SENSITIVITY ANALYSIS of TreeBLOSSIM: PhotoMARVL TREES from Experiment AK1056 (Woodhill) and NN529/1 (Golden Downs)

J. C. Grace
R. K. Brownlie

Report No. 116 June 2003

Stand Growth Modelling Cooperative

Forest Research Output

No. 35155

SENSITIVITY ANALYSIS of TreeBLOSSIM: PhotoMARVL TREES from Experiment AK1056 (Woodhill) and NN529/1 (Golden Downs)

J. C. Grace

R. K. Brownlie

REPORT NO. 116 June 2003

Forest Research/Industry RESEARCH COOPERATIVE

EXECUTIVE SUMMARY

TreeBLOSSIM is a linked individual tree and branch growth model that was developed to project mid-rotation inventory data forward in time. The branching data required to develop the model was obtained through detailed destructive sampling of a few trees. In this study, non-destructive sampling using PhotoMARVL was used to determine how well TreeBLOSSIM performed for a range of silvicultural treatments in the Woodhill and Golden Downs replicates of the 1975 final crop stocking trial.

At each site, 4 trees were PhotoMARVLed from each of 7 silvicultural treatments giving a total of 56 trees. The data from the PhotoMARVL images were compared with predictions from TreeBLOSSIM.

TreeBLOSSIM predictions of DBH (after a 13-year projection period) were within 11 cm of the measured value at Golden Downs but the predictions were much poorer at Woodhill. There was a negative correlation between "actual –predicted DBH" and predicted DBH.

Actual and predicted values for diameter of the largest branch in a cluster were assessed by comparing mean values for given zones within the stem. Each stem was divided into 3 zones. If the two means were within 2 cm, then the model prediction was considered acceptable. The model predictions were acceptable for all three zones for approximately 50% of the trees at both sites. There was only 1 tree at Woodhill and 2 trees at Golden Downs where the model prediction did not match the observed value in any zone. At Woodhill, the predicted variability in the diameter of the largest branch in a cluster tended to be larger than observed.

TreeBLOSSIM generally overpredicted the number of branch clusters per metre in a zone. The difference was generally not significant in the lowest zone.

Overall, it was considered that TreeBLOSSIM performed reasonably well for these two sites.

SENSITIVITY ANALYSIS OF TreeBLOSSIM:
PhotoMARVL trees from Experiment AK1056 (Woodhill) and NN529/1 (Golden Downs)

J.C. Grace and R.K. Brownlie

INTRODUCTION

TreeBLOSSIM is a linked individual tree and branch growth model that was developed to project mid-rotation inventory data forward in time. The branching data required to develop the model was obtained through detailed destructive sampling of a few trees. Non-destructive sampling using PhotoMARVL is considered to be an appropriate method to determine how well the model performs for a wider range of sites and silvicultural treatments.

In order to test how well TreeBLOSSIM predicts branch response to different silvicultural treatments, PhotoMARVL images have been collected in the 4 final crop-stocking trials planted in 1975. The data are documented in the following reports:

- Kaingaroa, RO2098 (SGMC Reports 93 and 99)
- Eyrewell, CY597 (SGMC Report 104)
- Woodhill, AK1056 (SGMC Report 112)
- Golden Downs, NN529/1 (SGMC Report 112)

TreeBLOSSIM was run using the associated permanent sample plot (PSP) tree size data and the predictions compared with PhotoMARVL data. This report documents the comparison for Woodhill and Golden Downs. SGMC Report 110 documents the comparison for Kaingaroa and SGMC Report 117 documents the comparison for Eyrewell.

METHODS

<u>Sample Plot Selection</u>

The final crop stocking trials were planted in 1975 as an "850" polycross trial with an initial stocking of 625 stems/ha. Permanent sample plots (PSPs) for the final crop stocking trial were established in 1986. There were 7 treatments (Table 1):

- an unthinned control (6 replicates),
- six different thinning treatments (3 replicates of each treatment).

Table 1. Silvicultural treatments imposed on the "850" polycross trials.

Treatment No.	Initial Stocking (stems/ha)	Final Stocking (stems/ha)	Age at thinning (years)
1	625	100	11
2	625	200	11
3	625	400	11
4	625	625	-
5	625	100	14
6	625	200	14
7	625	200	14

At all 4 sites, one sample plot per treatment was selected (the plot where the initial stocking and final stocking remained closest to the prescribed treatment and mortality was minimal). The sample plots selected at Woodhill and Golden Downs are shown in Table 2.

Table 2. Experiments, treatments and plots examined.

Site	Treatment	Plot examined
Woodhill, AK1056	Unthinned	9/14
	Thinned to 100sph at age 11 yrs	2/11
	Thinned to 200sph at age 11 yrs	5/12
	Thinned to 400sph at age 11 yrs	3/13
	Thinned to 100sph at age 14 yrs	8/15
	Thinned to 200sph at age 14 yrs	4/16
	Thinned to 400sph at age 14 yrs	1/17
Golden Downs, NN529/1	Unthinned	4/34
	Thinned to 100sph at age 11 yrs	6/31
	Thinned to 200sph at age 11 yrs	3/32
	Thinned to 400sph at age 11 yrs	5/33
	Thinned to 100sph at age 14 yrs	1/35
	Thinned to 200sph at age 14 yrs	7/36
	Thinned to 400sph at age 14 yrs	8/37

Selection of PhotoMARVL trees

For each selected plot, the trees present at the last (1999) PSP re-measurement were ranked according to the diameter at breast height (DBH), and their percentage rank calculated. Undamaged trees whose rank was closest to the 10^{th}, 40^{th}, 70^{th}, and 100^{th} percentile were selected to be PhotoMARVLed.

In the office, the following measurements were extracted from the photograph for each branch cluster using the AP190 analytical stereo plotter (Firth *et al*, 2000):

- stem diameter below the cluster,
- height to base and top of the cluster,
- diameter of the largest branch in the cluster that was visible on the photograph.

TreeBLOSSIM simulations

For each selected sample plot, the PSP measurements at age 14 years (after all silviculture had been completed) were imported into TreeBLOSSIM (Version 1.2 (12.4.2002)). This version is described in SGMC Report No. 113 and the model functions in SGMC Report No. 108. TreeBLOSSIM first calculated the position and size of all branches at age 14 years (including the effects of any previous silviculture). The stems and branches were then grown forward to age 27 years, the age at which the PhotoMARVL images were collected.

The model was set so that there was no tree mortality, a realistic assumption given the way the sample plots were selected. For Woodhill, the default values of N=2 and P=6 for nutritional status were used. The resulting branch data file was exported from TreeBLOSSIM and imported into a SAS program that synthesised the data generated to the following variables for each PhotoMARVL tree:

- tree diameter at breast height
- cluster height and diameter of largest branch in each cluster.

Comparisons

Difference between field-measured diameter at breast height DBH (measured using calipers across face visible in PhotoMARVL image at same time as the photograph was taken) and predicted DBH (after a 13-year projection period) was calculated and compared with predicted DBH.

Graphs of diameter of the largest branch in a cluster (both model prediction and PhotoMARVL estimate) were plotted against cluster height.

The stem was split into three zones based on a visual assessment of the graphs in SGMC Report 112:
For Golden Downs the zones were:

- Zone 1: less than or equal to 11 m, where pre-thinning stocking would have most influence on branch diameter,
- Zone 2: between 11 and 17 m, where branch diameter was likely to have been influenced by the thinning.
- Zone 3: greater than or equal to 17 m, where post-thinning stocking would have most influence on branch diameter.

For Woodhill the zones were:

- Zone 1: less than or equal to 9 m, where pre-thinning stocking would have most influence on branch diameter,
- Zone 2: between 9 and 15 m, where branch diameter was likely to have been influenced by the thinning.
- Zone 3: greater than or equal to 15 m, where post-thinning stocking would have most influence on branch diameter.

For each zone, the mean branch diameter (averaged over the largest branch in each cluster) was calculated for both the model predictions and PhotoMARVL estimates. The difference between the two means was calculated. If the difference was less than 2 cm, then the model was deemed acceptable for that zone.

