Validation of the New Zealand Douglas-fir growth model (DF NAT) using data from southwest Germany.

Ian Bromley[1] and Leith Knowles

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Abstract

Using data from 44 sample plots in Southwest Germany, the New Zealand Douglas-fir growth model (DF NAT) was validated for its general precision and possible application in Germany. To test the model, predictions of height, basal area, and mortality (stocking) were compared to actual data. Thinning coefficients were calculated directly from the data and were then used in the model, thus neutralising the effect of thinnings on basal area development.

Stand Basal Area Potential (SBAP) is a key driver of the growth model, so values were calculated for each sample plot. These were found to be relatively stable over time with the exception of three older sites, whose SBAP values increased erratically over the rotation. Despite great differences in silvicultural practices between New Zealand and Germany, the model's prediction of basal area was generally good, although several anomalies occurred in some older stands, and in some stands with basal areas above $45M^2$/ha.

The NZ based ht/age curve predicted mean top height (MTH) relatively accurately with error values of generally less than one metre, although, as with basal area, several anomalies did occur within older stands.

The model's mortality function, (which estimates stocking) consistently over-predicted the level of mortality over time. An adjustment was installed to reduce the attrition although this should be used with caution as it defies Reineke's (1933) –3/2 self-thinning rule.

Total standing volumes (TSV) were under-predicted by about 10% using the standard NZ Douglas-fir equation S36, which predicts volume from basal area, MTH, and stocking. A new equation form previously used for radiata pine within the NZ1 Growth model (S38) with coefficients refitted from the German Douglas-fir data showed a much better result.

Overall, it is concluded that the New Zealand growth model (with the mortality adjustment, and new volume function) validated well against the German sample plots. Some caution is necessary in using it for long rotations (>80 years). Productivity of Douglas-fir in Germany as represented by the 500 Index estimated from these 44 sample plots, is indicated to be about 15% less than in New Zealand

[1] University of Freiburg, Germany.

Introduction

The DF NAT Douglas-fir growth model was developed using extensive data sets from permanent sample plots within New Zealand in order to estimate the effects of site, stand age, and silviculture on growth of Douglas-fir plantations at the stand level. The three key components of the model and its sub-models are a basal area increment function, a height-age function, and a stocking (mortality) function (Knowles and Hansen, 2004). The model uses stocking, diameter and height information recorded from the stand as an initial starting point for the growth simulation, or can estimate such information if this is not available. The end result is a predicted growth trajectory, which can be linked to log merchandising algorithms to produce yield tables. In New Zealand it is available to users within the EXCEL based 'Douglas-fir Calculator' (Halliday and Knowles, 2003), or as a component of the 'STANDPAK' silvicultural evaluation and planning package (Whiteside and Sutton, 1983).

The model has been recently tested using data from sample plots in the Pacific Northwest. Despite being presented with a wider range of site conditions than can be found in New Zealand, this study showed a general adaptability of the model to the American data sets in terms of basal area development with error values of ± 10%. The height-age function within the model however, had to be refitted for the American data to account for the "flatter" height/age development in American stands (Knowles and Hansen, 2004).

The aim of this study was to expose the New Zealand growth model to data sets representing silvicultural and site conditions in Southwest Germany. German silviculture is generally based upon continuous cover forestry practices, long rotations of 80 – 150 years and a diverse species range and age structure (Kenk and Hradetzky, 1984). This form of silviculture is often called "Naturnahforstwirtschaft" ("close-to-nature forestry") and aims to fulfil many, if not all, of the natural functions of a forest whilst at the same time producing sustainable economic returns (Beiling, 2003). Some 120 final crop trees/hectare are selected early on in the rotation and these receive preferential treatment in terms of pruning and thinning. Thinning is carried out relatively intensively with cycles typically ranging between 5-10 years. The overall production aim of such forestry is large diameter trees, pruned to 5-15 metres. The aim is to use and promote natural regeneration with under-planting to fill any gaps (Kenk, 1989; Gürth, 2003).

This contrasts with New Zealand, where Douglas-fir silviculture is much simpler. Most stands receive one thinning to waste, however stands on easy terrain may receive an additional production thinning. Rotations are usually 40-50 years, and pruning is not commonly practised. Despite these limitations, the 1400 New Zealand Douglas-fir sample plots from which DF NAT is derived contain a range of different silvicultural treatments including multiple thinnings, pruning, and longer rotations.

Methods

Data

The data came from 44 sample plots located at several experimental sites belonging to the Forest Research Institute, Freiburg, in southwest Germany. The sites were a mixture of single research plots, and trials comprising up to 24 plots. The plots are monitored at regular intervals by the Forest Growth department and provide growth data across different site conditions, for a range of silviculture, including specifically stocking densities, and spacing patterns. A summary of the 44 plots used in this study is shown in table 1 below.

Table 1: Summary of the plots and trials used in the study.

No.	Location	Established	Age at 1st meas	Age at final meas.	No. of plots	Thinned
Dgl. 4	Bad Waldsee	1890	21	112	1	No
Dgl 27	Ehingen	1925	23	77	1	Yes
Dgl 81	Lörrach	1970	16	34	24	Yes
Dgl 86	Löwenstein	1969	19	31	4	Yes
Dgl 87	Ehingen	1970	20	31	11	Yes
Dgl 95	Bad Herrenalb	1888	62	112	1	No
Dgl 98	Kandern	1932	25	70	1	No
Dgl 105	Kirchzarten	1937	18	67	1	Yes

Figures 1 and 2 below give an indication of the site at Lörrach (Dgl 81). The open area in Figure 1 resulted from storm damage at Christmas, 1999, which affected several plots on the site. Figure 2 shows the current state of a plot that had an initial spacing of 2000 stems/hectare.

Figure 1. Plot 81-9 of the trial site at Lörrach. Photograph taken in September 2004 when the stand was 34 years old.

Figure 2. Plot 81-4 of the trial site at Lörrach. The initial spacing was 3m x 1.67 (2000 stems/hectare). The stand is now 34 years old.

