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Theme: Radiata Management

Task No: F10152
Milestone Number: 1.5.12

Report No. FFR- R010

Full Rotation Validation 300 Index Growth Model

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Scion

Date: June 2010

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EXECUTIVE SUMMARY

The 300 Index Growth Model was developed for predicting radiata pine BA, MTH, Stem Volume, and Stocking for a wide range of site types and silvicultural treatments. It is currently implemented in ATLAS Forecaster, and the Radiata Pine Calculator (among other applications).

The model has undergone considerable validation including various validation exercises for the Plantation Management Cooperative, along with more recent validations for FFR of its performance from mid-rotation to rotation end.

The objective of this study was to perform a comprehensive validation of the Radiata Pine 300 Index Growth Model over a full rotation from an early measurement using independent data from sites throughout New Zealand.

The validation dataset consisted of 393 PSPs. The initial measurement age averaged six years and the final measurement (last age) averaged 27.6 years. For comparison, the model was also tested using a mid-rotation measurement averaging 14.9 years using the same plots.

Overall the 300 Index Growth Model showed minimal bias when used to predict yield over a full rotation from the early measurement, although there were some variations in performance between regions and at extreme stockings. A preliminary test of the VBA and Forecaster implementations demonstrated that near-identical results were obtained for a 24.6 year projection for SPH, MTH, BA, and TSV. Additional checks will continue, to confirm this preliminary test.

The standard model used without drift factor adjustment showed some regional biases, especially for Southland (under-prediction) and North Island Coastal Sand forests (over-prediction), although both these biases were corrected using recommended regional drift factors. However, using the recommended regional drift factors, the model tended to over-predict in Nelson, and North Island East Coast regions and to under-predict in the North Island Clays region.

The model showed little bias over final stockings ranging between 150 and 550 stems/ha. However, it showed a tendency to under-predict at stockings > 550 stems/ha, and to over-predict at stockings < 150 stems/ha. The model also tended to under-predict in unthinned stands, this possibly being a reflection of the above-noted tendency to under-predict in highly stocked stands.

There was little bias when tested against timing of thinning. If anything, the model had a slight tendency to over-predict yield in stands thinned before age six years, and to under-predict in stands thinned after age 12 years. There was little bias for pruned stands, but a tendency to under-predict in unpruned stands.

Although the overall performance of the 300 Index Growth Model over a full rotation appears to be extremely robust, this validation has identified several areas in which the model may be improved. In particular, it appears that regional drift factors for some regions should be revised, especially for Nelson, North Island East Coast, and Northland Clays. The tendency of the model to under-predict at higher stockings and over-predict at very low stockings should also be corrected, especially given the current interest in using forest plantations for carbon sequestration.

INTRODUCTION

Model validation is an important step in the development of a forest growth model. According to Goulding [1], validation should be a formal, independent process concerned with evaluating the model as a whole. Validation is not a process of proving whether the model is 'correct' as no model will ever perfectly reflect reality and will always at best only present an approximation of the true situation. Goulding quotes Van Horn [2] as defining validation as "The process of building an acceptable level of confidence that an inference about a simulated process is a correct or valid inference about the actual process". Thus rather than proving that the model is absolutely correct, the validation step should aim to ensure that forest management decisions made on the basis of model predictions are valid and can be made with confidence.

Development of a model involves several stages that will generally include collection and processing of data, model formulation, parameter estimation, testing of model hypotheses and assumptions, programme coding and verification, and finally a formal validation. The validation should preferably be carried out using independent data, but sometimes model development data are used. However, Goulding [1] emphasises that the development of a forestry growth model is generally cyclic in nature. If the validation identifies shortcomings in the model, these will generally be corrected and a further validation performed to determine whether they have been rectified. This process may continue for several cycles before the model becomes widely accepted as able to provide reliable inferences about the system.

For a forest growth model, the validation procedure should answer several questions such as the following:

- How good the model is at predicting levels of growing stock?
- Over what site types are predictions accurate?
- How close is the model's behaviour to reality at predicting the effects of management treatments such as tree spacing, timing of thinning, and pruning?

The 300 Index Growth Model [3] has been developed for predicting radiata pine BA (basal area), MTH (mean top height), Stem Volume, and Stocking for a wide range of site types and silvicultural treatments. It is currently implemented in ATLAS Forecaster, and the Radiata Pine Calculator (among other applications). The model has undergone considerable validation including various validation exercises for the Plantation Management Cooperative [4, 5], along with more recent validations for FFR of its performance from mid-rotation to rotation end at predicting stand-level yields [6] and individual tree DBH and height distributions [7]. The 2009 validation exercises were constrained to mid-rotation onward due to the inclusion and limitation of the Individual-Tree Growth Model, as developed for the Stand Growth Modelling Cooperative [8, 9, 10, 11].

The objective of this current study was to perform a comprehensive validation of the Radiata Pine 300 Index Growth Model for predicting stand-level yields over a full rotation from an early measurement using independent data from sites throughout New Zealand.

METHODS

Assembly of Validation Dataset

The validation utilised Scion's permanent sample plot (PSP) System. Plots belonging to either Scion or FFR members were considered. The dataset was obtained by searching the PSP System for suitable PSPs (trials and growth plots) that had measurements started at an early age (5-10 years), and continued through to near full rotation (~25 years), and which were independent of data used to develop the growth model. Plots were selected to be well distributed throughout the country, covering a wide range of site types. Selected plots had to have full and accurate thinning and pruning history. Data were checked for errors, and then formatted into suitable formats ready for input into the Scion Visual Basic implementation of the 300 Index Growth Model (PRAD Calculator). A test of the VBA and Forecaster implementation was made to confirm similar output. Plots were checked for excessive levels of mortality. Those that showed excessive mortality from wind throw were excluded from the main analysis but included in a separate analysis.

Model Runs

The latest version of PRAD Calculator was used to perform this validation. This implementation can use standard PSP summary data either at the stand-level or individual tree level as starting inputs, and predicts stand-level yields or individual tree DBHs and heights at any specified future age. In this validation, stand-level data were used. The validation was performed using the standard national model, and also using regional 'drift' adjustments. The 300 Index Model has a facility to adjust for prediction bias using drift factors. Factors were tabulated by Kimberley [12] for use in different regions in New Zealand, and these were used in the current validation (Table 1).

Table 1. Regional drift factors recommended for use in the 300 Index Growth Model

Drift parameter	Region
-0.30	Auckland/Northland/Waikato Sands
-0.20	Auckland Clays
-0.05	Bay of Plenty, West Coast, Canterbury
0.00	Northland Clays, Wanganui/Manawatu, Southern NI Sands
0.05	Hawkes Bay, Nelson, Waikato
0.10	Marlborough
0.15	East Coast
0.25	Otago
0.30	Southland

The 300 Index and Site Index, and predicted values of BA, MTH, Volume and Stocking were then estimated using the Calculator. The validation was intended to test the model's ability to predict stand yield at full rotation using a measurement made in at an early age of 5-10 years for an assumed regime. Also, for comparison, the same plots were tested using a mid-rotation starting measurement age of ~15 years. To predict future yield for each plot, the initial measurement (or for the mid-rotation validation, the chosen mid-rotation measurement) consisting of Stocking, BA and MTH, was used to estimate the 300 Index and Site Index. These productivity indices were then used to predict yields at the age corresponding to the final measurement. Apart from the initial measurement, the only other information used to predict the final yield was the stocking, thinning and pruning history. The stocking history consisted of the initial stocking, and the age and stocking following each thinning. The pruning history consisted of the age, the number of stems pruned, and the mean pruned height of each pruning lift.

Prediction Error Analysis

The error in predicted yield expressed as a percentage (100×(actual-predicted)/actual) at the final measurement age was obtained for each plot for Volume, Stocking, BA, and MTH. Errors were then summarised across various management regime and site factors. The following factor groupings were used:

- Geographic location: Growth Model boundaries (i.e., GM Regions) were used except for coastal sand sites which were treated as a separate region.
- Stocking after last thinning: <150, 150-250, 250-350, 350-450, 450-550, >650 stems/ha.
- Pruned height: Unpruned, < 3m, > 3m.
- Thinning age: Unthinned, <8, 8-10, 10-12, >12 years.
- Mortality: Normal and High.
- Starting age of projection (years): Early pre-silviculture (<10 years), and mid-rotation or post-silviculture (~15 years).
- Length of projection: 25-30, 30-40, 40-60, >60 years.

RESULTS

Validation dataset

Table 2 provides a summary of the final validation dataset. The dataset consisted of 393 PSPs covering nine growth modelling regions. The initial measurement age of the pre-silviculture validation averaged six years and ranged from 5 to 9.9 years. For comparison, the model was also tested using a mid-rotation measurement averaging 14.9 years (post-silviculture starting age) using the same PSPs. The final measurement (last age) averaged 27.6 years and ranged from 16.2 to 52.5 years. An additional 98 plots with extreme or catastrophic mortality were excluded from the main validation analysis but were analysed separately.

Table 2. Descriptive information on the validation dataset by growth modelling region.

