Validation of the New Zealand National Douglas-fir growth model (DF NAT)

R.L. Knowles, L. Wichmann-Hansen

NZ Douglas-fir Cooperative

Report No. 54, February 2007

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ABSTRACT

The New Zealand National growth model for Douglas-fir (DFNAT) was validated against empirical growth data from 242 sample plots, with particularly emphasis on the effect of silviculture on site index and SBAP.

The results showed that there is little or no effect of silviculture on site index. The basal area growth index (SBAP), however, showed some bias (reduced growth) in the three years immediately following thinning. The reduction may be explained as a thinning-shock in excess of what has currently been modelled via the reduction in green crown-length.

A negative exponential function to reduce the SBAP in periods following thinning was proposed and tested. The results were positive both visually and in reducing the unexplained variance in periodic SBAP by 9.2 %. The thinning-shock correction function was subsequently implemented in the Douglas-fir Calculator.

The new functionality in the Douglas-fir calculator will have one major effect on existing knowledge; namely, all previous estimates of SBAP based on stand data from thinned stands may be slightly under-predicted. SBAPs estimates from unthinned stands have not changed. An updated table showing SBAP's for all sample plots by forest and region will be produced.

INTRODUCTION

The New Zealand national growth model for Douglas-fir (DFNAT) (Knowles and Hansen 2004), as implemented in the Douglas-fir Calculator version 2 (Knowles *et al.* 2003), is based on growth data from the permanent sample plot (PSP) database of New Zealand Forest Research Institute Ltd. (Ellis and Hayes 1997). In 2002, all relevant data in the database was used for the re-estimation of model parameters, and the upgraded model was released (Knowles and Hansen, 2004).

The model, in slightly altered forms, has been validated against growth data from the United Kingdom (*upub.*), Pacific Northwest (Knowles and Hansen 2004), and Germany (Bromley and Knowles 2005). These studies gave ample evidence that the model and model-form is performing well and with light modification could be applied outside its originally intended range. However, one important issue remains: Because very little systematic growth data for D-fir is available in New Zealand, apart from the PSP system, it has been virtually impossible to validate the growth model against any major New Zealand data sets since its last release.

One of the main tasks of validation that remains is whether the SBAP (site basal area potential - a growth index for basal area growth) is a consistent and reliable measure of site productivity. There is little doubt that in technical terms the SBAP serves the purpose of a growth index for basal area growth. It has, however, not been verified whether the SBAP is stable over time and independent of silviculture when compared to New Zealand datasets. New data is collected on an annual basis for the PSP system (Ellis and Hayes *op.cit.*), which includes a series of silvicultural trials. Hence, a range of data that was not used in the previous calibration/estimation of the model is now available.

Flewelling *et al.* (2001) showed that changes in stocking influenced the site index, a finding that was confirmed by Knowles and Hansen (2004) when they analysed PNW data. Furthermore, a new New Zealand height/age model, which incorporates latitude, has been published and implemented as an intrinsic part of the DFNAT growth model (van der Colff and Knowles 2004). Hence, another task of a validation exercise is to see if site index is independent of silviculture.

The purpose of this study is therefore two-fold: 1) to examine if the growth indices SBAP and site index are independent of stand age and silviculture, and 2) if any significant discrepancies are found, then propose and implement corrections to counter them.

METHODS AND MATERIALS

The data originates from a series of remeasured plots/trials in the PSP system. A total of 3,291 measurements of stand conditions (e.g. age, dbh, height, basal area, stocking, and crown height), from 242 different sample plots located on 16 different sites around New Zealand (Figure 1). The plots range in age from 11 to 73 years on sites with site index from 25-40 m (mean top height at age 40 years), and SBAP from 0.5 to 3.6 (m^2/ha/yr).