Basal Area

Thinning coefficients were specifically calculated for each thinning event in order to remove the obvious effect that thinning may have on prediction of basal area. These coefficients were calculated using the following formula (1):

$$\text{Thinning coefficient} = \frac{\log\left(\frac{BA_1}{BA_0}\right)}{\log\left(\frac{N_1}{N_0}\right)} \qquad (1)$$

where BA_0 is the basal area before thinning, BA_1 is the basal area following thinning, N_0 is the stocking before thinning, and N_1 is the stocking following thinning.

The calculated thinning coefficients were also compared with those typical for New Zealand, which gave information about the respective types of thinning in both countries.

The Stand Basal Area Potential (SBAP), which is site specific and needs to be calculated from the available data before running the model, was also calculated for each time interval between thinnings for each plot. These values were then weighted by the time period to give an SBAP value for each plot. This value enables basal area increment over a known period of time to be predicted, and is dependent upon crown length, age and competition. The predicted basal area was then compared with the actual basal area, and differences between the two sets of values were charted as errors.

Stocking

The stocking (mortality) function present in the model is based on the self-thinning rule developed by Reineke (1933), and also models the attrition of tree numbers in the period before the stand reaches the self-thinning line. The accuracy of this mortality function was investigated by examining predicted and actual values for stems per hectare and later led to an adjustment for use in Southwest Germany.

Height

Crucial to the model and its functioning is the use of a height-age curve. The fit of the New Zealand curve against the German data was assisted by the fact that the NZ curves include a latitude term. This in effect ‘bends’ the curve for any given site index (mean top height in metres at age 40 years - SI). The curves could therefore be adapted to the German data by changing the latitude value in the SI function. SI values were predicted for the plots at each measurement event within the data, which gave several SI predictions from which the average SI value for the plot could be determined. Differing latitude values were then used to ascertain which latitude resulted in the closest proximity of the data to the predicted values. The latitude value with least deviation from the mean was chosen as the most suitable. The latitude value is unlikely to have any bearing on real latitude values from Germany since the model was developed using New Zealand data, thus any correlation would be coincidence. Altering this value did however allow the shape of the curve to be adjusted convincingly to the German data. Model predictions of height were compared to actual values at a range of ages within the rotation. Similar to the basal area analysis, errors between predicted and actual values were plotted to visually identify any trends that were present.

Volume

Volume production is obviously of primary importance for the forest owner since this has a direct bearing on the financial revenue from the stand. In light of this importance, volume predictions as a product of the three factors discussed above - height, basal area and stocking - were compared with actual data and errors as deviations from actual values were recorded. Some refitting of the coefficients was required in the current DF NAT volume formula. Additional formulae were also tested in order to determine whether these could improve the current DF NAT volume function. The relative accuracy was evaluated for each equation by minimising the root mean square of residuals (RMSR) for deviations in cubic metres (m^3). These volume formulae are presented below.

$$V = BA(a + bMTH) \tag{2}$$

$$V = BA\left(a + bMTH + cN\frac{MTH}{BA}\right) \tag{3}$$

$$V = BA\left(a + bMTH + c\frac{MTH}{\sqrt{N}} + dN\frac{MTH}{BA}\right) \tag{4}$$

$$\log(V) = \frac{\begin{pmatrix}(\log(BA) - a - b\log(MTH) - d\log(N) - \\ e\log(N)^2 - f\log(MTH)^2 - g\log(MTH)\log(N)\end{pmatrix}}{(h\log(N) + c)} \tag{5}$$

Where *MTH* is plot mean top height (m),

N is stocking (stems/ha),

and *BA* is plot basal area (m^2/ha).

Equation (2) was originally developed by Beekhuis (1966) and is applicable for radiata pine (*Pinus radiata* D.Don) throughout New Zealand. The second model (equation 3), called 'S36', is the stand level volume formula as currently used in DF NAT and is thus currently in use for Douglas-fir New Zealand-wide (Katz, Dunningham and Gordon, 1984). In the following this formula will be referred to as 'DF NAT'. The third model (equation 4) has previously been used for radiata pine New Zealand-wide under the name 'NZ1' or 'S38' (Law and Knowles, 1994). The fourth and last model (equation 5) was a new model (Hansen, Kimberly and Knowles, in prep.).

500 Index

The 500 Index is an indicator of the mean annual volume increment (MAI) of a 40 year old stand of Douglas-fir planted at 1650 stems/ha with a thinning to waste to 500 stems/ha at a MTH of 15m. (Knowles and Hansen, 2004). Although such silviculture has no application in Germany due to multiple thinnings and normal rotations far exceeding that of 40 years, the index can provide an interesting comparison between the two countries in terms of productivity. The 500 Index was therefore calculated for all installations apart from Dgl 98 (due to lack of appropriate data) using the formula presented by Knowles (2005).

Since this index is unsuitable for use in Germany in its present form it was decided to develop a "Z-Baum" index that reflects the silvicultural situation in Germany much better than the 500 Index. A standard silviculture regime was devised on the basis of the yield tables from Kenk and Hradetzky (1984), the ministerial guidelines for Douglas-fir forest management in Baden-Württemberg (Landesforstverwaltung Ba-Wü, 1999), and values from previous runs in DF NAT. This standard regime aimed to create a stand of 200 Douglas-fir trees, of which 150 would be pruned to 12 metres. The initial stocking was set at 1400 and each of the five thinnings aimed to produce merchantable timber volumes without reducing stand stability. A matrix of different SI and SBAP values was established and total volumes at age 80 years were predicted using DF NAT. The Solver function in Excel was used so that the Z-Baum index corresponded to the mean annual volume increment (MAI) as calculated by DF NAT for a Douglas-fir stand managed according to current German silvicultural practices.