GM Region	No. Plots	Variable	Mean	Std Dev	Minimum	Maximum
CANTY	11	Final Stocking	198	145	48	571
		Pre-Silv start age	8.1	1.1	5.0	9.0
		Post-Silv start age	14.4	0.4	14.0	15.1
		Last age	27.4	1.3	25.0	29.0
CLAYS	46	Final Stocking	366	151	150	830
		Pre-Silv start age	5.7	0.4	5.1	6.2
		Post-Silv start age	14.3	0.4	14.0	15.1
		Last age	26.3	1.2	22.0	30.2
CNI	177	Final Stocking	269	92	89	553
		Pre-Silv start age	5.4	0.4	5.0	7.8
		Post-Silv start age	15.0	1.0	12.1	20.0
		Last age	28.9	5.2	18.3	52.5
ECOT	14	Final Stocking	242	83	110	380
		Pre-Silv start age	5.5	0.4	5.0	6.0
		Post-Silv start age	14.6	1.1	13.2	16.2
		Last age	26.1	1.8	21.0	28.6
HBAY	26	Final Stocking	375	249	130	1005
		Pre-Silv start age	5.7	1.1	5.1	9.1
		Post-Silv start age	14.7	1.0	14.0	17.0
		Last age	26.2	2.8	16.2	31.3
NELSON	22	Final Stocking	263	132	48	571
		Pre-Silv start age	5.8	0.4	5.0	6.0
		Post-Silv start age	14.6	0.9	14.0	17.2
		Last age	28.0	1.3	26.1	32.2
SANDS	50	Final Stocking	258	54	123	400
		Pre-Silv start age	6.0	0.9	5.0	9.1
		Post-Silv start age	15.2	1.0	14.0	19.1
		Last age	26.2	1.5	22.0	30.2
SOUTH	41	Final Stocking	247	100	48	469
		Pre-Silv start age	8.6	1.0	5.0	9.9
		Post-Silv start age	14.7	0.8	12.0	16.0
		Last age	26.3	1.6	22.0	29.2
WCOT	12	Final Stocking	261	46	200	360
		Pre-Silv start age	7.4	1.5	6.0	9.2
		Post-Silv start age	15.3	1.4	14.1	19.2
		Last age	27.3	4.3	20.0	33.1
Total	393	Final Stocking	279	121	48	1005
		Pre-Silv start age	6.0	1.2	5.0	9.9
		Post-Silv start age	14.9	1.0	12.0	20.0
		Last age	27.6	4.0	16.2	52.5

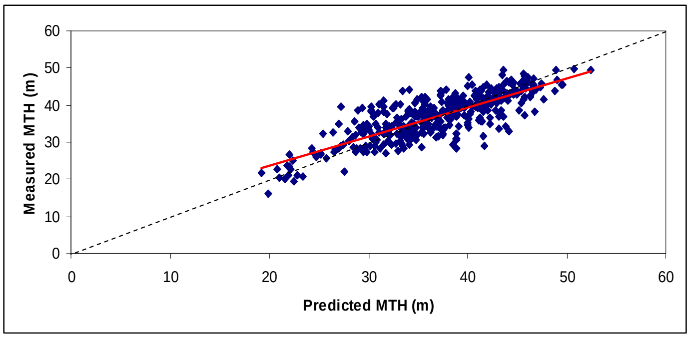
NOTE: CANTY=Canterbury; CLAYS= Clays; CNI=Central North Island; ECOT=East Coast; HBAY=Hawkes Bay; NELSON=Nelson ; SANDS=Sands; SOUTH=Southland; WCOT=West Coast.

Verification of VBA and Forecaster implementations

A preliminary test of the VBA and Forecaster implementations demonstrated that near-identical results were obtained for a 24.6 year projection (age 5.4 to 30) for SPH, MTH, BA, and TSV. Additional checks will continue to confirm this preliminary test.

Prediction Error Analysis

Actual yields at the prediction age are shown plotted against predicted yields in Figures 1-4 for MTH, BA, Stocking and Stem Volume. In each figure, predictions based on the early pre-silviculture measurement (age 5-10 years), and on the post-silviculture mid-rotation measurement (age ~15 years) are shown. In each case, mean predictions are indicated by fitted linear regression lines which can be compared with (dashed) y=x lines. Predictions were made without regional drift factors. For all stand yield variables, there was a good relationship between actual and predicted yields with little evidence of any overall bias. As would be expected, predictions were somewhat higher for a mid-rotation measurement compared with an early pre-silviculture measurement. For example, the root mean square error for predicted volume was 109 m^3/ha using a pre-silviculture measurement and 77 m^3/ha for using a post silviculture measurement.



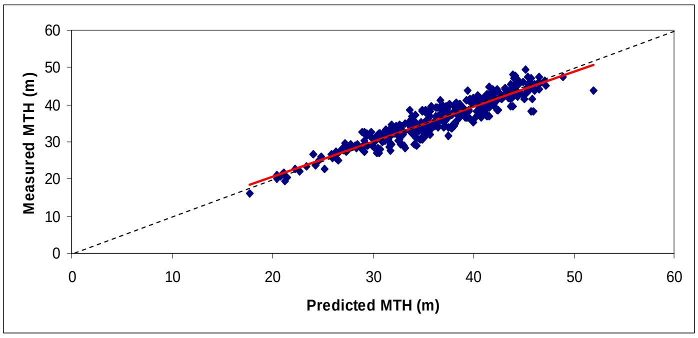
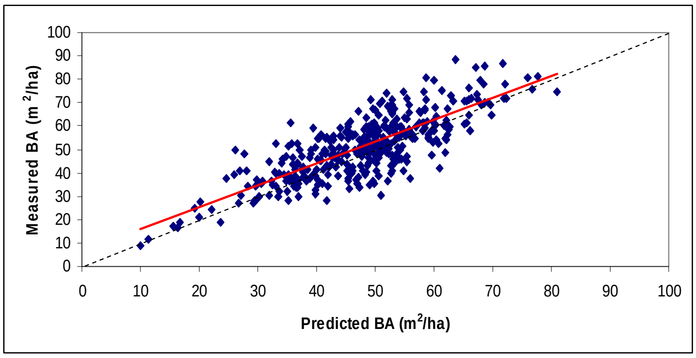


Figure 1. Measured vs predicted MTH using pre-silviculture (left) and post-silviculture (right) starting age.



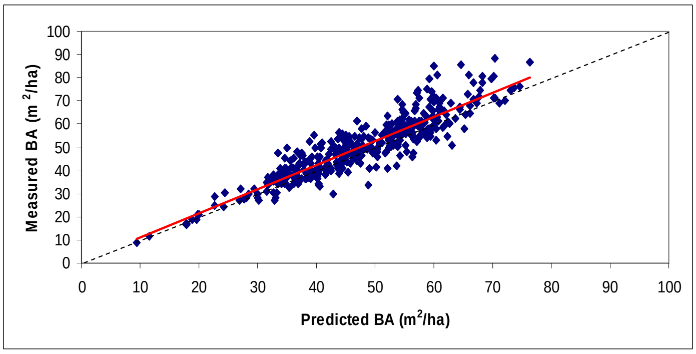


Figure 2. Measured vs predicted BA using pre-silviculture (left) and post-silviculture (right) starting age.

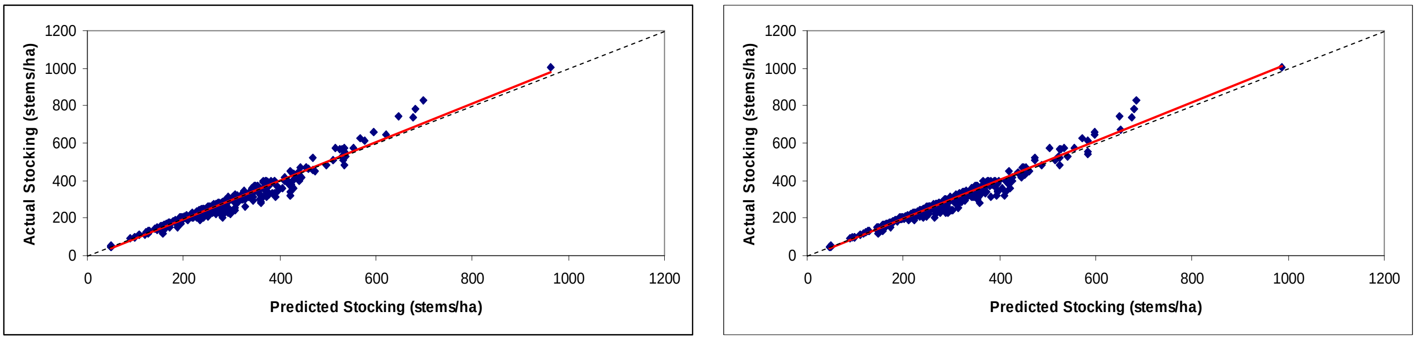


Figure 3. Measured vs predicted stocking using pre-silviculture (left) and post-silviculture (right) starting age.

