to refine the Alder et al. (2003) models or create new models entirely.
2. Forest inventory at stand or plantation level will provide information on the present state of the resource, e.g. for forest valuation or as pre-harvest inventory.

Models will help growers, to understand the dynamics of forests and the influence of interventions such as thinning. For plantations owners and investors in the processing industry alike these models will to help to make informed investment decisions.

The two basic objectives that forest inventories in commercial forestry in Uganda will have to fulfil require two different approaches.

1. For understanding of forest dynamics and modelling permanent sample plots (PSP) are needed. PSP’s must be spread over the entire plantation forest estate, representing as many site conditions and silvicultural practises as possible. Here it is very important that PSP’s are established at extreme ends of a given parameter, e.g. in plantations with very low and very high site index (SI). That means sample plots are not necessarily distributed relative to the area a forest strata (e.g. a certain SI or treatment group) covers. Rather each stratum should be covered by a minimum number of plots.
   - ➔ Growth plots represent growth conditions, not the forest estate
2. For inventories that have to reflect only the status quo of the resource the approach can be different. Small (and highly valuable) stand can be measured entirely. Most of the time however the sample plot approach will be taken. Sample plots can once again be permanent or temporary. Here however, sample plots are distributed in proportion to the strata size they represent. Meaning the larger the extent of one stratum the more sample plots must be established within that stratum.

➔ Static inventories represent the forest estate at the time of measurement, not the growth conditions

The parameters collected in both inventories systems can essentially be the same, meaning that both inventories can be combined, reducing likely redundancies.

3.3 Considerations when designing a forest inventory

Many of the recommendations/requirements stated here are based on the inventory design of Forestry Plantations Queensland (2009). However they must be seen as just that; ultimately Uganda must design its very own inventory system reflecting Ugandan conditions accurately.

Inventories for growth modelling

The most important factors when designing the inventory system for growth modelling are:

1. **Temporal distribution:** Growth varies from year to year, fluctuations can be extreme, and mortality tends to be clustered in both time and space. Also, tree growth dynamic changes over the years, requiring continued measurements over the entire life of a tree/stand. Therefore long-term commitment of resources is required.
2. **Spatial distribution:** Sample must cover an adequate geographical range, including latitude, longitude, elevation and other topographical features such as ridge and valley locations.
3. **Site characteristics:** Many factors that influence growth cannot be manipulated (e.g. climate and soil). The sampling system should ensure that the full range of these factors is included in the permanent plot system.
4. **Stand conditions:** Forest growth is influenced by stand structure and composition; these can and should be manipulated experimentally to provide the best database for modelling. This means that sample plots must be established in different forest management types, including some with zero interventions.

Stratification and plot location

Stratification of the plantation area is necessary in order to assure that different site characteristics and interventions types will be reflected properly. Good stratification will minimize variance between plots in one stratum and highlight the differences between strata.

It is important that PSP’s are representative for all forest strata. That means that differences in

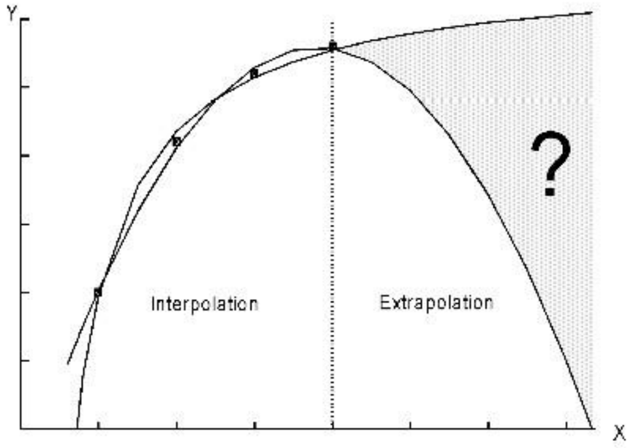
- Soil,
- Climate,
- Altitude and
- Forest management type

have to be reflected by the stratification of the forest estate.

Permanent plot systems should be designed to sample the widest possible range of site and stand conditions. Limited but reliable data at each extreme and at the mean are more useful than copious data clustered about the mean. Figure 3 displays the relationship between representativeness of sample plots, necessary inter- or extrapolation and uncertainty.

Plot distribution within strata should be randomized to avoid biased results.

Figure 3: The influence of plot location on quality of growth modelling



VANCLAY (1992), page 8: Interpolation delivers values of higher accuracy than extrapolation. Both curves have a high R^2 but nonetheless don't provide a good basis for prediction outside the data range.

Plot number

The primary objective when establishing sample plots for forest growth modelling is to provide data for the definition of relationships between several explanatory parameters and response parameters. Thus studies should involve many strata but with few samples in each strata. Therefore, the number of sample plots will be determined by the variability of the forest estate and the need to sample the full range of forest conditions.

