Examensarbeten 2014:20

Fakulteten för skogsvetenskap
Institutionen för skogens ekologi och skötsel

The growth dynamics of Douglas fir in Sweden and Finland

- Application of the 3-PG stand growth model

Wolfgang Nemec

Sveriges Lantbruksuniversitet — Utbytesprogram Erasmus
Examensarbete i skogshushållning, 30 hp, avancerad nivå A2E — ISSN 1654-1898
Handledare: Ulrik Ilstedt, SLU, Inst för skogens ekologi och skötsel
Bitr handledare: Tommy Mörling, SLU, Inst för skogens ekologi och skötsel
Examinator: Erik Valinger, SLU, Inst för skogens ekologi och skötsel — Umeå 2014

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ISSN 1654-1898 Umeå 2014
Sveriges Lantbruksuniversitet / *Swedish University of Agricultural Sciences*
Fakulteten för skogsvetenskap / *Faculty of Forest Sciences*
Utbytsprogram Erasmus / *Master of Science in European Forestry*
Examensarbete i skogshushållning / *Master degree thesis in Forest Management*
EX0770, 30 hp, avancerad nivå A2E/ *advanced level* A2E

Handledare / *Supervisor*: Ulrik Ilstedt
SLU, Inst för skogens ekologi och skötsel / *SLU, Dept of Forest Ecology and Management*
Biträdande handledare / *Assistant supervisor*: Tommy Mörling
SLU, Inst för skogens ekologi och skötsel / *SLU, Dept of Forest Ecology and Management*
Examinator / *Examiner:* Erik Valinger
SLU, Inst för skogens ekologi och skötsel / *SLU, Dept of Forest Ecology and Management*

Abstract

Little research has yet been conducted on the growth of Douglas fir (Pseudotsuga menziesii (Mirbel) Franco var. menziesii) in Sweden albeit its potentials as a commercial tree species in the future. Therefore, this study aimed at capturing currently available field and reference data for the purpose of evaluation. Another objective of this study was to predict the growth dynamics of Douglas fir in Sweden and Finland using the 3-PG stand growth model presented by Landsberg & Waring (2003). In order to test the validity of the simulated outcomes, the predictions were tested against the available field data. The findings showed that already in 1961, Karlberg (1961) made the attempt to gather available information on the growth of Douglas fir and created yield tables for height, DBH and volume development with the data he had found. Despite his extensive data collection from 187 field plots in southern Sweden and Denmark, there was a significant disagreement of volume increment compared to more recent measurements by SLU. The few available research plots managed by SLU indicate a low volume increment in the early years of the stand but pick up a fast growth rate at a later stand age. The Karlberg data (Karlberg, 1961) on the other hand, tends to increase strongly in the first 50 years but then levels out. The 3-PG stand growth model performed reasonably well for height and DBH predictions in comparison to the field data. Yet again, volume predictions were less successful to match the field data curves. A model validation calculating the mean average deviation (MAD) of the predicted from the field data showed a deviation from height in the range of 5.7 and 23%, from DBH in the range of 1.7 and 24.8%, and from volume between 25.5 and 103.4%, using 3-PG Version 1.0 or 2.7 and either a fertility rating of 0.5 or 0.8, respectively. The outcomes demonstrate that the application of the 3-PG stand growth model for simulating growth of an exotic tree species in Scandinavia is feasible with limitations. Special care should be laid on the calibration of species- and site-specific parameters.

Keywords
Douglas fir (Pseudotsuga menziesii) in Scandinavia, growth dynamics, 3-PG stand growth model, model validation,

Introduction

Douglas fir (Pseudotsuga menziesii) is arguably one of the most promising exotic tree species for commercial timber use in Europe (Hermann & Lavender 1999). Naturally regenerating forest plantations with this fast growing, resistant and low susceptible tree species have already been established in Austria, Germany, France, the Netherlands, Denmark and Great Britain (Van Loo et al. 2012). Ultimately, warmer temperatures and fewer days of frost in southern Sweden could favour the growth of Douglas fir over Norway spruce (Picea abies) (Hermann & Lavender 1999). Despite economic potentials for the forest industry only little research has been done, or is available, on the current growth dynamics of Douglas fir in Scandinavia (Karlberg 1961; Skogsstyrelsen 2009; Felton et al. 2013).

In 1961, Karlberg (1961) developed height curves from 187 Douglas fir research plots in Denmark and southern Sweden, and introduced yield tables for Douglas fir stands in Sweden. The results show height, DBH and volume growth predictions for four different site classes. Since then, no attempt for the development of a growth model for Douglas fir in the Swedish climate has been conducted. Generally, Douglas fir is not yet widely distributed in Sweden and Finland. According to Felton et al. (2013) this is due to high risks associated with a susceptibility to diseases and pests. High uncertainty and a lack of interest and need in exotic tree species for commercial uses might be the reasons for little research in this area. Nevertheless, from field databases of SLU and METLA I could identify four suitable long-term research plots in Sweden and another four in Finland.

The second way of exploring the growth potentials of Douglas fir is through modelling growth dynamics of Douglas fir prior planting to picture growth potentials at certain plots. One suitable tool is the physiological stand growth model 3-PG (Physiological Principles Predicting Growth). 3-PG is a partly process and partly empirical based model, which uses species-specific parameters for growth predictions. It is based on APAR, which calculates photosynthesis with the absorbed amount of photosynthetically active radiation (PAR) by the canopy and light-use efficiency parameters. The APAR calculations are modified by data from water flux and carbon allocation submodels, as well as a fertility rating (FR) which represents the soil nutrient status (Landsberg & Waring 1997). This procedure subsequently eliminates the use of a number of model parameters commonly needed in process-based models. Hence the model becomes easier to use than most process based models. It is intended to be applied by forest managers and simply uses readily available weather data, available soil water (ASW), altitude, elevation, and latitude (Monteith & Moss 1977). Some important output variables of interest for forest managers are standing volume (m^3/ha), mean annual increment (MAI, m^3/ha/yr), average DBH (cm), and basal area (m^2/ha).

Models in forest sciences are effective research tools to picture ecological dynamics in a simplified way (Landsberg & Waring 1997). The 3-PG model is a widely applied physiological stand growth model, which has been continuously improved (Landsberg & Waring 1997). Within the last 14 years the model has been applied in New Zealand (White et al. 2000), in Australia (Nightingale et al. 2008; Feikema et al. 2010), Brazil (Binkley et al. 2004), Spain (Rodríguez-Suárez et al. 2010), the United States of America (Wulder et al. 2007), British Colombia in Canada and the boreal forests in Central Canada (Coops et al. 2010; Raulier et al. 2008). Additionally, Landsberg et al. (2003) highlight in their presentation of the improved 3-PG model that this generalized stand model can be applied to a great range of plantations or relatively homogeneous forests.

Since Landsberg et al. (2003) claim that the 3-PG tool is applicable and has already been successfully applied to a wide range of species and climates, it may also work to model the growth dynamics of Douglas fir in the southern parts of Sweden and Finland. To do so, realistic growth parameters specifically for Douglas fir in Sweden and Finland have to be used.

3-PG operates with between 47 and 63 species-specific parameters, depending on its version. Besides species-specific parameters, 3-PG also needs basic site-specific parameters for accurate predictions. These are the local fertility rating, climate data, soil water availability (ASW), initial biomass and stocking. The fertility rating is a measure of nutrient availability in the soil on a scale between 0 (=very poor soils) and 1 (=very fertile soils). An appropriate relationship describing nutrient availability in soils effecting growth on forest land has not been discovered yet (Landsberg et al. 2003). Yet, Sands (2004) reports of the fertility rating as a highly influencing factor in the 3-PG model. Thus, correct results of the growth potentials of Douglas fir in Sweden and Finland will also depend on the assignment of an appropriate fertility rating. Currently there are five methods used for predicting the fertility rating of a specific forest stand: (1) a thorough soil analysis, including cation flow, N/C ratio, ASW and soil nutrient status as shown in Curt et al. (2001); (2) growth curves or site indices (SI) for adjusting the fertility rating similarly to Johansson (1999); (3) using N as an index for soil fertility, because N is a limiting factor in Scandinavian soils and stable in association with vegetation types (Swenson et al. 2005); (4) trial-and-error runs with the model in order to get close to real growth data as has been done by Sands (2004); And (5) assignments of site specific fertility ratings based on assumptions of experts as described in Paul et al. (2007). Also the climate data and soil water availability has a great impact on the outcome of the simulation. Emphasis has to be laid on the origin and methods used for collecting and processing this data. And although initial biomass and stocking is species-dependent it is related to the site conditions. In this context, Sands (2004) issued a classification of the sensitivity of species- and site-specific parameters. He points out that a small change of one parameter might have a strong impact on the final outcome.

This thesis was a new attempt to use the 3-PG stand growth model for exotic tree species in new habitats. The information and presumptions above lead to the objective and hypotheses of my work. The objective of my thesis was to test whether the 3-PG stand growth model is applicable for modelling growth of Douglas fir using available species-specific parameters on the basis of empirical data. Consequently it was also crucial to find and compare available data and information on the growth of Douglas fir in Sweden and Finland.

Karlberg (1961) developed his yield tables mainly from sample trees in Denmark. Therefore, I hypothesize that the standing volume [m^3/ha] will be higher due to a warmer climate and longer vegetation period, compared to the field data from Sweden and Finland. For the same reasons I would also expect to find taller trees [m] at the same age in Karlberg’s data (Karlberg, 1961). Since in 3-PG the species-specific parameters for Douglas fir were developed for the milder climates of the Pacific Northwest, I expect model outcomes similar to Karlberg’s yield tables (Karlberg, 1961).

Materials and Methods

Empirical Data

In order to find available data and information on the growth of Douglas fir in Sweden and Finland I conducted a thorough literature review and contacted researchers at SLU, METLA, University of Eastern Finland, Skogforsk and the University of Copenhagen, who deal with Douglas fir related research and/or field trials.

Swedish and Finnish Field Data

I found four research plots in Sweden and four research plots in Finland. The four research plots in Southern Sweden were located at Oxhult (56.441/13.272) with research ID 46 and growth measurements in five year intervals between 1927 and 2003, Tönnersjöheden (56.691/13.101 and 56.497/13.065) with research IDs 8057 between 1981 and 2002, and 8160 between 1985 and 2009, respectively, and Rössjöholm (56.330/13.127) with research ID 866 and regular growth measurements between 1952 and 1997 (refer to Figure 1 for overview). The total research area of Pseudotsuga menziesii (Mirbel) Franco var. menziesii in Sweden comprises slightly more than 0.5ha, and is managed by SLU, Sweden. The four research plots in Southern Finland were located at Solböle (60.046/23.037), Ruotsinkylä (60.611/26.456), Punkaharju (61.748/29.364) and Aulanko (61.023/24.450). The total area was purely planted with Pseudotsuga menziesii (Mirbel) Franco var. menziesii and managed by METLA, Finland. Regular growth and solar and climate measurements have been taken in annual time steps from 1950 to 1999 (Ojansuu & Henttonen 1983). Douglas fir was considered as an exotic coniferous tree species in Sweden and Finland. Thus availability of comparable data was limited. The presented plots have been chosen due to similarities of climatic conditions and longest regular measurements over time available.