Results and Discussion

Basal Area

The calculation of the thinning coefficients (ratio between basal area before and after thinning relative to stocking before and after thinning) revealed higher values for Germany than the typical values for New Zealand (0.705) and Great Britain (0.662) (Knowles and Hansen, 2004). The average thinning coefficient for Germany was calculated at 0.825 although older stands showed thinning coefficients much lower than those of the younger stands. This latter observation could certainly be due to the change in silvicultural systems in different periods of the 20th century. Older stands established in the first half of the century were generally managed according to the "Altersklassenwald" approach with monocultures, clearfells, and thinning focusing on smaller suppressed trees; similar to the present situation in New Zealand. Younger stands are now more likely to be managed using a "Z-Baum" approach, in which final crop trees (Z-Bäume) are selected early on in the stand's history, and receive progressive pruning up to 10m - 15 height, whilst the remaining stand undergoes progressive thinning focusing on trees which crowd the final crop trees, and these thinned trees therefore approach the stand's average tree size (Gürth, 2003).

Table 2: Summary of SI, SBAP values and thinning coefficients for German data.

Site	Site Index		SBAP		Thinn. Coeffic		500 Index	Age		No. Plots
	Mean	sd	Mean	sd	Mean	sd		Min.	Max.	
4	25.44	-	1.50	0.43	-	-	12.07	21	122	1
27	25.00	-	2.38	0.57	0.653	-	18.47	23	77	1
81	34.50	0.78	1.49	0.12	0.871	0.05	18.05	16	34	24
86	28.19	0.24	1.43	0.08	0.811	0.04	13.22	19	31	4
87	25.26	0.58	1.25	0.12	0.801	0.10	10.01	20	31	11
95	27.30	-	2.17	0.18	-	-	19.00	62	112	1
98	28.80	-	-	-	-	-		25	70	1
105	32.43	-	1.64	0.45	0.519	-	18.24	18	67	1
Mean[1]	**30,85**	**0.67**	**1,46**	**0.14**	**0.832**	**0.06**	**15.44**[2]	**-**	**-**	**-**
Total	**-**	**-**	**-**	**-**	**-**	**-**	-	**-**	**-**	**44**

[1] Mean values are the weighted averages according to number of plots.

[2] Mean 500 Index values are weighted averages according to number of plots, excluding site 98, for which no 500 Index could be calculated.

The calculated SBAP values showed no significant correlation between age and SBAP (R^2 = 0.172) although there was often considerable variation over time. The sample plots Dgl 27 and 105 for example, showed a large variation in SBAP with values ranging from 1.39 to 3.00 and 1.13 to 2.35 respectively within a period of less than 30 years (see figure 3).

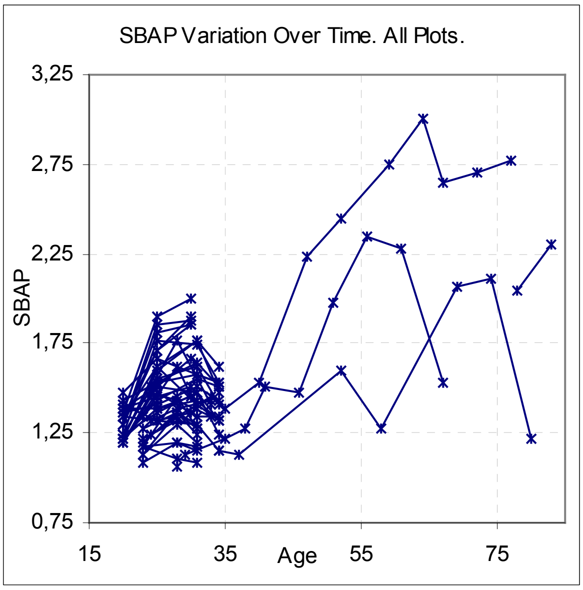


Figure 3: Variation of SBAP values over time for all plots. Points show individual SBAP estimates between thinnings. The plotted lines to the right of the graph represent single trial plots (e.g. Dgl 4, 27, 95 and 105) over the course of their history and show the greatest variation.

There was a weak correlation between site index (SI) and SBAP (R^2 = 0.529) indicating that increasing SBAP values may be expected on sites with higher levels of height growth. Although the correlation is weak, it is still much stronger than that in the Pacific Northwest (R^2 = 0.28), which itself is in line with findings in New Zealand and Great Britain (Knowles and Hansen, 2004).