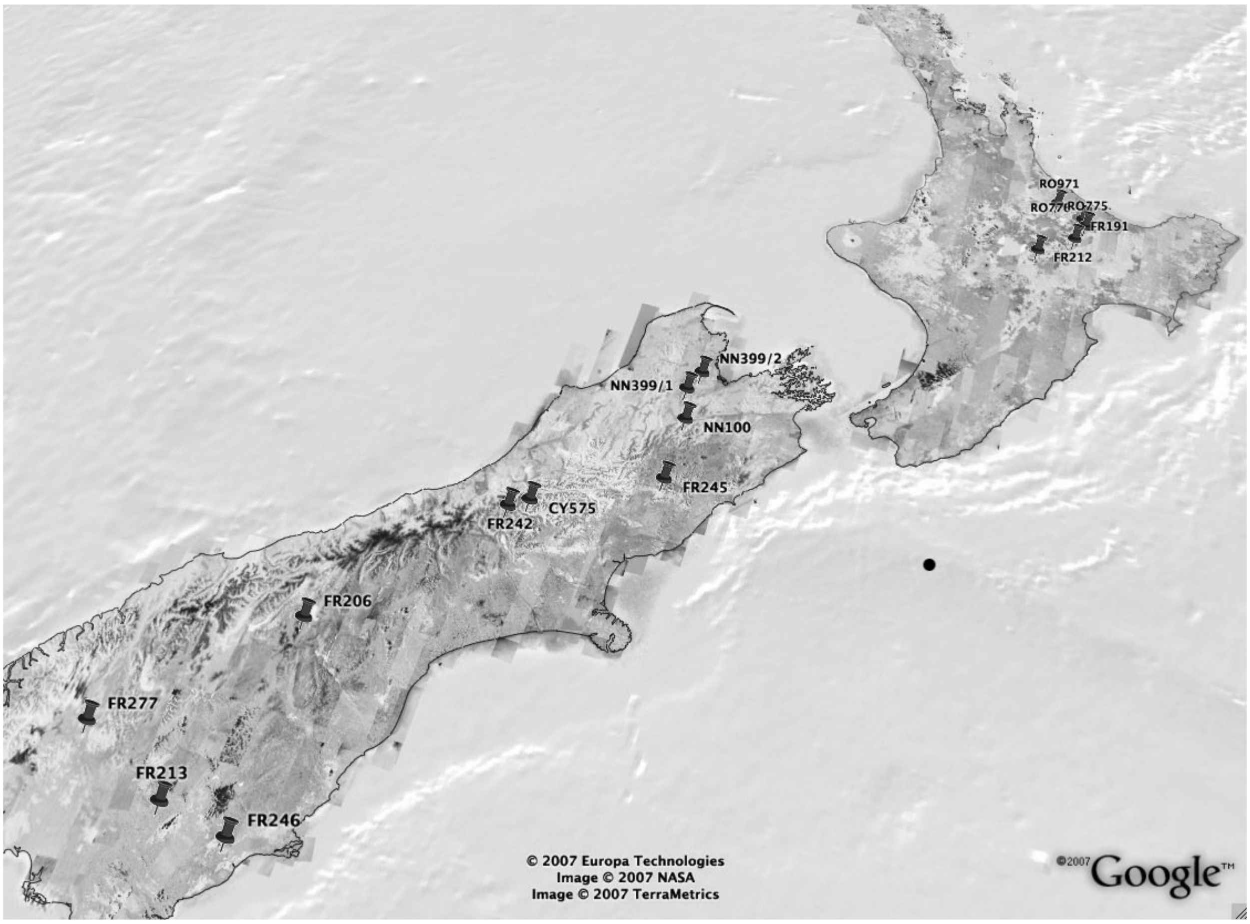

Figure 1. Location of plots/trials

The basal area increment in DFNAT is modelled by:

$$BAI = BA_0 + SBAP*crown*age*competition*(T_1\text{-}T_0)$$

Where *BAI* is basal area increment for the period T_0 to T_1, BA_0 is the basal area before the period and *crown*, *age* and *competition* are terms related to the sum of crown lengths/ha, stand age and stand competition, respectively. *SBAP* is a constant, which describes the stands ability to grow basal area.

For each individual plot, the SBAP was estimated for the period between two consecutive measurements (periodic SBAP). The estimation procedure used an iterative approach (binary search, as implemented in the Douglas-fir Calculator Version 2 (Knowles *et al.* 2003) to estimate the SBAP (to three decimal points). The periodic SBAP was estimated as the value which made the growth model predict the exact measured basal area at the second measurement, given the stand conditions at the first measurement as the starting point (i.e. stocking, basal area, height, crown-height, thinning history etc).

The above periodic SBAP estimation procedure was repeated for all plots and measurement periods, and the SBAP was recorded along with age, time between measurements, stocking and thinning history (thinned basal area and time since thinning). The data provided a total of 2,862 periods for which an SBAP could be estimated, and 1,764 of those were from plots that had received a thinning. Plots that had received green crown pruning were excluded from the analysis.

Plot mean SBAP was calculated as the period-weighted (time-weighted) mean SBAP, i.e. SBAP calculated for longer periods weighted more than those calculated for short periods.

The site index for each measurement occasion was estimated from the site index equation by Van der Colff and Knowles (2004), using the measured mean top height (meter), stand age (years) and latitude (degrees).

The complete record of SBAP and site index was analysed for all plots using analysis of variance (Rudemo 1979, Faraway 2002). Calculations were performed by the functions "*aov*" and "*anova*" of R - a statistical computing package (Faraway 2002, R Development Core Team 2007).

General descriptions of models employed are:

SBAP = c + var_1 + var_2 + ... var_n + e

SI = c + var_1 + var_2 + ... var_n + e

Where *c* is a constant, *e* is a Gauss distributed error term with zero mean and some variance, and the independent variables: *var1 ... var_n* are:

1. Site is a class variable for each site
2. Plot is a class variable for each plot within a site
3. Age of the stand at the time of SBAP estimation (years)
4. Period of time between measurements (years)
5. Stocking at the beginning of a period (stems/ha)
6. Mean tree height at the beginning of a period (m)
7. Stand basal area at the beginning of a period (m^2/ha)
8. Thinning ratio (basal area before thinning divided by basal area after thinning)
9. Time since last thinning (years)

Following the initial analysis of variance, each model was subject to backwards reduction of the independent variables to create reduced models with only highly significant variables.

To illustrate the statistical observations from the analysis of variance, a series of plots were produced. These depict the deviation of periodic SBAP from stand mean SBAP under various conditions: 1) as a function of time since thinning, 2) as a distribution for the first three years following a thinning, and 3) an example from one particular trial.

RESULTS

The analysis of variance for the full model for SBAP is presented in Table 1. From this it is evident that there are very significant effects of Site, Plot, Age, Stocking, and Thinning ratio on SBAP. The effects of Height, Basal area, and Time since thinning are also significant, but their explanatory power is less. The only insignificant variable in the full model is Period (length of time between measurements).