To compare the variability in the diameter of the largest branch in a cluster within a zone, the variance was calculated for both the PhotoMARVL data and TreeBLOSSIM predictions. The ratio was compared using an F test.

For each zone, the number of branch clusters was calculated for both the model prediction and PhotoMARVL assessment.

RESULTS

Tree DBH

Actual and predicted DBH at age 27 years are shown in Table 3 and Figure 1a (Woodhill) and Table 4 and Figure 1b (Golden Downs).

At Woodhill, there was a highly significant negative correlation coefficient of –0.88 between "actual – predicted DBH" and predicted DBH. The error was largest in the plots thinned to 100 stems/ha.
At Golden Downs, there was a negative correlation coefficient of –0.33 between "actual – predicted DBH" and predicted DBH. Even though the correlation was not significant at p=0.05, there was a similar trend with silvicultural treatment with DBH being overpredicted for trees thinned to 100 at age 11 years.

Table 3. Woodhill, AK1056 - Actual and predicted (after 13-year increment period) tree DBH at age 27 years

Plot	Treatment: Final Crop Stocking/ Age at thinning	Position in DBH distribution	Tree Number (PSP)	Tree Number: TreeBLOSSIM	Caliper Measured DBH (Age 27 years)	Predicted DBH (Age 27 years)
2/11	100 / 11	10%	16/1	76	36.5	61.6
		40%	1/5	5	46.5	84.8
		70%	2/1	6	59.5	89.9
		100%	11/5	57	60.5	90.9
5/12	200 / 11	10%	1/11	36	36.2	45.0
		40%	0/10	5	39.8	52.7
		70%	0/40	23	48.5	62.4
		100%	0/49	28	62.0	68.5
3/13	400 / 11	10%	0/19	4	28	37.7
		40%	0/13	2	32.8	34.8
		70%	4/20	20	41	43.1
		100%	0/18	3	56	55.7
8/15	100 / 14	10%	15/6	78	35.7	70.8
		40%	13/5	65	40.5	68.6
		70%	16/2	80	49.0	96.8
		100%	5/1	23	58.5	86.5
4/16	200 / 14	10%	1/8	31	32	35.4
		40%	0/21	11	42.5	42.8
		70%	4/48	48	44.5	40.1
		100%	0/46	26	53	48.6
1/17	400 / 14	10%	1/6	8	27	23.2
		40%	4/24	24	36	32.0
		70%	1/3	5	39.8	30.5
		100%	3/16	17	43.7	38.0
9/14	Unthinned	10%	4/22	23	18.5	25.7
		40%	2/15	15	30	32.3
		70%	1/7	7	36.5	33.4
		100%	4/23	24	45	43.3

Table 4. Golden Downs NN529/1 - Actual and predicted (after 13 year increment period) tree DBH at age 27 years

Plot	Treatment: Final Crop Stocking/ Age at Thinning	Position in DBH distribution	Tree Number (PSP)	Tree Number TreeBLOSSIM	Caliper Measured DBH (Age 27 years)	Predicted DBH (Age 27 years)
6/31	100 / 11	10%	10/2	53	53.7	59.2
		40%	4/5	23	57.1	65.6
		70%	1/5	5	59.5	64.2
		100%	16/3	87	66.4	68.5
3/32	200 / 11	10%	2/23	43	45.3	55.5
		40%	0/46	28	53.5	57.8
		70%	0/29	18	55	57.9
		100%	0/5	3	60.7	61.0
5/33	400 / 11	10%	0/9	3	31.1	34.8
		40%	3/20	22	42.1	42.0
		70%	4/26	27	49.1	47.6
		100%	4/25	26	60.7	51.7
1/35	100/ 14	10%	15/5	81	46.5	55.5
		40%	5/1	24	56.6	58.7
		70%	2/5	10	64.4	56.4
		100%	5/5	28	70.5	65.1
7/36	200 / 14	10%	2/16	41	47.7	50.2
		40%	0/37	23	51.2	53.5
		70%	4/45	52	58.4	51.2
		100%	0/18	11	67	61.3
8/37	400 / 14	10%	0/5	2	32.7	29.3
		40%	3/14	19	43.3	40.7
		70%	1 / 4	13	45.5	49.5
		100%	3/19	22	54.2	53.6
4/34	Unthinned	10%	2/8	10	32.8	28.4
		40%	3/14	16	40.8	32.8
		70%	4/18	19	44.7	45.6
		100%	0/15	1	51.6	50.2

Figure 1a. Error in predicting tree DBH for PhotoMARVL trees at Woodhill.

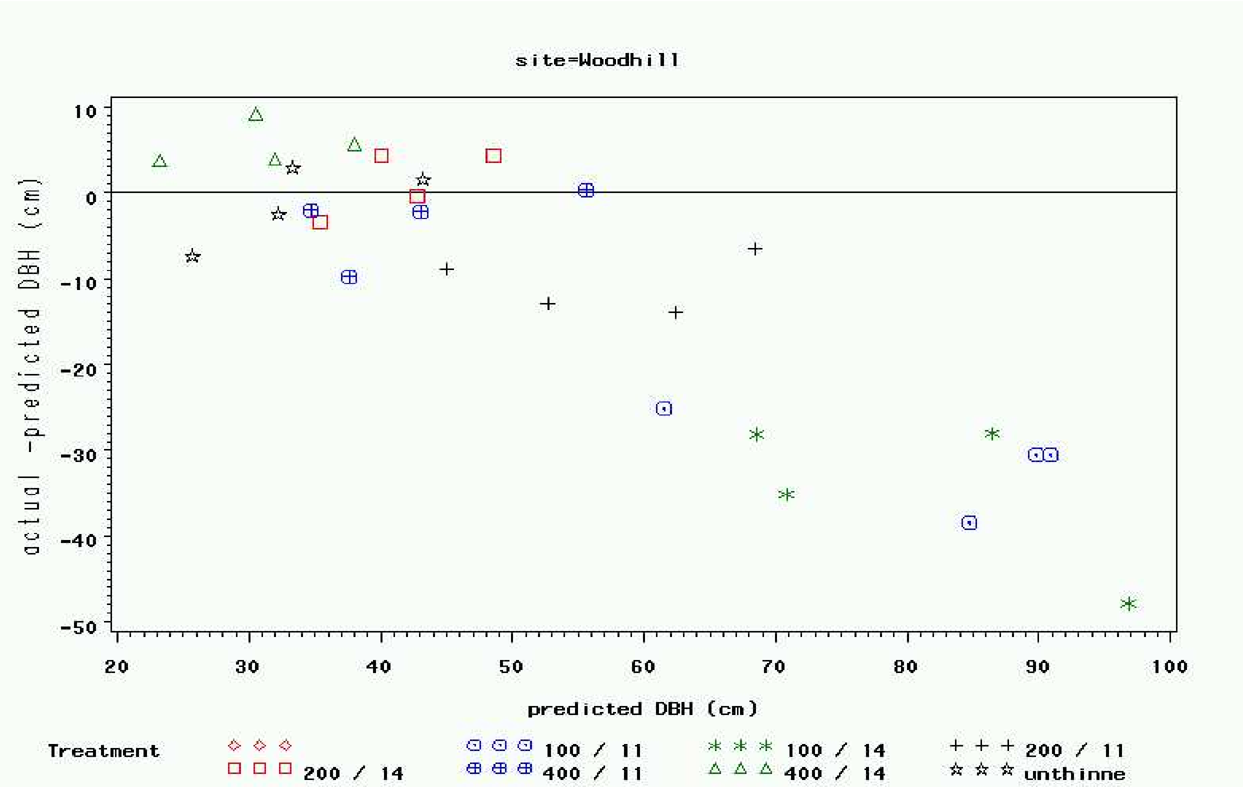
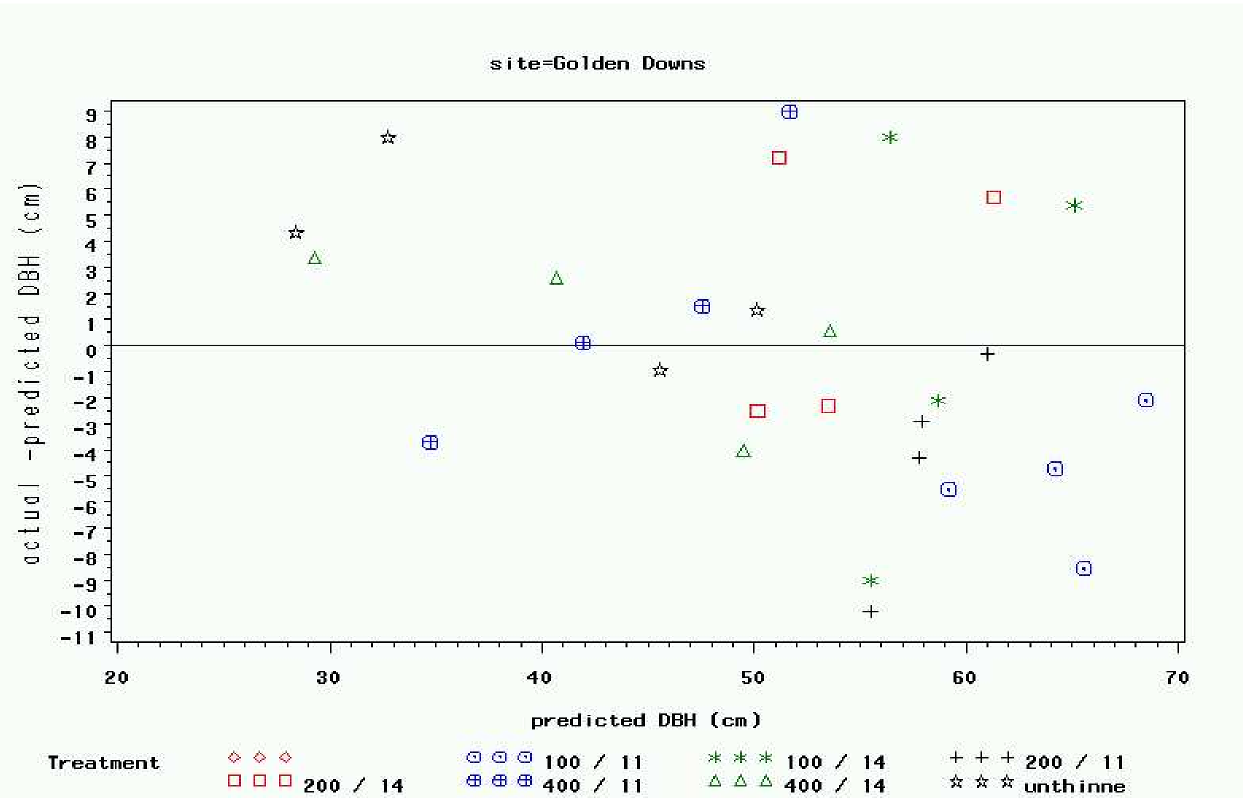