If the objective of the inventory is to reflect the plantation estate sample plots should be established systematically. The number of sample plots in a given strata will be proportional to the area of this strata.

Sample plot number is also dictated by the resources available. There is little point in establishing more plots than can be maintained. It is better to have few plots providing reliable data, than many plots that can't be maintained adequately.

Recommendations to the number of sample plots per area vary throughout the literature. For example Forestry Plantations Queensland (2009) establishes nine sample plots for strata above 200ha and at minimum three for smaller areas.

Time of PSP establishment

Sample plots can and should be established as early as two years after planting. This way the data collected can reflect early interventions like weeding and first thinning.

Frequency and time frame for measurements

Re-measurements are necessary to detect growth and changes in stand structure.

Commercial tree species like *Pinus caribaea* or *Eucalyptus grandis* grow fastest before age 20. Also most interventions will have taken place by that time. Accordingly intervals between measurements should be short to begin with and longer at later development stages. However, measurement intervals should be long enough to ensure that growth patterns are not obscured by measurement errors. Two to three year intervals can be used to begin with. Additionally measurements can coincide with interventions (e.g. just before thinning and a year after).

The time frame for measurements should cover the entire life of a tree or stand. Where the influence of climatic variation is of interest very long term measurements are required, i.e. continuing measurements once a stand is replanted.

Set up of permanent sample plots

Permanent sample plots must be retrievable. Accordingly the centre coordinate must be recorded and marked. The mark should remain inconspicuous so that management is unbiased.

In PSP's the location of the individual trees is usually recorded alongside other parameters, permitting the tracking of individual tree development.

Silvicultural interventions on sample plots

Sample plots should receive the usual silvicultural interventions, unless experimental treatments are considered. In this case sample plots must be paired and control plots (no or normal intervention) established.

Improving efficiency

As pointed out above fast growing plantation species generally have less variation in their pattern of growth from age 20 to 25 onwards. Measurements can occur less frequently and some sample plots might be abandoned where multiple plots of similar stand condition occur.

Once the inventory system is well established and first clear results are available different (but similar) strata may be combined and redundant PSP's discarded. There may be scope to rationalize plots of similar species across current regional growth boundaries.

Data storage

An inventory system across the country requires the storage, handling and processing of huge amounts of data over a long period. Procedures (e.g. field forms, storage of field forms, data transferral) and database must be designed accordingly.

Sample plots and trees within sample plots must have a unique identification. This not only offers more options for modelling, but also is the only sure way of detecting measurement errors.

An effective system requires a considerable long term commitment in staff and resources to initiate and maintain the PSP's and database.

Information that is often not collected while surveying the PSP's (like fire, weather, pests, silviculture) must nevertheless be part of the database and be attributable to single PSP's.

General recommendations

To obtain reliable data, it is necessary to:

- ensure consistent standards,
- number, mark and map all trees on all plots,
- repeat measurements frequently enough to enable relocation of plots, but allow enough time for growth to exceed measurement errors, and
- check that measurement records are unambiguous and secure.

4 Data for modelling of growth and yield in Uganda

4.1 Data requirements

During forest inventories a multitude of parameters can be collected:

Table 1: Parameters measured in forest inventories

Parameter	Details
Plot location	Depending on the purpose and type of forest inventory the location of the sample plot should be marked. • Coordinates (x;y)
Stand area	The area of stand or strata that is represented by the sample plot. • Area (ha)
Number (and position of trees)	The position of trees is relevant only in PSP's. • N • (distance in m; azimuth in ^{o})
Diameter at breast height (DBH)	Usually only trees above a preset minimum diameter are included (e.g. 10 cm) • DBH (cm)
Number of undersized trees	All trees within the sample plot that have a DBH smaller than the minimum DBH. For PSP's only. • N
Dominant height	Dominant height together with stand age can be used to determine the site index. • H_O
Mean height	Mean height is together with tree number and DBH needed for volume estimation. • H_A
Tree characteristics	A short description of certain characteristics of a tree such as • Dead / diseased / felled • Stem quality • Defects
Topographic features	Describing parameters such as • Altitude (m), • Slope (^{o}), • Aspect (point of compass) • distance to ridge (m)
Climatic features	Description of parameters taken from meteorological statistics for the area such as • Total and average rainfall (mm) • Rainfall distribution (mm/month), • Temperature (^oC)
Soil physical characteristics	e.g. • Depth, • Texture and • Parent material
Extreme events	Extreme events such as drought, pest and disease outbreaks, flooding and fire may cause significant fluctuations in the observed growth.

Obviously not every forest inventory will record all these parameters. The decision which ones to collect and where will be based on the objectives of the inventory and made during the inventory planning.