Figure 1. Locations of long-term research plots of Douglas fir in Sweden (blue tags) managed by SLU and Finland (red tags) managed by METLA

Karlberg Reference Data

In the early 1950s research on Douglas fir was financially supported by the Foundation for Forest Research in Sweden. With these means, Karlberg (1961) created a yield table designed for the milder climate of Southern Sweden and Denmark. Karlberg (1961) took annual height, DBH and volume measurements from 187 research plots over a sequence of 43 years at a stand age of 18 to 61). The research plots are in southern Sweden and Denmark, however, the exact locations were unknown. DBH was measured with a caliper; height was estimated with a Blume-Leiss hypsometer on the basis of two readings for each tree. From diameter measurements from some felled trees basal increment was calculated with the breast height form-factor. The growth curves were then modelled on the basis of these measurements according to a method used by Näslund (1936). Karlberg (1961) successfully tested his height curves against height curves established by McArdle (1930).

Climate Data

Only meteorological data from weather stations located in or close to the research plots were used and averaged for each country as input data for 3-PG. Monthly maximum and minimum temperature [°C], precipitation [mm/yr] and solar radiation [MJ/m^2/yr] and frost days are displayed in Table 1 as they were fed into 3-PG.

Table 1. Average climatic data for research plots of Douglas fir gathered by SLU in Sweden between 2003 and 2010 and Metla in Finland between 1950 and 1999. Shown is the mean average maximum and minimum temperature per month [C°], average precipitation [mm/yr], average solar radiation [MJ/m2/yr] and frost days. The data is used as site-specific input data in the 3-PG stand growth model

Sweden						Finland					
Month	Tmax (°C)	Tmin (°C)	Rain (mm/yr)	Solar rad (MJ/m2/yr)	Frost Days	Month	Tmax (°C)	Tmin (°C)	Rain (mm/yr)	Solar rad (MJ/m2/yr)	Frost Days
Jan	2.8	-6.7	115.0	0.687	31	Jan	-0.2	-21.7	43.9	1.152	31
Feb	3.0	-4.3	62.9	2.254	28	Feb	1.0	-18.4	32.5	3.960	28
March	5.0	-3.5	70.3	6.472	31	March	1.8	-11.4	32.0	8.784	31
April	9.1	4.9	47.5	11.892	2	April	6.3	-2.1	34.7	14.256	14
May	11.9	9.1	83.0	14.335	0	May	13.6	4.9	34.5	19.476	2
June	16.4	12.6	109.0	15.088	0	June	18.9	10.7	48.0	20.268	0
July	19.7	14.2	125.8	13.956	0	July	20.5	13.8	69.0	19.440	0
Aug	16.6	14.9	130.3	11.109	0	Aug	18.4	11.7	78.2	14.724	0
Sep	14.8	11.2	100.0	7.988	0	Sep	13.2	5.6	63.9	9.144	2
Oct	9.9	3.8	137.4	3.710	2	Oct	9.0	-0.8	64.9	4.248	7
Nov	5.9	1.0	128.9	1.142	30	Nov	4.0	-6.9	60.3	1.800	30
Dec	5.3	-7.6	109.9	0.419	31	Dec	2.0	-18.0	53.6	0.720	31

The climatic data to run the simulation for Finland was collected by the Finnish Meteorological Institute (Ojansuu & Henttonen 1983). The climate data of the four locations in Finland have been averaged to create one climate table. For Sweden the data was collected at Tönnersjöheden by the Swedish Meteorological and Hydrological Institute (SMHI) and issued by Ottosson-Löfvenius in an annual report for SLU (Ottosson-Löfvenius 2010). Temperatures were averaged figures over a period of eight years in Sweden and 50 years in Finland. Precipitation and solar radiation for Sweden were averaged figures over a period of eight years measured in monthly intervals from 2003 to 2010. Precipitation for Finland is again measured by the FMI over a period of 50 years from 1950 to 1999. The projections for solar radiation were observed at Jokioinen in southwestern Finland during the years 1971 to 2000 (Ruosteenoja & Räisänen 2009).

Methodology

The main idea of this study was to compare the available field and reference data, and then compare these with the simulated growth dynamics by the 3-PG model. Therefore, the 3-PG model was set with parameters for Douglas fir and climate data from Sweden and Finland. To do so, I adopted the methodology successfully applied by Landsberg et al. (2003) and tested the accuracy and consistency of the model output through two tests of variation inspired by

Legates & Mccabe (1999). Species-specific settings and different fertility ratings were applied for the purpose of comparison.

1. Douglas fir - specific 3-PG parameter values from the literature were entered into the parameter mask of the model.
2. Initial stocking was entered.
3. Stand-specific climate data was provided for model simulation.
4. Initialization values as well as site factors, including information about the latitude of the location for daylight calculations, at what age the rotation should end, initial foliage, root and stem biomass, and available soil water, CO_2 level, were set.
5. Fertility rating, soil class and minimum and maximum ASW must be parameterized.
6. Conduct model validation.

3-PG

An application of 3-PG simply requires an input of species-specific parameters (see Appendix 2 and 3), site-specific parameters, and climate data. The output variables can be chosen according to individual needs.

Technically, the 3-PG model is structured in five submodels. Those are in order of sequence: biomass production; biomass allocation; stem mortality; soil water balance; and a module to convert stem biomass into figures commonly used by forest managers, (Landsberg & Waring 1997). They facilitate closed-cycle physiological processes in single trees and project them to the stand level (Waring & McDowell 2002).

Biomass Production

An innovation and simplifying assumption makes the net primary production (NPP) in 3-PG a constant fraction of the gross primary production (GPP) (Coops et al. 2010). Where the GPP is proportional to the intercepted photosynthetically active radiation, which is calculated from the total incoming solar radiation and the LAI through Beer's law (Sands 2004). The calculation requires a proportionality factor, canopy quantum efficiency, which is expressed through multiplicative environmental modifiers based on mean air temperature, available soil water (ASW), atmospheric vapor pressure deficit (VPD), frost days per month, site fertility, and stand age. Climate data can either be fed in as actual or averaged monthly intervals.

Biomass Allocation

The availability of soil water, VPD and site fertility regulates the partitioning of NPP to the roots. More biomass is allocated to the roots if growing conditions are bad e.g. low availability of soil water and/or nutrients, or low temperatures (Sands 2004). While biomass allocation to foliage decreases and to stems increases with aging of the stand. Accumulation of biomass to foliage and stems depends on the tree size characteristics, such as diameter at breast height (DBH). DBH and other tree size characteristics are derived from the mean single-tree stem mass with species-specific allometric relationships and the amount of annual leaf turnover (Coops et al. 2010).

Stem Mortality

Stem mortality takes age and potential long-term stress factors (i.e. water stress) into account. Changes are applied monthly and also include self-thinning effects. The self-thinning law sets an upper limit to the mean single-tree mass of the simulated stand (Yoda et al. 1963). If the mean single-tree mass exceeds this limit, figures are adjusted to meet the upper limit. However, it is assumed that suppressed trees die first and thus, only a small fraction of the biomass of an average tree is removed (Sands 2004). Additionally, the density independent variable (gammaNx) implements natural mortality into the model. GammaNx is the annual mortality rate in percentage of the forest stand, due to frost, browsing, pests, windfall, and other natural catastrophes.

Soil Water Balance

Soil water is calculated on monthly intervals. For this purpose, rainfall and possible irrigation are balanced against evapotransporation, canopy rainfall interception, runoff or deep drainage, and canopy conductance. The Penman-Monteith equation is used to calculate evapotranspiration, canopy rainfall interception is dependent on the leaf area index (LAI), and runoff on the intrinsic water-holding capacity (Sands 2004). Canopy conductance is based on the canopy's LAI and stomatal conductance and is simplified by Landsberg & Waring (1997) through setting the maximum value of canopy conductance above an LAI of 3. The soil water balance is affected by available soil water (ASW), VPD and stand age.

Stand Characteristics

3-PG produces stem volume, DBH, basal area, mean annual increment (MAI) and other stand level characteristics through the biomass accumulation and adjusted stem numbers (Landsberg & Waring 1997). For forest managers it also provides tree height and merchantable stand volume, which derives from allometric relationships in terms of stocking and DBH. The interested reader can find the whole structure including input and output variables in Appendix 1. For further investigations, a more detailed description of variables is found in Sands (2004).

Parameters

Species-Specific Parameters

Parameters for physiological process models vary between species, location, climate, and management methods (Nippert & Marshall 2003). In order to run the 3-PG model correctly, site-specific climate data is needed, as well as empirical or estimated species-specific parameters. Therefore, the parameters have been parameterized for Douglas fir. I found eight sources of species-specific parameters in peer-reviewed literature, summarized in one parameter input sets. The figures derive from empirical experiments in Sweden (Näslund 1936), in the Pacific Northwest (Brown et al. 1949; McArdle 1961; Gholz 1982; Landsberg & Waring 1997; Waring & McDowell 2002; Nippert & Marshall 2003) and in-situ experiments (Lewis et al. 1999; Sands 2001). Appendix 2 and 3 present the Douglas fir-specific parameters for this study.

Since the release of 3-PG Version 1.0 there have been refinements in the calculations of biomass. In Version 2.7, a CO_2 modifier has been implemented, as well as mortality and seedling mortality rate have been taken into account. Additionally, minimum conductance can be adjusted from Version 2.7 onwards and also the age at which the basic density (rho) reaches the average density of the minimum density for young trees and the maximum density for mature trees. Furthermore, 3-PG Version 2.7 allows changes for height to stem and volume to stem relationships. These allometric equations enable mirroring of natural height and volume curves in 3-PG. The use of allometric relationships is optional, since it changes the standardized calculation settings.

Due to these refinements, model outputs will differ between Version 1.0 and 2.7. Model outputs predicted with Version 1.0 are referred to as 3PG[a]. Whereas, model outputs from

Version 2.7 are referred to as 3PG[b] from now on. For comparison, parameter sets from Version 1.0 and 2.7 are provided in Appendix 1.

Site-Specific Parameters

Besides species-specific parameters for growth, 3-PG needs site-specific information. This includes location, site fertility and soil type, minimum, maximum and initial ASW on site, initial stocking, rotation length, and importantly, information on the initial stem, root and foliage biomass.

In Sweden, all four research plots were located at 57° latitude and in Finland, the other four research plots were located along the east to west gradient at 61° latitude. All sites consisted of sandy-loam soils. A thorough nutrient analysis as suggested by Swenson et al. (2005) was not available for the described plots. In consistency with Sands (2004) and Paul et al. (2007) the fertility ratings have been set according to trial-and-error runs and general assumptions. Initially, I tested the model against fertility ratings of 0.4, 0.45, 0.5, 0.7, 0.75, and 0.8. For the evaluation of the outcome, I followed Urban et al. (2012) by classifying poor and rich soils in order to simplify the validation process. The fertility rating was 0.5 for sites with average site productivity, and 0.8 for sites of high site productivity.

Soil conditions were similar in both countries. Therefore, the maximum ASW was set to 120 mm following a previous 3-PG application in Asa by Landsberg et al. (2003). Minimum ASW was 0 mm since the stands were not irrigated. The initial ASW was 80mm. Naturally, the initial ASW was self-adjusted by the water balance and will only affect the stand in the first few months. A reasonable number for initial stocking of Douglas fir was 2500 trees per hectare (Coleman, 2008). As recommended by Simpson (2007), initial foliage biomass was 0.0012 Mg/ha, initial root biomass 0.0018 Mg/ha and initial stem biomass 0.0006 Mg/ha, as was realistic for 1 year old seedlings. The rotation length was set to 100 years.