Figure 1b. Error in predicting tree DBH at Golden Downs.



Branch diameter

Graphs illustrating the trend in diameter of the largest branch in a cluster (both TreeBLOSSIM predictions and PhotoMARVL measurements) with cluster height are shown in Appendix 1 (Woodhill) and Appendix 2 (Golden Downs).

A visual examination of the Woodhill graphs (Appendix 1, Figures 2-29), indicated that TreeBLOSSIM trends were reasonable but that TreeBLOSSIM predicted a larger than observed variation for the diameter of the largest branch in a cluster.

A visual examination of the Golden Downs graphs (Appendix 2, Figure 30-57) indicated that the model predictions were reasonable for most trees. Visually, the predicted variation in the diameter of the largest branch in a cluster was reasonable.

To compare predicted branch diameters with PhotoMARVL measurements, the stem of each tree was split into 3 zones. For each zone, the mean branch diameter (averaged over the largest branch in each cluster) was calculated for both TreeBLOSSIM predictions and PhotoMARVL estimates. The difference between the two means was calculated. If the difference was less than 2 cm, then the model was deemed acceptable for that zone. These results are summarised in 3 ways.

1. The number of trees for which the model was acceptable in a given percentage of zones is shown in Table 5. The results from Kaingaroa (SGMC Report NO. 110) are also shown for comparison.
2. The percentage of zones within a tree for which TreeBLOSSIM predictions were acceptable is shown in Table 6.
3. The percentage of trees for which TreeBLOSSIM predictions were acceptable in a given zone is shown in Table 7.

Table 5 indicates that the model predictions of branch diameter were acceptable in all three zones for 21 out of 27 trees at Kaingaroa, 17 out of 28 trees at Woodhill and 13 out of 28 trees at Golden Downs. The model predictions were not acceptable in any zones for 2 trees at Golden Downs. Both trees were from plots that had been thinned to 100 stems/ha. These trees were:

- 40th percentile tree in the plot thinned to 100 stems/ha at age 11 which had much larger branches than predicted by the model
- 100th percentile tree in the plot thinned to 100 stems/ha at age 14 which was somewhat unusual in that the branches increased linearly with increased height in the crown.

Table 5. Number of trees where difference between TreeBLOSSIM and PhotoMARVL estimate of mean branch diameter (averaged over largest branch in a cluster) is within 2 cm.

% of zones within a tree where difference is within 2 cm	Kaingaroa: Number of trees	Woodhill: Number of trees	Golden Downs: Number of trees
0	0	0	2
33.3	1	5	3
66.7	5	6	10
100	21	17	13

Table 6. Percentage of zones within a tree where the difference between TreeBLOSSIM and PhotoMARVL estimates, of mean branch diameter (averaged over the largest branch in each cluster), is within 2cm.

Plot / Treatment	Tree at 10th percentile (% of zones)	Tree at 40th percentile (% of zones)	Tree at 70th percentile (% of zones)	Tree at 100th percentile (% of zones)
Woodhill (AK1056)				
9/14 (unthinned)	100	100	100	66.7
2/11 (100 / 11)	66.7	100	100	66.7
5/12 (200 / 11)	100	33.3	100	33.3
3/13 (400 / 11)	100	100	100	100
8/15 (100 / 14)	66.7	100	66.7	66.7
4/16 (200 / 14)	33.3	33.3	33.3	100
1/17 (400 / 14)	100	100	100	100
Golden Downs (NN529/1)				
4/34 (unthinned)	100	100	66.7	66.7
6/31 (100 / 11)	100	0	100	33.3
3/32 (200 / 11)	100	66.7	100	66.7
5/33 (400 / 11)	100	100	100	100
1/35 (100 / 14)	66.7	66.7	33.3	0
7/36 (200 / 14)	100	100	66.7	33.3
8/37 (400 / 14)	66.7	66.7	66.7	100

Table 7. Percentage of trees where the difference between TreeBLOSSIM and PhotoMARVL estimates, of mean branch diameter (averaged over the largest branch in each cluster), is within 2cm for a given zone.

Plot	Zone 1 (lowest) % of trees	Zone 2 (middle) % of trees	Zone 3 (highest) % of trees
Woodhill (AK1056)			
9/14	75	100	100
2/11	100	100	50
5/12	50	100	50
3/13	100	100	100
8/15	75	100	33.3
4/16	25	75	50
1/17	100	100	100
Golden Downs (NN529/1)			
4/34	100	100	50
6/31	50	75	50
3/32	100	75	75
5/33	100	100	100
1/35	50	75	0
7/36	100	75	50
8/37	100	100	25

To compare the variability, the variance for the diameter of the largest branch in a cluster was calculated for each zone for both the PhotoMARVL data and TreeBLOSSIM predictions. The ratio was compared using an F test (Table 8).

- At Golden Downs, the two variances were generally not significantly different.
- At Woodhill, TreeBLOSSIM variance was generally significantly larger in plots 9/14 (unthinned) and 1/17 (late thinned to 400 stems/ha).