4.2 Review of available data sets

Several data sources are available in Uganda. Some of them are quite old, dating from the fifties while others or more recent compilations. We looked at the data sets or reports from the following sources:

- Uganda Forest Department – Technical Notes (1953-1974)
- Alder et al. (2003)
- Namaalwa (2008)
- National Forestry Authority
- Private plantation companies (recent and ongoing)

A more detailed review can be found in the Annex.

UNIQUE models (see separate MS Excel files) will work with the slightly adjusted Alder (2003) model.

4.2.1 Pinus caribaea

While inventory data for *Pinus caribaea* is available in Uganda, it is either in some cases not of sufficient quality (e.g. Technical Notes UFD), sufficient extend (SPGS PSP's, established 2006) or available only in aggregated form (Alder, 2003). More recent inventories of planters under the SPGS provide data for very young plantations only. That means these data sets cannot be used to model growth just yet because only the first measurement is available and the degree of extrapolation would be too high.

At later stages these recent data sets alongside with the SPGS PSP's and Alder et al. (2003) data can form a base for the modelling of growth and yield in Uganda.

4.2.2 Eucalyptus grandis

For *Eucalyptus grandis* the situation is worse. Few historical data exists, namely the one incorporated by Alder *et al*. (2003).

Investors with the SPGS grant planting eucalypts must be encouraged to establish plots that can provide data in the future. Additionally companies with older eucalypt stands (e.g. Rwenzori Highland Tee Company) should be sought out and collaborative forest inventories established.

4.3 Data gaps

Inventory data for commercial forest plantations for both, *Pinus caribaea* and *Eucalyptus grandis* is scarce and often not of sufficient quality or extend.

- PSP's at extreme sites (for growth modelling) are not established,
- Inventories at plantation level (for yield control as well as growth modelling) are insufficient,
- Not all major plantation areas are covered by forest inventories,

- The overall number of sample plots for commercial plantations is insufficient,
- Little data on older stands is available
- Explanatory parameters are not incorporated in inventories or of questionable quality (e.g. silvicultural interventions, site parameters) and
- Procedures for data collection and recording don't match between different inventories and are insufficiently documented.

5 Recommendations

Inventory design

It is recommended to design and plan for country wide forest inventories of commercial timber plantations to close the existing information gap in regards to growth modelling and yield prediction.

Designing an inventory of that scale requires considerable expertise for the design itself as well as for coordination and quality control. Therefore it is recommended to involve experts in forest inventories and modelling early on, e.g. in the framework of medium term technical assistance.

While the actual establishment and field work can be done by separate providers / plantation owners a centralized management approach is recommended to avoid discrepancies in the respective data sets, to streamline efforts and to ensure the accessibility of the data.

Some efforts to establish sample plots have already been made by SPGS and private plantation investors. However, sample plots are still few and partly not of the necessary quality or distribution. It must be stressed that such efforts should increase substantially soon and must be coordinated well in order to capture early development phases of stands. Those are needed in order to provide a complete picture of the development of a stand for the entire rotations, especially in regard to silvicultural interventions which tend to be early.

Related to that is the necessity to carefully analyse number and location of the current permanent sample plots as well as the kind and quality of parameters collected against the objectives of the forest inventories. Where PSP's and parameters collected don't fit the overall design adjustments have to be made. The data gaps outlined in chapter 4.3 already indicate the strong need for action.

Awareness and training

The success of the inventory is largely depended on the cooperation of plantation owners. They must understand all issues involved and perceive a need for the exercise. SPGS should strengthen efforts in that direction.

Where plantation owners or managers decide to contribute to the inventories they must receive guidance and training. A possible approach would be to set up a "forest inventory team" which could

- Establish and measure sample plots
- Train other providers and
- Aid where problems are encountered.

Obviously such a team should comprise experts in the actual field work that also have a good understanding of the broader subject. The set up and training of this team should be part of the inventory design and planning.

While not everybody can afford costly high precision equipment it should nevertheless be available. Either in cooperatives between interested planters, provided in a lending scheme by SPGS or through the team mentioned above.

Collaboration

Modelling of growth or future yields requires sound scientific knowledge and parameters not collected directly during the inventory (e.g. on climate). Here in particular collaboration with the scientific community becomes important. Long term studies like this are ideal to involve master or PhD studies.

Inventory efforts should not rely solely on investors under SPGS but be extended to other interested planters (e.g. tea estates in western Uganda).

Data management

The data collected must be complete and accessible. This requires a centralised data storage facility. At the moment of writing the SPGS offices are the obvious choice since inventory efforts are largely promoted and organised by SPGS.

Data quantities are huge requiring appropriate hard- and software and of course staff who can enter, control and analyse the data. These capacities have to be created before the data storage takes place.

Other points

Forest inventories envisioned to be the base for modelling are inherently long term exercises, requiring substantial commitment and finance.