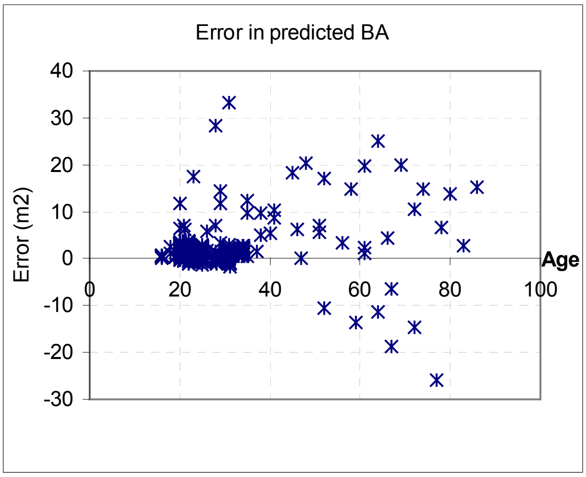


Figure 4: Basal area error vs. age

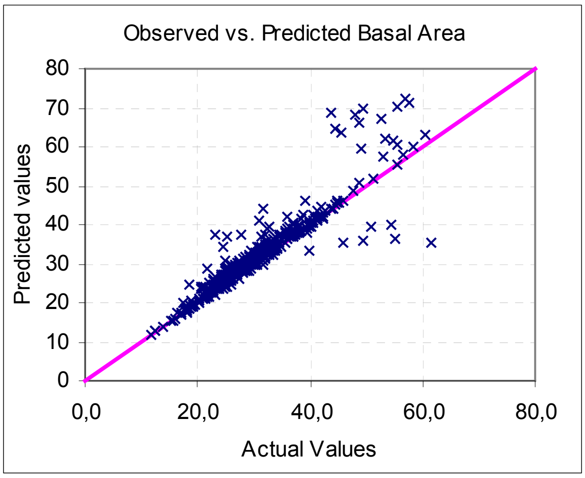
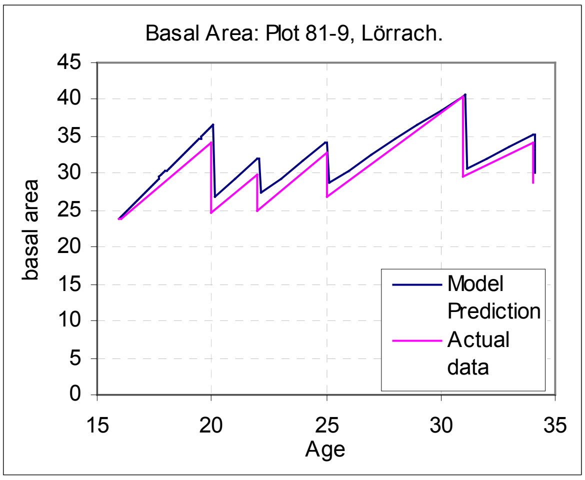


Figure 5: Basal area differences between observed and predicted values.

Figures 4 and 5 show the error values of predicted versus observed basal area. When compared to similar graphs for Mean Top Height (Figures 8 and 9) the graphs show a larger error and range. Nevertheless, the majority of values lie within an acceptable distance from the "0-error" line with typical values of +/- 5m^2. Common to both graphs however is the model's tendency to slightly over-predict basal area as the stand becomes older and/or contains more basal area. However, due to the small number of plot data it is difficult to determine the exact cause of this variation – especially as the scatter is both positive and negative.



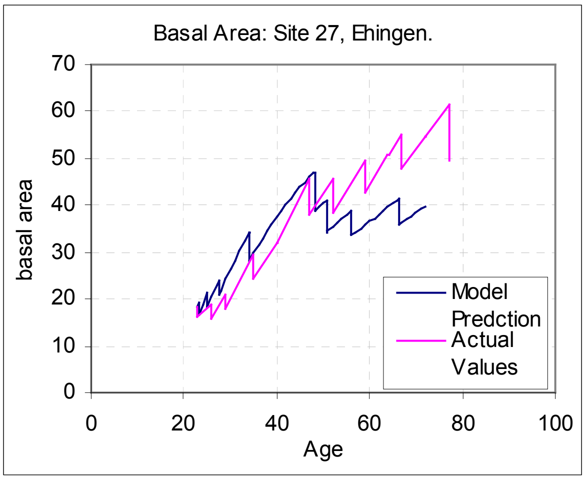


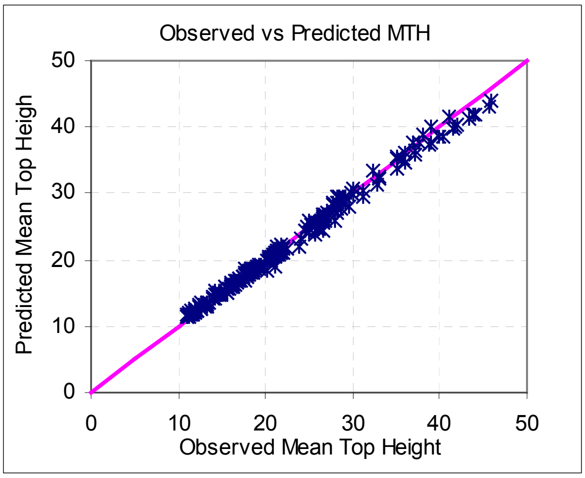
Figure 6: Example of basal area prediction a specifically established silvicultural trial: Plot 81-9, Lörrach.

Figure 7: Example of basal area in prediction for a single forest site trial: plot 27, Ehingen.

Figures 6 and 7 above show examples of the difference in accuracy of the model according to the type of trial. It is interesting to note that predictions for sites 81, 86 and 87 (trials specifically set up to test silviculture as apposed to single stands in normal forests) appear to be much more accurate than for the other, single stands (Figures 5 and 6 respectively).

<u>Height</u>

Comparing observed and predicted values for MTH along the range of ages found in the data showed a very convincing prediction by the New Zealand height-age curve (Figure 8). The majority of the predicted values lay between +/- 1.5m and overall showed little deviation from the shape of the curve, i.e. only a slightly greater error in predicted height values for young stands than in older stands (Figure 9).



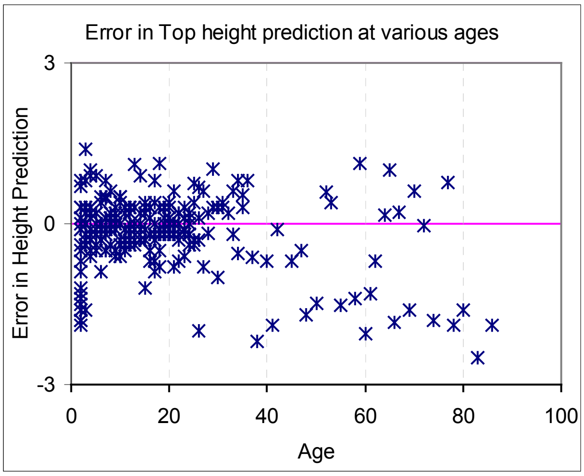


Figure 8: Height differences between observed and predicted values.

Figure 9: Deviation from actual data of predicted height values shown against age.

