Extension of the 300 index growth model for non-performing site types – Stage 1

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EXECUTIVE SUMMARY

EXTENSION OF THE 300 INDEX GROWTH MODEL FOR NON-PERFORMING SITE TYPES – STAGE 1

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A recent validation of the 300 Index Growth Model showed that it performs well across a wide range of site types and management regimes. However, a number of shortcomings were identified. Some of these were general model biases, such as a tendency to under-predict above age 30 years, and some were specific to certain site types or regional locations. A strategy is suggested for eliminating identified sources of bias in the model, and a method of correcting such bias using a '300 Index drift function' is described. The approach is powerful and will allow considerable fine tuning of the model and the elimination of specific and identified regions of bias. Several examples in which it is used successfully to eliminate identified shortcomings in the overall national model are given. It is envisaged that Stage 2 of this project will involve the completion of this process followed by the development of several site-specific variants of the model, although a single national model should still be suited to the majority of sites.

INTRODUCTION

The recently developed 300 Index Growth Model (Kimberley et al., 2005a) predicts radiata pine BA for a wide range of site types and silvicultural treatments. It is currently implemented in FORECASTER and the Radiata Pine Calculator. Validation of the model across a wide range of site types is described in Kimberley et al. (2005b) and Kimberley and Dean (2006). These validations showed that the model performs well across a wide range of site types and management regimes. However, a number of shortcomings were identified. These include:

- Under-prediction above age 30 years.
- Over-prediction at stockings greater than 800 stems/ha.
- A tendency to over-predict yield on very low productivity sites (i.e., 300 Index < 19 m^3/ha/yr).
- A slight tendency to under-predict on traditional forest sites.
- Some regional variation in performance, e.g., under-prediction in some South Island regions; over-prediction on North Island coastal sand sites.

The next step in developing the model is to develop a strategy to eliminate these shortcomings. This report describes a methodology that has been developed to correct identified model bias. Several examples will be presented of how the model can be improved to overcome some of the prediction inaccuracies listed above.

OBJECTIVE

Develop a methodology for improving the performance of the 300 Index Growth Model on sites types or in areas within the matrix of driving variables where its current performance can be improved.

A STRATEGY FOR CONTINUED DEVELOPMENT OF THE 300 INDEX GROWTH MODEL

Based on the recent validation of the model, the following strategy for improving performance of the model is proposed. The initial steps are intended to correct several systematic sources of bias that have been identified in the overall model:

1. Eliminate under-prediction for ages greater than 30 years.
2. Eliminate over-prediction for stockings greater than 800 stems/ha.
3. Eliminate over-prediction on low productivity sites (i.e., sites with 300 Index less than 19 m^3/ha/yr).
4. After correcting these deficiencies, it is expected that most sources of systematic bias will have been eliminated. At this stage, the validation routines developed by Kimberley and Dean (2006) will be re-run using the modified model to confirm that all systematic errors are eliminated, and that no further errors in the overall national model can be identified. If this validation detects any further evidence of systematic bias, further corrections should be made to correct them.

5. After the overall model has been improved as much as is possible, the focus will shift to developing various site-specific variants of the model. The first step in this stage is to develop separate model variants for use on Forest, Farm and Coastal Sand site types, and any other broad classification of site type that users can easily identify, which have different growth characteristics.
6. Rerun the validation procedure using these modified versions of the model. Identify where regional models may be desirable. For example, it appears that performance for much of the South Island could be improved using a regional version.
7. Ultimately, it may be possible to identify site characteristics (e.g., climatic or soil parameters) that can be used to improve the model.

As noted by Goulding (1979), development of a growth model should be regarded as a cyclic procedure, with deficiencies being identified and corrected in each cycle. Although it may be necessary to incorporate greater complexity into the model at each step in the cycle to improve performance, it should also be recognised that simplicity is a virtue and that modifications should only be carried out if there is a clear gain in performance.