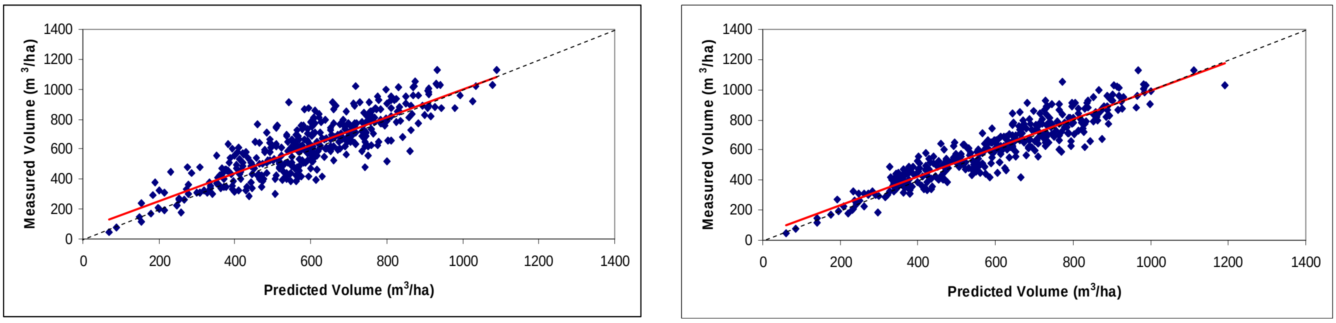


Figure 4. Measured vs predicted volume using pre-silviculture (left) and post-silviculture (right) starting age.

Actual and predicted stem volumes for the main validation dataset are compared with those for plots which were rejected from the validation due to excessive mortality and wind throw in Figure 5. As would be expected, volume tended to be over-predicted in plots with excessive levels of mortality. In contrast to the main dataset where volume was under-predicted by an average of 3.8% in the full-rotation validation, the model over-predicted high-mortality plots by an average of 15%. For the mid-rotation starting age, volume was under-predicted by 1.3% for the main dataset and over-predicted by 11% for the high-mortality plots.

Generally, it is recommended that excessive or catastrophic levels of mortality caused for example by events such as extreme storms, fire, or arrival of a new disease, should be considered separately when evaluating the risks of a forestry operation. The mortality function included in the 300 Index Growth Model does not therefore account for extreme events, and it is therefore appropriate to exclude plots with excessive mortality when validating the model. However, it is not easy to precisely define excessive mortality. In this study, 20% of the plots in the original dataset (98 out of 491 plots) were excluded from the main validation analysis as having excessive mortality. If some of these plots had been included in the main validation, the slight tendency of the model to under-predict noted above may have been eliminated.

The mortality function incorporated in the 300 Index model has the facility for a user to include higher than normal levels of mortality either as a multiplicative or additive adjustment. Kimberley [13] recommended that an additional additive mortality of 0.2% per annum could be used to account for excessive mortality due to wind throw.

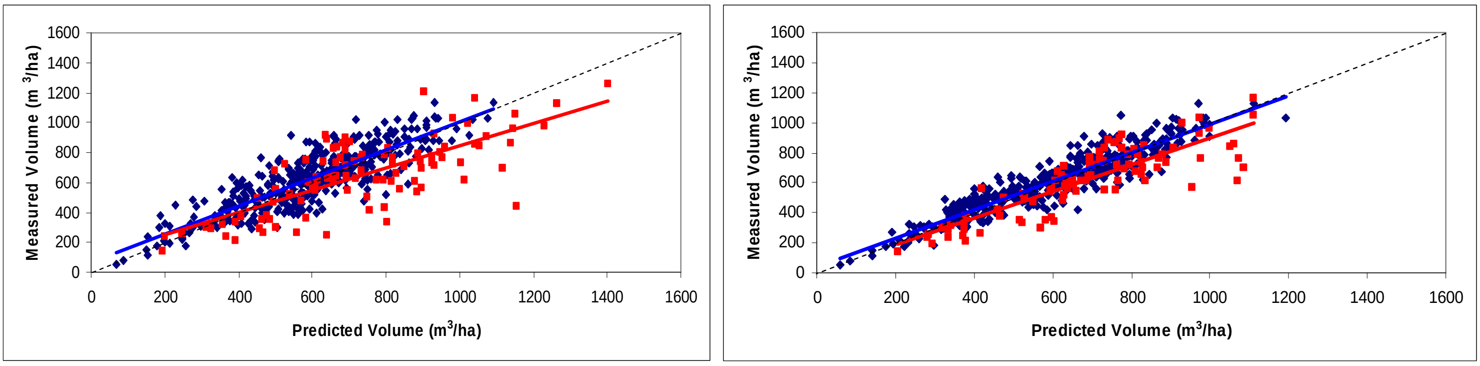


Figure 5. Measured vs predicted volume for pre-silviculture (left) and post-silviculture (right) starting age. The main validation set is shown in blue while plots with excessive mortality are shown in red.

Growth Modelling Region

Figures 6 and 7 (pre- and post-silviculture starting age respectively) show mean % errors in predicted volume by GM region. Results are shown, with and without adjustment using the recommended regional drift factors. Without drift factor adjustment, the model significantly under-predicted volume in SOUTH and over-predicted in SANDS. Both these model biases had been identified in earlier validations [12]. After adjustment using recommended regional drift factors, volume prediction was not significantly biased (for either under- or over-prediction), with mean errors being less than two standard errors from zero, except for three regions, namely CLAYS, ECOT, and NELSON. In fact, prediction with the drift factor adjustment was poorer for these three regions using the pre-silviculture starting age. The model under-predicted for CLAYS but over-predicted for ECOT and NELSON.

Predictions made using the mid-rotation starting age were not always less biased than to those made using the early measurement, and predictions made from mid rotation using drift factor adjustment were significantly biased for CANTY and NELSON (over-predicted), and HBAY and SANDS (under-predicted).

Overall, these results suggest that regional drift factors for HBAY, NELSON and CLAYS may need revising. Also, although predictions for SANDS clearly require drift factor adjustment when run from an early measurement, there appears to be little need for adjustment when using a mid-rotation measurement as the starting point.

In the Appendix, tables are provided that provide mean percentage errors for MTH, BA, Stocking and Volume by GM Regions and other factor groupings.

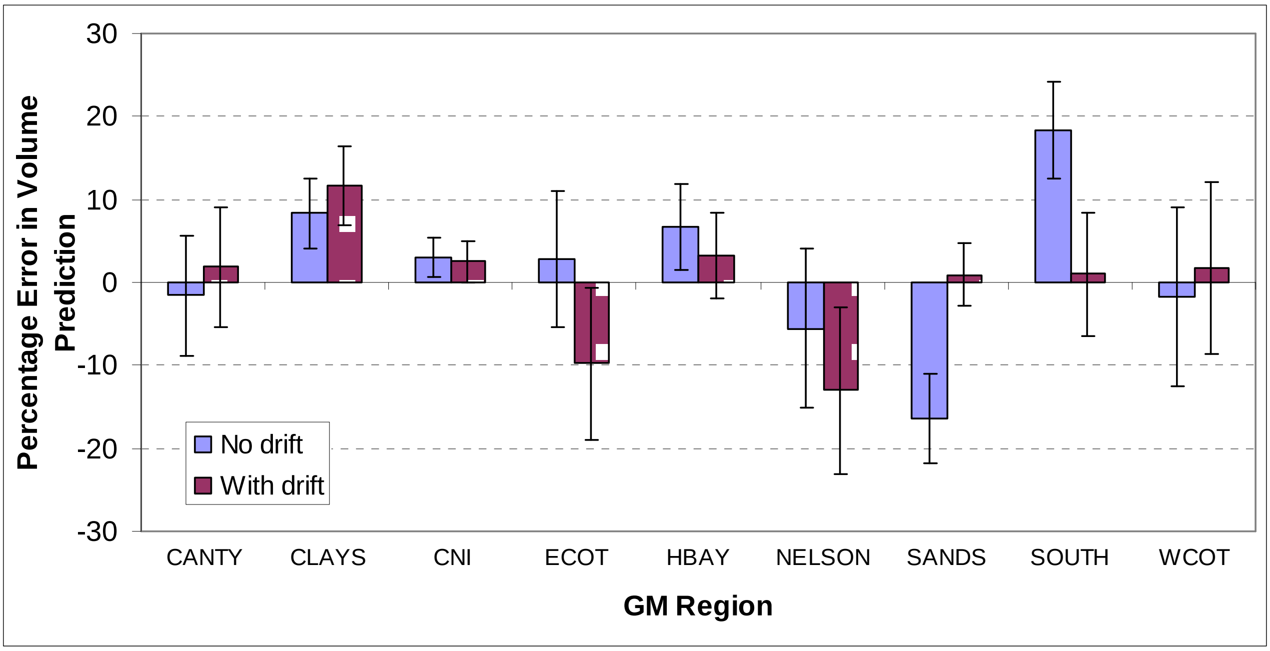


Figure 6. Percentage error in volume prediction by GM region using pre-silviculture starting age.