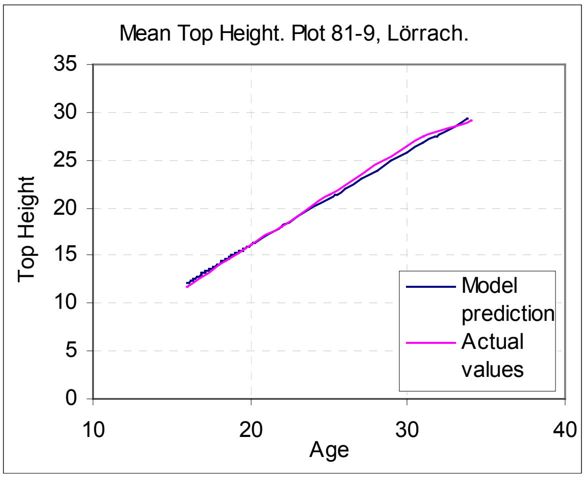


Figure 10: Example of top height prediction compared with actual top height data for a specifically established silviculture trial. Plot 81-9, Lörrach-

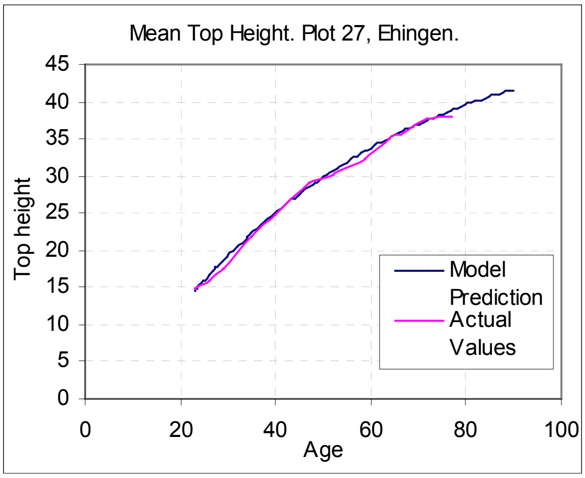


Figure 11: Example of top height compared with actual top height data from a single forest site trial. Plot 27, Ehingen.

Figures 10 and 11 above show that, unlike the basal area predictions, the top height predictions for both specifically established trials and single forest trials were equally good and furthermore that although the time scales are obviously different, the shapes of the curves fit well to actual height development. All plots illustrated here used a latitude value of 47.5^0 for calculating SI. That the height-age curve so closely fits that of the observed data shows that manipulation of the latitude value can indeed provide a simple and effective way of fitting the NZ height curves to external data.

We emphasize that the latitude value of 47.5^0 was only used in this exercise as it produced the best fit. Despite this, in terms of height development against age for a given site index, German data does appear to correspond approximately with Douglas-fir growth characteristics in New Zealand at similar latitudes. However, the NZ data covers a latitude range of 38^0 to 46^0, compared to 47.5^0-48.5^0 for Southwest Germany, so some extrapolation of the NZ ht/age function is necessary.

<u>Stocking</u>

Comparison of the stocking levels predicted by the model against the actual data showed quite clearly that the model was over predicting the level of mortality in managed German stands. Although the errors appeared rather small – around 2% of actual stocking per year – this error was strongest at higher stocking levels and could result in large numbers of trees being mistakenly classed as dead (see error vs. age graph). For example, at 4000 stems per hectare the mortality error is around 2.2% per year. If the thinning cycle is set at five years, this means a total error in stocking between thinnings of 11% or 440 stems per hectare.

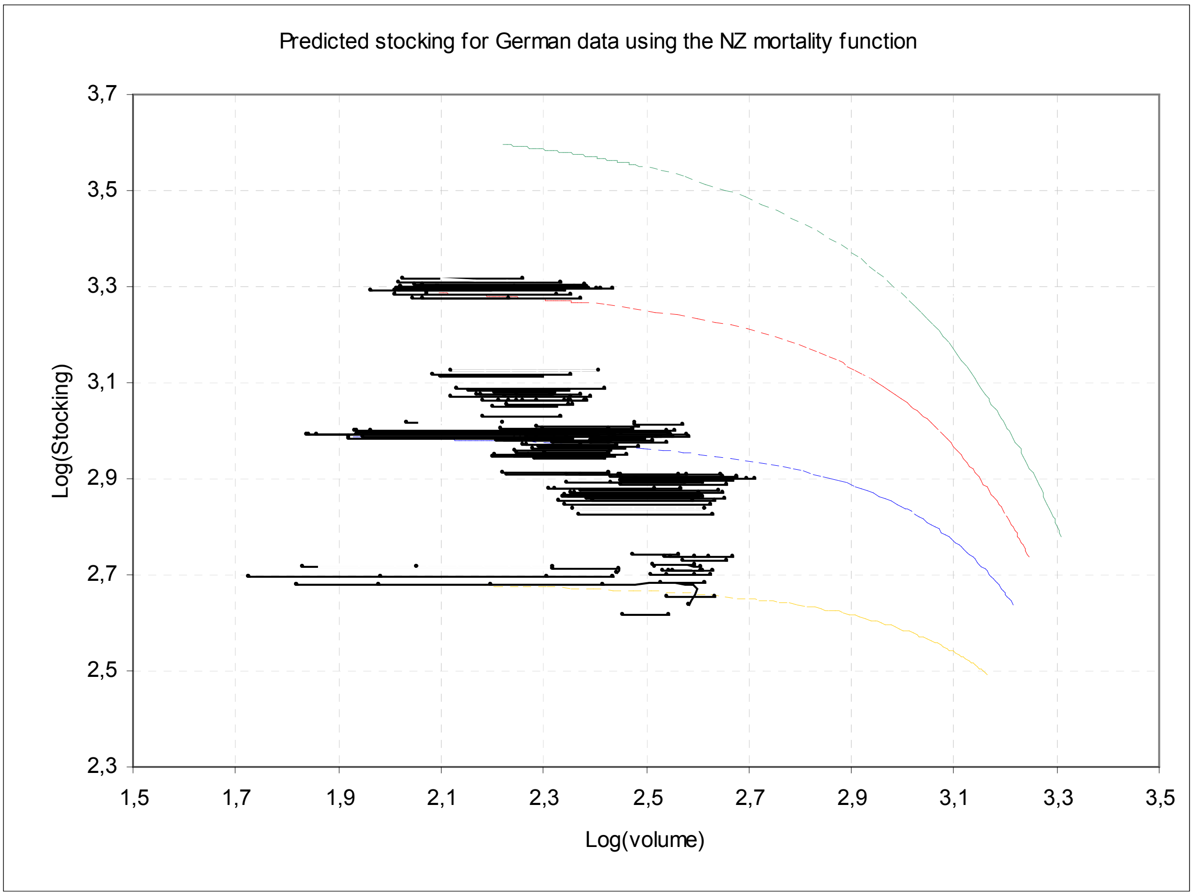


Figure 12: Observed (black lines) and predicted (coloured lines) stocking values for German data.

