PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: info@ffr.co.nz
Web: www.ffr.co.nz

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Comparison of Individual-tree Growth Models

Author(s):
B Shula, M Fritzsche, M Kimberley

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EXECUTIVE SUMMARY

There are a host of stand- and tree-level radiata pine growth models available to Future Forest Research Ltd (FFR) via ATLAS Technology and/or Silmetra Ltd. Growth models were produced for a specific purpose and/or client, and at a particular time (historic to present-day databases). This begs the question of the model's comparative prediction accuracy at the stand level (i.e., aggregated or per hectare) and tree level (i.e., disaggregated or individual-tree).

As per FFR's Growth Modelling and Wood Properties Strategy, FFR is moving through a phase of testing existing models before embarking on the development of new models. This not only applies to growth models, but also to wood quality models and their incorporation with growth models. The responsibility of model developers does not stop with the creation of a model, but also includes the provision of a software reference implementation of the model, implementation testing, and testing the model for accuracy of prediction.

The objective of this report is to document the tree-level performance of two tree-level growth models (ii and iii, below) using the same dataset and growth models that had previously been compared at the stand level. FFR report R016 documents the dataset and stand-level performance of:

i) the state-space methodology of Oscar Garcia (state-space) from the 1980s,
ii) the distance independent tree-level methodology of Bob Shula (ITGM) from the 1990s,
iii) the current 300 Index methodology (300I GM) of Mark Kimberley.

The stand- and tree-level comparisons are based on a Permanent Sample Plot dataset that i) was ex-Carter Holt Harvey, now managed by Hancock Forest Management (NZ) Ltd., ii) is independent of model development, and iii) represents the CLAYS, CNI, NELSON, and SANDS growth modelling regions. Herein, a total of 211 Permanent Sample Plots (PSPs) were used, representing 3,417 PSP x Projection Period combinations. PSPs were selected that were in close agreement for stand-level predictions of DBH and SPH. This approach ensured that any differences between the models that occurred at the tree level were not simply an artefact of differences that had originated from stand-level predictions.

At the tree level, the performance of 300I - IT and ITGM mirrors the comparison at the stand-level, i.e., similar, acceptable performance over Projection Periods approaching 15 years. Interestingly, each model uses significantly different methods to project tree-level DBH and Height (tree-size) into the future, but nonetheless, each is valid and robust, and provides acceptable, plausible predictions of future tree-size attributes.

Both models had relatively unbiased DBH residuals, although Height residuals tended toward over-prediction. Overall, 300I - IT tended to produce marginally superior tree-level DBH and Height residuals and variance ratios. Both models tended to maintain an unbiased consistent spread of DBH residuals after about a 6-year Projection Period, whereas an unbiased consistent spread of Height residuals occurred throughout all Projection Periods.

300I - IT provided greater DBH and Height variance, indicating greater statistical variability in predicted tree-size distributions. Nonetheless in a practical sense, a comparison of resulting tree-size distributions suggested similarity between the models. The use of a Weibull function to recover a tree-size distribution from stand-level models appeared both statistically and practically inferior to the explicit tree-level modelling approach.

Given the level of information required to drive each model, e.g., silivcultural management history for 300I - IT and stand- and tree-level variables for ITGM, each model is suited to a particular primary purpose. 300I - IT is suited to early rotation projection, where the effect of management history on prediction is paramount. ITGM is suited to mid-rotation projection, where post-silviculture inventory projection is paramount. Nonetheless overall, 300I - IT is the more robust and better adapted tree-level model because it is able to operate across a full rotation, inclusive of the early establishment years, silvicultural years, and mid-rotation onward years.

INTRODUCTION

As per Future Forest Research Ltd's (FFR's) Growth Modelling and Wood Properties Strategy [(1)], FFR is moving through a phase of testing existing models before embarking on the development of new models. This not only applies to growth models, but also to wood quality models and their incorporation with growth models. The responsibility of model developers does not stop with the creation of a model, but also includes the provision of a software reference implementation of the model, implementation testing, and testing the model for accuracy of prediction.

The objective of this report is to document the tree-level performance of two growth models (ii and iii, below) using the same dataset and growth models that had previously been compared at the stand-level. FFR report R016 [(2)] documents the dataset and stand-level performance of three radiata pine growth models, i.e.,:

i) the state-space methodology of Oscar Garcia (State-space) from the 1980s [(3)],
ii) the distance independent tree-level methodology of Bob Shula (ITGM) from the 1990s [(4)],
iii) the current 300I methodology (300I GM) of Mark Kimberley [(5)].

i) The State-space modelling approach directly predicts stand-level attributes at time2 based on stand-level attributes at time1. Tree size class distribution at time2 (e.g., predicted DBH distribution) is recovered by the use of a disaggregative function, such as, a Weibull function [(6)].

ii) ITGM is a distance-independent individual-tree growth model, whereby annual increment of tree DBH and total Height is directly predicted from a combination of tree- and stand-level variables. Predicted annual increment is added to starting DBHs and Heights at time1 (tree-list1) to derive ending DBHs and Heights at time2 (tree-list2). ITGM obtains stand-level predictions per hectare at time2 by summing predicted individual-tree attributes, weighted by plot-expansion factors that are modified by annual prediction of individual-tree probability of survival.

iii) Driven by the stand-level 300I GM, 300I – IT is a distance-independent tree-level growth model. To project from time1 to time2, the tree-level model relates relative growth rate of an individual tree (, i.e., the growth rate of a tree divided by the mean tree growth rate) to the relative size of an individual tree (i.e., the size of an individual tree divided by the mean tree size). Absolute growth rate of the mean tree (from time1 to time2) is driven by the stand-level 300I GM.

Tree-level comparisons are based on a PSP (Permanent Sample Plot) dataset that:

- was originally selected for the stand-level comparison of growth models,
- is ex-Carter Holt Harvey, now managed by Hancock Forest Management (NZ) Ltd.,
- is independent of growth model development, and
- represents four growth modelling Regions (**Table 1 and 1a**).

Table 1. Number of PSPs by Region in the analyses.

Region	No. of PSPs	
	Stand-Level	**Tree-Level**
CNI	487	**69**
SANDS	310	**61**
NELSON	214	**47**
CLAYS	149	**34**
ALL	1160	**211**

PSPs were not randomly selected, but rather chosen because they were in close agreement (see Methods) for stand-level predictions of DBH and SPH. This approach ensured that any differences between the models that occurred at the tree level were not simply an artefact of differences that had originated from stand-level predictions.

Table 1a. Number of simulated Projection Periods by Region in the tree-level analysis.

Region	No. of PSP x Projection Periods	No. of Tree-Level DBH Projections	No. of Tree-Level Height Projections
CNI	1692	63115	30467
SANDS	765	23264	11230
NELSON	512	11690	5643
CLAYS	448	12656	6109
ALL	3417	110725	53449

Previous stand-level comparisons indicated that the overall performances of the three models were very similar and each gave plausible results. Nonetheless, for all models and regions there were some stand-level predictions with large errors, and in these cases, all three models tended to produce similar large errors. These anomalies could be the subject of future investigations. Given the overall favourable results, no one model was recommended over and above another. This was not surprising since all three models had been derived with robust, statistical rigour and to a large extent, the use of common PSPs.

In the current tree-level model comparison, the approach taken was to accept the previous stand-level predictions of:

- mean top Height (MTH),
- basal area per hectare (BA), and
- Stocking per hectare (SPH);

but instead of comparing models at the stand level, compare the growth models' relative ability to predict individual-tree:

- DBH and
- total Height.

METHODS

The tree-level models and versions tested in this analysis were:

- ITGM (ATLAS Forecaster version 1.4),
- 300I - IT (tree-level version of the 300I GM, ATLAS Forecaster version 1.4), and
- 300I – Wb (tree-size distributions via Weibull functions, ATLAS Forecaster version 1.4).

In the current tree-level comparison, the approach taken was to select simulations from the previous stand-level comparison, where the two growth models were in close agreement, as described below. This approach ensured that any differences between the models that occurred at the tree level were not simply an artefact of differences that had originated from stand-level predictions. The strict criteria that were used to select simulations for comparison included stand-level simulations across the two models that were within difference limits of:

- 2 m^2 / ha BA and
- 2 SPH.

Simulation starting stand ages and Projection Periods, respectively, were from:

- 12 to 18 years (as constrained by ITGM, which is a post-silviculture, mid-rotation onwards tree-level growth model), and from
- ≤ 1 to 25 years.

Statistics and graphical analysis of tree-level model comparisons included:

i) prediction residuals of DBH and total Height,
ii) variance ratio (variance of the predicted / variance of the actual), and
iii) DBH distributions on a PSP at a given age and Projection Period.

i) Prediction residuals provide a quantitative measure of the prediction accuracy of a model. Ideally, the residuals are minimised (near zero) and unbiased (without trend). Herein, residuals are compared only for ITGM and 300I – IT.

ii) The variance ratio statistic was previously used and described in Stand Growth Modelling Cooperative Report No. 30 [(7)]. The variance ratio provides a relative measure of the dispersion (distribution) of tree size (e.g., DBH or total Height) on a PSP at a given age and Projection Period for the 'predicted' relative to the 'actual' attribute. As the size distribution (spread) of the 'predicted' and 'actual' approach parity, the variance ratio approaches 1. Variance ratios < 1 and > 1, respectively, indicate that predicted size distributions are either more narrowly or more widely spread than actual size distributions. Because a perceived advantage of tree-level models is the preservation of features at the individual-tree level (relative to a stand average), the inherent expectation is that variance ratios should be at least ≥ 1, i.e., size distribution is at least preserved, not truncated. Herein, variance ratios are compared for 300I – IT, 300I – Wb, and ITGM.

iii) DBH distributions provide a graphical demonstration of the tree-size distribution within a stand (or PSP that is representative of a stand). Ideally, actual and predicted DBH distributions are of identical form from tail to tail. The traditional approach of combining a stand-level growth model and the recovery of a size class distribution using a Weibull function was also included for a comparison of the 300I GM (300I – Wb) with 300I – IT and ITGM. 300I GM was used to predict BA, MTH and SPH, and then ATLAS Forecaster functions were used to predict DBH and Height distributions compatible with these stand parameters. The ATLAS functions consisted of a Weibull function to predict SPH within DBH classes, and a Petterson height curve [(8)] to predict the mean Height within each DBH class. The Weibull and Pettersen coefficients are specified for each growth modelling region, and the appropriate regional coefficients were therefore used, i.e., for CNI, SANDS, NELSON, and CLAYS. Having generated the DBH and Height distributions for each model run, DBH and Height variances were calculated and compared with actual variances using the variance ratio method, as described above.