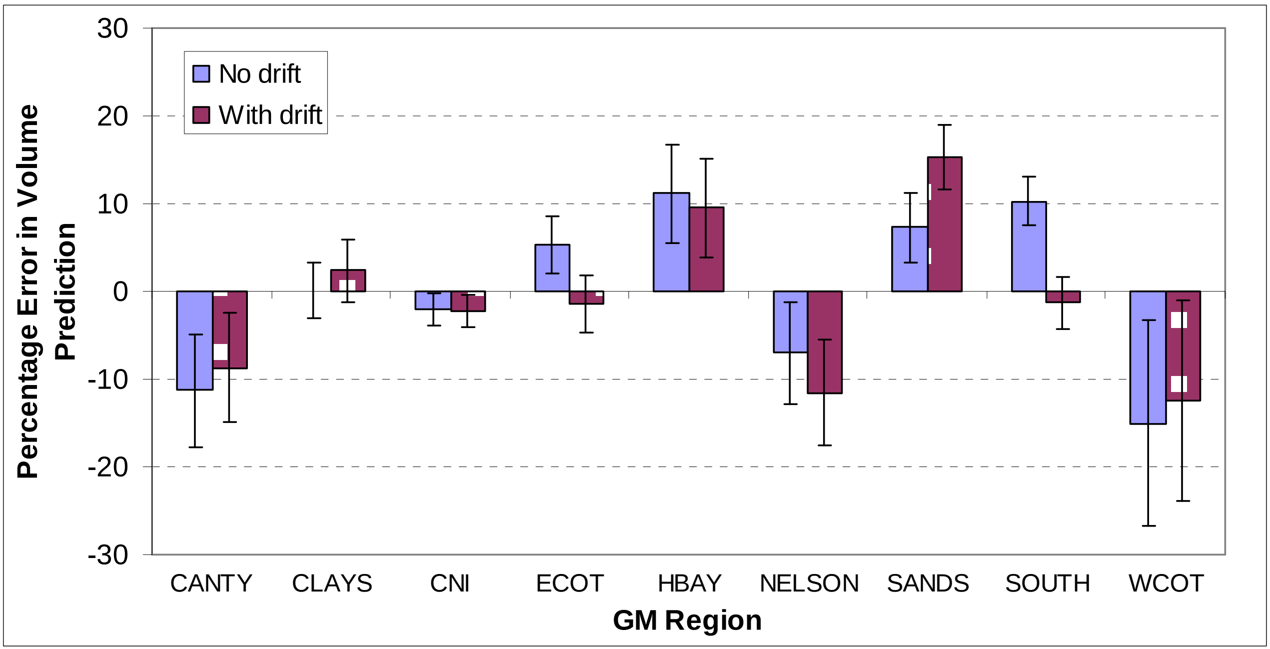


Figure 7. Percentage error in volume prediction by GM region using post-silviculture starting age.

Stocking after last thinning

Figures 8 and 9 (pre- and post-silviculture starting age, respectively) show mean % errors in volume estimation by stocking after final thinning, with and without drift factor adjustment. Across a broad range of final stockings between about 150 stems/ha and 550 stems/ha, the model was either unbiased or tended to slightly under-predict volume. There was a tendency to over-predict yield as extremely low stockings of less than 150 stems/ha, and to under-predict at very high stockings of greater than 550 stems/ha. The latter trend was particularly pronounced for a mid-rotation starting age but was also apparent for an early starting age. Generally, there was an improvement for higher final stocking (i.e., > 350 sph) when the drift factor was used.

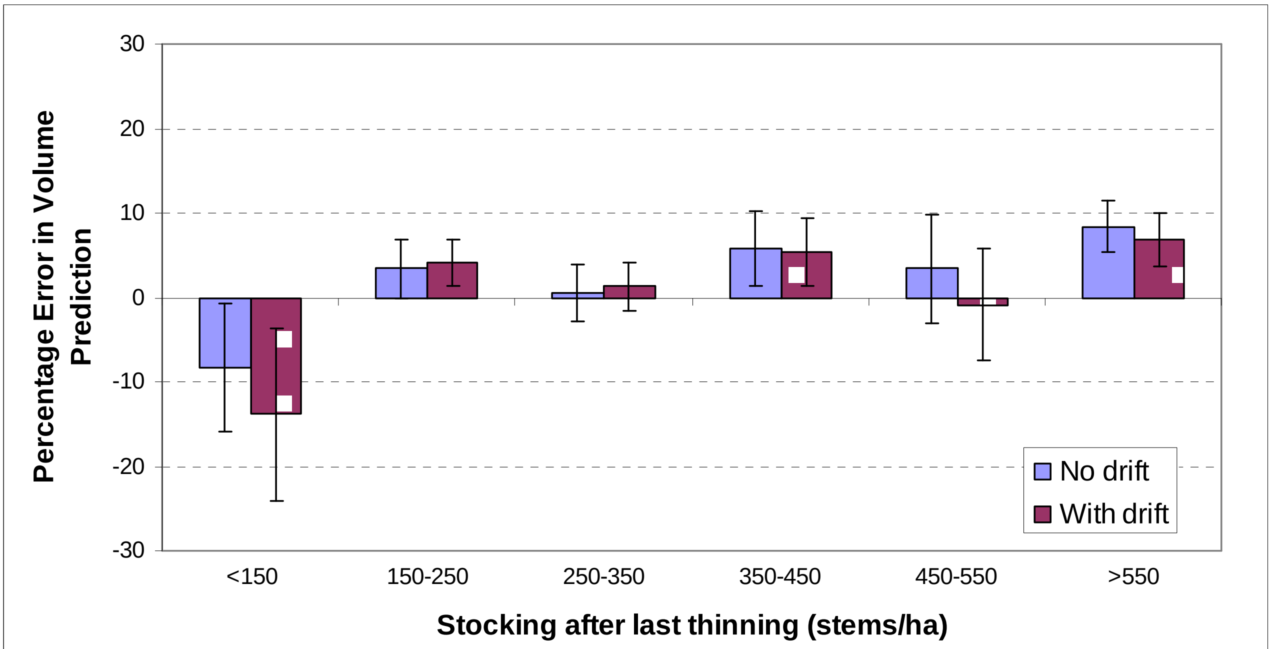


Figure 8. Percentage error in volume prediction by final stocking using pre-silviculture starting age.

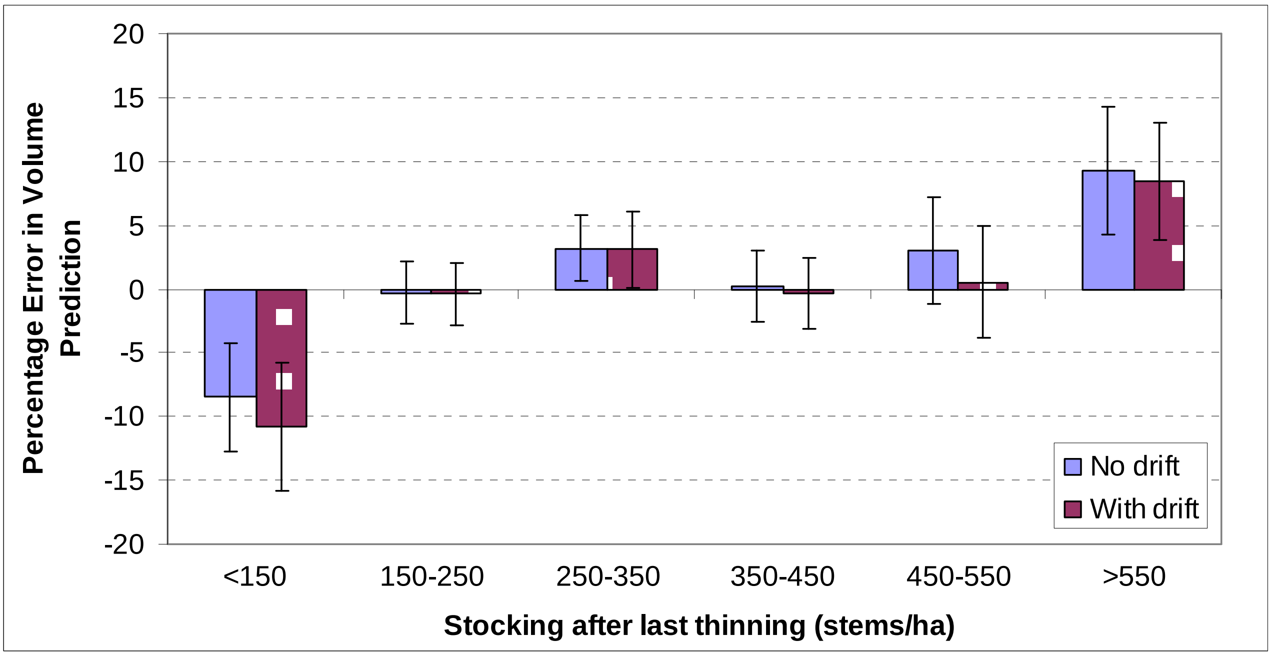


Figure 9. Percentage error in volume prediction by final stocking using post-silviculture starting age.

Time of thinning

Figures 10 and 11 (pre- and post-silviculture startage, respectively) show mean % errors in volume prediction by time of thinning, with and without drift factor. Consistently, standard error bars do not identify any significant biases due to time of thinning. Results were similar both with and without drift factors. There was a tendency of under-prediction bias increasing with increasing age of thinning. For example, on average, the model slightly (but statistically non-significantly) over-predicted volume for thinning age < 8 years, but under-predicted for thinning age > 8 years, significantly so for thinning age > 12 years. This result is of particular interest to some practitioners. In a recent comparison of growth model predictions, the 300 Index model was found to predict late thinning to have *less* impact on a final crop than other models (Mike Baker, pers. com.). If anything, the current validation suggests that the 300 Index model slightly *over-predicts* the effect of a delayed thinning on the final crop. For unthinned stands, over-prediction bias occurred with the use of drift factor (both pre- and post-silviculture starting age), but with no drift factor, the bias in prediction was zero with a pre-silviculture starting age.