Allometric Functions

The standardized allometric height relationships in Version 1.0 and 2.7 was

$$H = a^H B^{nHB} N^{nHN} \qquad (1)$$

where H is mean height (m), B is mean diameter (cm), a is the constant in the stem height relationship, and N is the number of stems (trees/ha). Test runs using Equation 1 resulted in highly overestimated results in height. Figure 2 shows the differences between height curves estimated with Equation 1 and 2, as well as field data of plot 46 for comparable reasons.

Therefore, I followed Urban et al.'s (2012) approach and used the Näslund's allometric height equation in order to calculate height (Näslund 1936):

$$H = 1.3 + \frac{DBH^2}{(a+bDBH)^2} \qquad (2)$$

where H is tree height (m), DBH (cm) and a and b are parameters in the equation. For sites with high site productivity a = 1.35 and b = 0.15, and for sites with average site productivity a = 1.32 and b = 0.15 as defined by Urban et al. (2012).

In terms of allometric volume relationships, both versions calculate volume directly from stem mass:

$$V = \frac{(1-p_{BB})W_S}{\rho} \qquad (3)$$

where p_{BB} the fraction of bark and branch biomass and ρ the basic density (t/m^3), and W_S is the mean single-tree stem biomass (kg/tree).

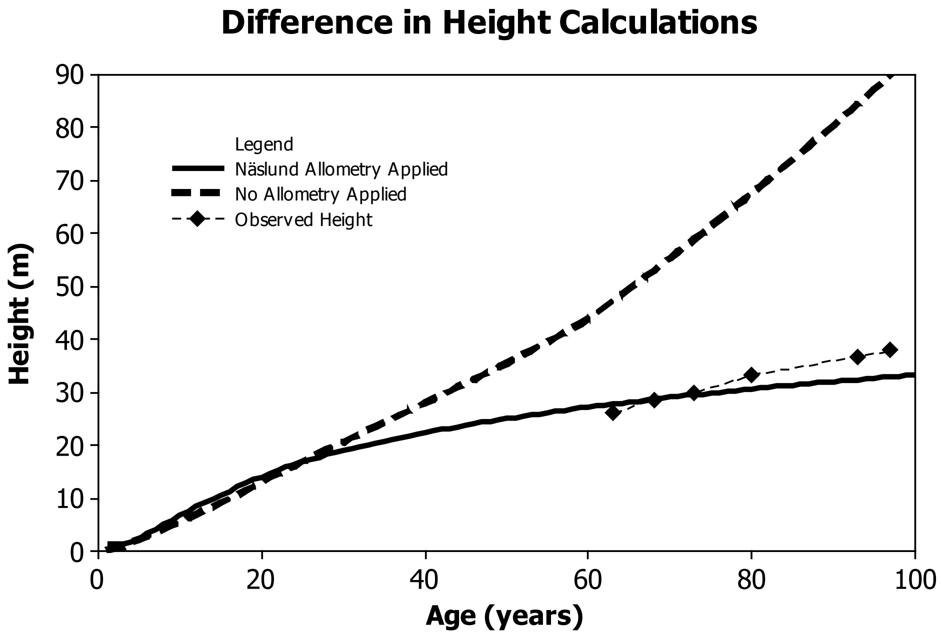


Figure 2 displays the comparison between a 3-PG^b test run using default settings for calculating height (dashed line) and the comparative 3PG^b test run using Näslunds allometric height function (straight line) to fit modelled height development to the observed height of the Swedish field plot 46 measured from stand age 63 to 97

Validity of the Model

Jorgensen & Bendoricchio (2001) propose a complementary model validation to check the accuracy and consistency of the model output. I used the empirical values from the field experiments in Sweden in comparison with simulated 3-PG outputs including model settings 3-PG^a and 3-PG^b. A coefficient of determination (R^2) analysis marked the first step of validation, but was not comprehensive enough. Thus it was rather insensitive for differences between observed and simulated values, because it merely assessed the linear relationship between variables and included the sensitivity to outliers (Legates & Mccabe 1999). Therefore, I complemented the validation of the model with a suggested method by Landsberg & Sands (2010). That was the mean average deviation (MAD) defined as the sum of the absolute average error from each simulated value divided by the number of observations:

$$MAD = \left(\frac{\sum |y_{obs} - y_{sim}|}{N}\right) \qquad (5)$$

Where y_{obs} is the observed value from the field experiment, y_{sim} is the simulated value of the 3-PG prediction, and N is the number of total height [m], DBH [cm] or volume [m^3/ha] observations, respectively. The MAD analysis indicated the level of agreement between the observed and the simulated values in percentage. But, no justified threshold value could be defined. Therefore the comparisons were made within and between plots, using 3PG^a and 3PG^b results with a fertility rating of 0.5 and 0.8, respectively.

Results

Evaluation of the Empirical Data

Shapes of height curves from Swedish field data (Figure 3A) were in good agreement between the four different sites. Plot 866 appeared to have a higher site productivity than plot 46, because after 60 years mean tree height is around 5m higher. A similar site productivity as at plot 866 could be assumed for plots 8057 and 8160, although the stand measurements were only available up to 54 years. The final stand height in Finland for all plots ranged lower than plot 46. Aulanko showed the best height within Finland with 29.3 m at age 70, followed by Solböle, Punkaharju and Ruotsinkylä.

Also DBH growth curves from the four Swedish plots (Figure 3C) agreed well between each other. Looking at the height development it could be assumed again, that plots 8057 and 8160 would grow better in terms of DBH, disregarding the thinning regime. Only plot 866 displayed a lower diameter/height ratio than 46. Trees in Finland were lower in height, but bigger in DBH. Moreover, the empirical data from Sweden showed a more moderate incline in comparison with the Karlberg data (Karlberg, 1961), and would be classified as Class IV at best in terms of Karlberg (1961). Both, the height and DBH curves were at the same scale nevertheless. Sampled trees reached a DBH of 40 cm at the age of 60 years on average.

The volume curves for Sweden followed the same course, but measurements from plot 46 indicated a steep incline of standing volume in stands older than 75 years. Again, plots 8057 and 8160 ranged around the same values. A volume production between 397 and 430 m^3/ha was reached after 50 years. Plot 866 continued with the same growth dynamics and 710 m^3/ha at age 77. At the same age, plot 46 presented the same volume, but inclined up to 1311 m^3/ha at age 97. In Finland, measurements between stand age 68 and 70 indicated a lower standing volume in comparison with the Swedish research plots. Differently to the previous comparisons between the empirical and the Karlberg data (Karlberg, 1961), the volume curves did not agree this time. The comparison between Figure 3E and 3F showed a significant difference in the development of the shape after around 30 years. Up to this age both curves matched with the Karlberg curves (Karlberg, 1961) levelling out early with a standing volume of around 484 and 327 between the four classes. The empirical data on the other hand indicated a constant upward trend. Noticeable were the similar growth dynamics of plots 8057 and 8160.

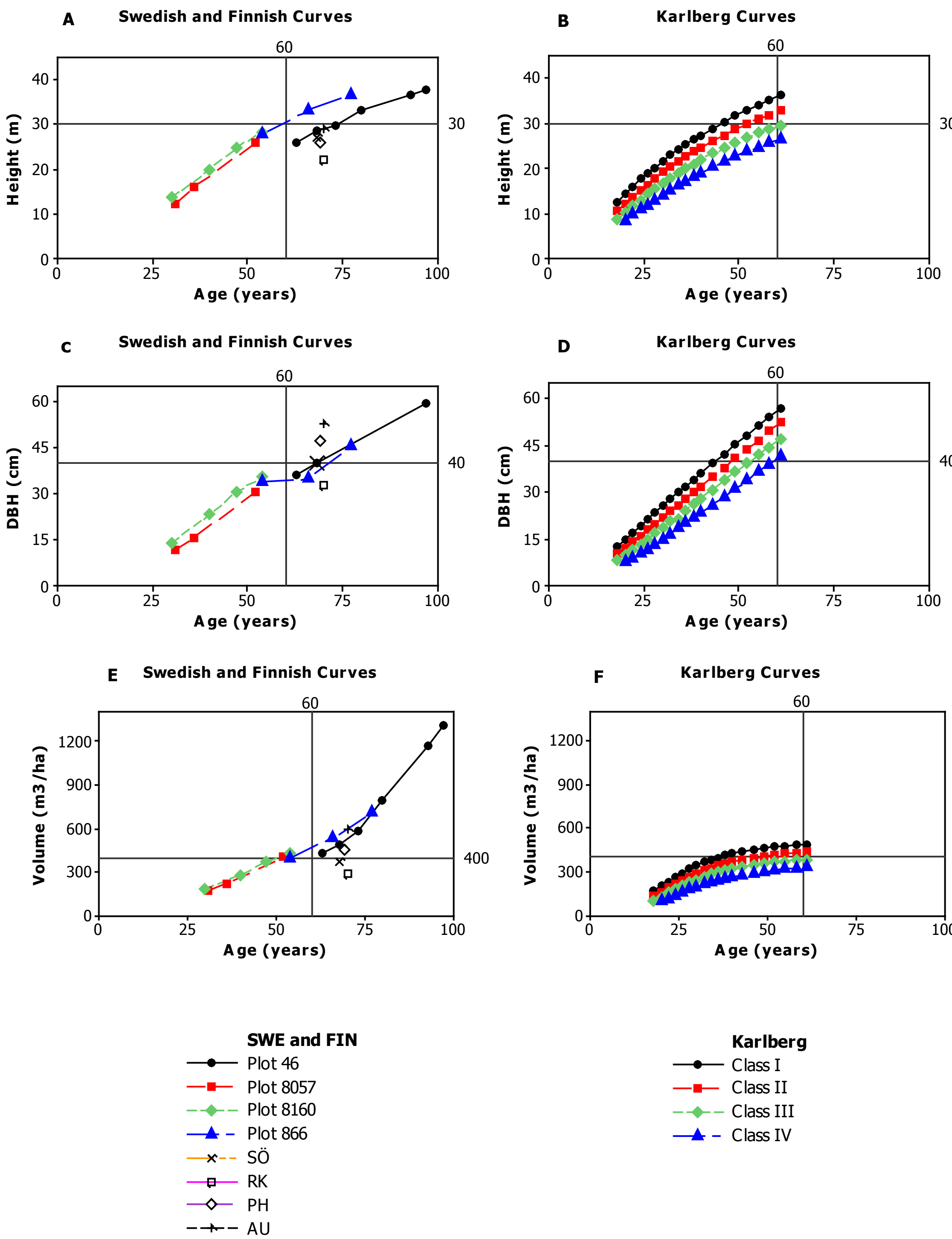
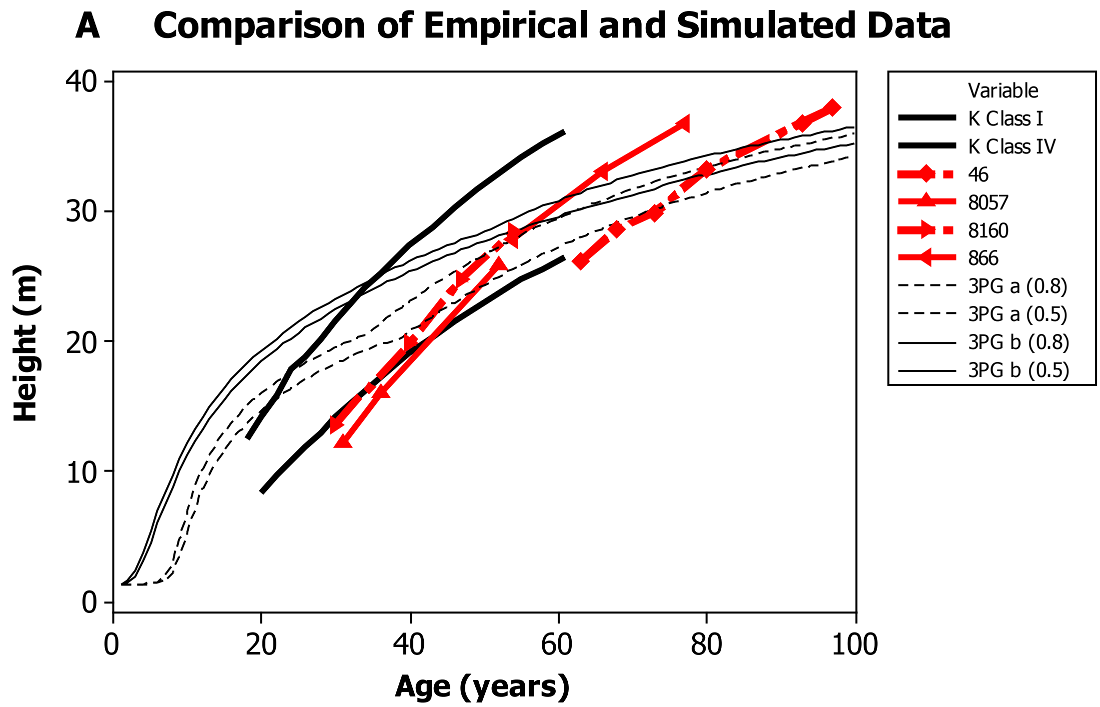