A Bias Correction Method

A number of approaches could be used for rectifying bias in the model. One approach would be to refit the model parameters to data from site types where the model has been identified as having poorer performance. Using this approach, several versions of the model having identical mathematical form, but different model coefficients, would be produced. However, this approach has a number of disadvantages. Correcting one model deficiency by refitting the coefficients might result in new problems emerging elsewhere. Also, it may not be possible to correct all model biases simply by refitting the parameters. Some may require model reformulation rather than simply refitting of parameters. It may also be impossible to precisely mimic the biological processes controlling stand growth with even quite complex nonlinear growth functions such as those used in the 300 Index.

An alternative approach that is based on the technique used to validate the model (Kimberley & Dean, 2006) has therefore been developed. This validation technique was to estimate the 300 Index for each plot measurement and test for any systematic 'drift' in the index over time within each measurement plot. If there is no systematic drift in the index, the model will provide unbiased predictions of yield over time. However, if there is a systematic drift, the model will be biased. A decreasing drift in the index indicates that the model will over-predict yield. Conversely, an increasing drift indicates that the model will under-predict yield. Therefore, if an empirical function expressing 300 Index drift can be obtained for site types or regimes where the model is under-performing, it should be possible to incorporate this function into the model in such a way as to cancel out the drift.

To show how this can be done, firstly note that at the core of the 300 Index Model is a function which predicts *DBH* for an unpruned, unthinned stand as a function of age (T), stocking (N), 300 Index ($I300$), and Site Index (SI). Let us call this function $DBH = f(T, N, I300, SI)$. It is defined so that, when $T = 28.6$ years and $N = 300$ stems/ha, the stem volume corresponding to the predicted DBH equals $I300$. Note that because pruning on average results in a loss in growth of 1.4 years, the 300 Index age for an unpruned stand is 28.6 rather than 30 years. Within a run, the variable T will increase resulting in the predicted *DBH* increasing during the run. The parameter N can also vary within a run (although it can never increase) in response to mortality or thinning. In contrast, in the current version of the model, *I300* and *SI* must remain constant within a run. However, the model can easily be re-coded to allow the *I300* parameter to change within a run. A sudden change in *I300* would cause an instantaneous jump or drop in predicted *DBH*, which would obviously be undesirable. However, a gradual change in *I300* need not result in any undesirable behaviour in predicted *DBH*.

Now, if $g(T)$ is a function expressing drift in the 300 Index over time, then this drift can be eliminated by predicting *DBH* using $DBH = f(T, N, I300', SI)$ where $I300' = I300 \times g(T) / g(28.6)$. This will have the effect of removing the 300 Index drift and hence eliminating model bias. It can be used both to remove general bias in the model, and to produce site-specific versions of the model. It will also be possible to simultaneously use more than one drift correction function to eliminate several sources of bias, or to combine corrections for general and site-specific bias.

The advantage of this approach is that it is much easier to fit a function to data that only deviates slightly from a constant value. This is almost always the case with the 300 Index, even in situations where there is significant drift. In many cases, $g(T)$ may be a simple linear function which adequately represents the departure from a constant value. Several examples are now given to show how this method can be used to correct some of the model biases described earlier.

Eliminating under-prediction above age 30 years

Kimberley & Dean (2006) showed using 300 Index drift charts that there was significant positive drift beyond age 30 years. This indicates that the model significantly under-predicts yield beyond this age. A plot of the overall drift based on all the validation data is shown in Fig. 1. The following function was fitted to this data with T being age in years:

$$[1] \quad \begin{aligned} g(T) &= 25.4, && \text{when } T < 25 \\ g(T) &= 25.4 + 0.0107 \times (T - 25)^2, && \text{when } 25 < T < 60 \\ g(T) &= -51.3 + 1.284 \times T, && \text{when } T > 60 \end{aligned}$$

Up to age 25 years, this function is constant. Between ages 25 and 60 years it is a quadratic function in T constrained to have a minimum at $T = 25$. Above age 60 years it changes smoothly to a linear function. Fig. 1 shows that this function fits the 300 Index drift pattern well.