Table 8. Percentage of zones within a tree where TreeBLOSSIM variance for diameter of largest branch is significantly greater ($p < 0.05$) than that of PhotoMARVL and percentage of zones where PhotoMARVL variance is significantly greater ($p < 0.05$) than that of TreeBLOSSIM.

Plot / Treatment	Number of zones	TreeBLOSSIM variance Significantly greater than PhotoMARVL variance	Variances not significantly different	PhotoMARVL variance significantly greater than TreeBLOSSIM variance
Woodhill (AK1056)				
9/14 (unthinned)	11	9	2	0
2/11 (100 / 11)	12	3	9	0
5/12 (200 / 11)	12	4	7	1
3/13 (400 / 11)	11	4	7	0
8/15 (100 / 14)	11	3	8	0
4/16 (200 / 14)	12	7	5	0
1/17 (400 / 14)	12	9	3	0
Golden Downs (NN529/1)				
4/34 (unthinned)	12	0	11	1
6/31 (100 / 11)	12	2	8	2
3/32 (200 / 11)	12	0	11	1
5/33 (400 / 11)	11	3	8	0
1/35 (100 / 14)	12	0	10	2
7/36 (200 / 14)	12	0	11	1
8/37 (400 / 14)	12	3	8	1

Number of branch clusters

Plot mean values, for the difference between TreeBLOSSIM estimate and PhotoMARVL measurement of the number of branch clusters per metre in each zone are shown in Table 9. The plot mean value was always less than 0 (i.e. on average TreeBLOSSIM predicted more clusters than observed in the field). The differences were smallest in the lowest zone (zone 1) and were generally not significantly different from zero. The differences were largest in zone 3. It is known to be difficult to pick up very small branch clusters on the photographic image, and some portion of the error is from this source. It is not known whether this accounts for all the error or whether the model is predicting too many branch clusters higher in the tree.

Table 9. Plot mean values for the difference between model and PhotoMARVL estimates, of number of clusters per metre, in each zone.

Site	Plot	Treatment: final stocking / age of thinning	Zone 1	Zone 2	Zone 3
Woodhill	9/14	Unthinned	-0.5	-0.7 *	-1.4 (3)
	2/11	100 / 11	-0.0	-0.6	-1.2 *
	5/12	200 / 11	-0.2	-0.9 *	-1.6 *
	3/13	400 / 11	-0.4	-0.8 *	-1.1
	8/15	100 / 14	-0.2	-0.4	-1.1 (3)
	4/16	200 / 14	-0.2	-0.4	-1.1
	1/17	400 / 14	-0.2	-0.3	-1.4 *
Golden Downs	4/34	Unthinned	-0.5 *	-0.7	-1.6 *
	6/31	100 / 11	-0.5	-0.6	-1.0 *
	3/32	200 / 11	-0.2	-0.3	-0.7
	5/33	400 / 11	-0.4	-0.7	-0.9 (3)
	1/35	100 / 14	-0.6 *	-0.7 *	-1.2 *
	7/36	200 / 14	-0.4	-0.7	-1.2 *
	8/37	400 / 14	-0.5	-0.9 *	-1.0 *

Notes: Sample size is shown in brackets if different from 4.
Means that are significant at p< 0.05 are marked with *.

DISCUSSION

PhotoMARVL is a non-destructive photogrammetric technique for measuring tree dimensions. It is considered to be an ideal tool for determining how well TreeBLOSSIM (an individual tree stem and branch growth model) can predict branch growth for different thinning regimes.

PhotoMARVL images were collected for 28 trees from each of two final crop stocking trials, AK1056, Woodhill and NN529/1, Golden Downs. PSP measurements of tree DBH at age 14 years were imported into TreeBLOSSIM and the trees grown forward to age 27 years (the tree age when the PhotoMARVL images were collected).

Tree DBH was measured when the PhotoMARVL images were collected. At both sites there was a negative correlation between “actual – predicted DBH” and predicted DBH. This correlation was significant at Woodhill with TreeBLOSSIM overpredicting tree DBH for the trees thinned to 100 stems/ha by 20 cm to 50 cm. While the correlation was not significant at Golden Downs, the pattern with respect to silviculture treatment was similar. These results suggest that a future study should be to investigate predictions of DBH increment for a wider range of silvicultural trials. This could be carried out independently from PhotoMARVL assessments of branching.

The variability in the diameter of the largest branch in a cluster as predicted by TreeBLOSSIM was generally larger than that observed with PhotoMARVL at Woodhill. This variability is mainly influenced by the cluster potential (see SGMC Report 108). This result is surprising as the equation predicting cluster potential was derived from data collected in the “850” diallel at Woodhill which is adjacent to the final crop stocking trial. The reason for this result needs further investigation.

The number of clusters per metre is influenced by two functions:

- height growth
- the number of branch clusters in an annual shoot (see SGMC Report No. 108).

TreeBLOSSIM generally overpredicted the number of branch clusters per metre in a zone. The overprediction was generally least in zone 1, and highest in the zone 3. The differences were similar on both sites.

For zone 3, part of the problem is considered to be the inability to distinguish clusters on the PhotoMARVL image. This should not be the case in zone 1.

REFERENCES

Stand Growth Modelling Cooperative Reports.

93: Grace, J.C.; Brownlie, R.K. 2000: Suitability of PhotoMARVL for measuring crown structure.

99: Grace, J.C.; Brownlie, R.K. 2001: Use of PhotoMARVL to determine response to thinning: Further results from Experiment RO2098.

104: Grace, J.C.; Brownlie, R.K. 2001: Branch response to thinning in Experiment CY597, results from using PhotoMARVL.

108: Grace, J.C.; Pont, D. 2001: Branch functions within TreeBLOSSIM – Version 1.1.

110: Grace, J.C. 2001: Sensitivity analysis of TreeBLOSSIM: PhotoMARVL trees from Experiment RO2098.

112: Grace, J.C.; Brownlie, R.K. 2002: Branch response to thinning in Woodhill (AK1056) and Golden Downs (NN529/1) – PhotoMARVL data.

113: Pont, D.; Grace, J.C.; Gordon, A.; Shula, B. 2002: A guide to using TreeBLOSSIM Version 1.2.

117: Grace, J.C.; Brownlie, R.K. 2003: Sensitivity analysis of TreeBLOSSIM: PhotoMARVL trees from Experiment CY 597 (Eyrewell).

Other reports/ papers.

Firth, J.G.; Brownlie, R.K.; Carson, W.W. 2000: Accurate stem measurements, key to new image-based system. New Zealand Journal of Forestry 45 (2): 25-29.

APPENDIX 1: Woodhill (AK1056) - Diameter of largest branch in a cluster - *PhotoMARVL* measurements and TreeBLOSSIM predictions.