Figure 12 shows plotted logarithmic values of stocking and volume and shows that the model's prediction of attrition (the level of mortality leading up to the –3/2 self thinning line) is generally too great with actual data values lying above the predicted mortality lines. The black lines represent individual periods between thinnings and typically show very little loss of trees due to attrition. The model however, predicts for the same period of time at least some mortality (coloured dashed lines). If mortality were predicted correctly, the lines would move in unison. Due to this error it was deemed necessary to add an adjustment factor that would allow the model to accurately predict the level of mortality over time for managed German stands. This adjustment factor allows the user to determine to what extent the mortality effect should be reduced. The solid coloured lines in Figure 13 show the adjustment set at -95% of modelled mortality for four different stocking examples.

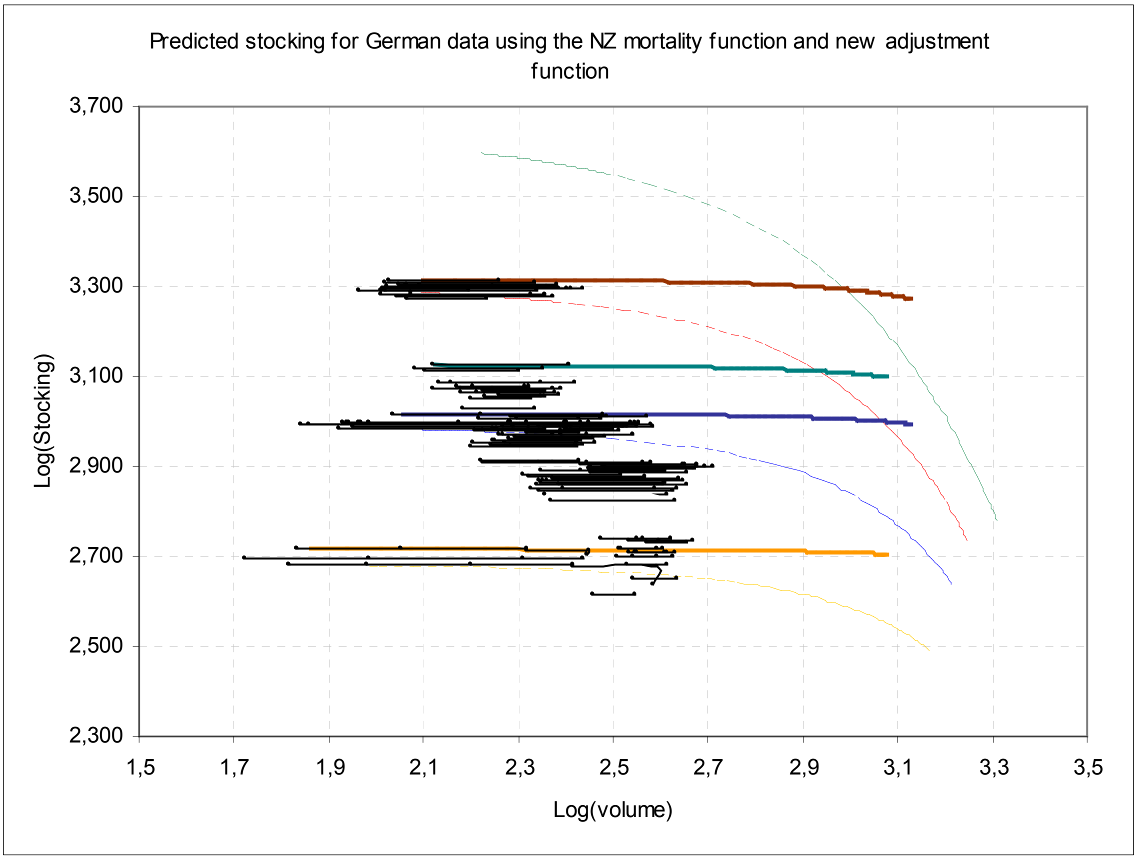


Figure 13: Adjusted mortality function applied to the graph in Figure 7. The adjustment level is set at –95%.

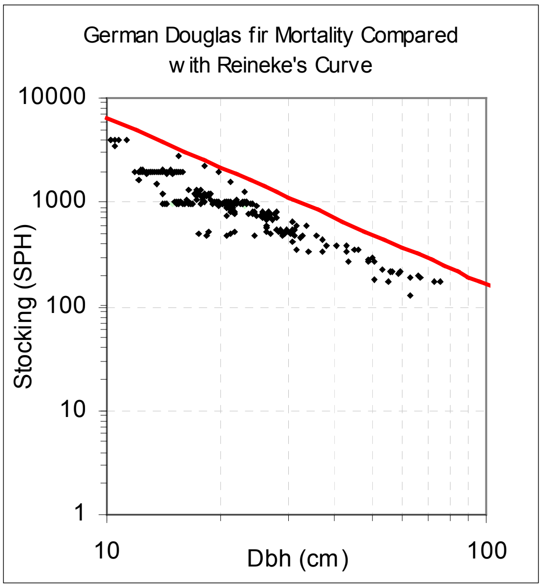


Figure 14: German data plotted against Reineke's curve.