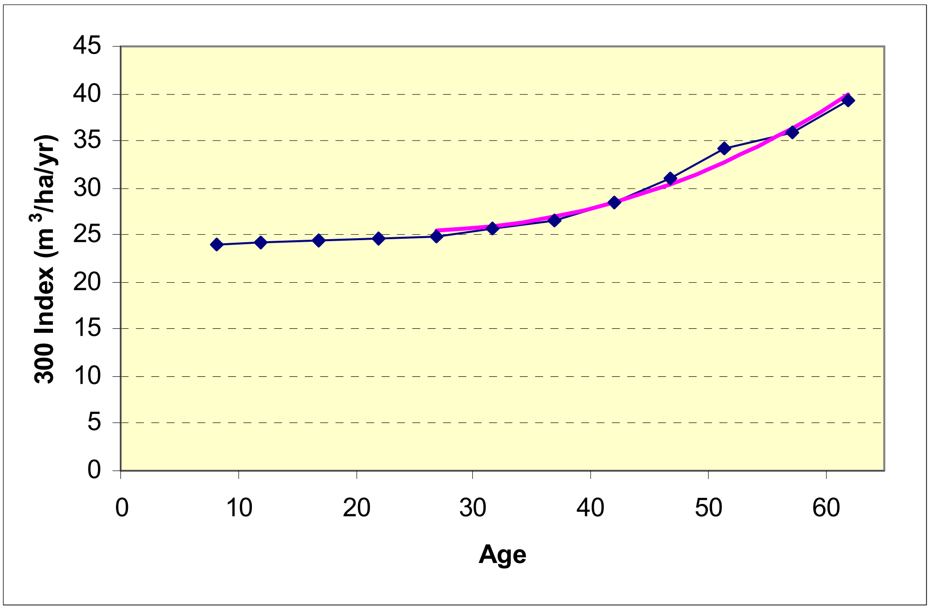

Fig. 1. Function [1] fitted to 300 Index values estimated in 5-year age classes using validation data.

Examples of the current model and the model modified using the above drift function, applied to data from plots in two 1st crop Kaingaroa Forest stands are shown in Figs. 2 & 3. Note that more recently planted stands aged much greater than 30 years do not exist in the database for radiata pine in New Zealand. Both stands were planted in about 1930 and measured regularly from age 20 to 50 years during which time their stockings were between 150-190 stems/ha. In both plots, the current and modified models were used to project BA using the initial age 20 year measurement as a starting value. The modified model clearly performs better than the current model at ages greater than 30 years for these plots. Because the aim was to test the BA function independently of any mortality effect, BA was predicted using actual stocking rather than predicted stocking. The drop in both actual and predicted BA at age 43 years for RO541 is caused by mortality.

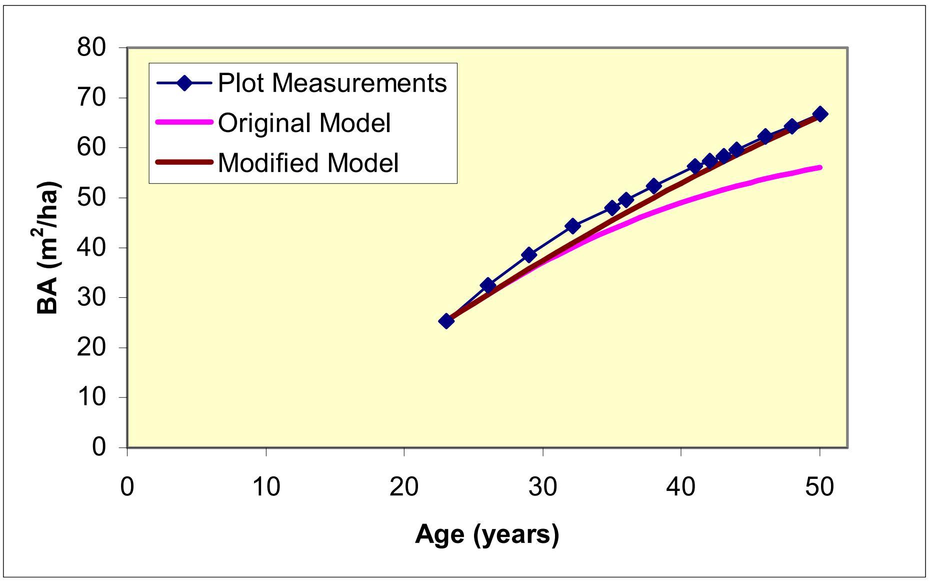

Fig. 2. Fits of the current 300 Index model and the modified model against data from Kaingaroa permanent sample plot no. RO105.