The reduced model is presented in Table 2. From this it may be seen that leaving out the least significant variables: Period, Time since thinning, Height and Basal area, increase the sum of squares for the residuals by 7 (or 4.2%), and reduces the r-squared by 0.01. Hence, those four variables seem to have only little influence on the stand mean SBAP despite being statistically significant.

Table 1: Analysis of variance table for the full SBAP model (adjusted r-squared = 0.70)

Variable	DF	Sum sq.	Mean sq.	F value	Pr (>F)
Site	15	285.879	19.059	301.1343	< 2.2E-16 ***
Plot	241	104.400	0.433	6.8447	< 2.2E-16 ***
Age	1	27.232	27.232	430.2833	< 2.2E-16 ***
Period	1	0.003	0.003	0.0539	0.816396
SPH	1	15.855	15.855	250.5149	< 2.2E-16 ***
Height	1	1.045	1.045	16.5111	4.98E-05 ***
Basal area	1	0.488	0.488	7.7129	0.005522 **
Thin ratio	1	7.867	7.867	124.3032	< 2.2E-16 ***
T since thin	1	0.461	0.461	7.2856	0.006996 **
Residuals	2590	163.919	0.063		

Table 2: Analysis of variance for the backwards reduced SBAP model (adjusted r-squared = 0.69)

Variable	DF	Sum sq.	Mean sq.	F value	Pr (>F)
Site	15	285.411	19.027	292.1118	< 2.2E-16 ***
Plot	241	102.272	0.424	6.4748	< 2.2E-16 ***
Age	1	29.539	29.539	450.6965	< 2.2E-16 ***
SPH	1	15.743	15.743	240.2013	< 2.2E-16 ***
Thin ratio	1	7.489	7.489	114.2710	< 2.2E-16 ***
Residuals	2602	170.537	0.066		

The analysis of variance for site index is presented in (full model) and Table 4 (reduced model). From these it is apparent that Site and Plot explain most of the variation in site index in the data. Other variables are significant, however, once the non-significant variables are eliminated - in the backward elimination procedure - most of the previously significant variables become insignificant. The reduced model contains Site and Plot only (Table 4).

Table 3: Analysis of variance table for the full site index model (adjusted r-squared = 0.90)

Variable	DF	Sum sq.	Mean sq.	F value	Pr (>F)
Site	15	12083.5	805.6	1141.1954	< 2.2E-16 ***
Plot	241	5487.8	22.8	32.2582	< 2.2E-16 ***
Age	1	3.8	3.8	5.4393	0.01976 *
Period	1	2.4	2.4	3.3523	0.06723
SPH	1	90.7	90.7	128.4877	< 2.2E-16 ***
Height	1	115.6	115.6	163.7331	< 2.2E-16 ***
Basal area	1	90	90	127.4908	< 2.2E-16 ***
Thin ratio	1	3.7	3.7	5.1852	0.2286 *
T since thin	1	12.2	12.2	17.2851	3.322E-05 ***
Residuals	2590	1828.3	0.7		

Table 4: Analysis of variance for the backwards reduced site index model (adjusted r-squared = 0.88)

Variable	DF	Sum sq.	Mean sq.	F value	Pr (>F)
Site	15	12039.5	802.6	947.450	< 2.2E-16 ***
Plot	241	5504.4	22.8	26.961	< 2.2E-16 ***
Residuals	2605	2206.8	0.8		