RESULTS

DBH residuals – Table and figures

DBH mean residuals for Regions by Projection Period and Stocking are presented in **Table 2 and Figures 1-2**; commentary follows on the next page. DBH mean residuals by Region, and tree-level residuals by Region, Projection Period, and Stocking are provided in **Appendix 1a, 1b, and 1c.**

Table 2. DBH mean residuals (cm) by Region and Projection Period.

		Projection Period (years)				
		All	**<5**	**5-10**	**10-15**	**>15**
All Regions	ITGM	-0.88	-0.41	-1.3	-1.78	-1.74
	300I - IT	-0.23	-0.18	-0.53	0.2	0.75
Clays	ITGM	-0.45	-0.35	-0.69	-1.2	na
	300I - IT	0.15	0.13	0.2	0.27	na
CNI	ITGM	-0.93	-0.4	-1.26	-1.61	-1.67
	300I - IT	-0.04	-0.16	-0.26	0.58	0.83
Nelson	ITGM	-1.12	-0.72	-1.83	-1.47	na
	300I - IT	0.06	-0.03	0.05	1.4	na
Sands	ITGM	-0.89	-0.32	-1.37	-3.08	-4.63
	300I - IT	-1.08	-0.5	-1.74	-2.57	-2.67

Figure 1. DBH Mean Residuals by Projection Period
All Regions

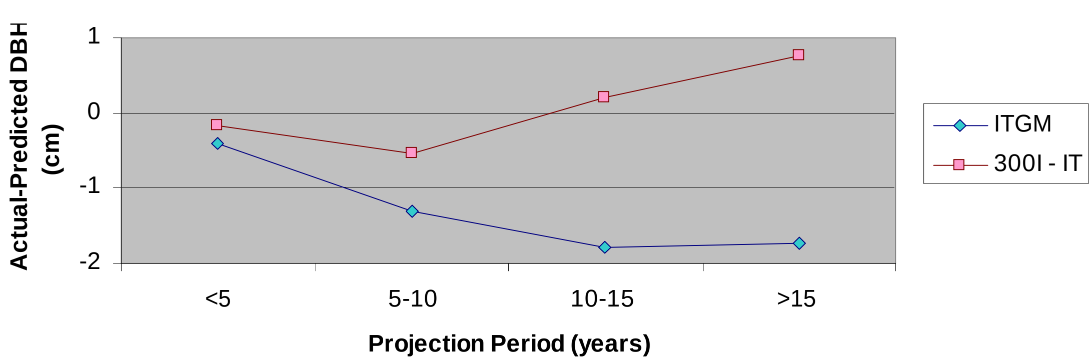
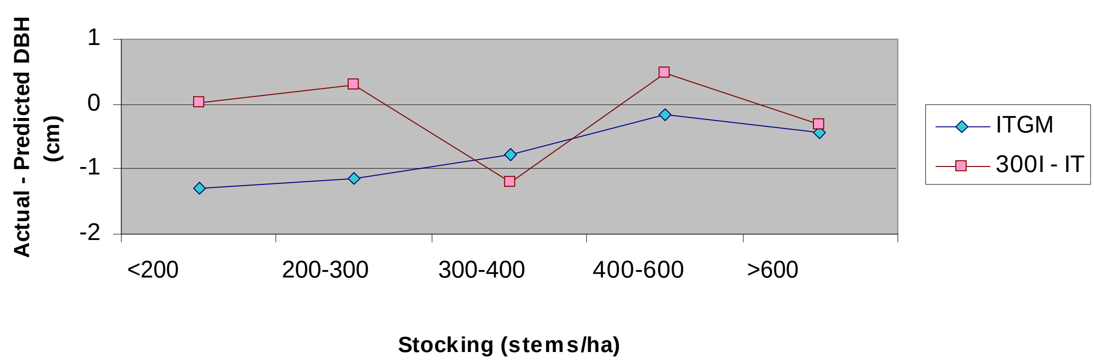


Figure 2. DBH Mean Residuals by Stocking
All Regions



DBH Residuals - Commentary

Table 2 and Figure 1 demonstrate that averaged across all Regions and Projection Periods, 300I - IT and ITGM both over-estimate tree-level DBH (negative mean residual), although 300I - IT performed better, minimising DBH mean residuals by 0.65 cm relative to ITGM. As Projection Period increased beyond 10 years to > 15 years, 300I - IT under-estimated DBH (approaching 1 cm), but ITGM continued to over-estimate DBH (approaching 2 cm). This trend is similar by Region (**Appendix 1a**), except for the Sands region, where unexplainably, both models consistently over-estimated DBH (ITGM approaching 5 cm, 300I - IT approaching 3 cm). **Figure 2** demonstrates that as stocking increases, 300I - IT generally maintains unbiased residuals, whereas, ITGM is more biased at lower stockings (< 300-400 SPH), but less biased at higher stocking (> 400 SPH).

As Projection Period increased (by Region, **Appendix 1b**), trend lines in tree-level DBH residuals demonstrate a relatively unbiased spread by both models (although, in opposite directions for Clays, CNI, and Nelson regions). However in the Sands region, both models, unexplainably, are biased toward over-estimation. Notably, the Nelson region has some residuals at a 6-year Projection Period, where unexplainably, both models struggled (ITGM more so) to predict DBH accurately.

As Projection Period and stocking increase (All Regions), trend lines in tree-level DBH residuals for ITGM (**Appendix 1c**) demonstrate a relatively unbiased spread at higher stocking (400-600 SPH), but more biased over-estimates at lower stockings (< 300 SPH). Tree-level DBH residuals for 300I - IT demonstrate a relatively unbiased spread at stocking 300-400 SPH, but biased over-estimates at higher stocking (400-600 SPH) and biased under-estimates at lower stocking (< 300 SPH).

Height Residuals – Commentary

(Tables and Figures follow on the next page)

Table 3 and Figure 3 demonstrate that averaged across all Regions and Projection Periods, 300I - IT and ITGM both over-estimate tree-level Height (negative mean residual), although again, 300I - IT performed better, minimising Height mean residuals by 0.25 m relative to ITGM. As Projection Period increased to > 15 years, both models were biased toward over-estimation, although 300I - IT was consistently less biased (approaching 1.5 m; ITGM approaching 2 m). The trend is similar by Region (**Appendix 2a**), except for the Sands region, where the models perform very similarly.

As Projection Period increases (by Region, **Appendix 2b;** all Regions, **Appendix 2c**), trend lines for both models in tree-level Height residuals demonstrate a consistent bias toward over-prediction, although 300I - IT performed better with less bias in the Clays and CNI regions, and ITGM performed better with less bias in the Nelson and Sands regions.

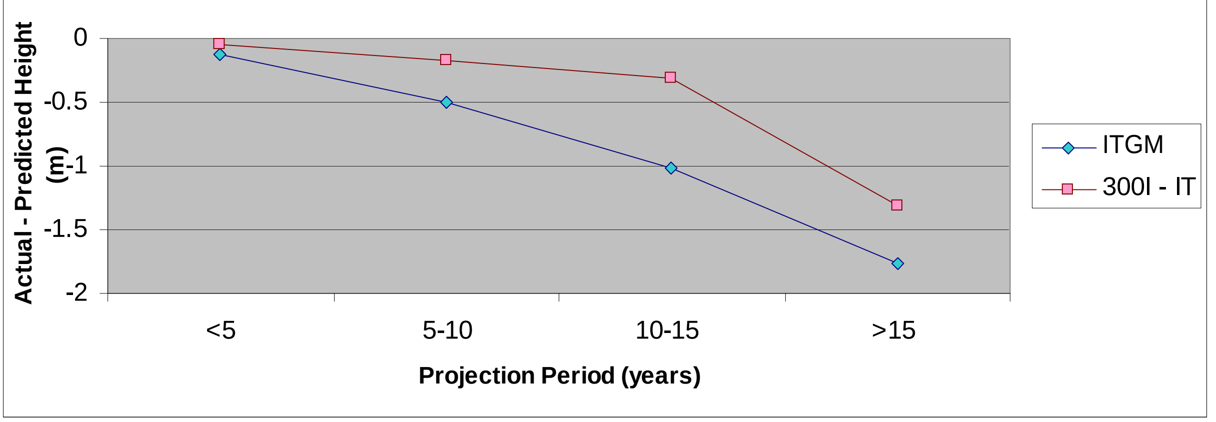
Height Residuals – Table and Figures

Height mean residuals for Regions by Projection Period are presented in **Table 3 and Figure 3**; commentary was provided on the previous page. Height mean residuals by Region, and tree-level residuals by Region and Projection Period are provided in **Appendix 2a, 2b, and 2c.**

Table 3. Height mean residuals (m) by Region and Projection Period.

		Projection Period (years)				
		All	**<5**	**5-10**	**10-15**	**>15**
All Regions	ITGM	-0.41	-0.13	-0.50	-1.01	-1.77
	300I - IT	-0.16	-0.05	-0.17	-0.31	-1.32
Clays	ITGM	-0.21	-0.06	-0.64	-1.68	na
	300I - IT	-0.07	-0.04	-0.14	-0.83	na
CNI	ITGM	-0.52	-0.14	-0.60	-1.09	-1.69
	300I - IT	-0.08	0.04	-0.02	-0.18	-1.21
Nelson	ITGM	-0.48	-0.32	-0.66	-1.15	na
	300I - IT	-0.63	-0.33	-0.93	-2.24	na
Sands	ITGM	-0.02	0.02	0.13	-0.29	-3.75
	300I - IT	-0.30	-0.18	-0.33	-0.44	-4.12

Figure 3. Height Mean Residuals by Projection Period
All Regions



DBH Mean Variance Ratio – Table and figures

DBH mean variance ratio for Regions by Projection Period and Stocking are presented in **Table 4 and Figures 4-5**; commentary was provided on the previous page. DBH mean variance ratio by Region and Projection Period is provided in **Appendix 3.**

Table 4. DBH mean variance ratio by Region and Projection Period.