Figure 2. Tree at 10th percentile of DBH distribution in unthinned plot

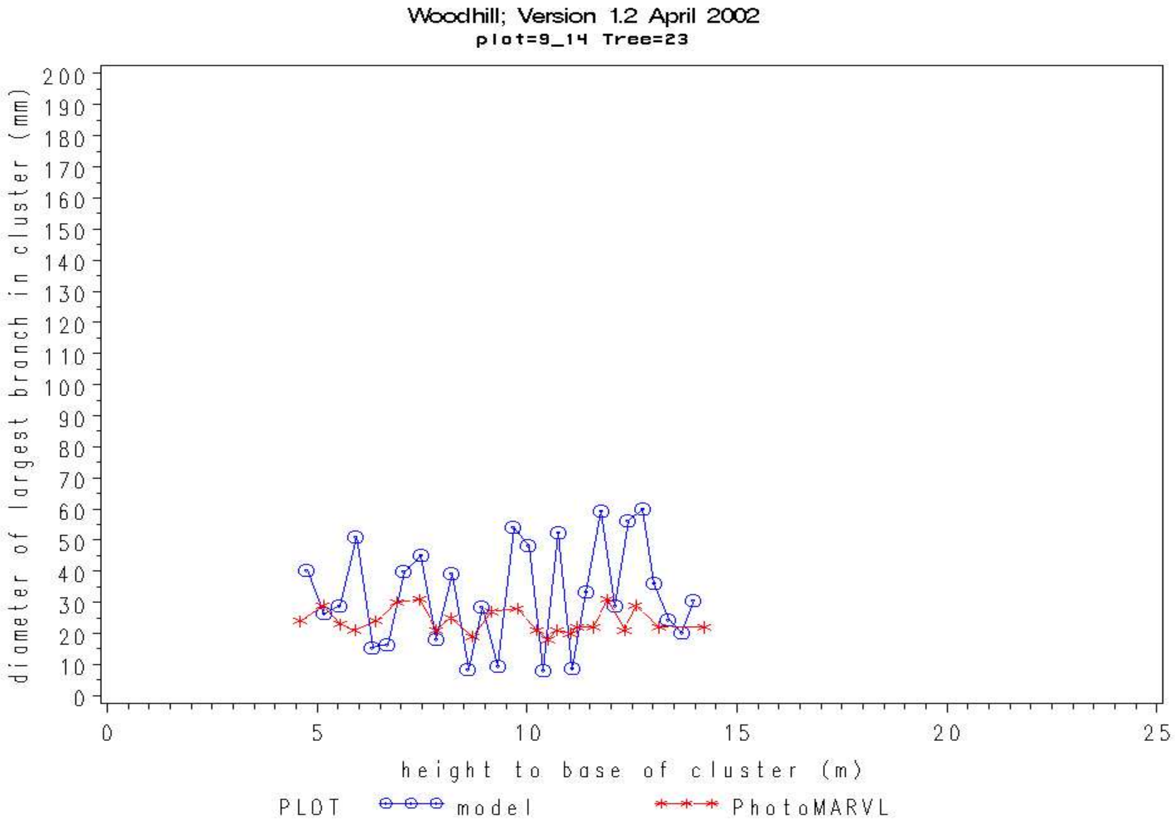


Figure 3. Tree at 40th percentile of DBH distribution in unthinned plot

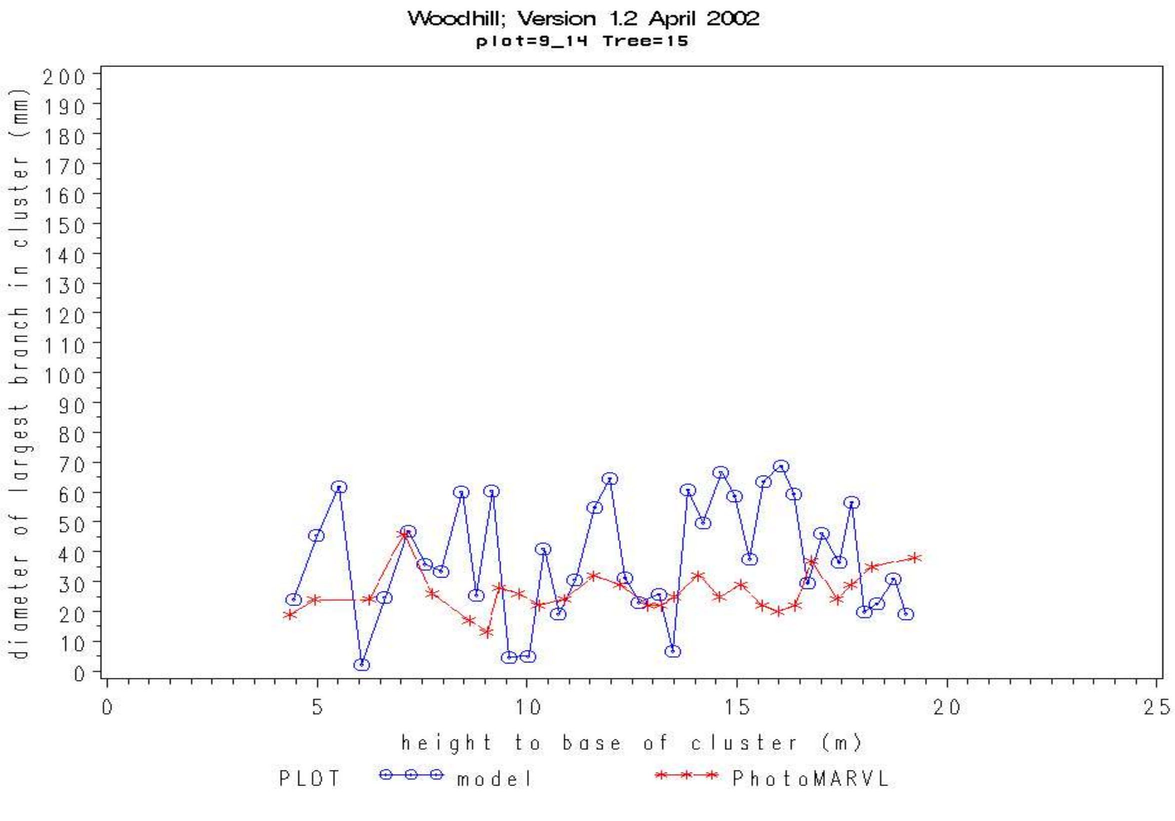


Figure 4. Tree at 70th percentile of DBH distribution in unthinned plot