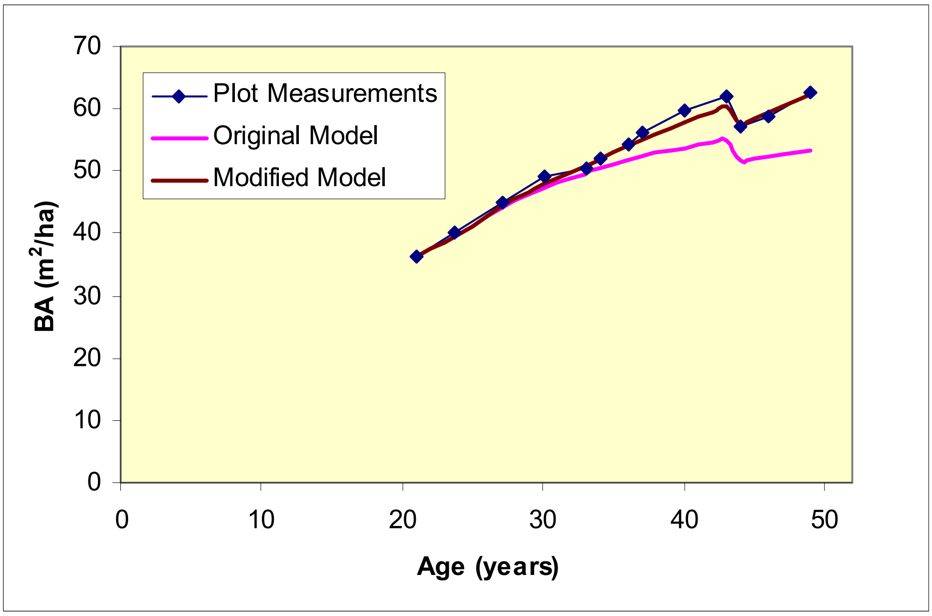

Fig. 3. Fits of the current 300 Index model and the modified model against data from Kaingaroa permanent sample plot no. RO541.

Eliminating over-prediction for stockings greater than 800 stems/ha

The validation process identified some tendency to over-predict yield for regimes with more than 800 stems/ha final crop stocking. Applying the drift-correction approach would be one possible means of correcting this. However, the drift function would need to be expressed as a function of stocking, N, rather than age, T. Therefore, the drift function would be $g(N)$, and the transformed 300 Index parameter used in the model would be: $I300' = I300 \times g(N) / g(300)$.

However, this approach could lead to some inconsistencies in the behaviour of the model. The function $f(T, N, I300, SI)$ has been formulated so that at young ages before competition begins, predicted *DBH* is not affected by stocking, i.e., at an early age, trees grow at the same rate regardless of stocking. Transforming the 300 Index parameter as a function of stocking would destroy this desirable property.

Therefore, an alternative approach will be needed to eliminate this model bias. One idea would be to transform the stocking parameter N rather than the 300 Index parameter *I300*. It should be possible to eliminate over-prediction at high stockings by replacing N with a transformation, N', with behaviour similar to that shown in Fig. 4. This approach to eliminating bias at higher stockings will be tested fully and implemented in Stage 2 of this project.