		Projection Period (years)				
		All	< 5	5-10	10-15	>15
All Regions	300I - IT	1.09	1.04	1.13	1.19	1.26
	ITGM	0.91	0.96	0.87	0.80	0.70
	300I - Wb	0.87	0.87	0.87	0.88	0.99
Clays	300I - IT	1.20	1.11	1.41	2.03	na
	ITGM	1.07	1.03	1.18	1.49	na
	300I - Wb	0.97	0.96	0.98	1.12	na
CNI	300I - IT	1.07	1.03	1.09	1.13	1.26
	ITGM	0.86	0.94	0.82	0.73	0.70
	300I - Wb	0.76	0.74	0.74	0.77	0.99
Nelson	300I - IT	1.01	1.01	1.01	0.99	na
	ITGM	0.87	0.92	0.80	0.66	na
	300I - Wb	0.91	0.89	0.92	1.08	na
Sands	300I - IT	1.12	1.05	1.17	1.35	1.02
	ITGM	0.94	0.96	0.91	0.95	0.59
	300I - Wb	1.05	1.04	1.05	1.15	1.13

Figure 4. DBH Mean Variance Ratio by Projection Period - All Regions

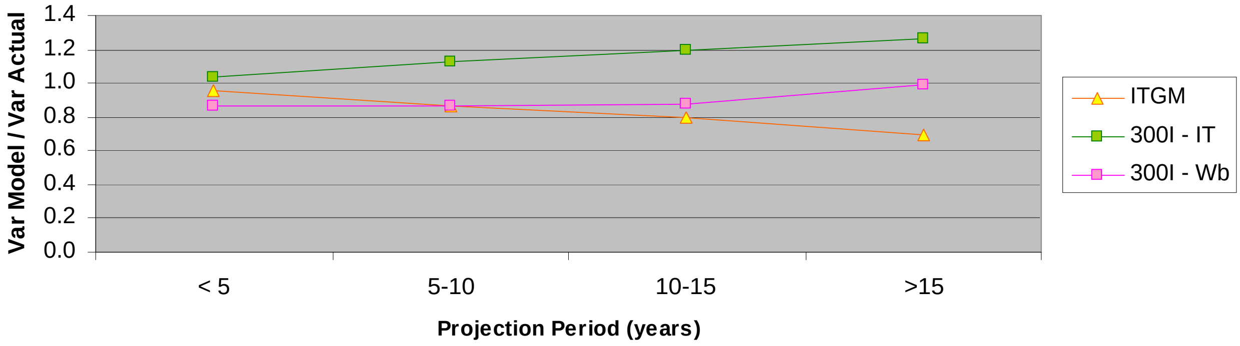
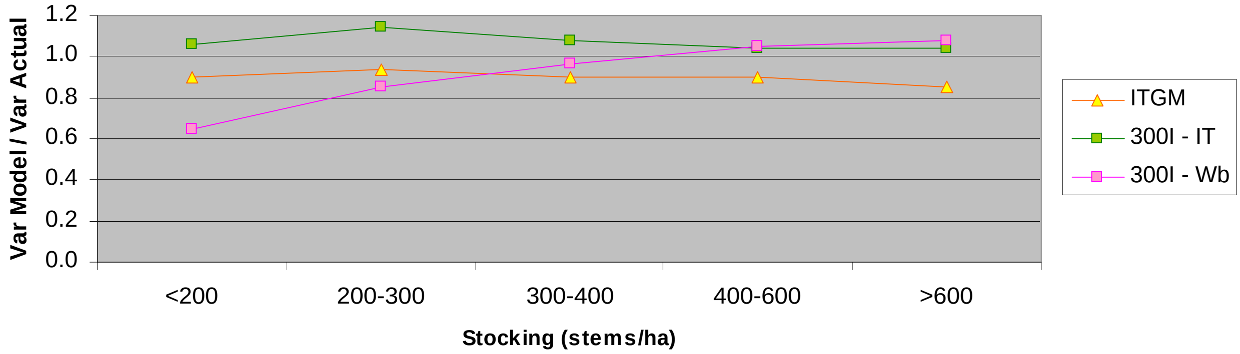


Figure 5. DBH Mean Variance Ratio by Stocking - All Regions



DBH Mean Variance Ratio - Commentary

Table 4 and Figure 4 demonstrate that averaged across all Regions and Projection Periods, 300I - IT and ITGM over- and under-estimate DBH variance by about 9%, respectively. The Weibull function under-estimated DBH variance by an additional 4%. As Projection Period increased, 300I - IT consistently over-estimated DBH variance (approaching 120%), while ITGM consistently under-estimated DBH variance (approaching 70%). The Weibull Function maintained an under-estimation of DBH variance; however it reversed and approached 100% at the longest Projection Period (> 15 years). This trend in DBH variance ratio by the models is similar by Region (**Appendix 3**), except for the Clays region, where ITGM consistently over-estimated DBH variance as Projection Period increased.

Figure 5 demonstrates that as stocking increases, 300I - IT and ITGM both maintain consistent DBH variance ratios, while the Weibull Function increased in DBH variance ratio, as stocking increased.

Height Mean Variance Ratio – Commentary

(note: Tables and Figures follow on the next page)

Table 5 and Figure 6 demonstrate that averaged across all Regions and Projection Periods, 300I - IT estimated near perfectly (1% over-estimation) Height variance, whereas ITGM and the Weibull function significantly under-estimated Height variance, i.e., 23% and 70%, respectively.

As Projection Period increased, 300I - IT maintained an excellent Height variance ratio, except at the longest Projection Period (> 15 years), where Height variance was under-estimated by nearly 40%. In contrast, ITGM consistently under-estimated Height variance from a high of nearly 80% to a low approaching 20%. The Weibull function maintained a consistent significant under-prediction around < 40%.

This trend in Height variance ratio by the models is similar by Region (**Appendix 4**), except for the Nelson and Sands regions, where the Weibull function maintained a much higher level of Height variance ratio (i.e., >80%). ITGM consistently under-estimated Height variance as Projection Period increased, as did 300I - IT in the CNI region.

Figure 7 demonstrates that as stocking increased, 300I - IT and ITGM both maintain consistent Height variance ratios. To the contrary, as stocking increased, the Weibull Function increased in DBH variance ratio from a low of <10% to a high of 50%.

Height Mean Variance Ratio – Table and figures

Height mean variance ratio for Regions by Projection Period and Stocking are presented in **Table 5 and Figures 6-7**; commentary was provided on the previous page. Height mean variance ratio by Region and Projection Period is provided in **Appendix 4.**

Table 5. Height mean variance ratio by Region and Projection Period.

		Projection Period (years)				
		All	**< 5**	**5-10**	**10-15**	**>15**
All Regions	300I - IT	1.01	1.02	1.03	0.99	0.61
	ITGM	0.77	0.88	0.69	0.56	0.22
	300I - Wb	0.30	0.32	0.28	0.27	0.32
Clays	300I - IT	0.97	0.98	0.95	1.04	na
	ITGM	0.77	0.83	0.64	0.53	na
	300I - Wb	0.20	0.18	0.25	0.24	na
CNI	300I - IT	0.91	0.95	0.91	0.84	0.62
	ITGM	0.68	0.83	0.61	0.47	0.22
	300I - Wb	0.24	0.22	0.22	0.28	0.32
Nelson	300I - IT	1.11	1.15	1.09	0.65	na
	ITGM	0.85	0.97	0.70	0.35	na
	300I - Wb	0.52	0.54	0.50	0.49	na
Sands	300I - IT	1.19	1.08	1.26	1.63	0.37
	ITGM	0.93	0.96	0.88	0.93	0.30
	300I - Wb	0.36	0.45	0.28	0.15	0.17

Figure 6. Height Mean Variance Ratio by Projection Period - All Regions

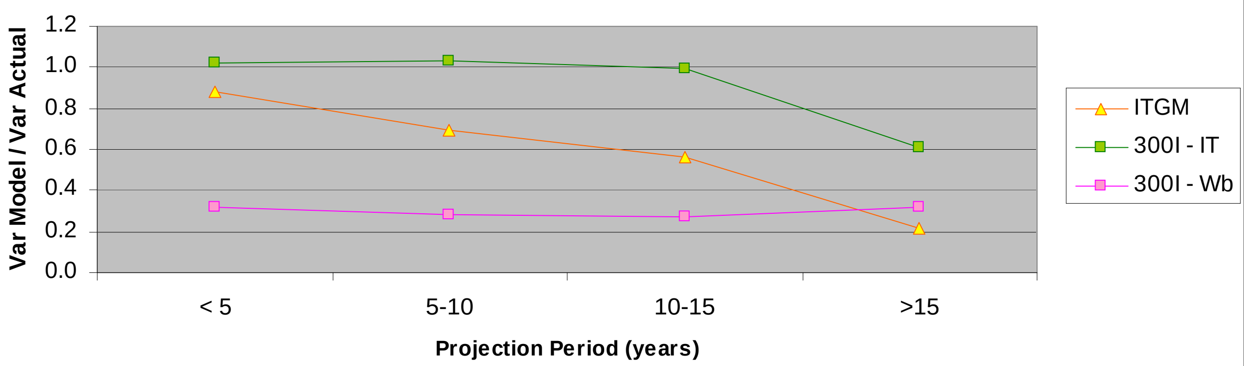
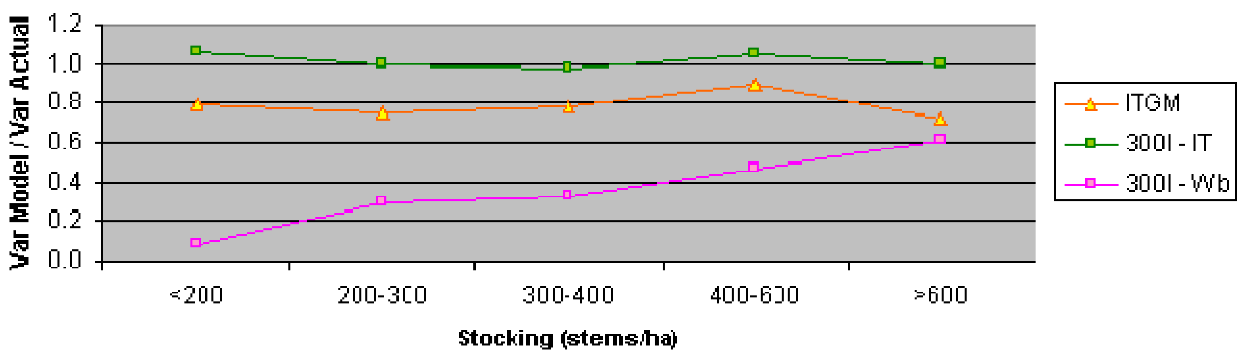


Figure 7. Height Mean Variance Ratio by Stocking - All Regions



DBH Distributions – Commentary

(note: Figures follow on the next page)