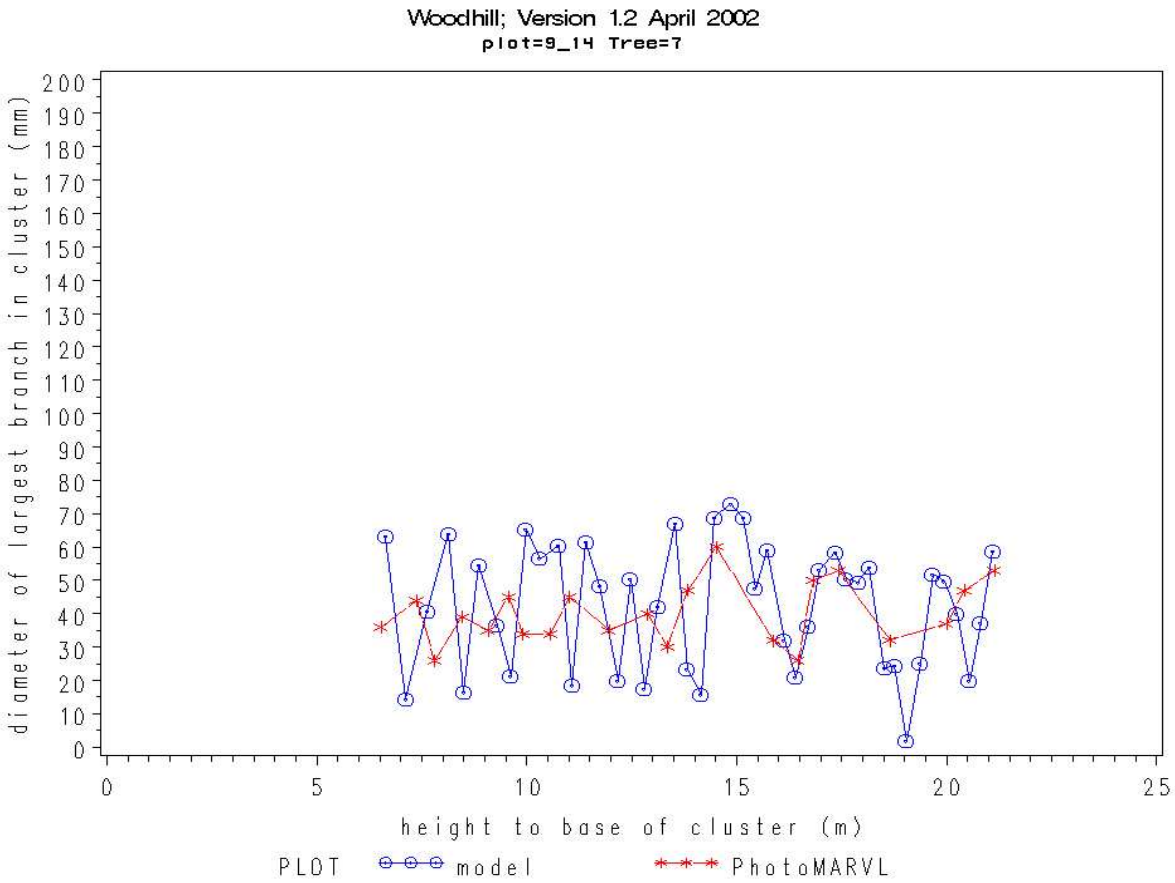


Figure 5. Tree at 100th percentile of DBH distribution in unthinned plot

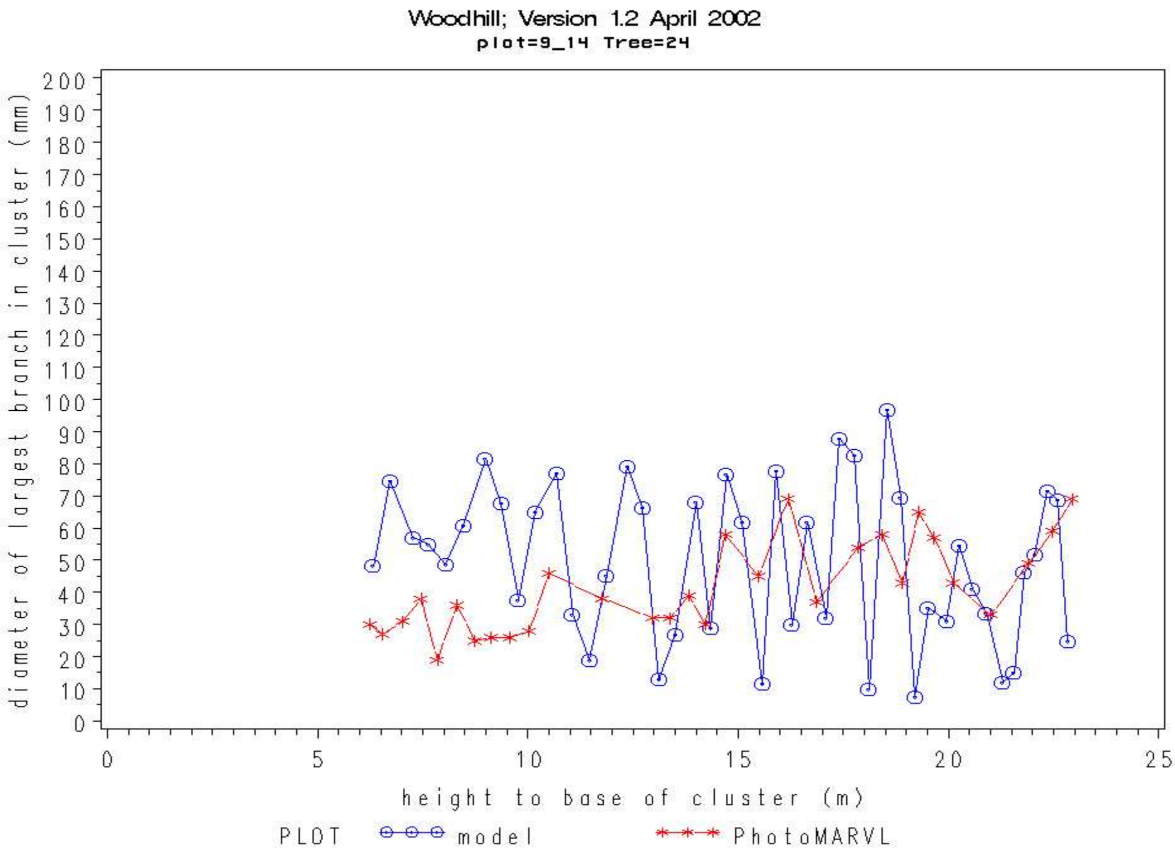


Figure 6. Tree at 10th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

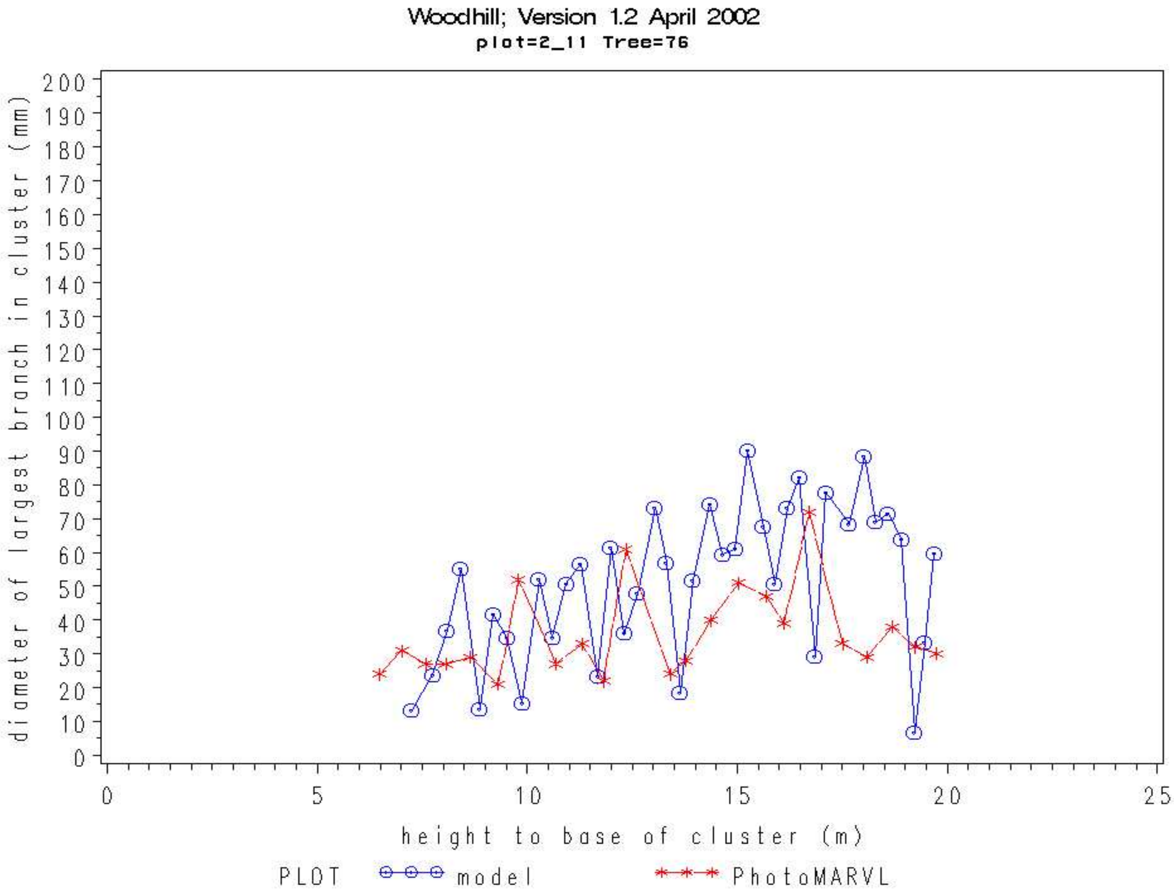


Figure 7. Tree at 40th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