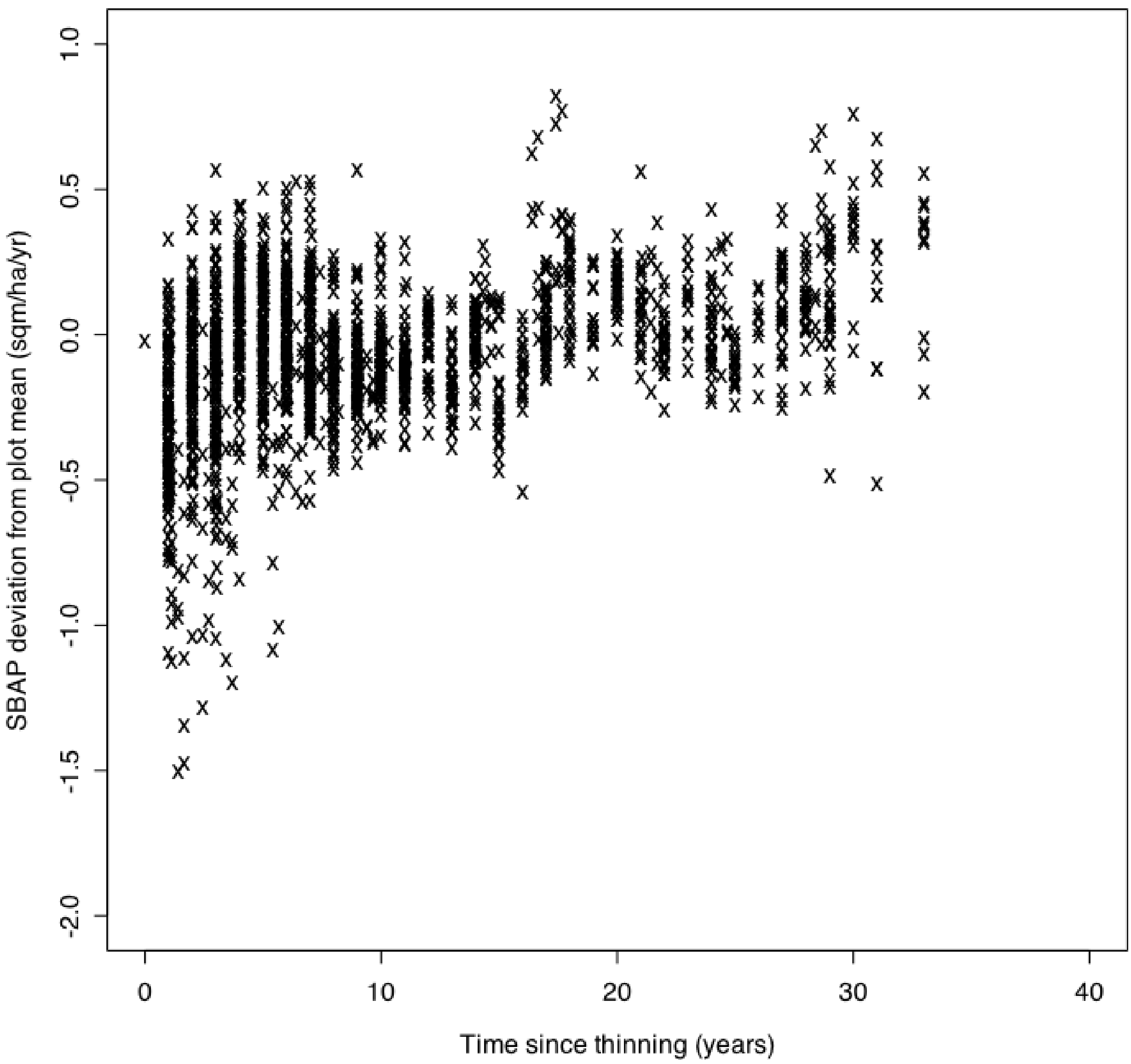

Figure 2. Deviation of periodic SBAP from stand mean SBAP plotted against time since last thinning.

In Figure 2 the deviation of periodic SBAP from the stand mean is plotted versus time since thinning. From this it is apparent that the deviations show a tail towards negative deviations 0 to 3 years following a thinning. Once past three years after thinning the deviation from stand period-weighted mean SBAP is more normal. This is further illustrated in Figure 3, where it is apparent that the distribution of deviation from stand mean SBAP for the first three years following a thinning is clearly skewed towards negative values. The overall distribution is very close to normal with a mean of -0.038 and a variance of 0.07.