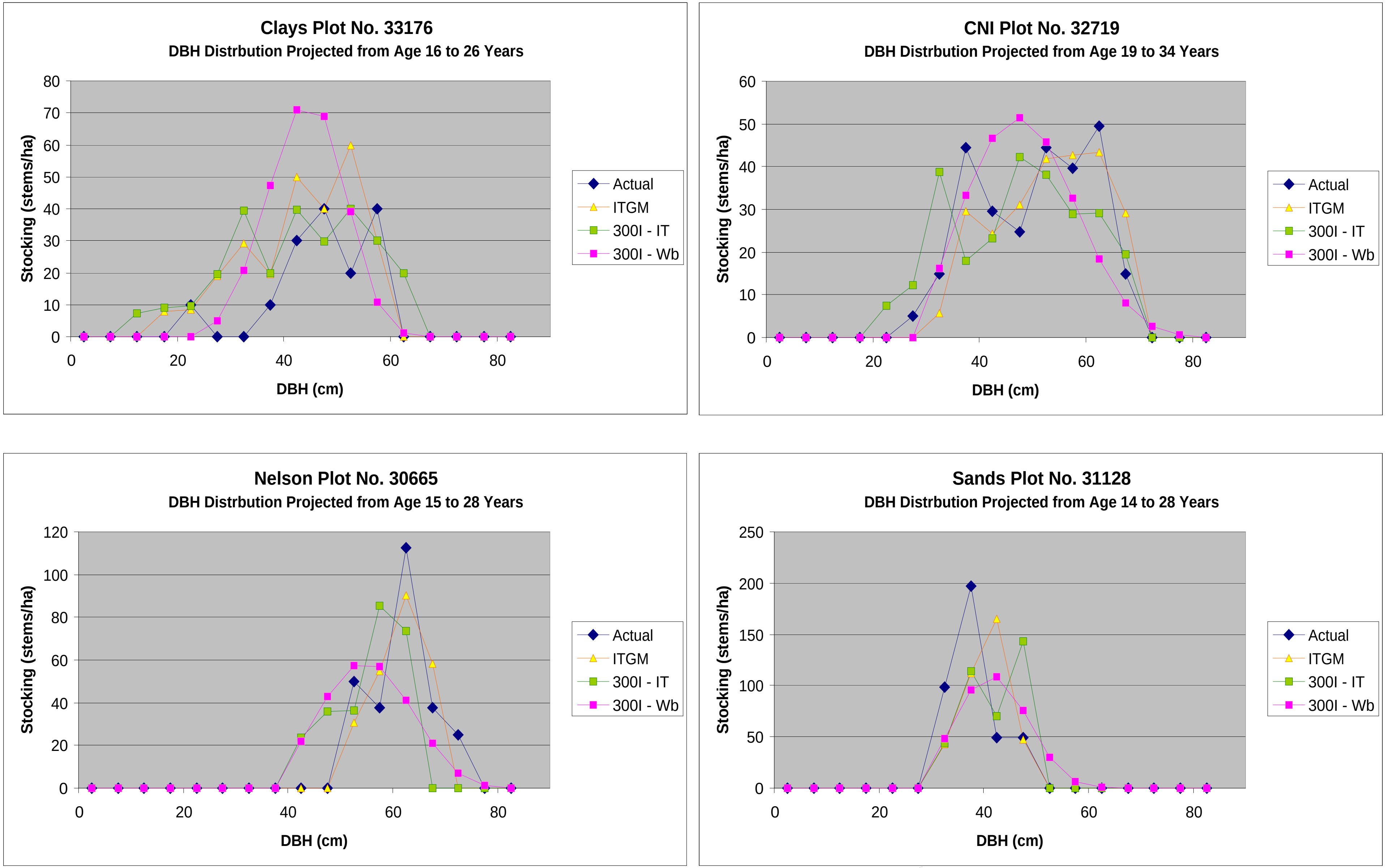
"Representative" PSPs by region were selected on the basis of nearest similarity to DBH mean variance ratio by Region and long Projection Period (Table 4) for the two primary comparative models (300I - IT and ITGM). **Table 6** provides the DBH mean variance ratios by region and growth model represented by the selected PSPs.

Table 6. DBH Mean Variance Ratio by Region and Growth Model.

Region	Projection Period (years)	DBH Variance Ratio		
		300I - IT	ITGM	300I - Wb
CLAYS	10	2.10	1.44	0.59
CNI	15	1.27	0.81	0.73
NELSON	13	1.00	0.59	1.51
SANDS	14	1.33	0.88	2.22

Figure 8 (see next page) demonstrates that the predicted DBH distributions from the tree-level models appear to capture the overall nature of the actual tree-size distribution over long Projection Periods, i.e., 10-14 years, better than the Weibull function. The tails of the distributions contribute significantly to the DBH mean variance, and the figures reveal that both tails and mid-sections of the DBH distributions are relatively well accommodated. The predicted DBH distribution from the Weibull distribution misses some of the shape changes, and as expected by a distribution function, generally provides a smoother distribution.

Figure 8. DBH distributions from representative PSPs and long Projection Periods (10-15 years) by Region



CONCLUSION

The performance of 300I - IT and ITGM at the tree-level mirrors the comparison at the stand-level, i.e., similar, acceptable performance over Projection Periods approaching 15 years. Even though the PSPs that were used for tree-level comparisons were specifically selected for their near identical stand-level predictions, if the tree-level models had produced significantly worrisome tree-list predictions (DBH distributions), then this would have been revealed in the comparative analyses. Interestingly, each model uses significantly different methods to project tree-level DBH and Height (tree-size) into the future, but nonetheless, each is valid and robust, and provides acceptable, plausible predictions of future tree-size attributes.

Both models had relatively unbiased DBH residuals, although Height residuals tended toward over-prediction. Overall, 300I - IT tended to produce marginally superior tree-level DBH and Height residuals and variance ratios. Neither model evidenced a cascade of errors during long Projection Periods, i.e., errors were not compounded through time. As 300I - IT is a projection model, that directly predicts from time1 to time2 (e.g., from age 15 to 28 years), a cascade of errors is not expected. However, as ITGM predicts DBH and Height increment in annual steps, based on iteratively predicted ‘initial’ conditions (e.g., from age 15 to 16 years, from age 16 to 17 years, etc. to 28 years), a cascade of errors could occur. Both models tended to maintain an unbiased consistent spread of DBH residuals after about a 6-year Projection Period, whereas an unbiased consistent spread of Height residuals occurred throughout all Projection Periods.

300I - IT provided greater DBH and Height variance, indicating greater statistical variability in predicted tree-size distributions. Nonetheless in a practical sense, a comparison of resulting tree-size distributions suggested similarity between the models. The use of a Weibull function to recover a tree-size distribution from stand-level model appeared both statistically and practically inferior to the tree-level modelling approach.

Given the level of information required to drive each model, e.g., silivcultural management history for 300I - IT and stand- and tree-level variables for ITGM, each model is suited to a particular primary purpose. 300I - IT is suited to early rotation projection, where the effect of management history on prediction is paramount. ITGM is suited to mid-rotation projection, where post-silviculture inventory projection is paramount. Nonetheless overall, 300I - IT is the better adapted model because it is able to operate across a full rotation.

ACKNOWLEDGEMENTS

With thanks, the authors acknowledge the efforts of:

- Jenny Grace, who initiated this comparative model task,
- Brian Rawley (Silmetra Ltd) who provided review comments on behalf of the FFR TST, and
- Joel Gordon and Jeremy Snook of ATLAS Technology, who provided Forecaster model runs and output at the stand- and tree-level.