Although the reduced attrition level corresponds well with the level of attrition between thinnings in the German stands, this function also drastically reduces the eventual effect of the -3/2 self-thinning rule and thus will not correspond to natural mortality in unthinned stands, which will eventually reach the carrying capacity of the site. Figure 14 shows that German data may correspond with the self-thinning rule since all plots are below Reineke's curve. It is therefore important to be aware of this when applying the adjustment factor in order to reduce the levels of attrition. This reduced level of attrition found in the observed data from Germany could be explained by the comparatively intensive thinning regimes implemented there as well as by the type of tree removed during thinnings. The average thinning coefficient for managed stands in Germany indicates a larger tree than would be removed during a thinning in New Zealand with a tendency towards crown-thinning (thinning from above) rather than thinning from below. This type of thinning, as well as repeated interventions in the stand, leaves the final crop trees with ample space for development and growth and could be seen as pre-empting mortality. As seen in Figures 12, 13, and 14, the growth of the thinned German plots rarely, if ever, reaches the natural mortality line where more rapid stocking reduction through mortality could be expected. Instead, the stands are thinned which moves the plotted lines down the graph and further away from the mortality frontier. It is acknowledged that the current rate of timber production in Germany is about 30 –50% lower than the possible sustainable yield (Kenk, 1989) and it can be shown that the stands in Germany do not reach their full potential since the trees could effectively grow on longer than is possible with the present management. To strive for a change in this situation however, would ignore the aims and objectives of forest management in Germany, which endeavours to create a diverse age and species structure within the stand.

Volume

As mentioned previously, volume is a function of the three parameters basal area, mean top height and stocking. Based on the relative accuracy of these three parameters as shown above, one could reasonably expect a relatively accurate volume prediction using DF NAT. However, using DF NAT in its current form consistently showed that volume predictions contained a bias and were lower than the actual observed volumes within the data set (see figures 15 and 16 below).

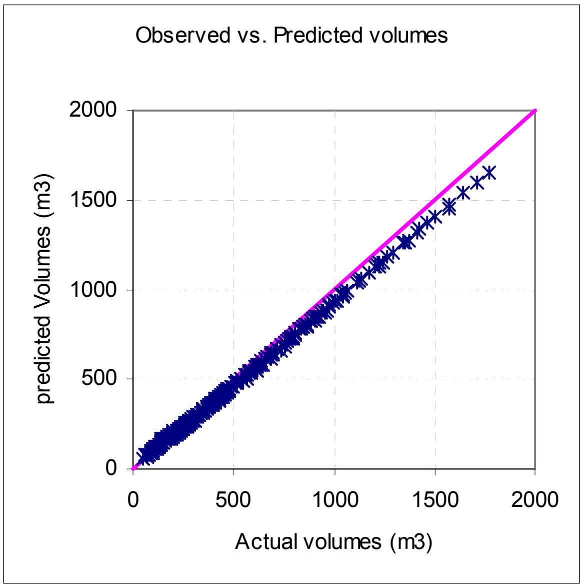


Figure 15: Observed vs. Predicted volumes (m^3) using DF NAT and original coefficients

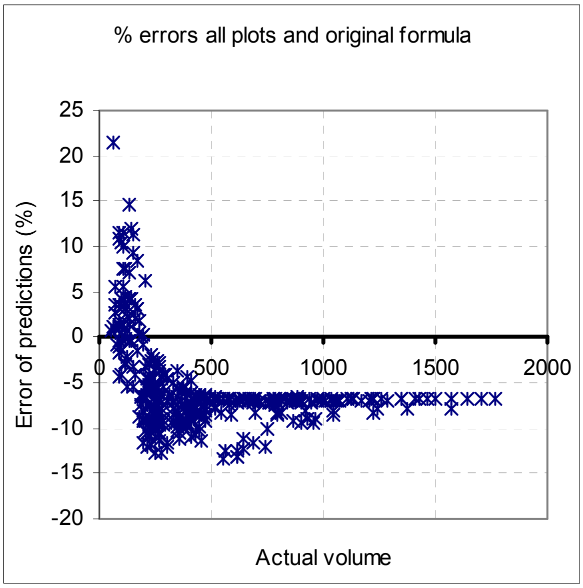


Figure 16: Percent deviations of predicted volume from observed volume (m^3) using DF NAT and original coefficients

Using the ‘Solver’ function in EXCEL to minimise the root mean square of residuals, the original coefficients were refitted for the DF NAT formula, which enabled a tighter fit between predicted and observed values (see figures 17 and 18 below) without significant bias. The RMSR value in this case improved from 40.72m^3 average error to 9.54m^3. Average percentage RMSR errors improved from 7.55% to 4.37%.

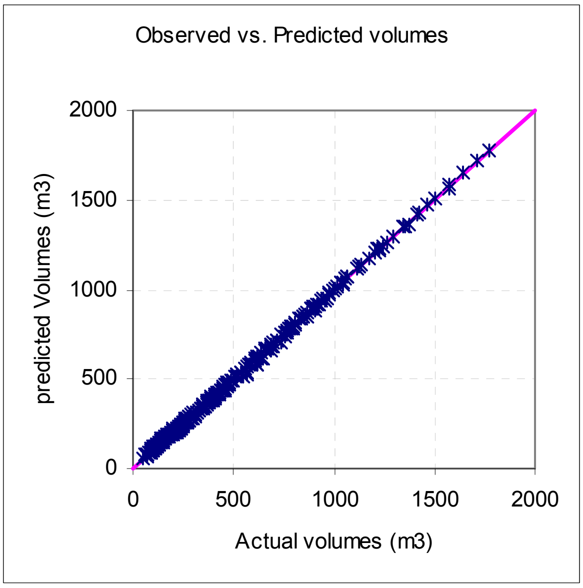


Figure 17: Observed vs. Predicted volumes (m^3) using DF NAT and refitted coefficients