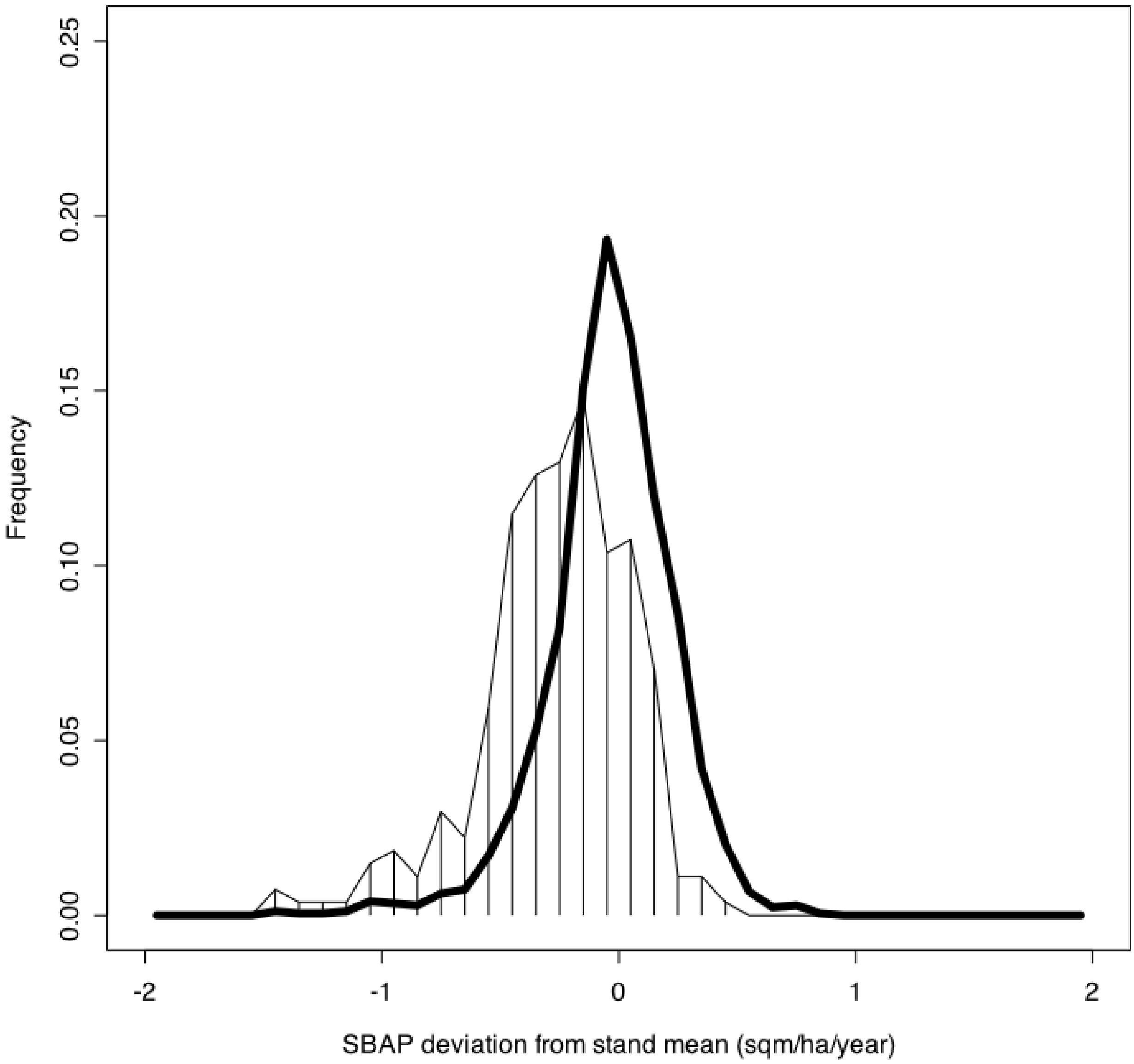

Figure 3. Periodic SBAP deviation from stand mean SBAP for the first three years following a thinning (striped) and overall (bold line).

Figure 4 is an example of the periodic SBAP for a range of plots in the silvicultural trial NN399 located in Compartment 214, Golden Downs. The trial consists of plots with different thinning intensities, leaving the stand either unthinned, with 750, 500 or 250 stems per hectare at age 20 years (all stands thinned just before first measurement). It may be observed from Figure 4 that the stronger the thinning, the more pronounced the drift in SBAP with stand age (e.g. linear regressions = dashed line). However, from the moving average SBAP (solid lines) it is evident that the drift in SBAP seems to level off with time since thinning.

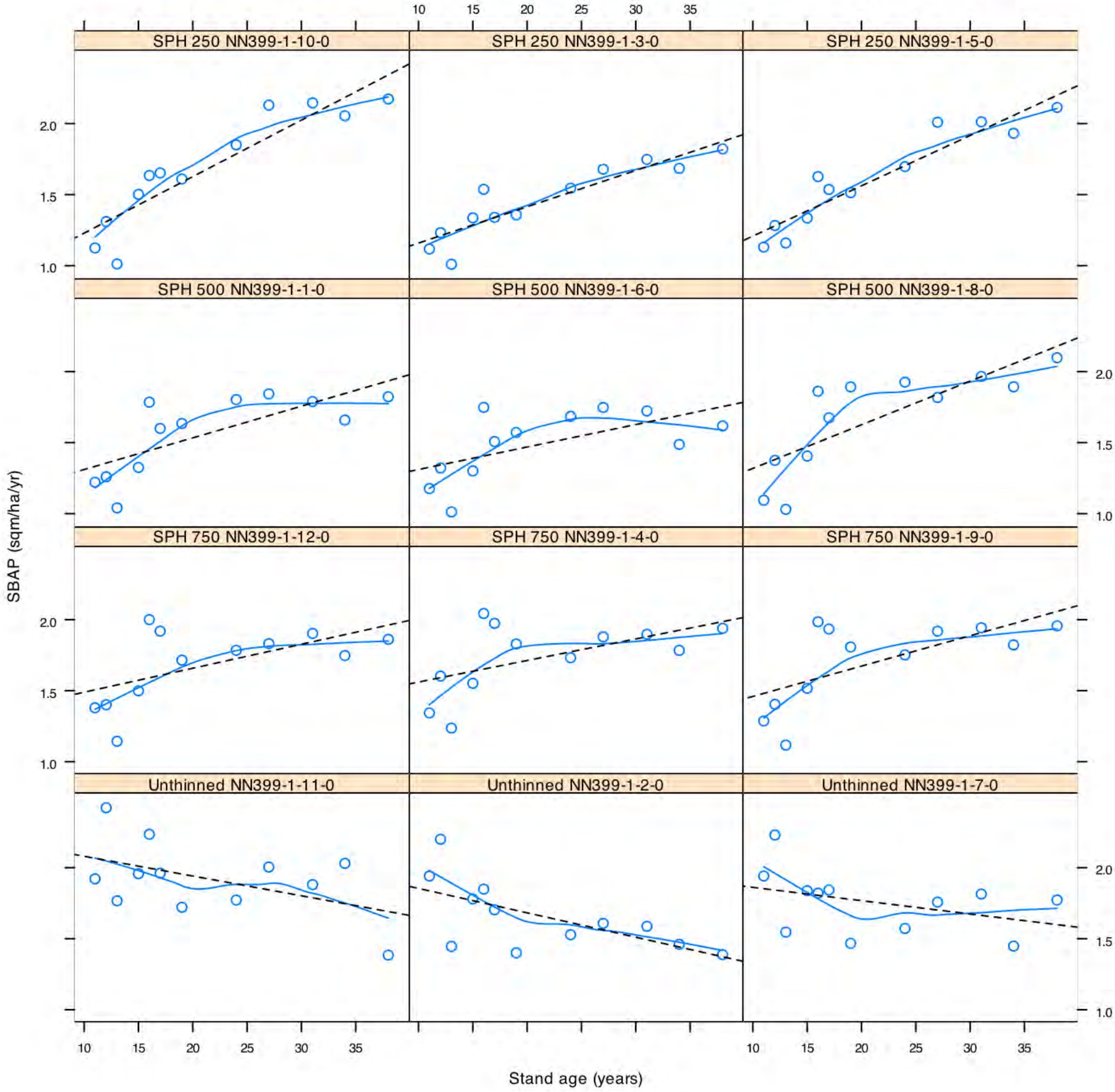

Figure 4. Example of drift in periodic SBAP with stand age following a thinning for silvicultural trial NN399, Golden Downs

DISCUSSION

The analysis of variance with respect to site index reveals that the least significant variable in explaining the variation in site index is period length followed by thinning ratio, stand age and time since thinning. Furthermore, in the reduced model only Site and Plot were significant, and no other stand variables had any significant effect. This result - unlike the findings of Flewelling *et al.* (2001) for Douglas-fir in the PNW - clearly confirms existing knowledge (e.g. Avery and Burkhart 2001) that site index is largely independent of silviculture.