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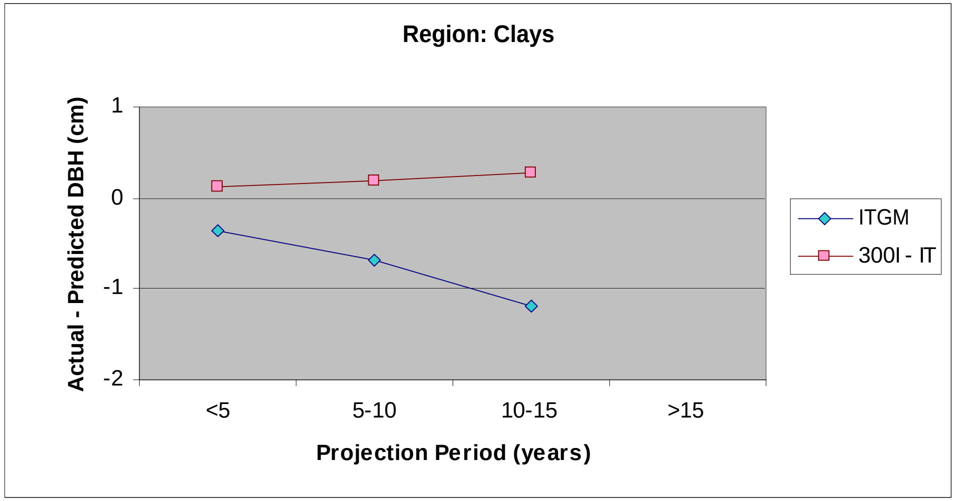
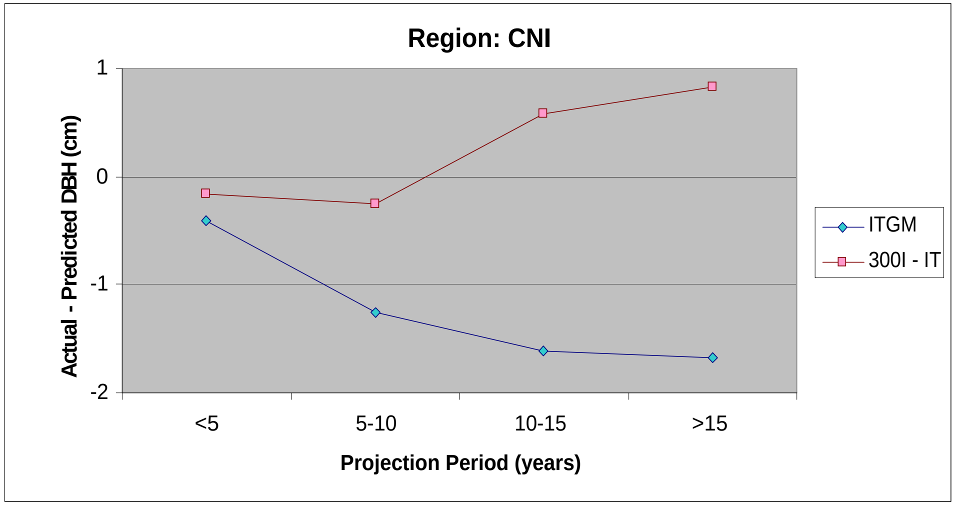
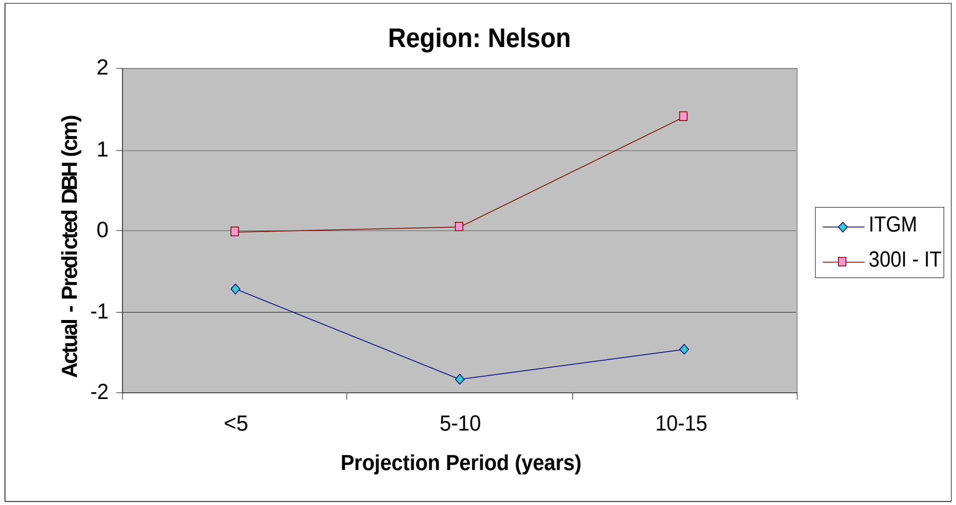
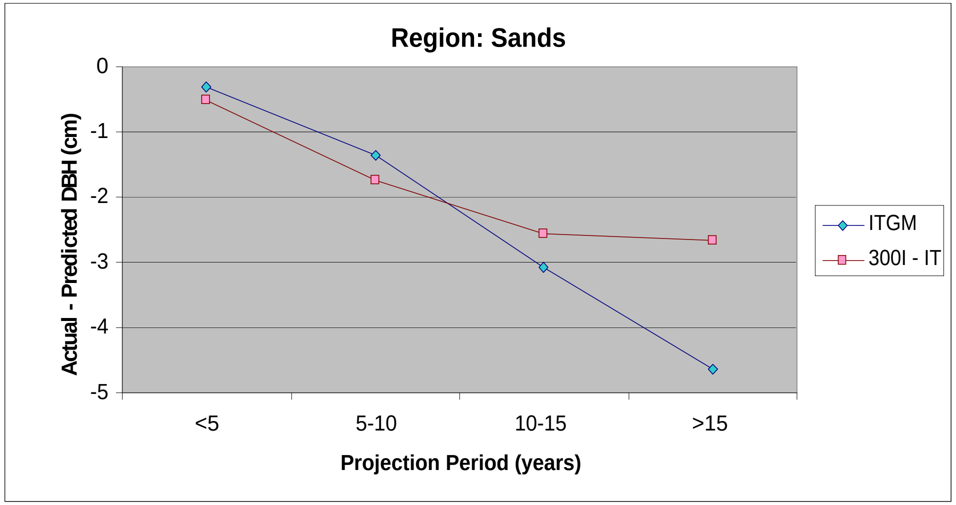
Appendix 1a – Tree-level DBH mean residuals (cm) by Projection Period (years) by Region