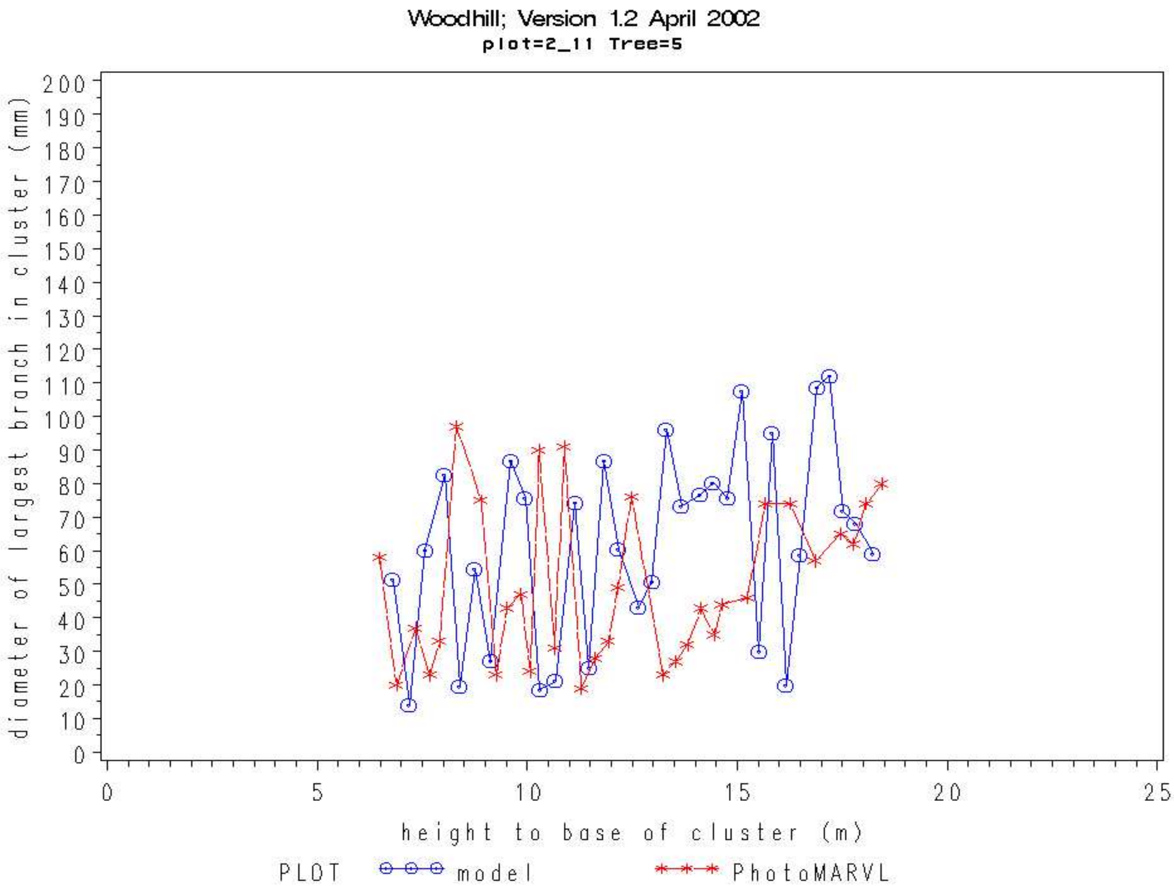


Figure 8. Tree at 70th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

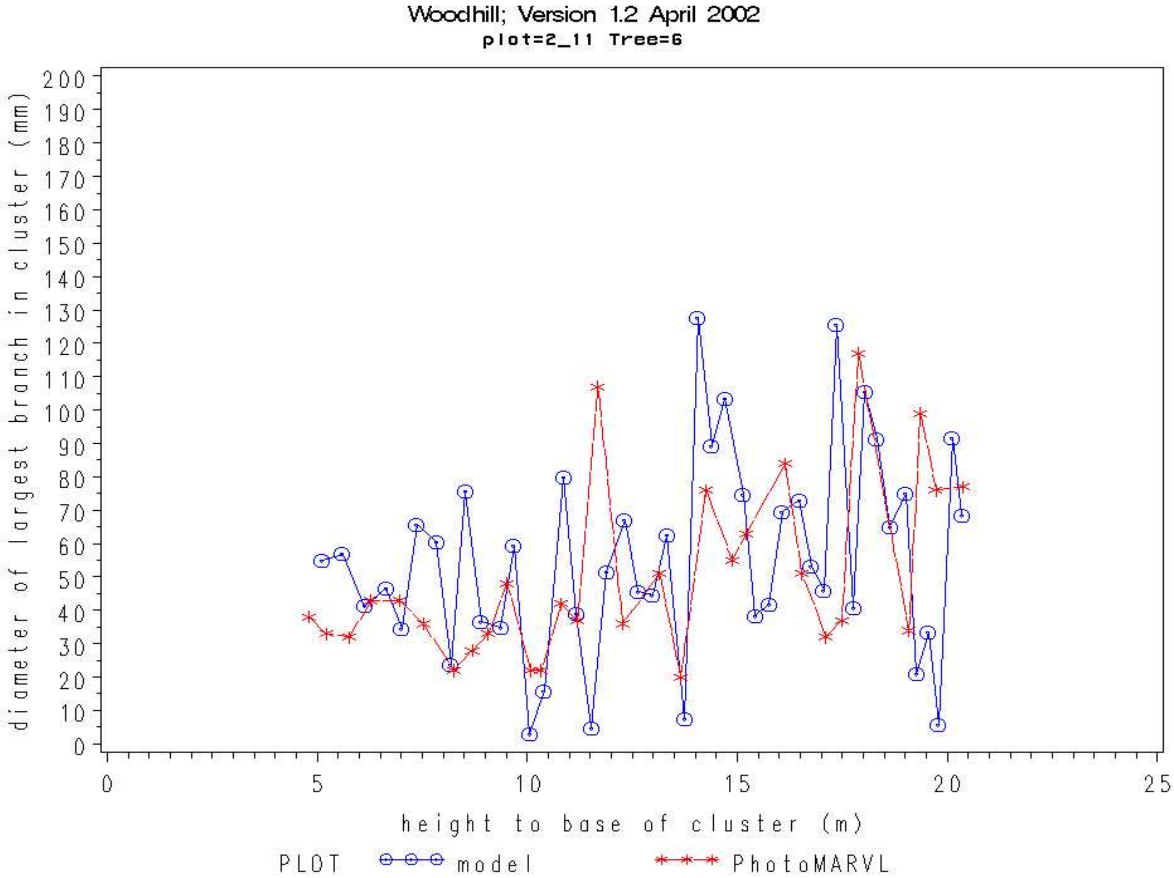


Figure 9. Tree at 100th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

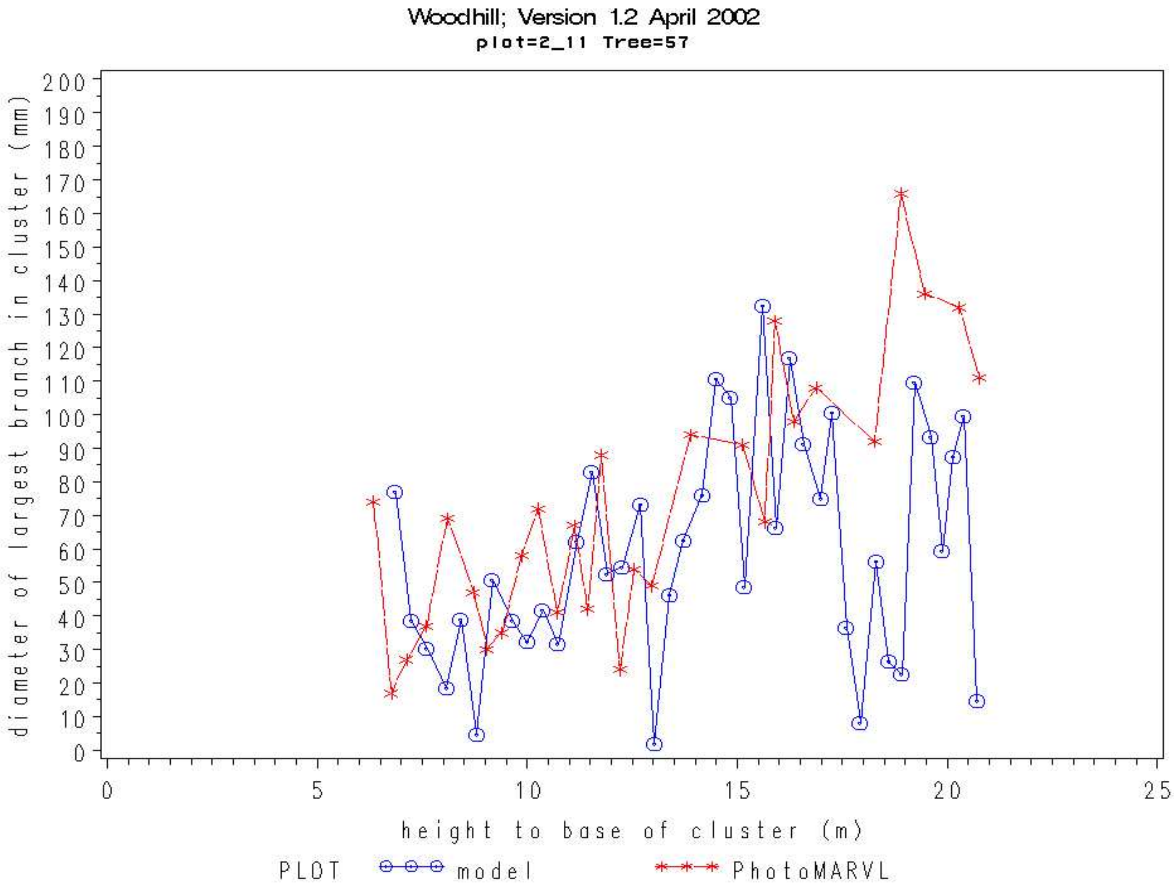