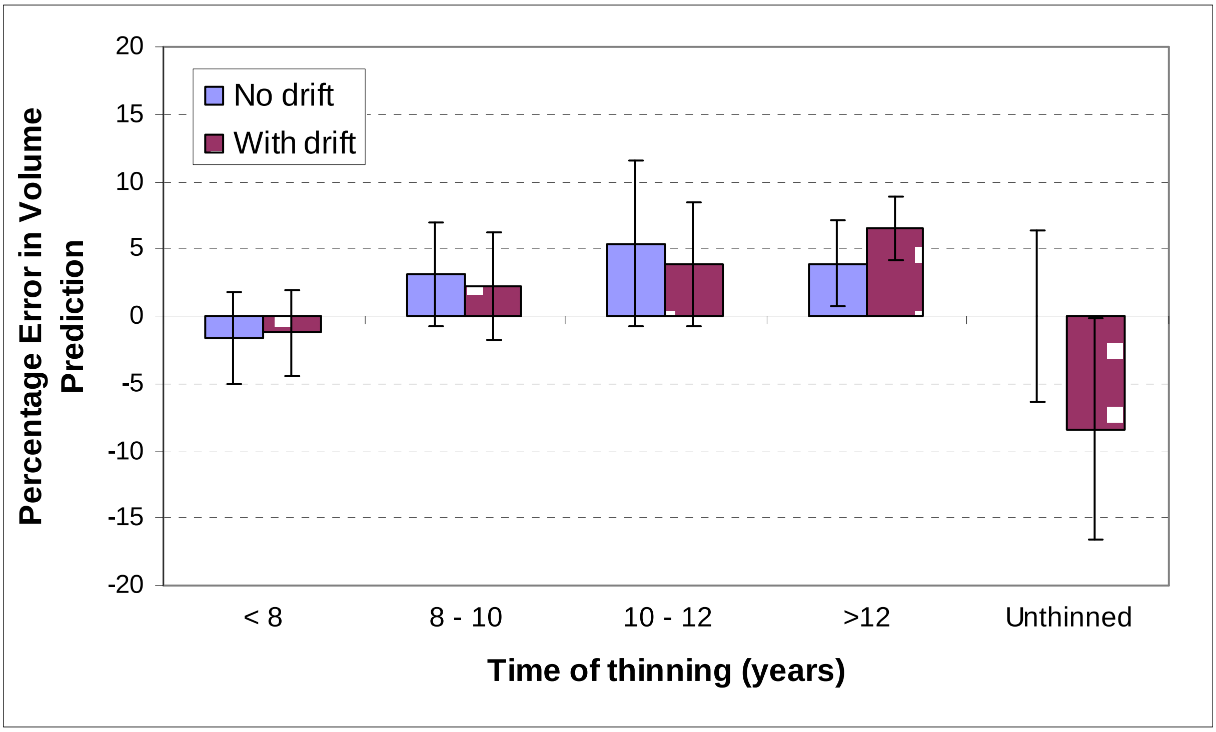


Figure 10. Percentage error in volume prediction by time of thinning using pre-silviculture starting age.

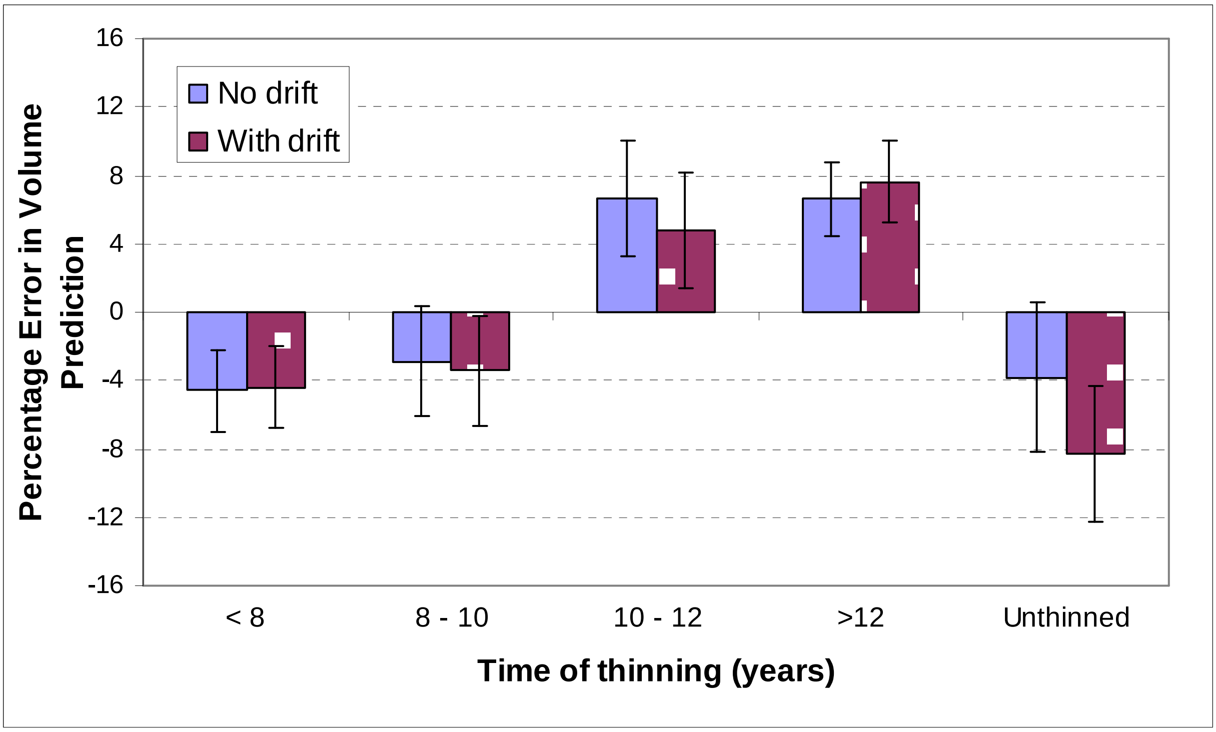


Figure 11. Percentage error in volume prediction by time of thinning using post-silviculture starting age.

Pruned height

Figures 12 and 13 (pre- and post-silviculture startage, respectively) demonstrate mean % volume error by pruned height, with and without drift factor. Generally, the model was unbiased for pruned stands. For unpruned stands, there was generally an under-prediction bias, although there was less error with post-silviculture starting age.

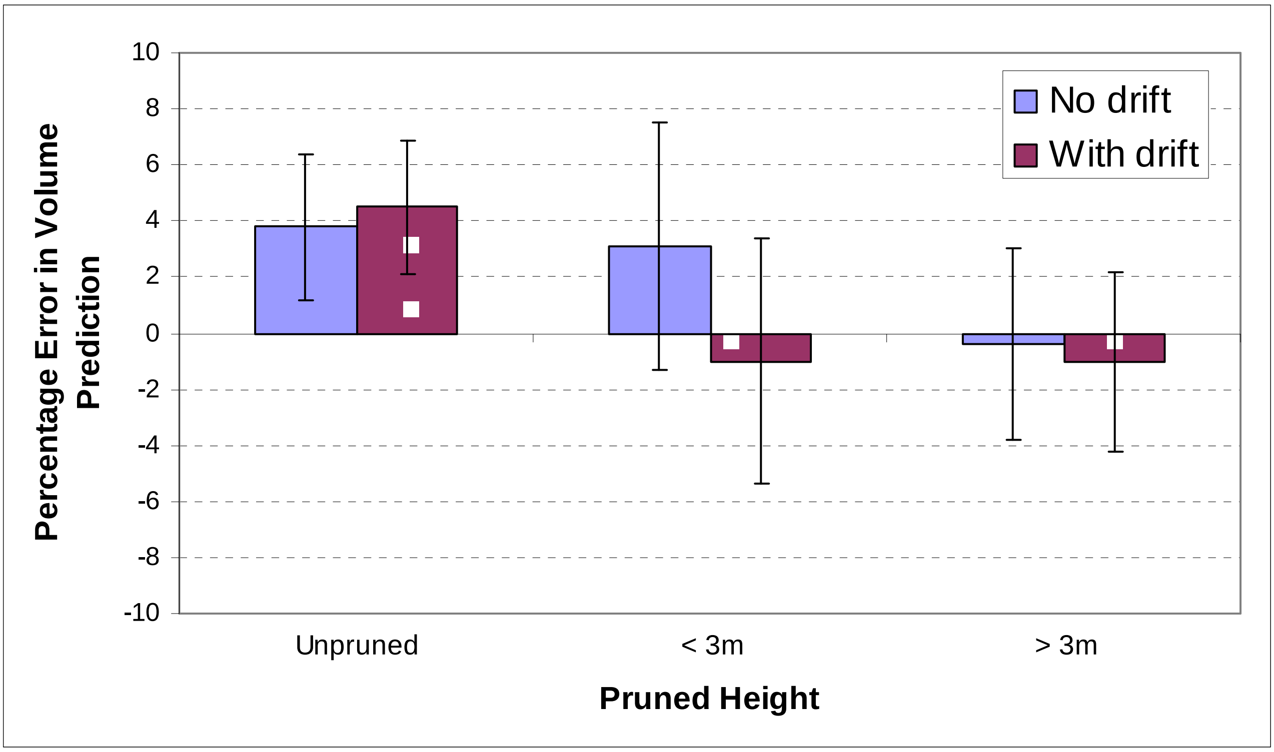


Figure 12. Percentage error in volume prediction by pruned height using pre-silviculture starting age.