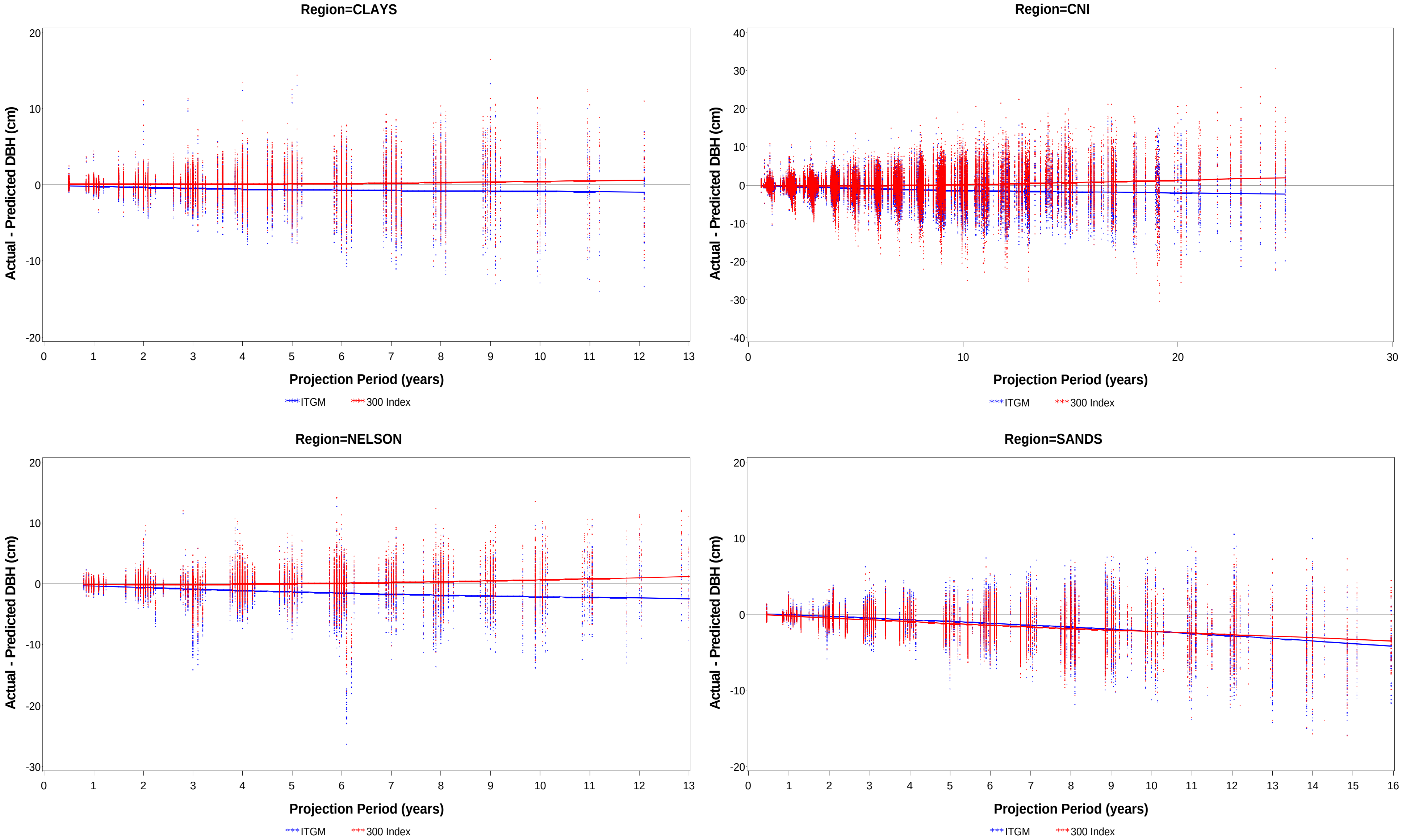




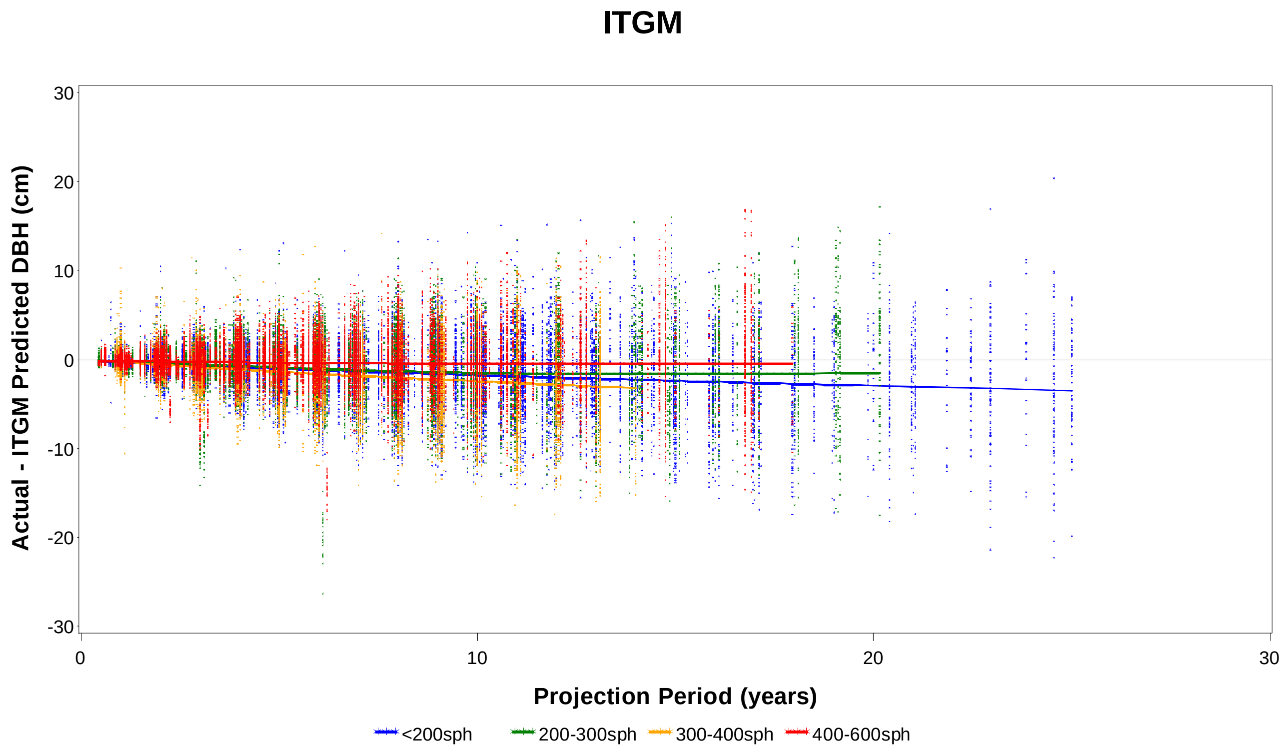


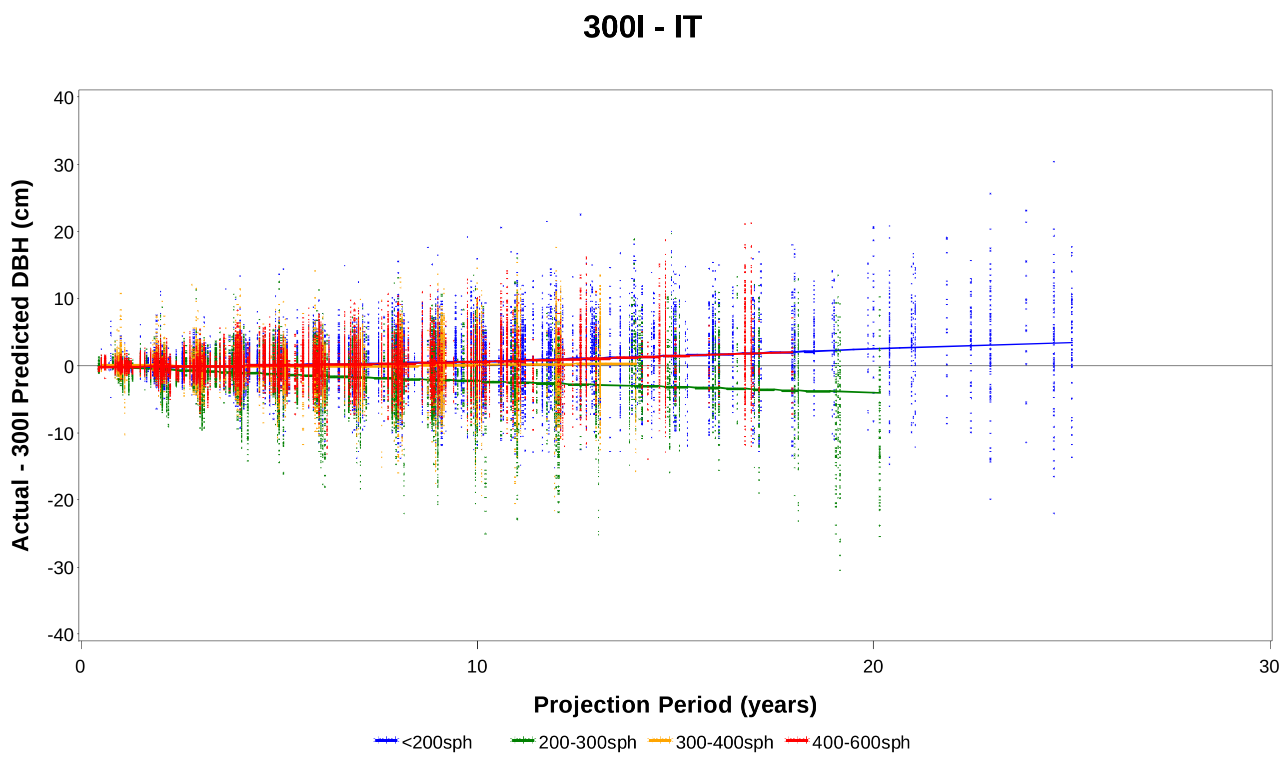


Appendix 1b – Tree-level DBH residuals (cm) by Projection Period (years) – By Region

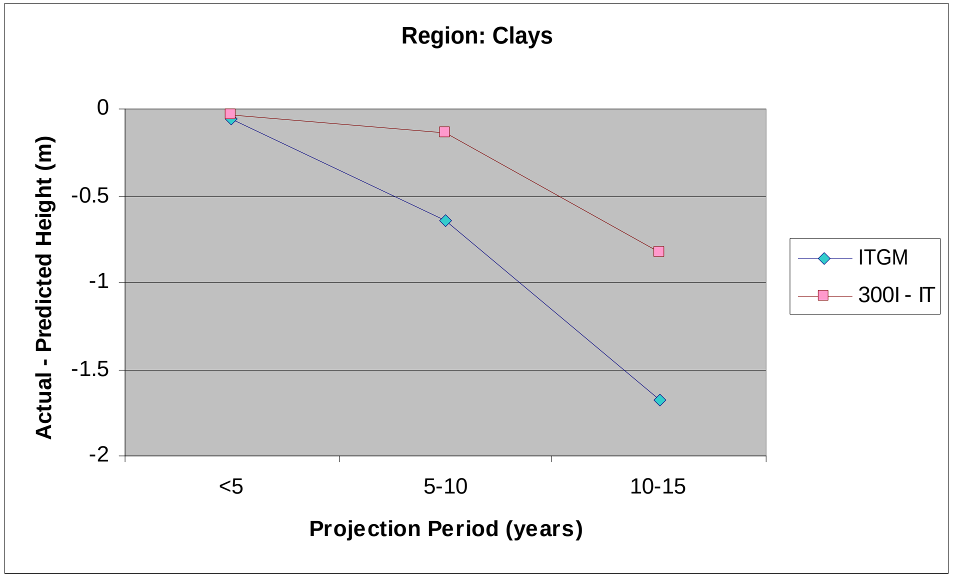


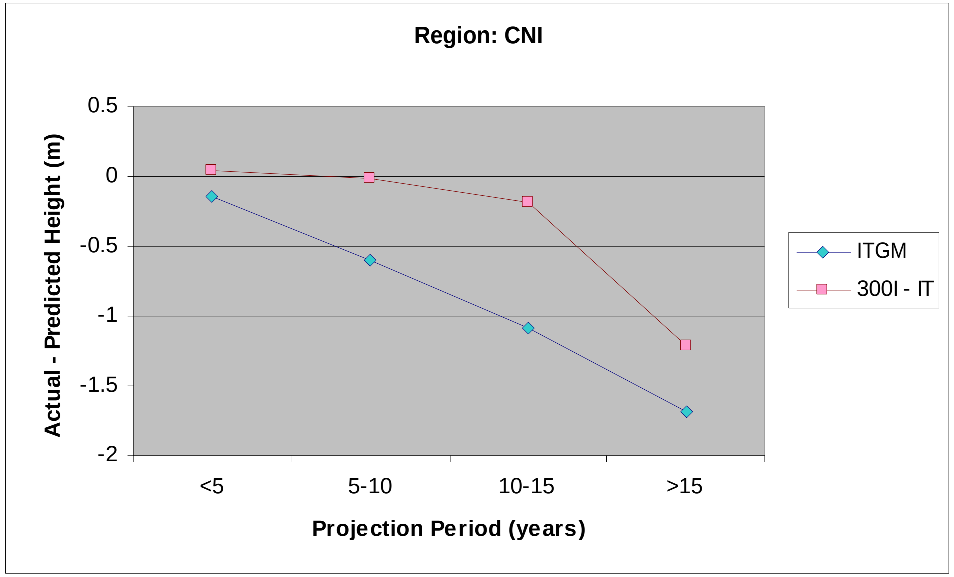
Appendix 1c – DBH residuals (cm) by Projection Period (years) and Stocking (sph) - All Regions

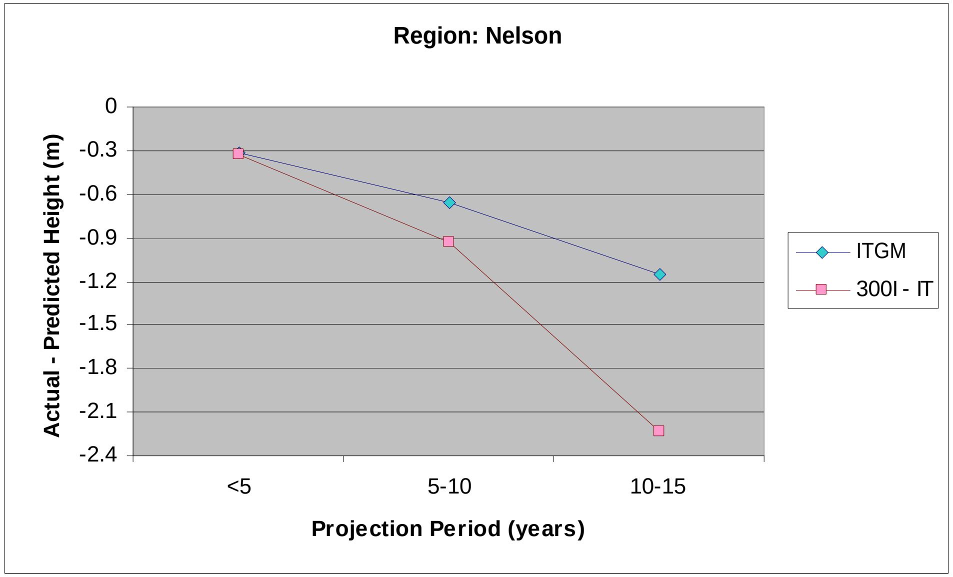


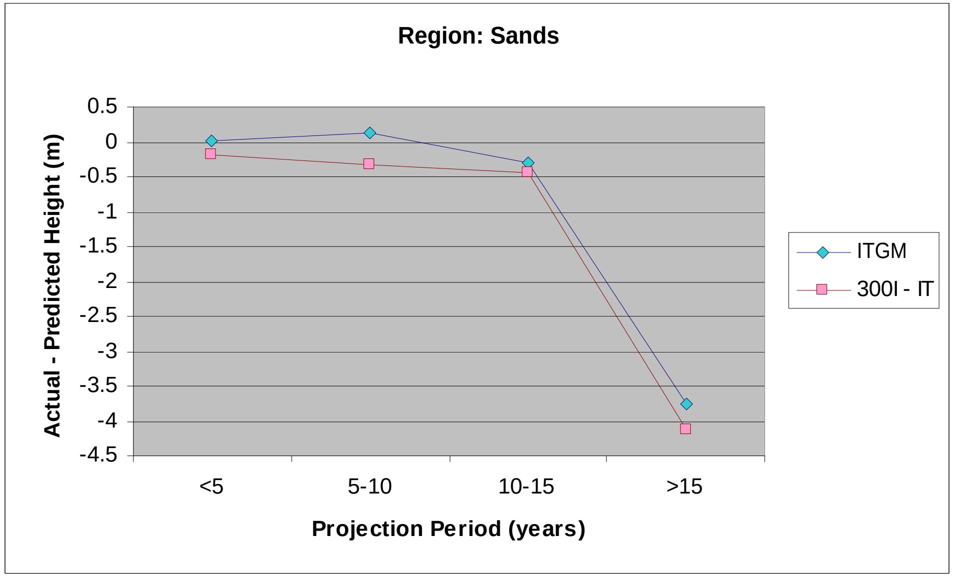


Appendix 2a – Tree-level Height mean residuals (m) by Projection Period (years) by Region