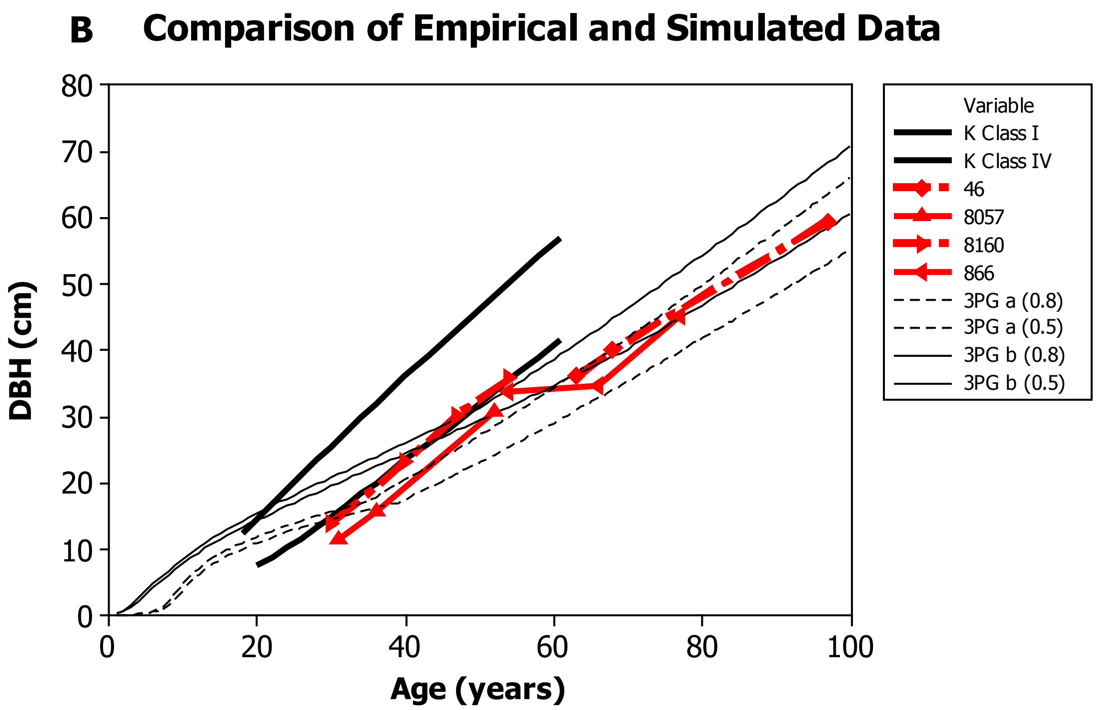
Figure 3 presents the comparison of available field data of Douglas fir in Sweden and Finland. Graphs A, C and E describe the height, DBH and stand volume curves for field data measured by SLU and Finnish final stand data collected by Metla. Graphs B, D and F illustrate the classified yield table data by Karlberg (1961) to compare with the field data. Stand characteristics are plotted over a stand age of 100 years. In order to facilitate and easier comparison reference lines are included in the graphs. Reference points (Y/X) for Graphs A and B are 30/60, for graphs C and D are 40/60 and for graphs E and F are 400/60

Comparison of Empirical and Simulated Data

Simulations from 3-PG Version 1.0 using model settings 3PG[a] and simulations from 3-PG Version 2.7 using model settings 3PG[b] resulted in different outcomes. Height of the empirical data from Sweden, the Karlberg data (Karlberg, 1961) and the simulated data was plotted over stand age (Figure 4A). Visualized by the graph, it became evident that the simulated data had limitations describing the shape of the empirical or Karlberg data (Karlberg, 1961). The simulated curves could be described as fast growing in the early years of the stand and then levelling out getting closer to the final stand age at 100 years. It could be noticed that simulations with a fertility rating of 0.8 and 0.5 were lying close together with both model settings. The difference between 3PGa and 3PGb laid in the shape of the height curves. Height development modelled with 3PGb had a higher increment in the first 35 years when compared to 3PGb. Apparently mean tree height in 3PGb at around 35 reached the maximum stem mass of 330kg per 1000 trees/ha which induced self-thinning. The self-thinning effect enhanced height growth of the remaining trees, which became apparent in the strong increment of the 3PGb curves.

Another characteristic when comparing the empirical with the simulated data was the late increment of height, DBH and volume of the Swedish data at a stand age of around 20 years. In detail, plots 46, 866, 8057, and 8160 indicated a late but strong growth from year 20 onwards which laid in contrast with the growth curve of the simulated data. However, the model appeared to adjust its early growth with a more moderate incline from stand age 20. Taking the Karlberg data (Karlberg, 1961) into account, the simulated data matched the curve shape approximately and could be classified between Class II and Class III.





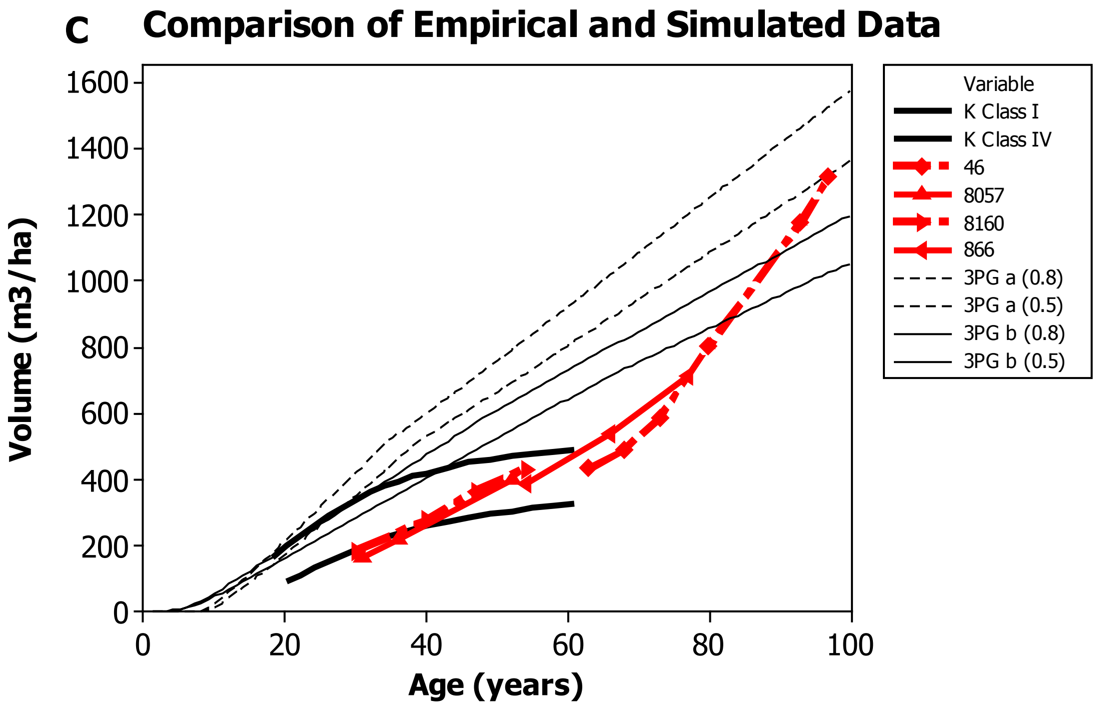


Figure 4 presents an overall comparison of field and simulated data. Height curves of Karlberg Class I and IV (bold black straight lines), field plots 46, 866, 8057 and 8160 (bold red straight lines), and also the simulated height curves for model settings 3PG[a] (dashed lines) and 3PG[b] (straight lines) with fertility ratings 0.5 and 0.8 are overlaid in Graph A. Graph B shows the same measured and simulated data for DBH, Graph C for volume. Matter-of-factly, fertility rating 0.5 is always below fertility rating 0.8 of each model setting

Simulated DBH curves in Figure 4B delivered the best match with the empirical data from Sweden. Again, the modelled curves with different fertility ratings from each model setting laid close together, which proved a low sensitivity of fertility rating on the simulation. The simulated curves indicated a slight S-shape, which probably derived from self-thinning effects. It could be observed that the empirical data had again a late start in growth, but compensated it with a steep incline in increment. According to the simulation the empirical data could be best described with model settings 3PG[b] with a high (0.8) or low (0.5) fertility rating and $3PG^a$ with a high fertility rating. The Karlberg data (Karlberg, 1961) fell out of the range of the model predictions. However, the same features as with the simulated height curves could be observed again. The modelled curves started strong and levelled out early to adjust to the final growth values of the empirical data.

Finally, the simulated volume data was put in context with the empirical and Karlberg data (Karlberg, 1961). Yet, the results displayed almost invers curve shapes. The simulated data is characterized by an early and steady increase in biomass, reaching 1580 m^3/ha with model setting $3PG^a$ and a fertility rating of 0.8. Whereas, the empirical data was defined as late and slow curve with a late but steep increment peaking at 1311 m^3/ha as described previously. As expected, the standing volume at final stand age of Karlberg (1961) stayed well below the simulated values.

Evaluation of the Simulated Data

The outcomes in Table 2A showed that simulated values with a lower fertility rating ($3PG^a$ FR0.5; $3PG^b$ FR0.5) agreed better with the observed values with plot 866 as the only exception. In detail, model simulations 3PGb FR0.8 with an MAD = 5.7% of plot 866 and 3PGa FR0.5 with an MAD = 6.2% of plot 46 represented the best agreements between any observed and simulated height values. Generally, model predictions appeared to be better for plots 46 and 866 than for plots 8057 and 8160. This could be explained by the curve shapes, visualized in Figure 3A. On the basis of the few plots I used, height predictions seemed more accurate for older than for younger stands. The R^2 for all predicted values plotted against the observations was significantly high with $R^2 \geq 0.998$. This means that the values follow the same trend, and that no outliers have been detected.