Examples from other countries with a strong commercial plantation forestry sector show that the cost is often – at least partly – carried by the users. That means that companies or individuals interested in growth and or yield modelling will have to provide primary data free of cost and pay for the results of modelling. This however, is not considered entirely feasible in Uganda at the moment. Other means of finance e.g. donor funding will have to be found.

Literature

Alder D., Drichi P., Elungat D., (2003): Yields of Eucalyptus and Caribbean Pine in Uganda. Uganda Forest Resources Management and Conservation Programme. Kampala, Uganda (available from SPGS).

Forestry Plantation Queensland (2009): Plantation Volume Growth Summaries from Growth Plots in Queensland (unpublished).

Namaalwa J. (2008): Assessing the Yield and Growth of Some Plantation Species in Uganda. Study for Sawlog Production Grant Scheme. Kampala, Uganda

Uganda Forest Department (1953-1974): Technical Notes. Uganda Forest Department. Kampala, Uganda (available from SPGS).

Annex

Uganda Forest Department – Technical Notes 1953-1972

The Technical Notes of the Ugandan Forest Department (UFD) from 1953 to 1974 made available by SPGS were checked for information of growth performance as well as data quality and quantity.

It turned out that silvicultural information provided by the UFD Technical Notes is diverse, but with regard to UNIQUE´s specific task only the technical notes of Kriek (22 reports) have the potential to provide an appropriate quantity of data. Kriek's sample plots were distributed across Uganda and more than 30 species. Due to manifold reasons several aspects that commonly characterize silvicultural inventories/trials were not applied in early works being reported in most of UFD-Technical Notes. Furthermore, it has to be mentioned that even if trials were conducted under appropriate methodology, important information on site conditions like soil and climate often were scarce or had to be derived from secondary data sources. Thus important site information had not been gathered on the level of sample plots itself. This results in a significant lack of accuracy when drawing correlations between site condition and growth performance.

While reviewing the reports of Kriek the following issues became apparent:

- The collected data on growth refers to diverse provenances and planting conditions (different seed batches, origins and years of planting). However this was poorly documented.
- The diameter graphs are considered of limited value, especially those of arboretum plots, since thinning regimes differed greatly.
- Volume increments are inaccurate, since early thinnings often were not measured.
- Height measurements are not quite reliable, especially for trees over 30 m.
- Data of plots with different characteristics were merged, influencing the usefulness of the results negatively.
- Different sites were combined in groups by drawing boundaries along altitudinal and moisture relation class lines. Each group contained one or more phytogeographical units. The stratification approach is not clearly comprehensible.
- Last but not least, the hypothesis may appear that general environmental conditions in Uganda within the last sixty years may have changed to a certain extent.

Due to the issues mentioned Kriek's data cannot be incorporated in UNIQUE's yield model.

Alder *et al.* (2003)

Alder *et al*. (2003) used inventory data from the Forestry Rehabilitation Project (FRP) 1989-1993 for *Pinus caribaea*. Data was collected for 868 plots. For *Eucalyptus grandis* Alder *et al*. (2003) used data from permanent sample plots (PSP) which were established in peri-urban plantations by the Forest Department between 1990 and1996. Additionally Alder *et al*. (2003) had access to data from PSP's of Rwenzori Highland Tee Company.

Volume equations were derived from earlier FAO studies conducted in Uganda and compared to internationally available equations. Also the data from FRP inventory was reanalysed and incorporated.

According to Alder et al. (2003) the developed models have limitations especially in regard to the effects of spacing and thinning on diameter growth.

The primary data used by Alder et al. (2003) could not be accessed.

Namaalwa (2008)

Namaalwa (2008) assessed and re-measured 52 PSP's established by the SPGS in 2006. Plots are distributed across 9 plantation estates (Mubende, Central, South West and Victoria clusters) and five species (*Pinus oocarpa, P. patula, P. caribaea, Eucalyptus grandis, Maesopsis eminii*).

Namaalwa pointed out inconsistencies in measurement/recording between the two data sets, difficulties in identification of the PSP's and an insufficient number of PSP's given the large area and amount of species covered. Therefore, no conclusive or comparative assessment of growth and yield was possible.

National Forest Authority

All data currently available from the National Forestry Authority was analysed by Alder *et al*. (2003) and has been published within his report mentioned above. The National Biomass Study does not aim to deliver data on growth and yield but rather on land use, land use change and is therefore not applicable.

Reports of private plantation companies

Apart from the PSP's established be SPGS in 2006 (see Namaalwa, 2008) on private plantations additional sample plots were established recently or are in the process of establishment (Global Woods 2010, New Forests Company, Green Resources). All of these plantations have in common that they are still very young; data for older stands is not available. Data has been provided to UNIQUE for analysis or was promised to be made available. However the available data could not be incorporated into UNIQUE's yield modelling.