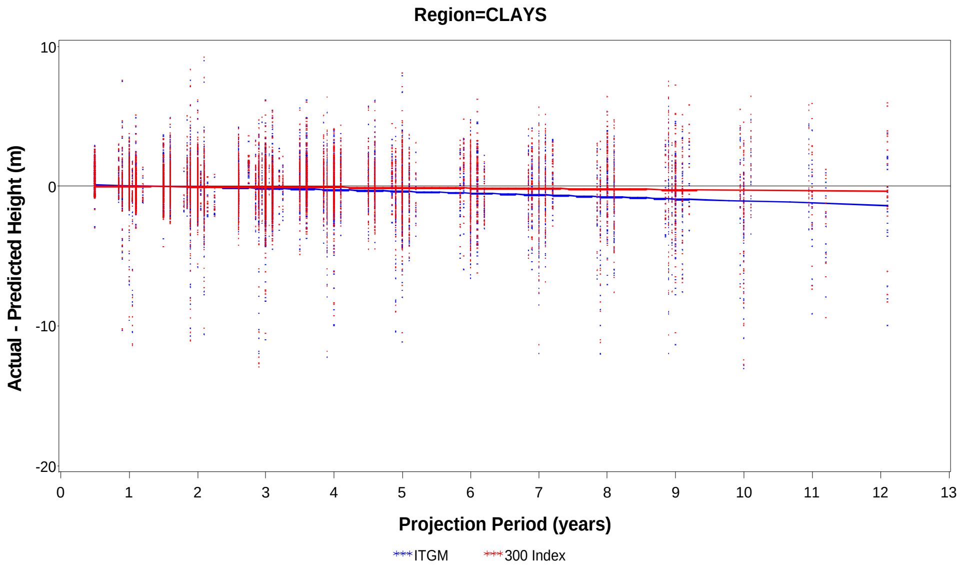


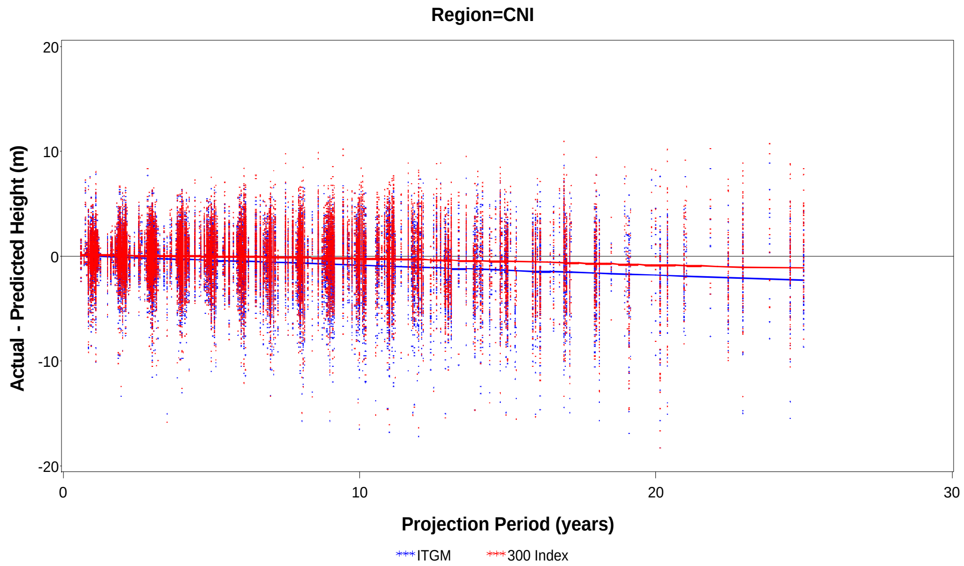


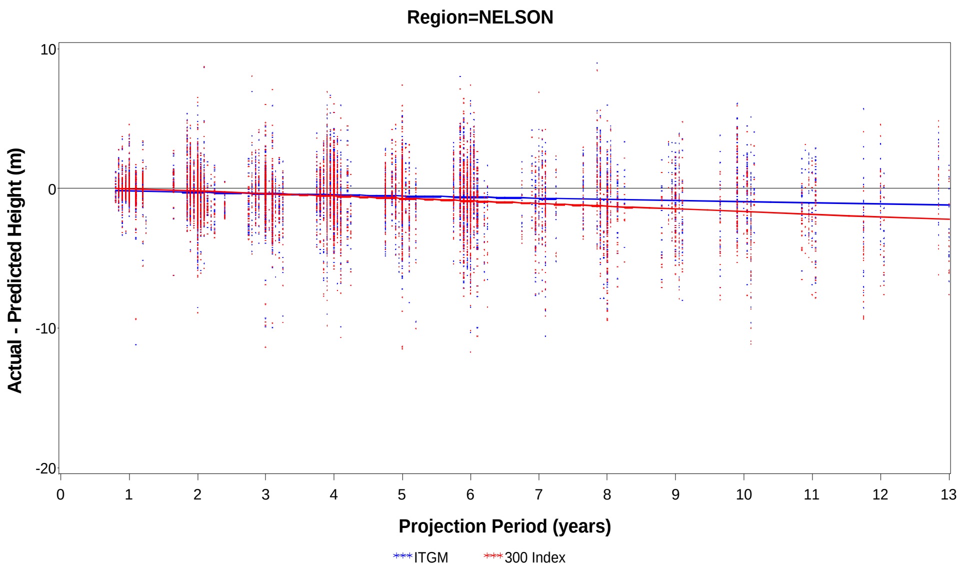


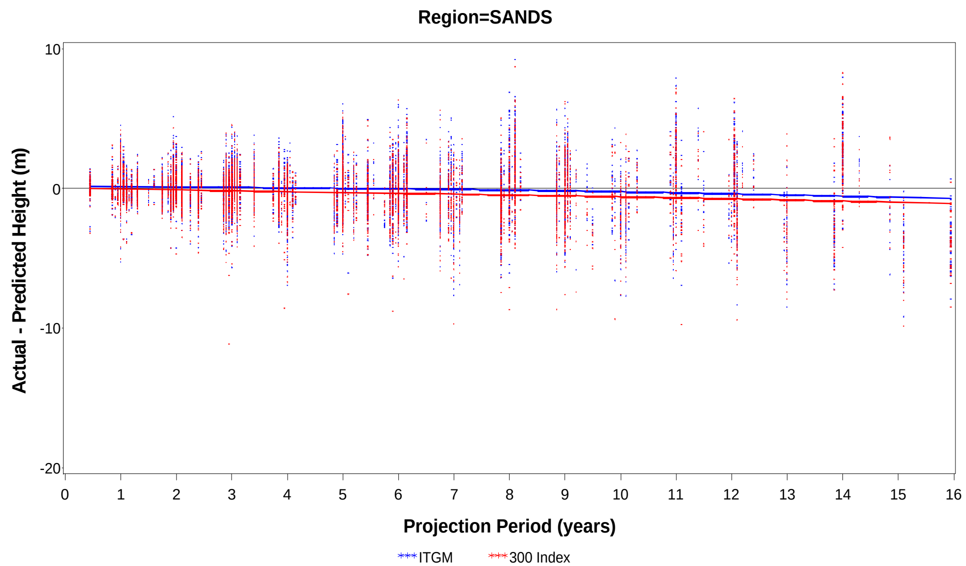


Appendix 2b – Tree-level Height residuals (m) by Projection Period (years) – By Region