MAD figures for DBH in Table 2B pictured a different trend in terms of best agreement of observed and modelled values. Here, best agreement with the observed values was always given when predictions were either modelled with $3PG^a$ and a fertility rate of 0.8 or $3PG^b$ with a fertility rating of 0.5. This trend was true for all plots. The curve agreement was specifically good for poor sites when modelled with $3PG^b$ (1.7%). The results were similar for plots 46 and 866 which were measured at an older stand age. The R^2 ranged at ≥ 0.966 for plots 46, 8057 and 8160. Plot 866 presented a R^2 between 0.799 and 0825 depending on the model setting and fertility rating, which indicated that the DBH growth was not following a straight trend.

Evidently, large deviations for all plots, model settings and fertility tunings in Table 2C showed bad agreement between the observed and the simulated values. In general, deviations were lower when calculated for poor sites. Within poor sites a better match was achieved if model-setting $3PG^b$ was used for simulations. In numbers, standing volume predictions ranged between 27.6% at best and 103.4% at worst from the empirical observations. A lower fertility rating might have resulted in better outcomes for standing volume, but would have negatively affected the outcomes for height and DBH. The R^2, however, was very high with $R^2 \geq 0.992$, indicating a high degree of linear correlation between the observed and the simulated values.

Table 2 contains outcomes of the mean average deviation (MAD) and the coefficient of determination (R^2) validation process for height (A), DBH (B) and Volume (C) for all research plots in Sweden and model settings 3PG[a] and 3PG[b]. The table also includes the number of observations (measurements) per plot. For each fertility rating one column describes the actual MAD value, another the deviation in percentage to enable a global comparison and a third column the R^2 value

A	Height		FR = 0.5			FR = 0.8		
ID	Obs.	Model Setting	MAD		R^2	MAD		R^2
			Value	%	Value	Value	%	Value
46	6	3-PG[a]	1.99	6.2%	0.996	2.21	6.9%	0.996
		3-PG[b]	2.32	7.2%	0.996	2.69	8.4%	0.996
866	3	3-PG[a]	4.23	13.0%	1.000	2.05	6.3%	0.998
		3-PG[b]	2.50	7.7%	0.999	1.87	5.7%	0.999
8057	3	3-PG[a]	1.81	10.1%	0.989	2.39	13.3%	0.999
		3-PG[b]	3.51	19.5%	0.993	3.93	21.8%	1.000
8160	4	3-PG[a]	2.45	11.3%	0.989	2.61	12.1%	0.995
		3-PG[b]	4.14	19.1%	0.999	4.98	23.0%	0.996

B	DBH		FR = 0.5			FR = 0.8		
ID	Obs.	Model Setting	MAD		R^2	MAD		R^2
			Value	%	Value	Value	%	Value
46	3	3-PG[a]	2.92	12.92%	0.999	0.82	3.6%	0.998
		3-PG[b]	0.38	1.7%	0.999	3.07	13.6%	0.999
866	3	3-PG[a]	5.27	13.9%	0.800	3.38	8.9%	0.825
		3-PG[b]	1.97	5.2%	0.800	5.18	13.6%	0.799
8057	3	3-PG[a]	1.70	8.8%	0.995	1.45	7.5%	0.999
		3-PG[b]	2.57	13.3%	0.997	3.36	17.4%	0.999
8160	4	3-PG[a]	6.40	24.8%	0.966	3.89	15.1%	0.998
		3-PG[b]	3.40	13.2%	0.985	3.00	11.6%	0.992

C	Volume		FR = 0.5			FR = 0.8		
ID	Obs.	Model Setting	MAD		R^2	MAD		R^2
			Value	%	Value	Value	%	Value
46	6	3-PG[a]	269.29	33.7%	0.997	431.80	54.1%	0.995
		3-PG[b]	203.65	25.51%	0.997	222.65	27.9%	0.997
866	3	3-PG[a]	336.91	61.8%	1.000	467.32	85.8%	1.000
		3-PG[b]	156.70	28.8%	0.999	249.64	45.8%	1.000
8057	3	3-PG[a]	124.59	48.2%	0.995	165.48	64.1%	0.996
		3-PG[b]	71.24	27.6%	0.999	103.87	40.2%	0.999
8160	4	3-PG[a]	242.26	77.3%	0.992	324.06	103.4%	0.997
		3-PG[b]	124.26	39.6%	0.999	194.68	62.1%	0.999

Discussion

Discussion of the Empirical Data

The comparison between Swedish and Finnish Douglas fir field plots revealed that increments of height and volume are considerably higher in the observed Swedish plots than in the Finnish ones. This could indicate less favourable site and climatic conditions in Finland. Bearing height and DBH developments from plot 46 in mind, it is very likely that the other three plots would also exhibit similar volume at an older age. But when compared to the Karlberg data (Karlberg, 1961), the empirical data from Sweden would be classified between Class III and Class IV. Due to the limited data for the Finnish plots it is unsure how their volume would develop, and a classification by Karlberg (1961) is not feasible. Overall, Swedish and Finnish height curves (Figure 3A) were in good agreement with Karlberg height curves (Karlberg, 1961; Figure 3B). The average DBH, however, was bigger of trees in Finland. One explanation could be a greater exposure of trees to wind in Finland. Findings from Karlberg (1961) about testing the influence of wind on tree growth, showed that forest stands in windy areas develop a higher diameter/height ratio. Another explanation could be water stress due to less rain. Looking at the climatic data in Table 1, Finland exhibited less than half the amount of rain in the vegetation period than Sweden. The response could be enhanced root growth instead of above ground increment. A closer inspection of the measured data within Sweden shows that plots 8057 and 8160 are very similar in their growth dynamics. This might trace back to the fact that both plots are geographically very close and share very similar climatic conditions. Nevertheless,

The comparison between Swedish field plot data and Karlberg data (Karlberg, 1961) illustrated that height and DBH curves agree well, but volume curves were strongly disagreeing. Findings showed that there are differences in data processing. Inventories at SLU expressed volume as a function derived from Norway spruce (Karlsson et al. 2012). To differentiate climatic zones, volume functions for the South and the North of Sweden were available. Karlberg (1961) on the other hand, objected the use of Norway spruce as an aid in developing site curves for Douglas fir. He observed that Norway spruce would describe a more level curve course in comparison. Instead he extrapolated the data, but probably used unsuitable regression models, which resulted in an underestimation of the real potential at ages more than 50 years. It can be assumed that Karlberg (1961) approved these results, since no old-growth stands were available in Sweden at that time for validation. Also in terms of height functions Karlberg (1961) used a different approach than SLU methods. SLU height curves are calculated with Näslunds height equation (Näslund, 1936) with $p = 3$ as it is used for picea, abies and pseudotsuga species. Näslund's equation is also used for the 3-PG simulation in this study. Karlberg (1961) used a logarithmic derivation of a normal frequency function, where he found that half the height was reached at an age of 50 years. Arguably, Karlberg's data (Karlberg, 1961) reflects a greater variation of sites, which would imply that very good or very bad stands are not as influential since the curves get smoothened by the average.

Finally, in both data sets it was not clear whether the same trees were measured over time. Karlberg (1961) admitted that in order to generate site curves and establish yield tables he used a mix of continuously measured tree data from Denmark, but also single-measured tree data from random trees in Sweden from which he knew their age. In respect of SLU data collection was standardized and the empirical data for this study always derived from the same research plots. But also with this data, abnormalities were found. Plots 46 and 866 exhibited a drop DBH between years 68 and 97. Considering the drastic decrease in DBH and a physiologically impossible increase at age 97, I assume a measurement error in this case or a possible change in the volume function for the calculations.

I experienced limitations in conducting an extensive comparison of data due to the low availability of research on Douglas fir in Sweden and Finland. Naturally, the majority of research on Douglas fir has been conducted in the Pacific Northwest, or in warmer climates where natural reproduction has already been achieved, such as Central Europe. Therefore, the outcome of literature review, search for field experiments and silvicultural experts dealing with growth dynamics of Douglas fir in Sweden and Finland presented a sparse source. Furthermore, no indication of site fertility or site productivity came with the data. But, it can be assumed that Douglas fir stands originally have been established on sites with high soil fertility. Thus, other site factors such as climate, ASW, wind, and disturbances must be taken into account.

Discussion of the Predicted Data

The predicted data matched better with field plots 46, 866, 8057 and 8160 than with the Karlberg data (Karlberg, 1961), against the assumptions of my hypothesis. Arguably, the simulated data uses a closer-to-nature approach to describe height, DBH and stand volume than Karlberg (1961), because species-specific as well as site-specific parameters, and not only regression models are utilized. There were 63 species-specific parameters to run 3-PG (Version 2.7). I want to stress that the majority of Douglas fir – specific parameters have been elaborated specifically for the Pacific Northwest. Landsberg et al. (2003) reported of an average temperature in summer (15-17°C) and winter (3-7°C), precipitation (1042-2743 mm/yr) and solar radiation (3800-4500 $MJ/m^2/yr$) in the Pacific Northwest. Southern Sweden experienced an average temperature of 15.63°C in summer and 0.95°C in winter, a precipitation of 1219.75 mm/yr, and an average solar radiation of 2718 $MJ/m^2/yr$. Finland had similar climatic conditions with and average temperature of 15.37°C in summer and -6.56°C in winter, a precipitation of 615.30 mm/yr, and an average solar radiation of 3277 $MJ/m^2/yr$. Although the presented climate statistics show similar growing conditions for Douglas fir in all three regions, already a few degrees difference around 0°C during the cold months of the year could mean a longer vegetation period and thus, a high difference in the growth dynamics.

Hence it is understandable that the simulated growth curves demonstrate a different shape than measured counterparts. Looking at the development of volume, since other characteristics are calculated on the basis of biomass accumulation in 3-PG, it becomes evident that simulations predict a stronger volume increment starting from an earlier stand age. In contrast with the measured stands managed by SLU, where the late growth is unexpected and difficult to explain. Possible reasons could be high seedling mortality, little growth due to the short vegetation period and cold climate, browsing by animals, water stress, and/or low site productivity for which seedlings are more sensitive. Another explanation could be that the measured stands were thinned from above or a natural catastrophe happened before the age of 20. However, this seems unlikely because the same trends were apparent for different locations. Possibly, the parameter *Canopy Closure* influences the simulation. Age of canopy closure was set to 10 years in the parameter settings. This physiological principle is closely linked to photosynthetic production and rate of litter fall. To serve a reduction in complexity, full photosynthetic production and litter fall rate are calculated from a fully closed canopy cover within 3-PG. Consequently, the production of biomass of the stand changes with the age of canopy closure. I altered the age of canopy closure between 0 and 25 years, but could not find a better fit than with the age of canopy closure in year 10.

In this respect, is the 3-PG stand growth model applicable for modelling the growth dynamics of Douglas fir in Scandinavia according to the objective of this study? Basically the answer is yes, but with limitations. 3-PG is applicable because the model is easy to handle and the submodels easy to understand. Allometric functions as well as parameters are included, excluded or changed without needs of advanced IT-skills. Limitations of accuracy of the results lie in the calibration of the species-specific parameters. Due to constraints on available data, only parameters calibrated specifically for Douglas fir from the Pacific Northwest could be used. Accuracy of the outcomes might be achieved by calibrating the parameters for Douglas fir growth in Sweden and run the model again.