The analyses of SBAP (Table 1 and Table 2, and Figure 2 - Figure 4), however, reveal that there is an effect of thinning on periodic SBAP. In the three years following a thinning there is, for some stands (particularly NN399, RO698 and FR277), a clear reduction in the periodic SBAP. This reduction may be interpreted in ecological/biological terms as a form of thinning-shock in excess of what is already incorporated into the model by modeling increment based partly on the green crown length of the stand (which is reduced when the stand is thinned).

The above hypothesis (thinning-shock) is in accordance with the observation that the reduction in SBAP is temporary, and after a number of years the deviation from the stand mean SBAP is again normally distributed with a mean of close to zero (e.g. around age 4-8 years in Figure 2). In conclusion, a thinning operation may reduce the stand's ability to grow to a point below its full ecological potential. However, after a few years of recuperation the stand is again able to grow normally. Consequently, there is a need for improving the existing growth model to take the temporary thinning-shock into account.

The following exponential function was applied to model a temporary and time-dependent reduction in SBAP:

$$SBAP = SBAP * (1-k_1*\exp(-k_2*T_t)) \quad \text{for } T_t < 10 \text{ years.}$$

Where k_1 and k_2 are parameters and T_t is the time since the last thinning. The functional form was fitted to the data (periodic SBAP deviations from stand mean SBAP as a function of time since thinning) using the function 'nlm' of R. This gave the parameters: $k_1 = 0.31$ and $k_2 = 0.27$. The idea in the proposed thinning-shock correction is the following: A stands ability to grow is reduced in the period immediately following a thinning. SBAP is a measure of the stands ability to grow, thus, a reduction in SBAP would mimic the observed reduction. However, the reduction itself also reduces in time since thinning, so once past 4-5 years the SBAP is back to its original level.

The reduction function was implemented in the Douglas-fir Calculator, and the periodic SBAP re-estimated for all data. The results are presented in Figure 5 - Figure 7. The graphs in Figure 5 show the periodic deviation from stand mean SBAP plotted against time since thinning, after the correction for thinning-shock. From a comparison to Figure 2 it may be observed that the thinning-shock reduction has indeed removed a significant proportion of the skewness for the years immediately following a thinning. This is even more apparent from a comparison of Figure 2 and Figure 6, where the distribution of deviations 0-3 years from thinning is clearly much closer to normal than they were previously. Also the example from the silvicultural trial NN399 in Figure 4 and Figure 7 shows a clear effect of the thinning-shock reduction, e.g. quite marked for 500 SPH, NN399-1-6-0. Finally, the corrected model showed a sum of deviations squared of 113.90, as compared to 125.33 for the original model – or the equivalent of a 9.2 % reduction in SBAP deviation.