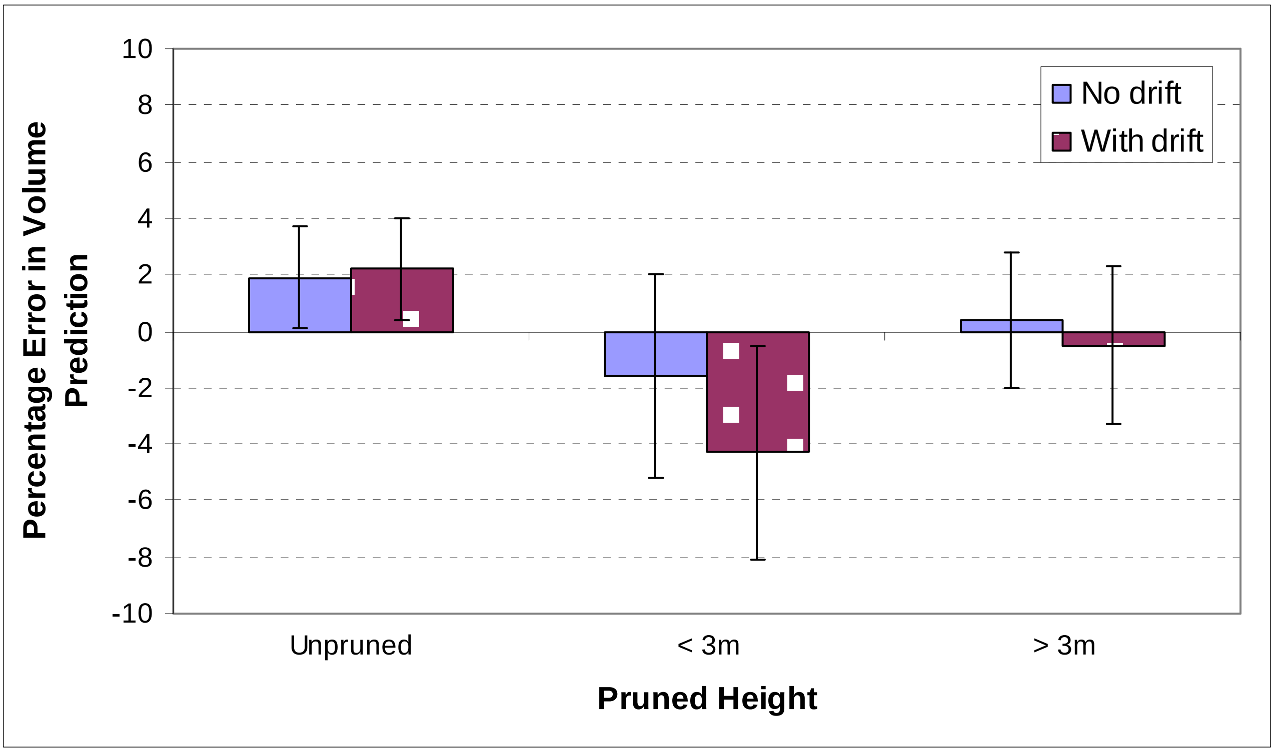


Figure 13. Percentage error in volume prediction by pruned height using post-silviculture starting age.

Length of projection

Figures 14 and 15 (pre- and post-silviculture startage, respectively) show mean % error in volume prediction by length of projection, with and without drift factor adjustment. Note, there were only 10 PSPs with lengths of projection > 30 years and only 13 PSPs with projections between 30-40 years, meaning that these results are indicative only. For lengths of projection less than 30 years, the model was either unbiased or slightly under-predicted volume. For projection lengths of 30-40 years (pre-silviculture starting age) there was a stronger tendency to under-predict, while for prediction lengths longer than 40 years there was a slight (but statistically non-significant) tendency to over-predict volume. With post-silviculture starting age, the length of projection was naturally shorter on average, and only a handful of plots had projection lengths greater than 20 years.

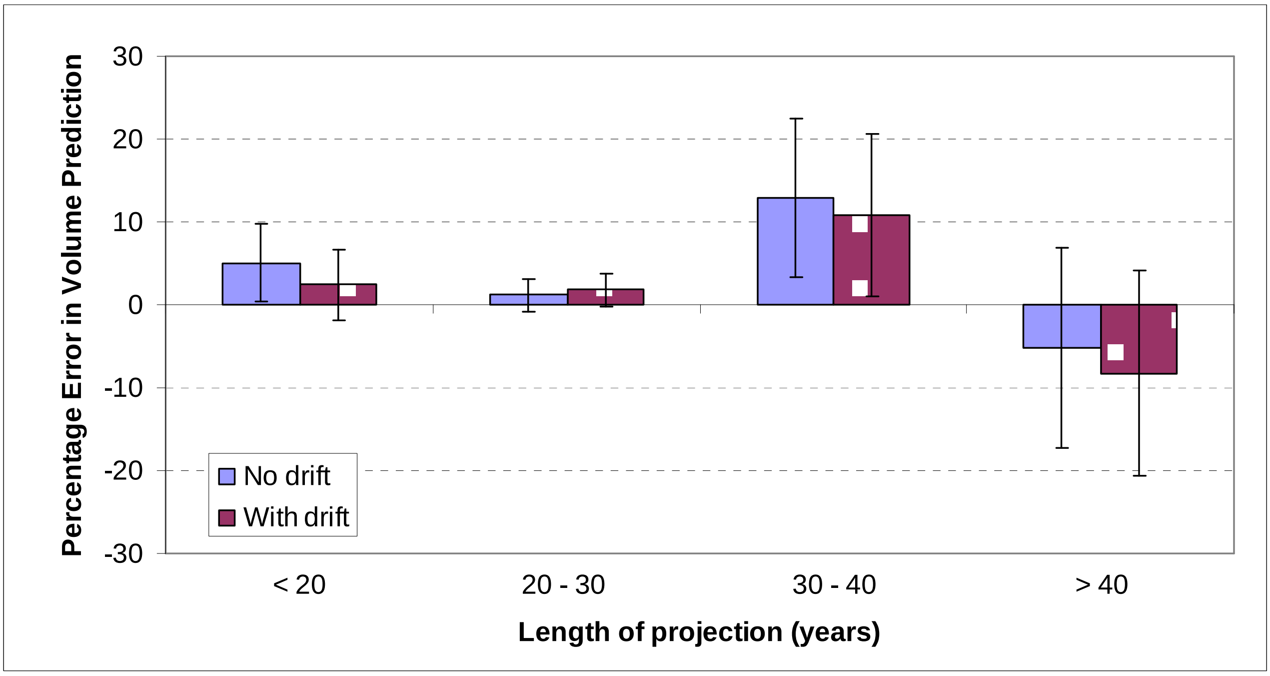


Figure 14. Percentage error in volume prediction by length of projection using pre-silviculture starting age.

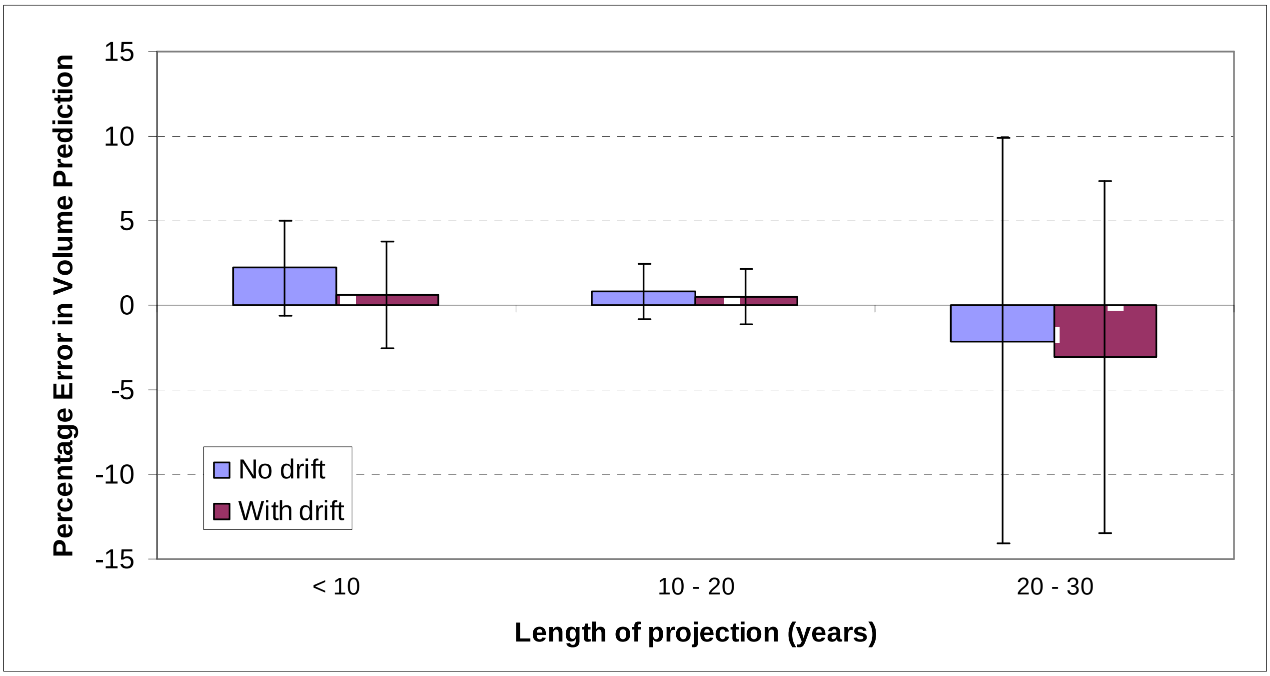


Figure 15. Percentage error in volume prediction by length of projection using post-silviculture starting age.