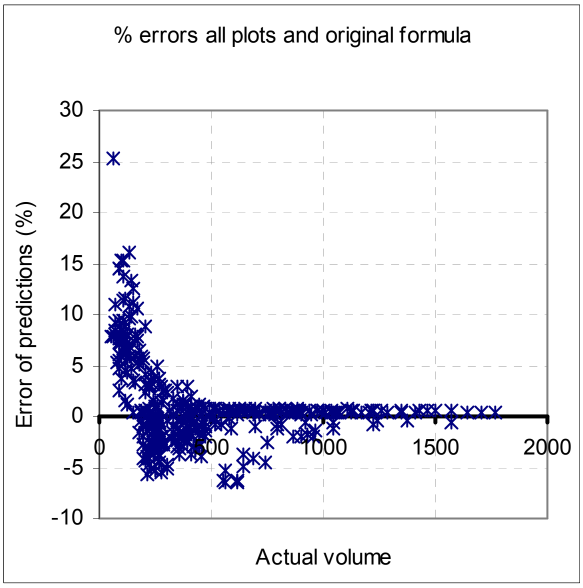


Figure 18: Percent deviations of predicted volume from observed volume (m^3) using DF NAT and refitted coefficients

The volume formula as developed by Beekhuis (1966) is a simpler form of the one contained at present within DF NAT containing only two coefficients as apposed to three. The other formulae tested here represented increasing levels of complexity and their relative levels of accuracy as well as the coefficients used are shown in table 3 below. In all cases the coefficients were refitted to the German data set.

Table 3. Accuracy of various volume formulae using RMSR for cubic metres (m3) and percent deviation from observed volumes.

Volume model	Root mean square of residuals – Combined (m^3)	Deviation from observed volume as % of observed volume	Coefficients used
Original DF NAT	40.715	7.552	a = 0.8502 b = 0.33337 c = 0.000473
Beekhuis	9.659	4.585	a = 0.86322674 b = 0.35922121
Refitted DF NAT	9.543	4.373	a = 1.099298 b = 0.354812 c = -0.00024
'NZ1'	7.199	3.210	a = 0.101311684 b = 0.417157649 c = -0.565940961 d = -0.000118419

New formula	6.791	3.368	a = -1.69578988 b = -0.11719656 c = 1.08575739 d = 0.3264207 e = -0.00850067 f = -0.08485367 g = -0.05839778 h = -0.01010231

For the continuing assessment of DF NAT with German data the third volume formula, NZ1, was installed into DF NAT. This formula improves the accuracy of DF NAT's volume predictions (compare with DF NAT's original formula) whilst avoiding unnecessary complexity, which itself is no guarantee of significantly increased accuracy as can be seen when comparing the outcomes of the two formulae NZ1 and the new formula in table 3 above). Here, a noticeable increase in complexity (new formula) yields only a small increase in accuracy (RMSR) over the previous formula (NZ1).

500 Index

The lower SBAP and SI values found in Germany compared to NZ were confirmed by the 500 Index calculations, which are presented in Table 2. Results returned an average 500 Index of 15.44 and were thus below the average 500 Index calculated for NZ at 18.4. Results of the 500 Index for the different German sites can be found in table 2 above.

The creation of a Z-Baum index allows MAI to be calculated for German Douglas-fir stands using SBAP and SI in the following equation:

$$\text{Z-Baum Index} = 1.35 * SI^{0.66} * SBAP^{0.99}$$

The results of this index correspond closely (R^2= 0.9999) to the MAI of a Douglas-fir stand aged 80 years managed according to current German silvicultural practices.

Conclusion

This study shows that the NZ Douglas-fir growth model DF NAT can be successfully applied to external data from very different situations from that in which it was developed. After simple preliminary calibration of the model for SI and SBAP the model proved to be capable of providing useful growth predictions for forest stands in Southwest Germany. The model's prediction for mean top height showed a convincing fit to the actual data simply by calculating and applying an appropriate latitude value that changes the curve shape. Although the height predictions in this study appear to be very good, it should be noted that most of the data used here is comparatively young when compared to the typically long rotations in Germany. In order to accurately assess the height-age function for all rotation ages in Germany, many more sample plot data sets covering an age range up to 120 –140 years would have to be used.

Basal area predictions, although providing a reasonable estimate of actual values, do seem to show significant errors when compared to data from stands older than 35 - 40 years. Deviations between observed and predicted basal area values were typically greatest in stands that have not been established specifically as part of a silviculture trial. This could be due to inconsistent management regimes over the last century and the absence of a fixed management regime. This inaccuracy is however limited to only five plots of the 44 observed here. Plots and sites managed in a consistent manner showed much less variation in basal area prediction. Once again, it should be noted that the accuracy of predictions for older stands is of great interest to German foresters and that for such an assessment more data sets would have to be made available.

The addition of an adjustment to the mortality function allowed the model to cope with greatly reduced levels of attrition found in Germany, although care should be exercised with this function for unthinned or lightly thinned stands as it defies the underlying logic of Reineke's self-thinning rule. Where regular thinning of the stand takes place, this adjustment factor can in all likelihood be used without infringing on the models accuracy. Problems with the adjustment factor are only likely to occur when the stands naturally reach the self-thinning line, i.e. in unthinned or highly stocked stands.

Improved prediction of volume at the stand level was achieved by using a slightly more complex model form (S38 compared to S36) and by fitting new coefficients. An error in volume prediction of around 8% was thus removed.

During the study large differences between the silvicultural techniques of the two countries have also come to light. Using the thinning coefficients one can see that there is generally a tendency to remove larger trees during thinning in Germany, i.e. a crown thinning, when compared to the New Zealand situation. The level of stocking and reduced level of mortality in the German data is another difference between the two countries. One could argue that the carrying capacities of the sites in Germany are not being used to their full potential, as may be the case in New Zealand. Although the differences in silviculture between the two countries have many and diverse causes, a study of this nature provides a useful and interesting insight into the relative advantages and disadvantages of the applied silvicultural techniques.

Further work to be undertaken as part of this project includes a sensitivity analysis of the key parameters used for calibrating the model such as basal area and mean top height. This should enable users of the model to determine how accurate any initial measurements need to be and what effects inaccuracy at this early data collection stage could have on the model's predictions.

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