I also noticed a significant impact of the climatic data on the final results. Fewer frost days, more precipitation and solar radiation, but foremost an average temperature close around the optimum temperature of growth as been calibrated in the parameters resulted in a higher biomass production and hence, to higher outcomes for DBH and height, respectively. A weak point of this study lies in the use of the climate data presented in Table 1. It represents climate data that is averaged for all plots within one country. Therefore, results could be biased due to slightly different climatic conditions between the field plots. Yet, climate data for each individual plot was not available. Therefore, I assumed the same climatic conditions for all plots within Sweden because of the geographical proximity of the stands.

Another limitation in comparison concerned the growth data from Finland. Metla, as the only available source on growth dynamics of Douglas fir in Finland, could only provide final stand measurements. As presented above this comprised mean stand height, DBH and volume at an stand age of around 70 years. As a consequence model predictions with site-specific parameters for Finland have been conducted but the results were not comparable due to the lack of field data. This is the reason why only field plots in Sweden and the Karlberg data (Karlberg, 1961) were compared against the simulated outcomes.

Discussion of the 3-PG Stand Growth Model

Taking the functionality of the 3-PG model into account, it enables the application on a wide range of climates and species, due to its relatively small number of parameters that can be derived from the literature and field measurements (White et al. 2000; Landsberg et al. 2003).

Since the development of the process-based, physiological stand growth model 3-PG by Landsberg & Waring in 1997, it has been field-tested and analysed continuously (Waring & McDowell 2002). Although simplifications in the description of natural processes have been undertaken, it evidently delivered reasonable estimates on stand growth and canopy photosynthesis in many situations (Amaral et al. s.a.; Law et al. 2000; White et al. 2000; Landsberg et al. 2003; Almeida et al. 2004; Binkley et al. 2004; Paul et al. 2007; Erskine et al. 2008; Coops et al. 2010; Rodríguez-Suárez et al. 2010).

Initially, the model was tested on Eucalypt plantations in Australia (Landsberg & Waring 1997; Almeida et al. 2004). This is exemplified in detail in the paper by Almeida et al. (2004) in which the authors concluded that the 3-PG model was able to detect differences in production between eucalypt clones. Additionally, they stated that this model would also deliver useful results of growth and yield in areas, which it has not been calibrated for. Following this further, Binkley et al. (2004) tested actual growth and yield with simulated data on Eucalypt plantations in Brazil. They reported that the 3-PG model responded well to different soil and climatic conditions, and is highly suitable as a management tool for homogeneous forest stands.

More related to the Swedish climate as well as the objective of comparing real with simulated data was the follow-up study by Landsberg et al. (2003) where it was shown that 3-PG is reliable and can be used to estimate growth in areas where exotic trees have not been grown before. They also highlighted the possibilities to predict site productivity and investigate influencing environmental effects on stand growth. However, they acknowledged the challenge of setting appropriate values for the fertility rating. Swenson et al. (2005) suggested a thorough nutrient/nitrogen availability analysis on the respective site and additional expert opinions for optimal results of site-specific fertility ratings. Another method by Paul et al. (2007) includeed general assumptions on soil fertility according to expert opinions to find the suitable fertility rating for each site. Yet in both cases, this data was not available for this study and would have been too costly and time-consuming to acquire. Therefore, I applied Sands (2004) approach that encompasses trial-and-error runs with the model in order to get close to real growth data. As can be seen from the results, the influence of fertility ratings is rather small for Douglas fir predictions using the underlying parameters.

Sensitivity of Parameters

When Sands (2004) detected a globally increasing interest in the use of 3-PG, he developed a guidebook for parameter assignment for novel species. It basically describes the structure of the model in a more elaborated way than in the two original papers by Landsberg and Waring (Landsberg & Waring 1997; Landsberg et al. 2003). But he also included advice on the assignment and selection of species-specific parameters values. And furthermore, in cooperation with Esprey et al. (2004), a sensitivity analysis on the *"classification of parameters according to the accuracy with which they must be assigned"* (Sands 2004). The classes are defined as low (L), medium (M) and high (H) sensitivity. In order to test the accuracy of my parameter values I ran several test runs.

Optimum temperature for growth: Defined as the temperature where photosynthetic efficiency is best for plant growth. Brix (1971) reports an optimal growth temperature for Douglas fir of 18°-24° Celsius. Esprey et al. (2004) and Sands (2004) classified optimum temperature for growth as a class M parameter. Following the expertise of Lewis et al. (1999) this parameter was set at 20°C. Test runs revealed that shifting the temperature between 18 and 24 with unchanging climatic conditions, did not affect the model output significantly.

Atmospheric CO_2: Defined as the current level of CO_2 in ppm in the atmosphere. This parameter is a new implementation since 3-PG stand growth model version 2.5. It is directly linked to biomass production. A high CO_2 level favors biomass production. Biomass is then partitioned into stem, root and foliage mass. Since this parameter is newly implemented, no classification has been made yet. Test runs revealed significant changes in the results with changes of only +/- 10 ppm. Therefore, we would classify this parameter as class H. The Earth System Research Laboratory measured a CO_2 level of 390 ppm on average for Sweden and Norway in 2012[1].

Maximum stand age: Defined as the age at which the forest stand shows old growth features. According to the growing conditions in Sweden and Finland, maximum stand age for Douglas fir has been set at 200 years to match reality, taking stand age of native tree species into account. Changing maximum stand age resulted in an earlier flattening of volume, DBH and height curves. Arguably, setting a maximum stand age by default is one of the major weaknesses of the model. This parameter should be dependent on the overall productivity of

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[1] 390 ppm in the global CO_2 trend data for 2012. Websource:
ftp://aftp.cmdl.noaa.gov/data/trace_gases/co2/flask/surface/co2_zep_surface-flask_1_ccgg_month.txt

the site as well as the stocking. But if well-spaced or thinned stands are considered there may be little influence.

Mortality rate: Defined as the density independent mortality of stems in percentage per year. A mortality rate of 2%/year accurately matched the empirical data from Sweden and Finland. Natural processes include mortality due to frost, browsing, windfall, insects, fire, and/or drought. The mortality of stems directly affects stand volume and indirectly DBH and height. A higher mortality resulted in larger DBH due to lower stem numbers.

Maximum stem mass per tree: Defined as the kg of mass per tree at 1000 trees/ha (Sands 2004). Although classified as a class L parameter, maximum stem mass has a significant impact on density-dependent stem mortality. As a result, the impact of this parameter is low in thinned stands. Waring & McDowell (2002) suggested a maximum stem mass for Douglas fir of 330. Increasing the parameter started the self-thinning process at an older stand age, and vice versa. Later self-thinning affected volume and DBH levels negatively.

Age at canopy cover: Defined as age at which canopy fully covers ground in years. Landsberg et al. (2003) suggested a canopy cover at age 0 for Douglas fir, which indicates either very high initial stocking, stocking of rather big seedlings, or stocking at progressed stand age. I realistically set the age at canopy cover at 10 years according to the natural growth conditions of young seedlings in Sweden. Age at canopy cover is a class M parameter. Changing the value between 0 and 15 years had a lower impact than altering the directly related initial stem, root and foliage mass.

Discussion on the Validation Methods

In a study about the meaning of validation, Rykiel (1996) states that model validation is not determining the scientific correctness of a model. Model validation rather evaluates whether a model *is acceptable for its intended use* (Rykiel 1996). Therefore, model validation in the context of this study means testing the results of 3-PG by comparing the field versus the predicted data.

In this respect, the MAD and regression (R^2) analyses have been chosen for this study because they serve the purpose of identifying the goodness of fit of the 3-PG model outcomes. Consequently, the prerequisites for a suitable model validation by definition of Rykiel are given. The advantage of a MAD analysis lies in setting the deviation from the reference points into absolute values. This gave out the actual deviation for a comparison between the measured and the predicted figures. The R^2 on the other hand helped to identify how well the measured and predicted data fitted the regression line. This was useful for identifying outliers. In plot 46 outliers were identified in the DBH measurements, the R^2 ranged around 0.28. After eliminating the outliers the R^2 raised up to 0.98. This also changed the MAD value in a positive way. The elimination of outliers is justified because looking at the data it must have been a mistake in measuring the stand. The other stand characteristics, height and volume, did not show the same signs.

Conclusion

I expected to find taller trees and a higher standing volume in the South of Sweden due to the warmer climate and longer vegetation period. The available growth data on Douglas fir in Sweden and Finland confirmed my hypothesis. Yet, Karlberg (1961) recorded lower volume increment in comparison to the other field plots further north, which might be the results of unsuitable regression models or wrong extrapolation. The second objective about applying the 3-PG stand growth model to predict the growth dynamics of Douglas fir in Sweden and Finland was successful. Despite the fact that some parameters are only calibrated for the Pacific Northwest, they delivered comparable results. The findings show that predicted height and DBH curves were in good agreement with measured height and DBH curves. But volume predictions failed to deliver accurate results, because 3-PG predictions were overestimating stand productivity. I see the achievement of this research in collecting the current available data on long-term field plots of Douglas fir and a comparison to available data in Finland. Moreover, the applicability of 3-PG to predict the growth of Douglas fir in Sweden and Finland will be more accurate if the species-specific parameters are calibrated for local physiological processes. A higher accuracy can also be achieved if daily time-steps instead of monthly time-steps are used for the weather data input. Improvements of the model can be made if more complexity in form of more submodels are added to 3-PG. Yet, a higher complexity will reduce the practicality of the use for foresters. Attention should be laid on the allometric functions used, since they depend on physiological properties and site conditions. Consequently, results might differ from location to location. Eventually, the establishment of more Douglas fir field trials in the Swedish climate will lead to a better understanding of the species' physiology and help in calibrating the species-specific parameters of growth models.

References

Almeida, A. C., Landsberg, J. J., & Sands, P. J. (2004). Parameterisation of 3-PG model for fast-growing Eucalyptus grandis plantations. *Forest Ecology and Management*, *193*(1-2), 179–195. doi:10.1016/j.foreco.2004.01.029

Amaral, A., Salas, R., Pascoa, F., Tome, M., & Soares, P. (n.d.). Application of the forest growth model 3PG to Eucalyptus globulus stands in the central region of Portugal. *N.n.*

Binkley, D., Ryan, M. G., & Stape, J. L. (2004). Testing the utility of the 3-PG model for growth of with natural and manipulated supplies of water and nutrients. *Forest Ecology and Management*, *193*(1-2), 219–234. doi:10.1016/j.foreco.2004.01.031

Brix, H. (1971). Growth response of western hemlock and Douglas-fir seedlings to temperature regimes during day and night. *Canadian Journal of Botany*, *49*(2), 289–294. doi:10.1139/b71-047

Brown, H. P., Panshin, A. J., & Forsaith, C. C. (1949). *Textbook of Wood Technology. Vol. 1.* (p. 52). New York: McGraw-Hill Book Company.

Coleman, R. (2008). The Douglas fir alternative. *Neslon Marlborough Rural News*. Retrieved May 13, 2014, from http://www.sp.co.nz/rural_news/articles/fir.html

Coops, N. C., Hember, R. a., & Waring, R. H. (2010). Assessing the impact of current and projected climates on Douglas-Fir productivity in British Columbia, Canada, using a process-based model (3-PG). *Canadian Journal of Forest Research*, *40*(3), 511–524. doi:10.1139/X09-201

Coops, N. C., & Waring, R. H. (2001). Estimating forest productivity in the eastern Siskiyou Mountains of southwestern Oregon using a satellite driven process model, 3-PGS. *Can. J. For. Res.*, *31*, 143–154.