CONCLUSIONS

- Overall the 300 Index Growth Model showed minimal bias when used to predict yield over a full rotation from a stand measurement made at age 5-10 years.
- A preliminary test of the VBA and Forecaster implementations demonstrated that near-identical results were obtained for a 24.6 year projection for SPH, MTH, BA, and TSV. Additional checks will continue, to confirm this preliminary test.
- The standard model used without drift factor adjustment showed some regional biases especially for Southland (under-prediction) and North Island Coastal Sand forests (over-prediction). However, biases in both these sites were corrected using recommended regional drift factors.
- Using the recommended drift factors, the model appeared to over-predict in Nelson, and North Island East Coast regions and to under-predict in the North Island Clays region, suggesting that drift factors should be revised for these regions.
- The model showed little bias over final stockings ranging between 150 and 550 stems/ha. However, it showed some tendency to under-predict at stockings > 550 stems/ha, and to over-predict at stockings < 150 stems/ha.
- The model showed little bias when tested against timing of thinning. If anything, it had a slight tendency to over-predict yield in stands thinned before age 6 years, and to under-predict in stands thinned after age 12 years.
- When used with recommended regional drift factor adjustments, the model tended to under-predict unthinned stands. This is possibly a reflection of the above-noted tendency to under-predict in highly stocked stands.
- The model showed little bias for pruned stands, but has a tendency to under-predict in unpruned stands.
- The validation dataset contained limited data with projection lengths longer than 30 years. If anything there was a tendency to under-predict over projection lengths of 30-40 years and over-predict for projections > 40 years.

ACKNOWLEDGEMENTS

The authors thank all the organisations who allowed access to their data for this task, Carolyn Andersen for extracting the data from the PSP System, and Les Dowling and Jeremy Snook (ATLAS Technology) for assistance in running Forecaster.

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APPENDIX

Tabulation of percentage mean error of yield variables by factor groupings

Table A1. % Errors by GM Region: Pre-silviculture startage - no drift factor

GM Region	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
CANTY	11	5.9	3.5	-6.1	1.7	-0.1	1.5	-1.6	3.6
CLAYS	46	9.9	1.5	4.1	1.4	0.3	1.3	8.4	2.1
CNI	177	3.5	0.9	1.9	0.8	-4	0.7	3	1.2
ECOT	14	8.2	2.9	-4.5	2.2	-6.3	1.5	2.9	4.1
HBAY	22	8.7	2.6	0.5	1.5	-0.9	2	6.7	2.6
NELSON	21	8.8	4.2	-8.4	3	-2.1	2.4	-5.6	4.8
SANDS	49	-17.9	2.3	-4.6	1.5	0.1	0.8	-16.5	2.7
SOUTH	41	21.8	2.1	-1.6	1.4	-2	1	18.4	2.9
WCOT	12	7.2	3.1	-0.7	3.5	-9.5	2.9	-1.7	5.4
All	**393**	**4.4**	**0.8**	**-0.2**	**0.5**	**-2.6**	**0.4**	**2.3**	**0.9**

Table A2. % Errors by GM Region: Pre-silviculture startage - with drift factor

GM Region	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
CANTY	11	9.2	3.4	-6.1	1.7	-0.1	1.5	1.9	3.6
CLAYS	46	13.1	1.8	4.1	1.4	0.6	1.2	11.6	2.4
CNI	177	2.9	1	1.9	0.8	-4.1	0.7	2.5	1.2
ECOT	14	-3.8	3.3	-4.5	2.2	-6.9	1.5	-9.8	4.6
HBAY	22	5.4	2.6	0.5	1.5	-1.1	2	3.2	2.6
NELSON	21	2.5	4.1	-8.4	3	-2.3	2.4	-13	5
SANDS	49	-0.7	1.9	-4.6	1.5	0.4	0.8	0.9	1.9
SOUTH	41	5.1	2.7	-1.6	1.4	-2.2	1	1	3.7
WCOT	12	10.3	2.9	-0.7	3.5	-9.5	2.9	1.7	5.2
All	**393**	**4.2**	**0.7**	**-0.2**	**0.5**	**-2.7**	**0.4**	**2**	**0.9**

Table A3. % Errors by stocking after last thinning: Pre-silviculture startage - no drift factor

Stocking Class	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 150	27	2.3	2.5	-6.5	3	-2.3	0.9	-8.3	3.8
150 - 250	143	6.3	1.4	-0.6	0.9	-1.2	0.5	3.4	1.7
250 - 350	118	2.1	1.6	-1.6	0.8	-4.2	0.9	0.5	1.7
350 - 450	61	6.1	2	2.9	1.4	-4	1.2	5.8	2.2
450 - 500	27	-0.2	3.4	5.1	2	-6.2	2.1	3.4	3.2
> 550	17	8.4	2	3.9	2.5	6.6	1.2	8.4	1.5
All	**393**	**4.4**	**0.8**	**-0.2**	**0.5**	**-2.6**	**0.4**	**2.3**	**0.9**

Table A4. % Errors by stocking after last thinning: Pre-silviculture startage-with drift factor

Stocking Class	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 150	27	-2.1	3.3	-6.5	3	-2.3	0.9	-13.8	5.1
150 - 250	143	7	1.2	-0.6	0.9	-1.2	0.5	4.1	1.4
250 - 350	118	3.1	1.2	-1.6	0.8	-4.3	0.9	1.3	1.4
350 - 450	61	5.6	1.8	2.9	1.4	-4	1.2	5.3	2
450 - 500	27	-4.7	3.6	5.1	2	-6.4	2.2	-0.9	3.3
> 550	17	7.1	1.8	3.9	2.5	6.4	1.2	6.9	1.6
All	**393**	**4.2**	**0.7**	**-0.2**	**0.5**	**-2.7**	**0.4**	**2**	**0.9**

Table A5. % Errors by time of thinning: Pre-silviculture startage - no drift factor

Time of Thinning (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 8	92	3.5	1.3	-0.6	1.2	-4.4	1.2	-1.6	1.7
8 - 10	77	4.8	1.8	-0.1	0.9	-3	0.9	3.1	1.9
10 - 12	59	5.5	3	0.2	1.3	-2.1	1.1	5.4	3.1
> 12	126	2.4	1.5	1.9	1	-2.4	0.6	3.9	1.6
Unthinned	39	10.7	2	-6.4	2.1	0.5	0.6	0	3.2
All	**393**	**4.4**	**0.8**	**-0.2**	**0.5**	**-2.6**	**0.4**	**2.3**	**0.9**

Table A6. % Errors by time of thinning: Pre-silviculture startage - with drift factor

Time of Thinning (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 8	92	3.5	1.4	-0.6	1.2	-4.4	1.2	-1.2	1.6
8 - 10	77	4	1.8	-0.1	0.9	-3	0.9	2.2	2
10 - 12	59	4	2.1	0.2	1.3	-2.2	1.1	3.8	2.3
> 12	126	5	1.1	1.9	1	-2.4	0.6	6.5	1.2
Unthinned	39	3.5	2.8	-6.4	2.1	0.4	0.6	-8.4	4.1
All	**393**	**4.2**	**0.7**	**-0.2**	**0.5**	**-2.7**	**0.4**	**2**	**0.9**

Table A7. % Errors by pruned height: Pre-silviculture startage - no drift factor

Pruned Height (m)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Unpruned	212	5	1.1	1.2	0.8	-1.5	0.5	3.8	1.3
< 3m	50	1.2	2.1	3.2	1.1	-10.2	1.7	3.1	2.2
> 3m	131	4.6	1.6	-3.7	0.9	-1.6	0.6	-0.4	1.7
All	**393**	**4.4**	**0.8**	**-0.2**	**0.5**	**-2.6**	**0.4**	**2.3**	**0.9**

Table A8. % Errors by pruned height: Pre-silviculture startage - with drift factor