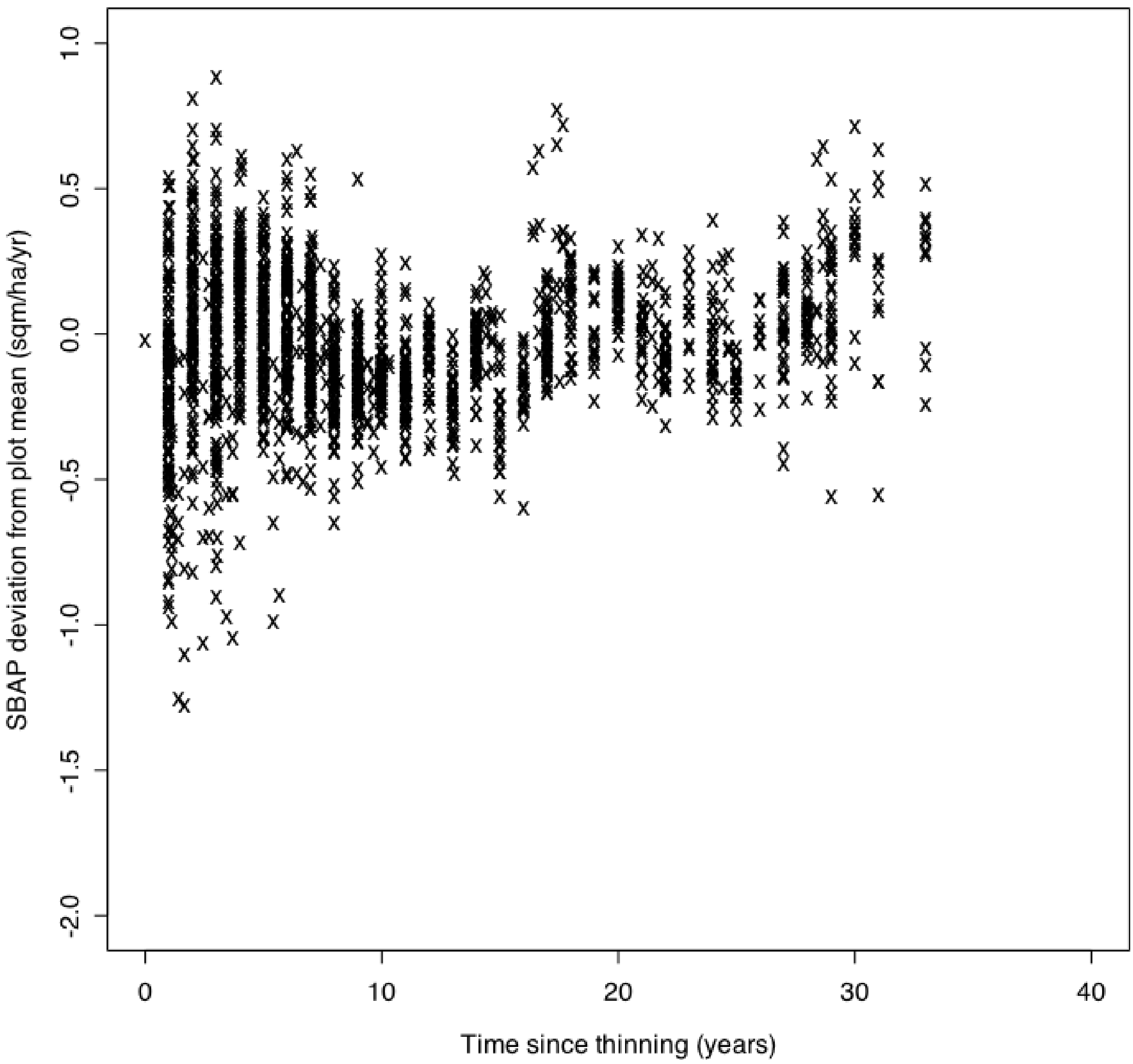

Figure 5. The periodic deviations from stand mean SBAP plotted against time since thinning using the corrected model.

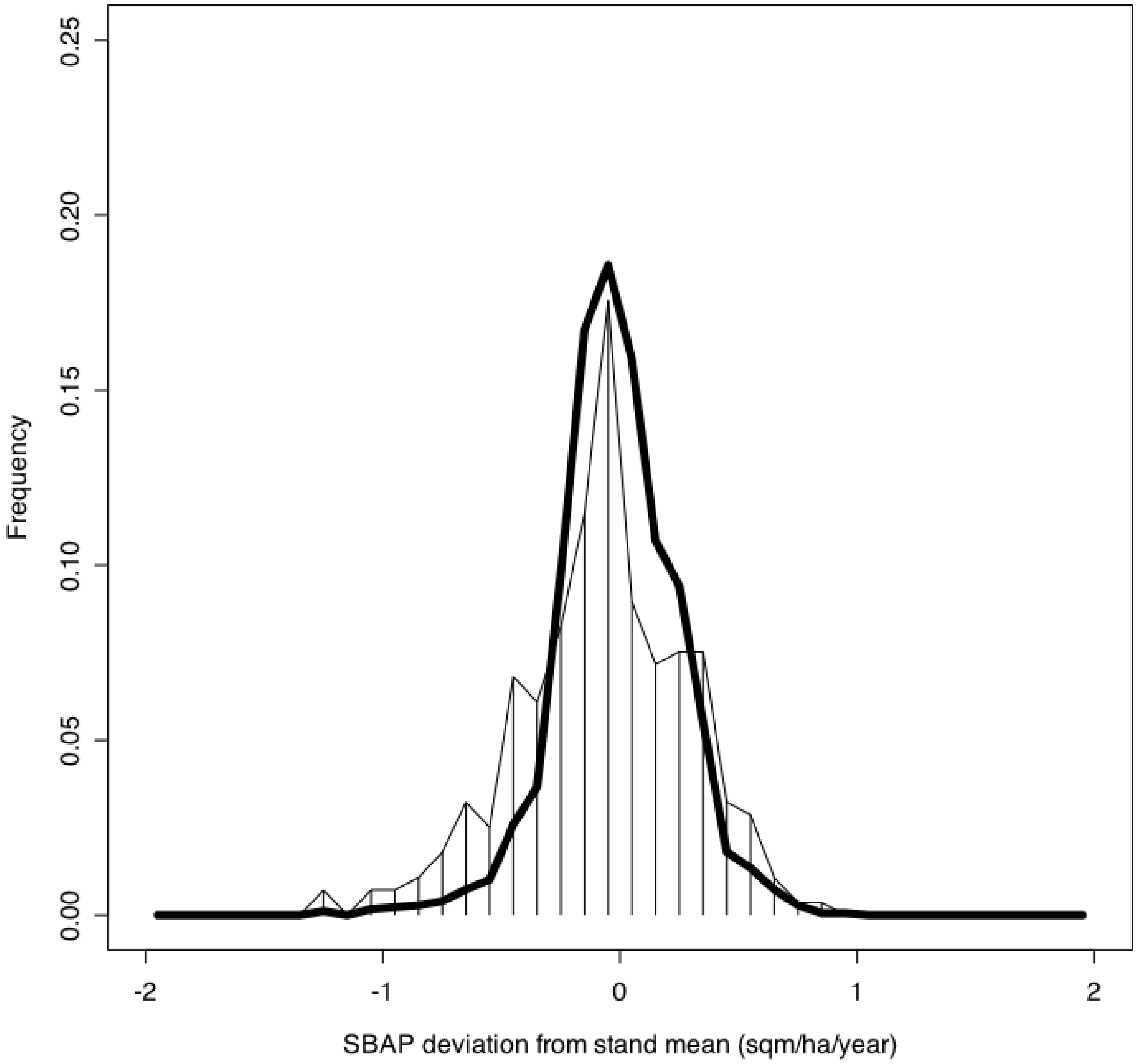

Figure 6. Distribution of periodic deviations from stand mean SBAP after inclusion of the thinning-shock reduction, for 0-3 years following thinning (striped) and overall (bold line).