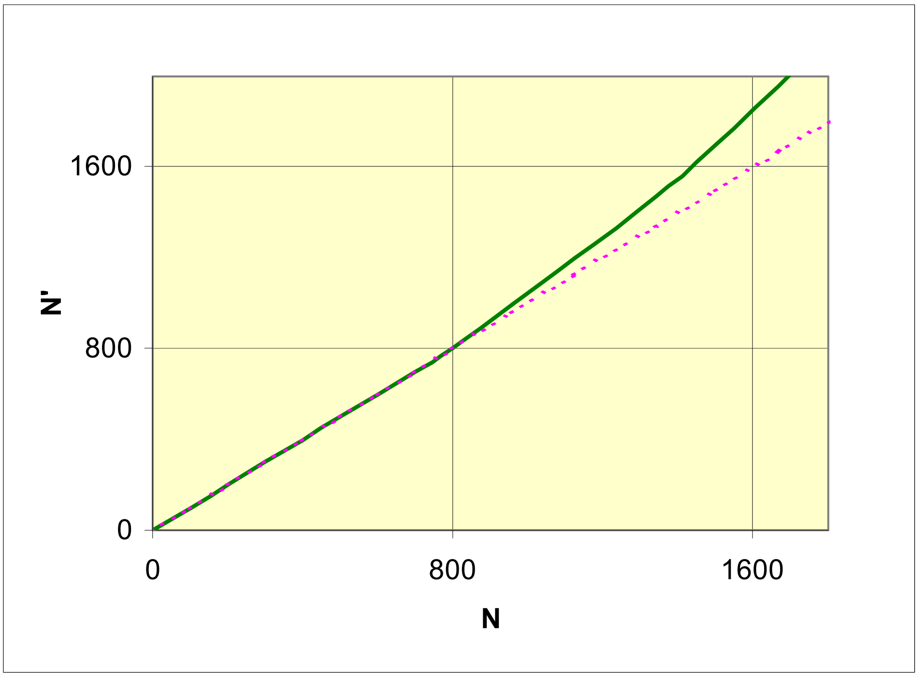

Fig. 4. Possible transformation of stocking, *N*, to eliminate over-prediction at high stockings.

Eliminating over-prediction in low-productivity sites

The validation process identified some tendency to over-predict yield on sites with a 300 Index of less than 19 m^3/ha/yr. Applying the drift-correction approach to correct this bias should be straightforward. Examination of the validation data suggests that the model needs no adjustment when the 300 Index is greater than 20, but for 300 Index values below 20, the drift becomes negative and increases by about 0.03 units per unit of index. Thus, at a 300 Index of 17 m^3/ha/yr, the drift is about -0.09 m^3/ha/yr^2, and at a 300 Index of 14 m^3/ha/yr, the drift is about -0.18 m^3/ha/yr^2. By assuming linear drift using these average values, the behaviour of the modified model for these low productivity sites compared with the current model is shown in Fig. 5.

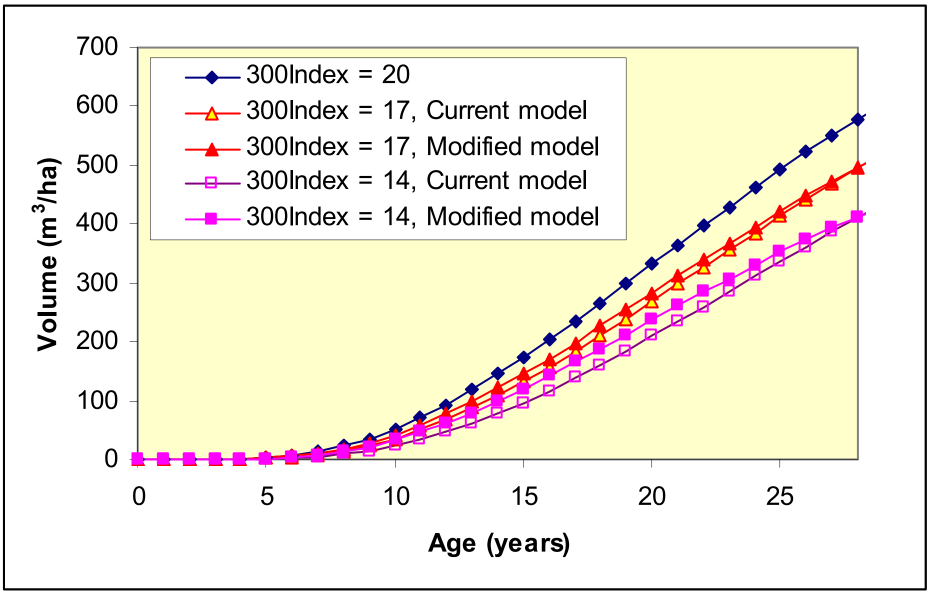

Fig. 5. Predictions using the current model and a version modified to eliminate over-prediction on low productivity sites.