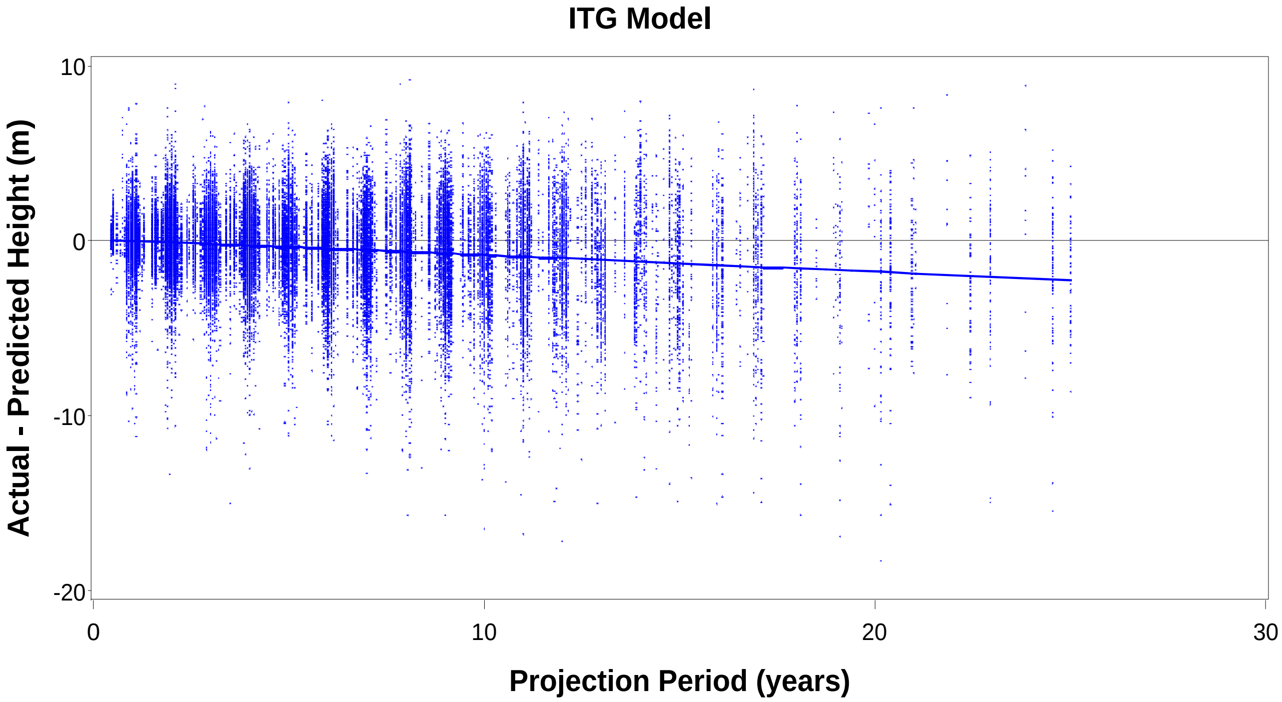


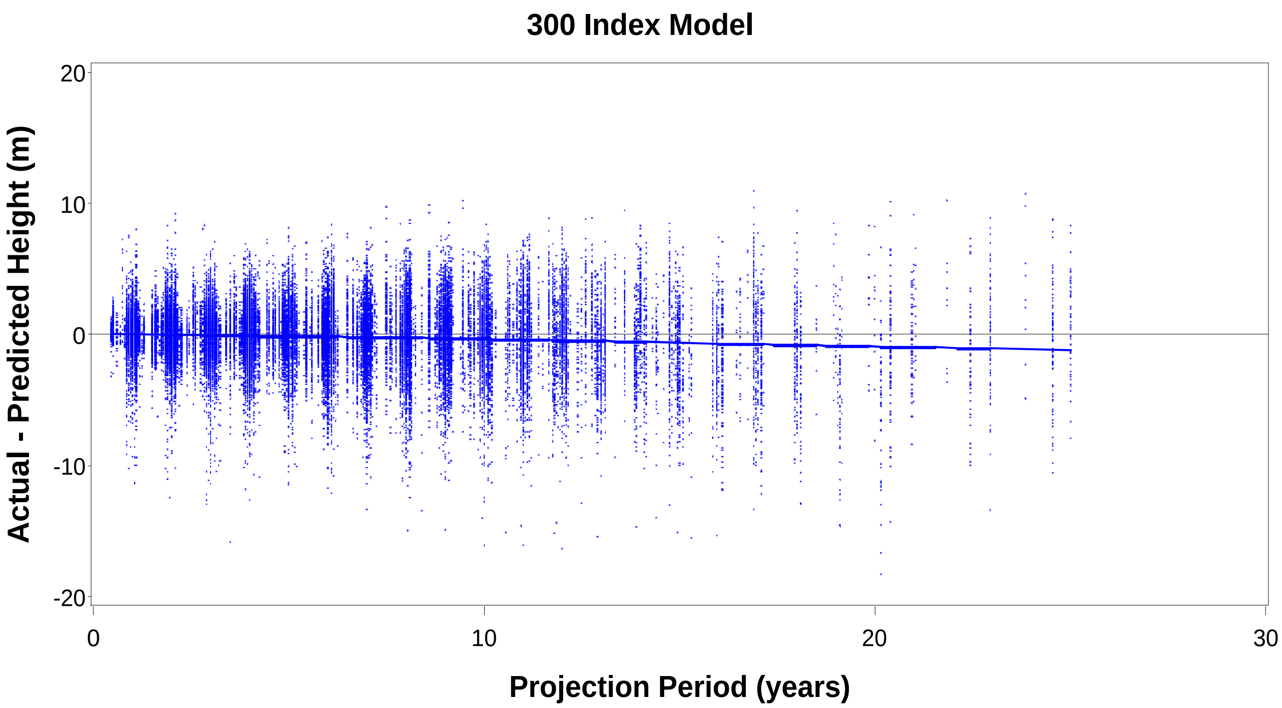




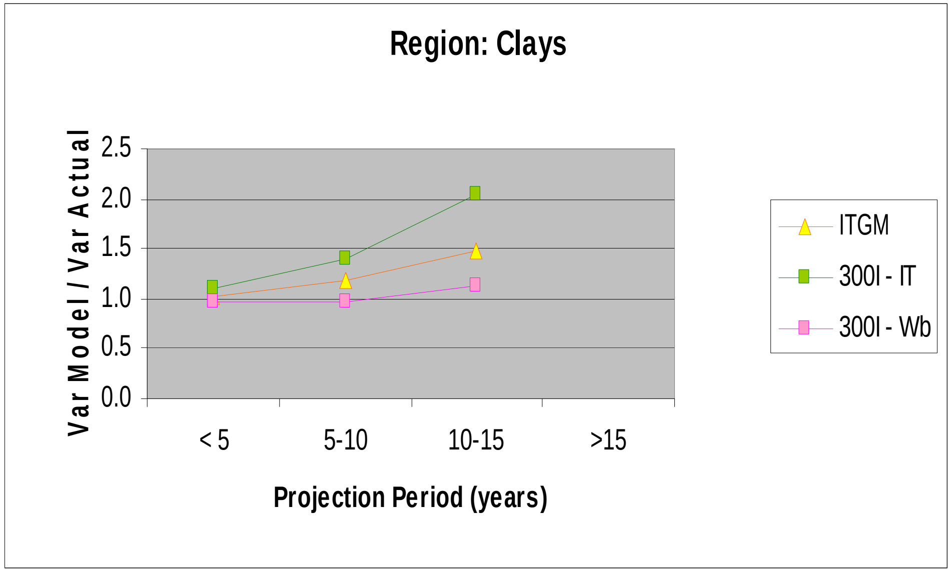


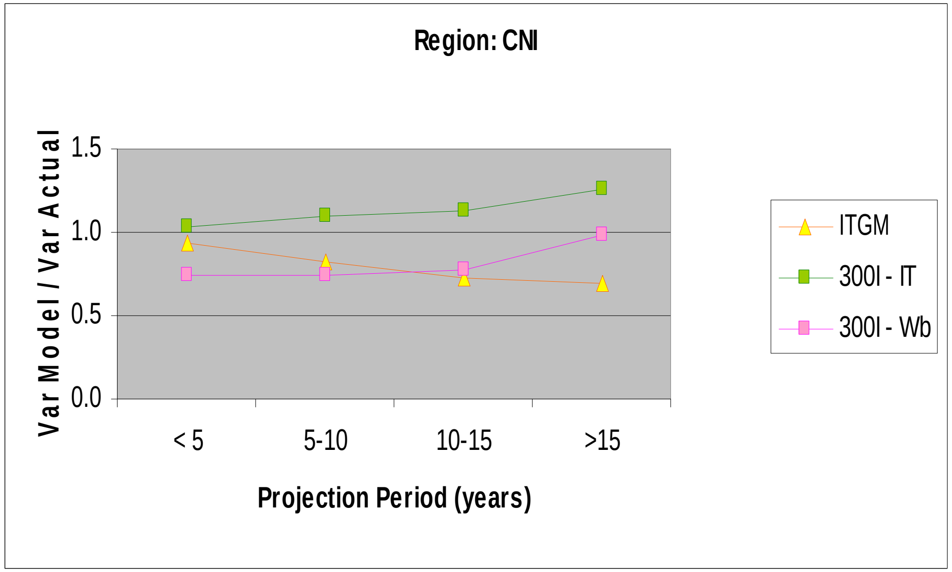
Appendix 2c – Height residuals (m) by Projection Period (years) - All Regions

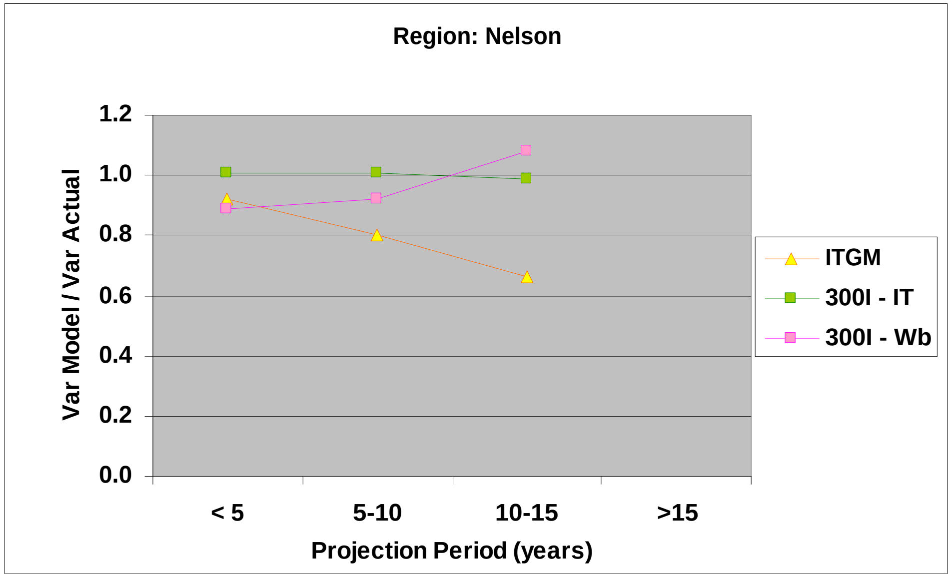


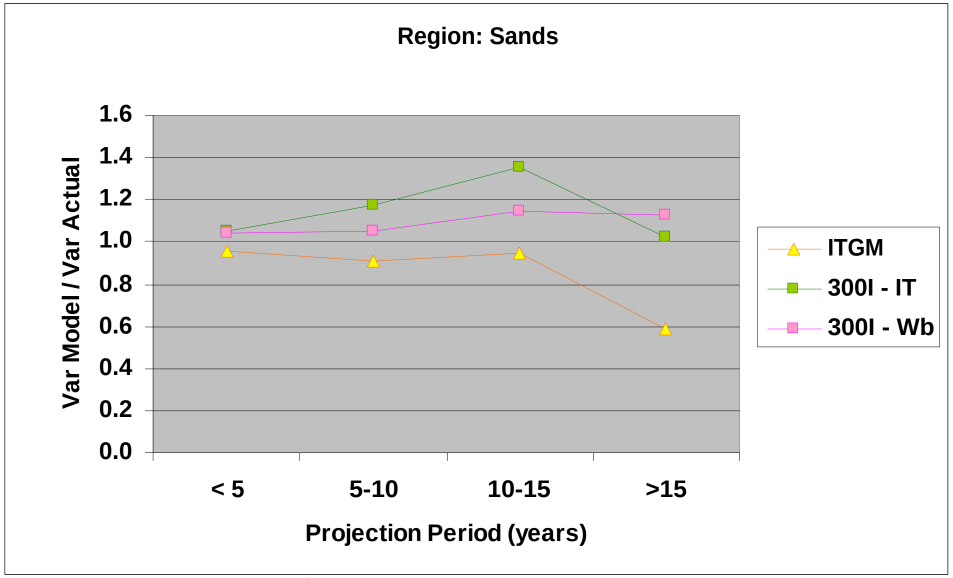


Appendix 3 – DBH mean variance ratio by Projection Period (years) for each Region









Appendix 4 – Height mean variance ratio by Projection Period (years) for each Region