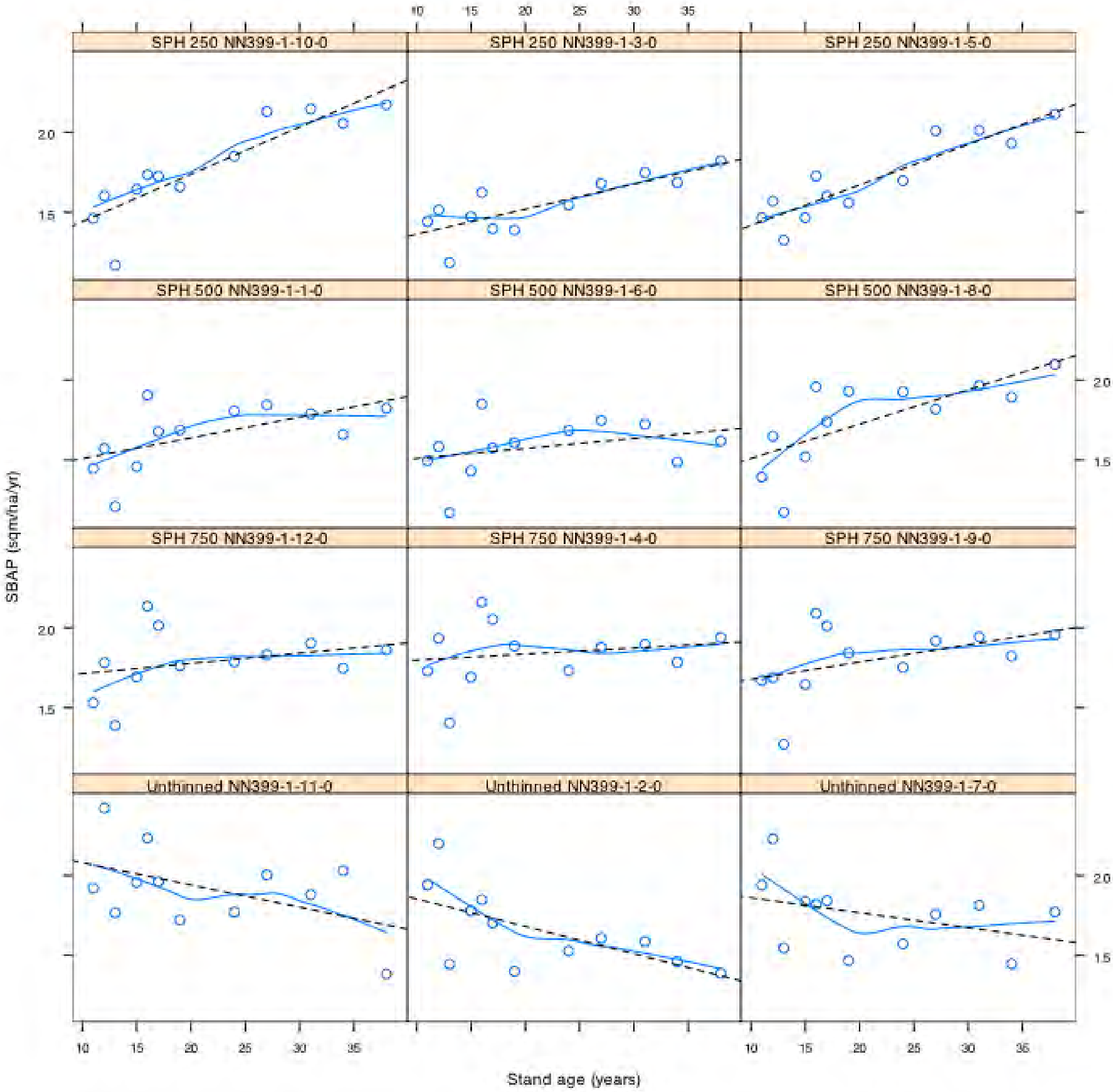

Figure 7. Periodic SBAP deviation from stand mean SBAP for silvicultural trial NN399 after correction for thinning-shock.

CONCLUSION

The analyses clearly showed that there was little or no effect of silviculture on site index. The basal area growth index (SBAP), however, showed some bias (reduced growth) in years immediately following thinning. The reduction may be explained as a sort of thinning-shock in excess of what has currently been modelled via a reduction in green crown-length.

A correction for the growth-reduction discrepancy using a negative exponential function to reduce the SBAP in periods following thinning was proposed and tested. The results were positive both visually and in reducing the unexplained variance in periodic SBAP by 9.2 %. Hence, the thinning-shock correction function was subsequently implemented in the Douglas-fir Calculator.

The new functionality in the Douglas-fir calculator will have one major effect on existing knowledge; namely, all previous estimates of SBAP based on stand data from thinned stands may be slightly under-predicted. SBAPs estimates from unthinned stands have not changed. An updated table showing SBAP's for all sample plots by forest and region will be produced.

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