Curt, T., Bouchaud, M., & Agrech, G. (2001). Predicting site index of Douglas-Fir plantations from ecological variables in the Massif Central area of France. *Forest Ecology and Management*, *149*(1-3), 61–74.

Esprey, L. ., Sands, P. ., & Smith, C. . (2004). Understanding 3-PG using a sensitivity analysis. *Forest Ecology and Management*, *193*(1-2), 235–250. doi:10.1016/j.foreco.2004.01.032

Feikema, P. M., Morris, J. D., Beverly, C. R., Collopy, J. J., Baker, T. G., & Lane, P. N. J. (2010). Validation of plantation transpiration in south-eastern Australia estimated using the 3PG+forest growth model. *Forest Ecology and Management*, *260*(5), 663–678 ST – Validation of plantation transpirati. doi:10.1016/j.foreco.2010.05.022

Felton, A., Boberg, J., Björkman, C., & Widenfalk, O. (2013). Identifying and managing the ecological risks of using introduced tree species in Sweden's production forestry. *Forest Ecology and Management*, *307*, 165–177. doi:10.1016/j.foreco.2013.06.059

Gholz, H. L. (1982). Environmental Limits on Aboveground Net Primary Production, Leaf Area, and Biomass in Vegetation Zones of the Pacific Northwest. *Ecology*, *63*(2), 469–481.

Hermann, R. K., & Lavender, D. P. (1999). Douglas-fir planted forests, 53–70.

Johansson, T. (1999). Site Index Curves for Common Alder and Grey Alder Growing on Different Types of Forest Soil in Sweden. *Scandinavian Journal of Forest Research*, *14*(5), 441–453. doi:10.1080/02827589950154140

Jorgensen, S. E., & Bendoricchio, G. (2001). *Fundamentals of Ecological Modelling* (p. 530). Elsevier.

Karlberg, S. (1961). Development and yield of Douglas fir (Pseudotsuga taxifolia) and Sitka spruce (Picea sitchensis) in Southern Scandinavia and on the Pacific Coast. *Bulletin of the Royal School of Forestry Stockholm, Sweden*, *34*(34), 141.

Karlsson, K., Mossberg, M., & Ulvcrona, T. (2012). Fältdatasystem för skogliga fältförsök.

Landsberg, J. ., Waring, R. ., & Coops, N. . (2003). Performance of the forest productivity model 3-PG applied to a wide range of forest types. *Forest Ecology and Management*, *172*(2-3), 199–214. doi:10.1016/S0378-1127(01)00804-0

Landsberg, J. J., & Waring, R. H. (1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning. *Forest Ecology and Management*, *95*(3), 209–228. doi:10.1016/S0378-1127(97)00026-1

Law, B. E., Waring, R. H., Anthoni, P. M., & Aber, J. D. (2000). Measurements of gross and net ecosystem productivity and water vapour exchange of a Pinus ponderosa ecosystem , and an evaluation of two generalized models. *Global Change Biology*, *6*, 155–168.

Legates, D. R., & Mccabe, G. J. J. (1999). Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation, *35*(1), 233–241.

Lewis, J. D., Olszyk, D., & Tingey, D. T. (1999). Seasonal patterns of photosynthetic light response in Douglas-fir seedlings subjected to elevated atmospheric CO(2) and temperature. *Tree Physiology*, *19*(4_5), 243–252.

McArdle, R. E. (1961). The Yield of Douglas Fir in the Pacific Northwest. *Technical Bulletin*, *201*, 74.

Monteith, J., & Moss, C. (1977). Climate and the Efficiency of Crop Production in Britain. *Philosophical Transactions of …*, *281*, 277–294.

Näslund, M. (1936). Skogsförsöksanstaltens gallringsförsök i tallskog. *Meddelanden Från Statens Skogsförsöksanstalt*, *28(1)*.

Nightingale, J. M., Hill, M. J., Phinn, S. R., Davies, I. D., Held, A. A., & Erskine, P. D. (2008). Use of 3-PG and 3-PGS to simulate forest growth dynamics of Australian tropical rainforests. *Forest Ecology and Management*, *254*(2), 107–121. doi:10.1016/j.foreco.2007.03.041

Nippert, J. B., & Marshall, J. D. (2003). Sources of variation in ecophysiological parameters in Douglas-fir and grand fir canopies. *Tree Physiology*, *23*(9), 591–601.

Ojansuu, R., & Henttonen, H. (1983). Estimation of the local values of monthly mean temperature, effective temperature sum and precipitation sum from the measurements made by the Finnish Meteorological Office. *Silva. Fenn.*, *17*(2), 143–160.

Ottosson-Löfvenius, M. (2010). *Referensmätning av klimat vid Skokliga Försöksparkerna. Årsrapport 2003 - 2010. Sveriges lantbruksuniversitet.*

Paul, K. I., Booth, T. H., Jovanovic, T., Sands, P. J., & Morris, J. D. (2007). Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. *Forest Ecology and Management*, *243*(2-3), 237–247. doi:10.1016/j.foreco.2007.03.029

Raulier, F., Bernier, P. Y., Girardin, M. P., & Tardif, J. C. (2008). Response of tree growth to a changing climate in boreal central Canada: A comparison of empirical, process-based, and hybrid modelling approaches. *Ecological Modelling*, *213*(2), 209–228. doi:10.1016/j.ecolmodel.2007.12.010

Rodríguez-Suárez, J. a., Iglesias, M. L., Diaz-Fierros, F., & Soto, B. (2010). Application of the 3PG forest growth model to a Eucalyptus globulus plantation in Northwest Spain. *European Journal of Forest Research*, *129*(4), 573–583. doi:10.1007/s10342-010-0355-6

Ruosteenoja, K., & Räisänen, J. (2009). Solar Radiation Projections Derived from Global Climate Models. *Finish Meteorological Institute*, (September).

Rykiel, E. J. (1996). Testing ecological models: the meaning of validation. *Ecological Modelling*, *90*, 229–244.

Sands, P. (2001). *3PG(PJS)—a user-friendly interface to 3-PG, the Landsberg and Waring model of forest productivity. Technical Report No. 29. 2nd Edn. Cooperative Research Centre for Sustainable Production Forestry and CSIRO Forestry and Forest Products. Hobart, Tasmania, Australia, 24 p.* (Vol. 29, p. 24).

Sands, P. (2004). *Adaptation of 3-PG to novel species : guidelines for data collection and parameter assignment* (p. 36).

Simpson, D. G. (2007). Stand Yield Prediction for a changing Climate. BC Ministry of Forests and Range. Kalamalaka Research Station, Vernon, Canada.

Skogsstyrelsen. (2009). *Regler om användning av främmande trädslag. (Rules on the use of alien species).*

Swenson, J. J., Waring, R. H., Fan, W., & Coops, N. (2005). Predicting site index with a physiologically based growth model across Oregon , USA, *1707*, 1697–1707. doi:10.1139/X05-089

Urban, J., Holušová, K., Menšík, L., Čermák, J., & Kantor, P. (2012). Tree allometry of Douglas fir and Norway spruce on a nutrient-poor and a nutrient-rich site. *Trees*, *27*(1), 97–110. doi:10.1007/s00468-012-0771-y

Van Loo, M., Hintsteiner, W., & Hasenauer, H. (2012). Douglasie: Zukunft passiert jetzt, begann aber schon gestern. *Forstzeitung*, *10*, 20–21.

Waring, R. H., & McDowell, N. (2002). Use of a physiological process model with forestry yield tables to set limits on annual carbon balances. *Tree Physiology*, *22*(2-3), 179–88.

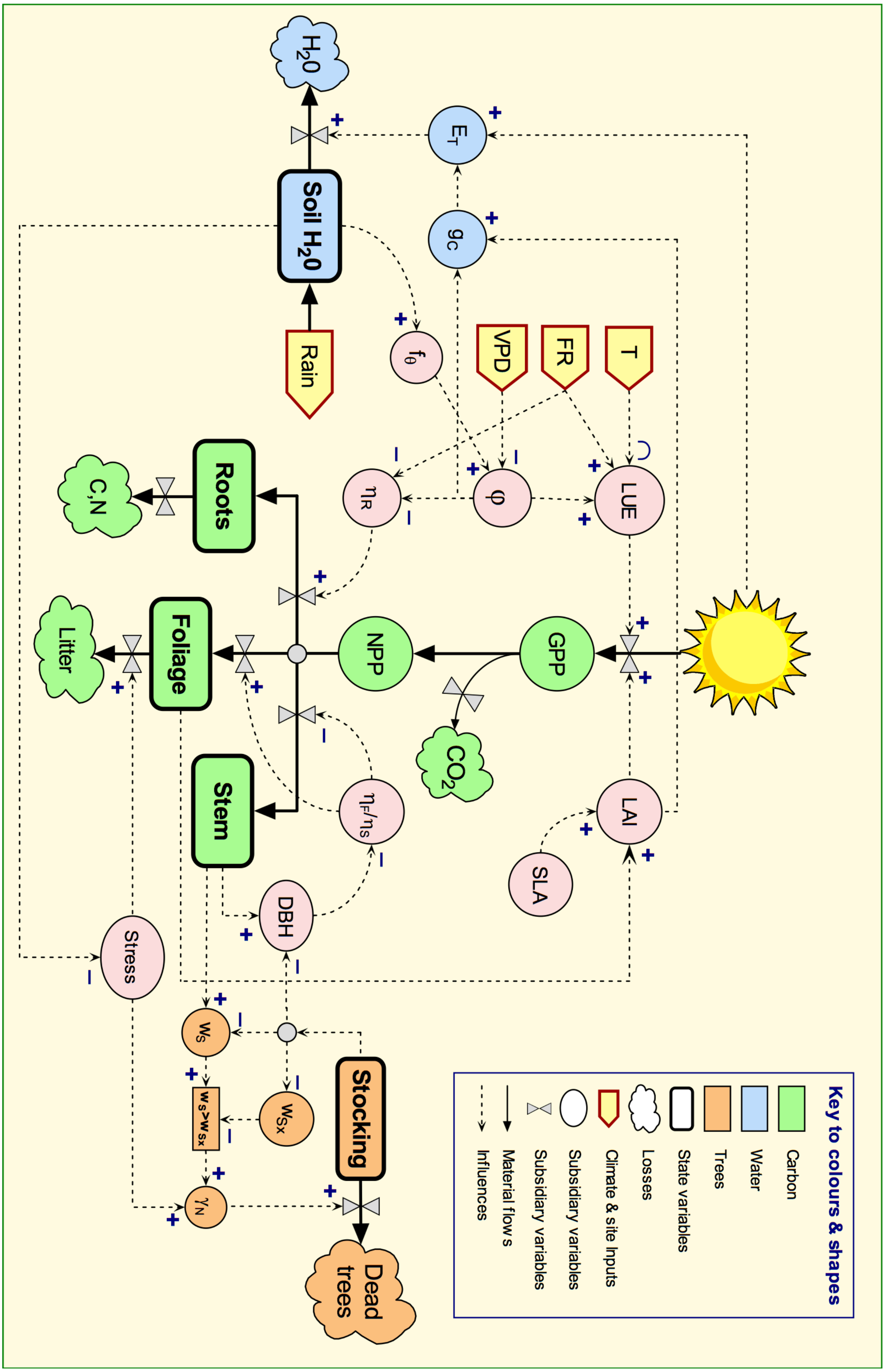
White, J. ., Coops, N. ., & Scott, N. . (2000). Estimates of New Zealand forest and scrub biomass from the 3-PG model. *Ecological Modelling*, *131*(2-3), 175–190.