Site-specific Forest and Farm models

The validation suggested that the model has a slight tendency to under-predict on traditional Forest sites, and to be unbiased or to slightly over-predict on Farm sites. The average drift on Forest sites below age 30 years was 0.107, while the average drift on Forest sites was –0.026. By assuming linear drift and using these average values, two site-specific variants of the model can be produced using the drift correction method. Comparison of predictions using these models against the current model for typical Farm and Forest sites is shown in Fig. 6.

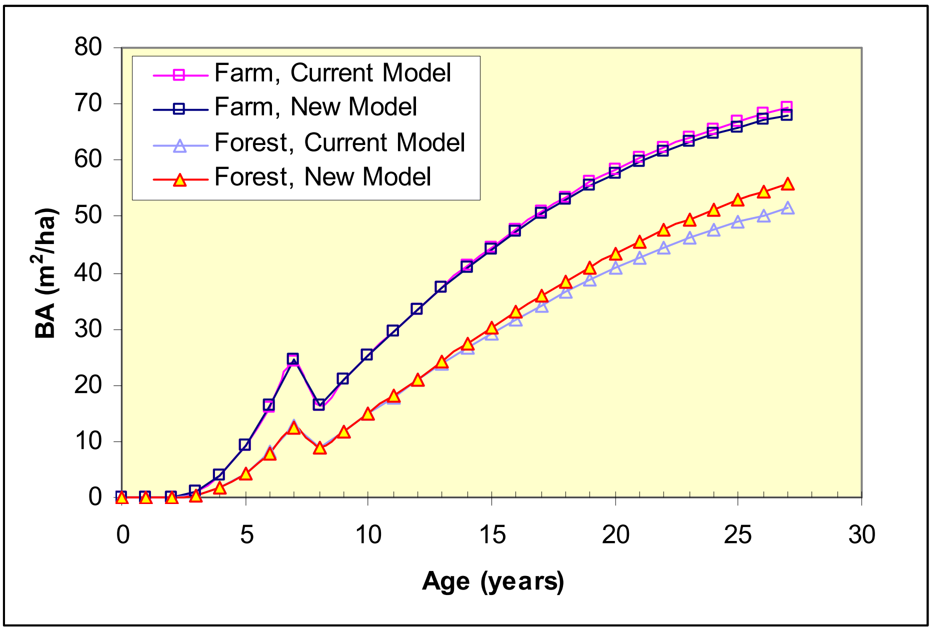

Fig. 6. Predicted BA growth for a standard regime on typical Farm and Forest sites using the current 300 Index Model, and the modified Farm and Forest versions of the model.

Regional models

Based on the validation (Kimberley and Dean, 2006), it appears that performance of the model may be improved by developing several regional variants. The 300 Index drift correction method would be an appropriate means of creating these models. In most cases, a simple linear drift function such as shown above for the Farm and Forest variants, or a quadratic drift function similar to that used to correct bias at ages greater than 30 years, should suffice. The development of regional versions of the model will be implemented in Stage 2 of this project.

CONCLUSIONS

- Procedures for modifying the 300 Index model to account for general and site-specific bias have been developed.
- The approach is powerful and will allow considerable fine tuning of the model and the elimination of specific and identified regions of bias.
- The method has been used successfully to eliminate several identified shortcomings in the overall national model.
- It is envisaged that Stage 2 of this project will involve the completion of this process followed by the development of several site-specific variants of the model, although a single national model should still be suited to the majority of sites.

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