Pruned Height (m)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Unpruned	212	5.7	0.9	1.2	0.8	-1.5	0.5	4.5	1.2
< 3m	50	-3	2.1	3.2	1.1	-10.4	1.7	-1	2.2
> 3m	131	4.4	1.3	-3.7	0.9	-1.6	0.6	-1	1.6
All	**393**	**4.2**	**0.7**	**-0.2**	**0.5**	**-2.7**	**0.4**	**2**	**0.9**

Table A9. % Errors by length of projection: Pre-silviculture startage - no drift factor

Length of projection (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 20	100	7	2.1	-1.4	1	-2.1	0.7	5.1	2.3
20 - 30	280	3.4	0.9	0	0.7	-2.8	0.5	1.2	1
30 - 40	7	9.4	3.4	9.2	3.7	-5.6	3.3	12.9	4.8
> 40	6	1.1	5.2	-0.4	2.4	1.2	1	-5.2	6
All	**393**	**4.4**	**0.8**	**-0.2**	**0.5**	**-2.6**	**0.4**	**2.3**	**0.9**

Table A10. % Errors by length of projection: Pre-silviculture startage - with drift factor

Length of projection (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 20	100	4.6	1.7	-1.4	1	-2.1	0.7	2.4	2.1
20 - 30	280	4.1	0.8	0	0.7	-2.9	0.5	1.8	1
30 - 40	7	7.3	3.2	9.2	3.7	-5.7	3.2	10.8	4.9
> 40	6	-1.8	5.3	-0.4	2.4	1.1	1	-8.3	6.2
All	**393**	**4.2**	**0.7**	**-0.2**	**0.5**	**-2.7**	**0.4**	**2**	**0.9**

Table A11. % Errors by GM Region: Post-silviculture startage - no drift factor

GM Region	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
CANTY	13	-3	2.5	-5.9	1	-0.1	1.3	-11.3	3.2
CLAYS	45	5	1	0.6	0.6	1.6	0.9	0.1	1.6
CNI	161	0.5	0.8	-0.6	0.4	-3.2	0.6	-2.1	0.9
ECOT	13	6	1.7	0.8	1.4	-3.7	1.8	5.3	1.6
HBAY	26	12.9	2.6	0.5	1.1	0.6	1.3	11.2	2.8
NELSON	21	7	2.6	-7.2	1.3	-2.2	2.4	-7	2.9
SANDS	50	3.4	1.1	-0.6	0.9	1	0.5	7.3	2
SOUTH	44	13.5	1	-1.8	0.8	-0.1	0.6	10.3	1.4
WCOT	13	3.4	3.2	-8.8	1.6	-4.1	2.7	-15	5.9
All	**386**	**4.2**	**0.5**	**-1.3**	**0.3**	**-1.4**	**0.4**	**1**	**0**

Table A12. % Errors by GM Region: Post-silviculture startage - with drift factor

GM Region	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
CANTY	13	-0.6	2.4	-5.9	1	-0.1	1.3	-8.7	3.1
CLAYS	45	7.3	1.1	0.6	0.6	1.8	0.9	2.4	1.8
CNI	161	0.3	0.9	-0.6	0.4	-3.2	0.6	-2.3	0.9
ECOT	13	-0.6	1.9	0.8	1.4	-4	1.9	-1.2	1.7
HBAY	26	11.3	2.6	0.5	1.1	0.5	1.3	9.5	2.8
NELSON	21	3	2.6	-7.2	1.3	-2.4	2.4	-11.6	3
SANDS	50	11.8	1.2	-0.6	0.9	1.1	0.5	15.3	1.8
SOUTH	44	2.4	1.2	-1.8	0.8	-0.3	0.6	-1.3	1.5
WCOT	13	5.4	3.1	-8.8	1.6	-4.1	2.7	-12.5	5.7
All	**386**	**3.8**	**0.6**	**-1.3**	**0.3**	**-1.4**	**0.4**	**0.5**	**0.7**

Table A13. % Errors by stocking after last thin: Post-silvi startage - no drift factor

Stocking Class	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 150	26	0.1	1.5	-4.1	1.3	-0.7	0.8	-8.5	2.1
150 - 250	136	3.1	1	-1.2	0.5	-0.5	0.4	-0.3	1.2
250 - 350	120	4.7	1	-1.1	0.5	-2.6	0.7	3.2	1.3
350 - 450	59	4.2	1	-0.7	0.8	-2.1	1	0.1	1.4
450 - 500	27	4.7	2	0.1	1.1	-4.9	1.9	3	2.1
> 550	18	15.4	2	-2.7	1.2	7.2	1.1	9.3	2.5
All	**386**	**4.2**	**0.5**	**-1.3**	**0.3**	**-1.4**	**0.4**	**1**	**0.7**

Table A14. % Error by stocking after last thin: Post-silviculture startage - with drift factor

Stocking Class	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 150	26	-1.9	1.7	-4.1	1.3	-0.6	0.8	-10.8	2.5
150 - 250	136	3.1	1	-1.3	0.5	-0.5	0.4	-0.4	1.2
250 - 350	120	4.7	1.1	-1.1	0.5	-2.7	0.7	3.1	1.5
350 - 450	59	3.9	1.1	-0.7	0.8	-2.1	1	-0.3	1.4
450 - 500	27	2.1	2.1	0.1	1.1	-5.2	1.9	0.5	2.2
> 550	18	14.7	1.7	-2.7	1.2	7.1	1.1	8.5	2.3
All	**386**	**3.8**	**0.6**	**-1.3**	**0.3**	**-1.4**	**0.4**	**0.5**	**0.7**

Table A15. % Errors by time of thinning: Post-silviculture startage - no drift factor

Time of Thinning (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 8	92	0.6	1	-0.5	0.5	-2.5	1	-4.6	1.2
8 - 10	73	0.4	1.4	-1.8	0.6	-1.3	0.8	-2.9	1.6
10 - 12	62	8.6	1.5	-1.6	0.7	-0.5	0.8	6.7	1.7
> 12	115	7.2	0.9	-0.6	0.6	-1.9	0.6	6.6	1.1
Unthinned	44	4.5	1.4	-3.4	1	1.1	0.5	-3.8	2.2
All	**386**	**4.2**	**0.5**	**-1.3**	**0.3**	**-1.4**	**0.4**	**1**	**0.7**

Table A16. % Errors by time of thinning: Post-silviculture startage - with drift factor

Time of Thinning (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 8	92	0.8	1	-0.6	0.5	-2.5	1	-4.3	1.1
8 - 10	73	-0.1	1.4	-1.8	0.6	-1.3	0.8	-3.4	1.6
10 - 12	62	6.9	1.4	-1.6	0.7	-0.6	0.8	4.8	1.7
> 12	115	8.5	0.9	-0.6	0.6	-1.9	0.6	7.7	1.2
Unthinned	44	0.3	1.2	-3.4	1	1	0.5	-8.3	2
All	**386**	**3.8**	**0.6**	**-1.3**	**0.3**	**-1.4**	**0.4**	**0.5**	**0.7**

Table A17. % Errors by pruned height: Post-silviculture startage - no drift factor

Pruned Height (m)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Unpruned	205	5.2	0.7	-1	0.4	-0.4	0.5	1.9	0.9
< 3m	50	-0.4	2	-0.2	0.7	-7.5	1.4	-1.6	1.8
> 3m	131	4.5	0.9	-2.2	0.5	-0.6	0.5	0.4	1.2
All	**386**	**4.2**	**0.5**	**-1.3**	**0.3**	**-1.4**	**0.4**	**1**	**0.7**

Table A18. % Errors by pruned height: Post-silviculture startage - with drift factor

Pruned Height (m)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
Unpruned	205	5.5	0.6	-1	0.4	-0.4	0.5	2.2	0.9
< 3m	50	-3	2	-0.2	0.7	-7.7	1.4	-4.3	1.9
> 3m	131	3.9	1	-2.2	0.5	-0.6	0.5	-0.5	1.4
All	**386**	**3.8**	**0.6**	**-1.3**	**0.3**	**-1.4**	**0.4**	**0.5**	**0.7**

Table A19. % Errors by length of projection: Post-silviculture startage - no drift factor

Length of projection (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 10	56	3.4	1.1	-1.2	0.7	-0.1	0.5	2.2	1.4
10 - 20	327	4.4	0.6	-1.3	0.3	-1.5	0.4	0.8	0.8
20 - 30	3	4.5	5.9	-3	1	-7.3	8.5	-2.1	6
All	**386**	**4.2**	**0.5**	**-1.3**	**0.3**	**-1.4**	**0.4**	**1**	**0.7**

Table A20. % Errors by length of projection: Post-silviculture startage - with drift factor

Length of projection (years)	No. Plots	BA (m^2/ha)		MTH (m)		Stocking (stems/ha)		Volume (m^3/ha)	
		Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err
< 10	56	2.1	1.1	-1.2	0.7	-0.2	0.5	0.6	1.6
10 - 20	327	4.2	0.6	-1.3	0.3	-1.6	0.4	0.5	0.8
20 - 30	3	3.6	5.3	-3	1	-7.4	8.5	-3.1	5.2
All	**386**	**3.8**	**0.6**	**-1.3**	**0.3**	**-1.4**	**0.4**	**0.5**	**0.7**