Wulder, M., White, J., Coops, N., Nelson, T., & Boots, B. (2007). Using local spatial autocorrelation to compare outputs from a forest growth model. *Ecological Modelling*, *209*(2-4), 276, 264. doi:10.1016/j.ecolmodel.2007.06.033

Yoda, K., Kira, T., & Hozumi, K. (1963). Self-thinning in overcrowded pure stands under cultivated and natural conditions (Intraspecific competition among higher plants. XI.). *Journal of Biology*, *Osaka City*(14), 107–129.

Appendix

Appendix 1: Basic structure of 3-PG and the causal influence of its variables and processes. Source: Sands, 2004



Appendix 2: Species-specific parameters for Douglas fir using 3-PG version 1.0.

Meanings	3-PG Name	Units	Ps me 2	Source	Sensitivity
Allometric relationships & partitioning					
Foliage:stem partitioning ratio @ D=2 cm	pFS2	-	1.3	LW	H
Foliage:stem partitioning ratio @ D=20 cm	pFS20	-	0.7	LW	H
Constant in the stem mass v. diam. relationship	StemConst	-	0.0843	McA	M
Power in the stem mass v. diam. relationship	StemPower	-	2.436	McA	H
Maximum fraction of NPP to roots	pRx	-	0.8	SP	M
Minimum fraction of NPP to roots	pRn	-	0.25	SP	M
Temperature modifier (fT)					
Minimum temperature for growth	Tmin	deg. C	-2	LE	L
Optimum temperature for growth	Topt	deg. C	20	LE	M
Maximum temperature for growth	Tmax	deg. C	40	LE	L
Frost modifier (fFRost)					
Days production lost per frost day	kF	days	1	LW	L
Soil water modifier (fSW)					
Moisture ratio deficit for $f_\theta = 0.5$	SWconst	-	0.7	LW	H
Power of moisture ratio deficit	SWpower	-	9	LW	L
Fertitlity effects					
Value of 'm' when FR = 0	m0	-	0.015	LW	M
Value of 'fNutr' when FR = 0	fN0	-	1	LW	L
Age modifier (fAge)					
Maximum stand age used in age modifier	MaxAge	years	200	WMcD	L
Power of relative age in function for fAge	nAge	-	4	LW	L
Relative age to give fAge = 0.5	rAge	-	0.95	LW	L
Litterfall & root turnover					
Maximum litterfall rate	gammaFx	1/month	0.021	GZ	L
Litterfall rate at t = 0	gammaF0	1/month	0.001	LW	H
Age at which litterfall rate has median value	tgammaF	month	36	LW	L
Average monthly root turnover rate	Rttover	1/month	0.0161	GZ	L
Conductance					
Maximum canopy conductance	MaxCond	m/s	0.018	CW	H
LAI for maximum canopy conductance	LAIgcx	-	3.33	LW	L
Defines stomatal response to VPD	CoeffCond	1/mBar	0.05	LW	L
Canopy boundary layer conductance	BLcond	m/s	0.2	LW	L
Stem numbers					
Max. stem mass per tree @ 1000 trees/hectare	wSx1000	kg/tree	330	WMcD	L
Power in self-thinning rule	thinPower	-	1.5	LW	L
Fraction mean single-tree foliage biomass lost per dead tree	mF	-	0	LW	L
Fraction mean single-tree root biomass lost per dead tree	mR	-	0.2	LW	L
Fraction mean single-tree stem biomass lost per dead tree	mS	-	0.2	LW	L
Canopy structure and processes					
Specific leaf area at age 0	SLA0	m^2/kg	6	MA	L
Specific leaf area for mature leaves	SLA1	m^2/kg	6	MA	H
Age at which specific leaf area = (SLA0+SLA1)/2	tSLA	years	5	LW	L
Extinction coefficient for absorption of PAR by canopy	k	-	0.5	LW	M
Age at canopy cover	fullCanAge	years	0	LW	M
Maximum proportion of rainfall evaporated from canopy	MaxIntcptn	-	0.15	LW	M
LAI for maximum rainfall interception	LAImaxIntcptn	-	0	LW	L
Canopy quantum efficiency	alpha	molC/molPAR	0.043	WMcD	H
Branch and bark fraction (fracBB)					
Branch and bark fraction at age 0	fracBB0	-	0.15	LW	L
Branch and bark fraction for mature stands	fracBB1	-	0.1	LW	L
Age at which fracBB = (fracBB0+fracBB1)/2	tBB	years	20	LW	L

Various					
Ratio NPP/GPP	Y	-	0.47	LW	H
Basic density	Density	t/m3	0.36	BR	H
Conversion factors					
Intercept of net v. solar radiation relationship	Qa	W/m2	-90	LW	H
Slope of net v. solar radiation relationship	Qb	-	0.9	LW	H
Molecular weight of dry matter	gDM_mol	gDM/mol	24	LW	H
Conversion of solar radiation to PAR	molPAR_MJ	mol/MJ	2.37	WmcD	H

LW … Landsberg & Waring 1997; McA … McArdle 1961; SP … Sands 2001; LE … Lewis et al. 1999; WMcD … Waring & McDowell 2002; GZ … Gholz 1982; and CW … Coops & Waring 2001.

Appendix 3: Species-specific parameters for Douglas fir using 3-PG version 2.7.

Meaning/comments	Name	Units	Ps me 2	Source	Sensitivity
Biomass partitioning and turnover					
Allometric relationships & partitioning					
Foliage:stem partitioning ratio @ D=2 cm	pFS2	-	1.3	LW	H
Foliage:stem partitioning ratio @ D=20 cm	pFS20	-	0.7	LW	H
Constant in the stem mass v. diam. relationship	aS	-	0.0843	McA	M
Power in the stem mass v. diam. relationship	nS	-	2.436	McA	H
Maximum fraction of NPP to roots	pRx	-	0.8	SP	M
Minimum fraction of NPP to roots	pRn	-	0.25	SP	M
Litterfall & root turnover					
Maximum litterfall rate	gammaFx	1/month	0.021	GZ	L
Litterfall rate at t = 0	gammaF0	1/month	0.001	LW	H
Age at which litterfall rate has median value	tgammaF	months	36	LW	L
Average monthly root turnover rate	gammaR	1/month	0.0161	GZ	L
NPP & conductance modifiers					
Temperature modifier (fT)					
Minimum temperature for growth	Tmin	deg. C	-2	LE	L
Optimum temperature for growth	Topt	deg. C	20	LE	M
Maximum temperature for growth	Tmax	deg. C	40	LE	L
Frost modifier (fFRost)					
Days production lost per frost day	kF	days	1	LW	L
Soil water modifier (fSW)					
Moisture ratio deficit for f_θ = 0.5	SWconst	-	0.7	LW	H
Power of moisture ratio deficit	SWpower	-	9	LW	L
Atmospheric CO2 modifier (fCO2)					
Assimialtion enhancement factor at 700 ppm	fCalpha700	-	1.4	LW	
Canopy conductance enhancement factor at 700 ppm	fCg700	-	0.7	LW	
Fertitlity effects					
Value of 'm' when FR = 0	m0	-	0.015	LW	M
Value of 'fNutr' when FR = 0	fN0	-	1	LW	L
Power of (1-FR) in 'fNutr'	fNn	-	0	LW	?
Age modifier (fAge)					
Maximum stand age used in age modifier	MaxAge	years	200	WMcD	L
Power of relative age in function for fAge	nAge	-	4	LW	L
Relative age to give fAge = 0.5	rAge	-	0.95	LW	L
Stem mortality & self-thinning					
Mortality rate for large t	gammaNx	%/year	2	Trial&Error	?
Seedling mortality rate (t = 0)	gammaN0	%/year	0	LW	?
Age at which mortality rate has median value	tgammaN	years	0	LW	?
Shape of mortality response	ngammaN	-	1	LW	?
Max. stem mass per tree @ 1000 trees/hectare	wSx1000	kg/tree	330	WMcD	L
Power in self-thinning rule	thinPower	-	1.5	LW	L
Fraction mean single-tree foliage biomass lost per dead tree	mF	-	0	LW	L
Fraction mean single-tree root biomass lost per dead tree	mR	-	0.2	LW	L
Fraction mean single-tree stem biomass lost per dead tree	mS	-	0.2	LW	L

Canopy structure and processes					
Specific leaf area					
Specific leaf area at age 0	SLA0	m^2/kg	6	MA	L
Specific leaf area for mature leaves	SLA1	m^2/kg	6	MA	H
Age at which specific leaf area = (SLA0+SLA1)/2	tSLA	years	5	LW	L
Light interception					
Extinction coefficient for absorption of PAR by canopy	k	-	0.5	LW	M
Age at canopy cover	fullCanAge	years	10	Trial&Error	M
Maximum proportion of rainfall evaporated from canopy	MaxIntcptn	-	0.15	LW	M
LAI for maximum rainfall interception	LAImaxIntcptn	-	0	LW	L
Production and respiration					
Canopy quantum efficiency	alpha	molC/molPAR	0.043	WMcD	H
Ratio NPP/GPP	Y	-	0.47	LW	H
Conductance					
Minimum canopy conductance	MinCond	m/s	0	CW	H
Maximum canopy conductance	MaxCond	m/s	0.018	CW	H
LAI for maximum canopy conductance	LAIgcx	-	3.33	LW	L
Defines stomatal response to VPD	CoeffCond	1/mBar	0.05	LW	L
Canopy boundary layer conductance	BLcond	m/s	0.2	LW	L
Wood and stand properties					
Branch and bark fraction (fracBB)					
Branch and bark fraction at age 0	fracBB0	-	0.15	LW	L
Branch and bark fraction for mature stands	fracBB1	-	0.1	LW	L
Age at which fracBB = (fracBB0+fracBB1)/2	tBB	years	20	LW	L
Basic Density					
Minimum basic density - for young trees	rhoMin	t/m3	0.5	Trial&Error	H
Maximum basic density - for older trees	rhoMax	t/m3	0.5	Trial&Error	H
Age at which rho = (rhoMin+rhoMax)/2	tRho	years	4	LW	M
Stem height					
Constant in the stem height relationship	aH	-	0	NÄ	?
Power of DBH in the stem height relationship	nHB	-	0	NÄ	?
Power of stocking in the stem height relationship	nHN	-	0	LW	?
Stem volume					
Constant in the stem volume relationship	aV	-	0	Trial&Error	?
Power of DBH in the stem volume relationship	nVB	-	0	Trial&Error	?
Power of stocking in the stem volume relationship	nVN	-	0	LW	?
Conversion factors					
Intercept of net v. solar radiation relationship	Qa	W/m2	-90	LW	H
Slope of net v. solar radiation relationship	Qb	-	0.9	LW	H
Molecular weight of dry matter	gDM_mol	gDM/mol	24	LW	H
Conversion of solar radiation to PAR	molPAR_MJ	mol/MJ	2.37	LW	H

LW … Landsberg & Waring 1997; McA … McArdle 1961; SP … Sands 2001; LE … Lewis et al. 1999; WMcD … Waring & McDowell 2002; GZ … Gholz 1982; CW … Coops & Waring 2001; and Näslund 1936.

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