Figure 10. Tree at 10th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

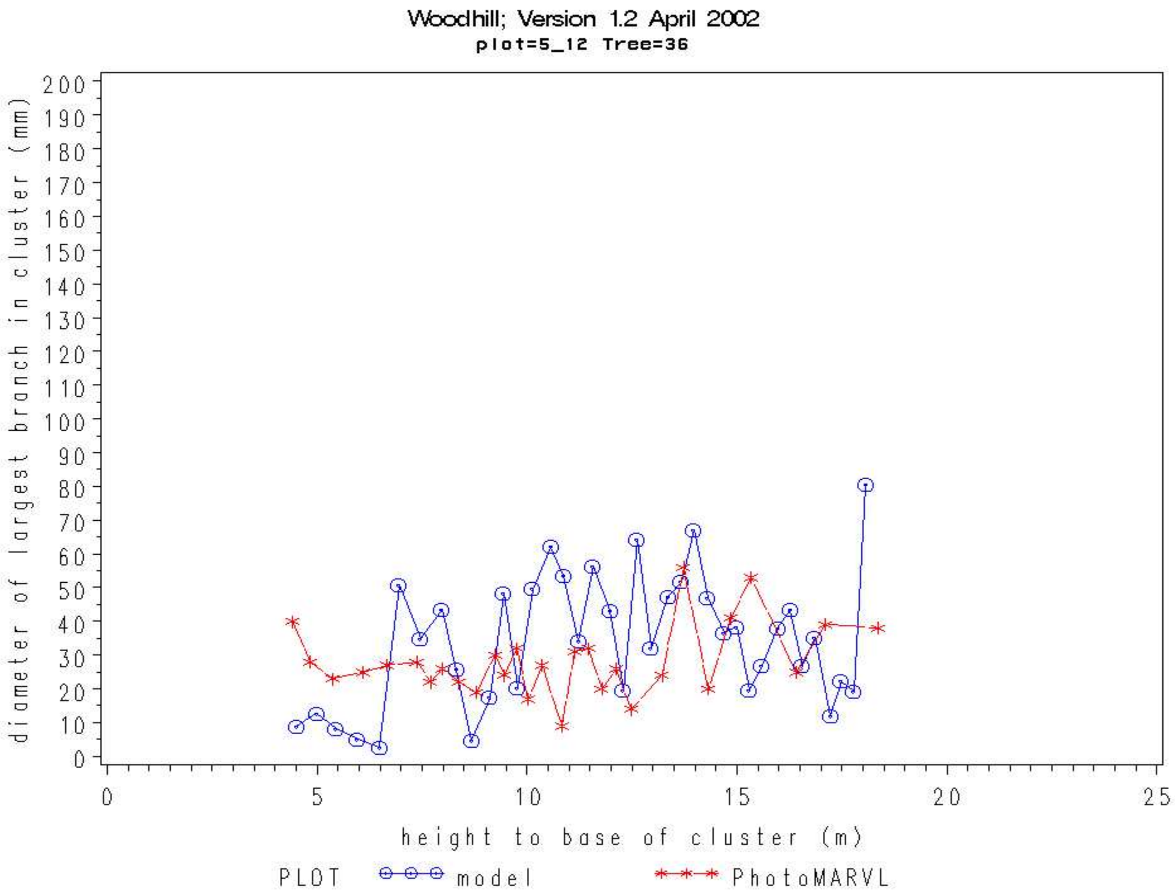


Figure 11. Tree at 40th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

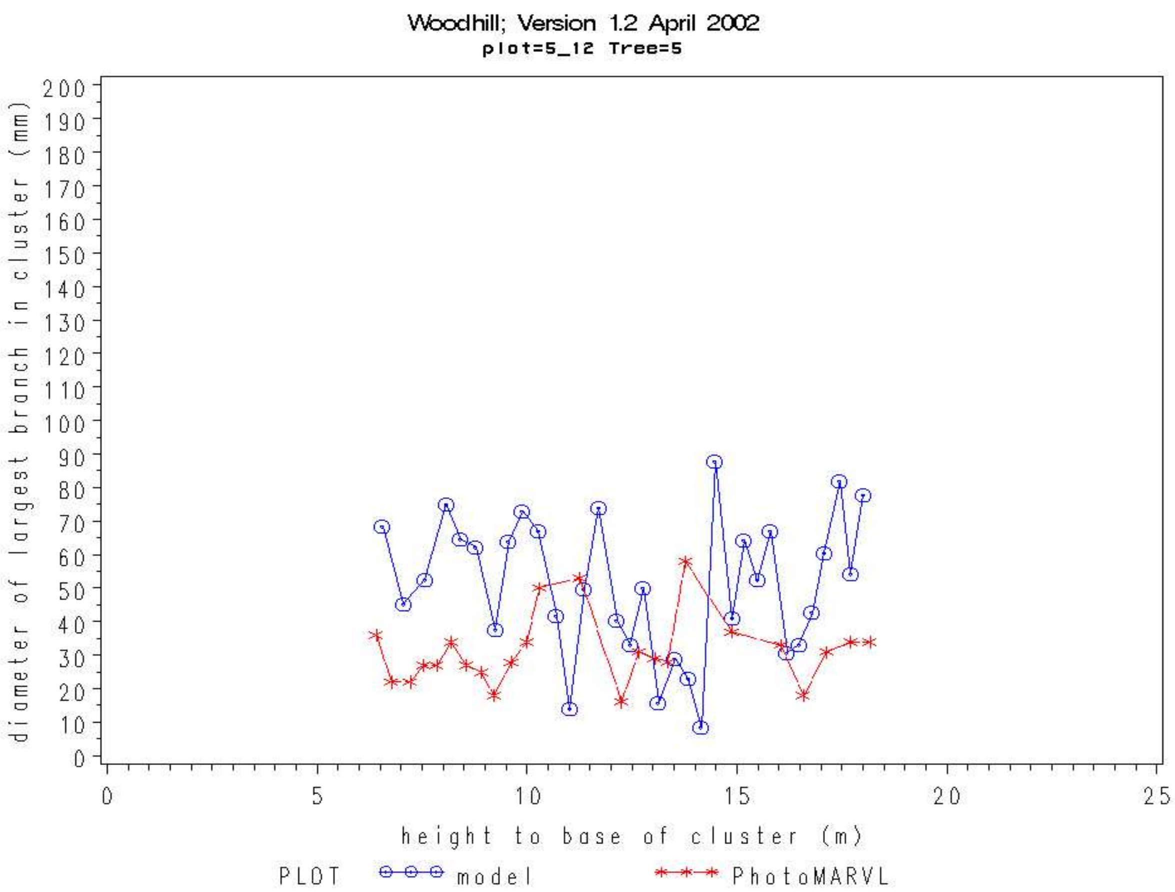


Figure 12. Tree at 70th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

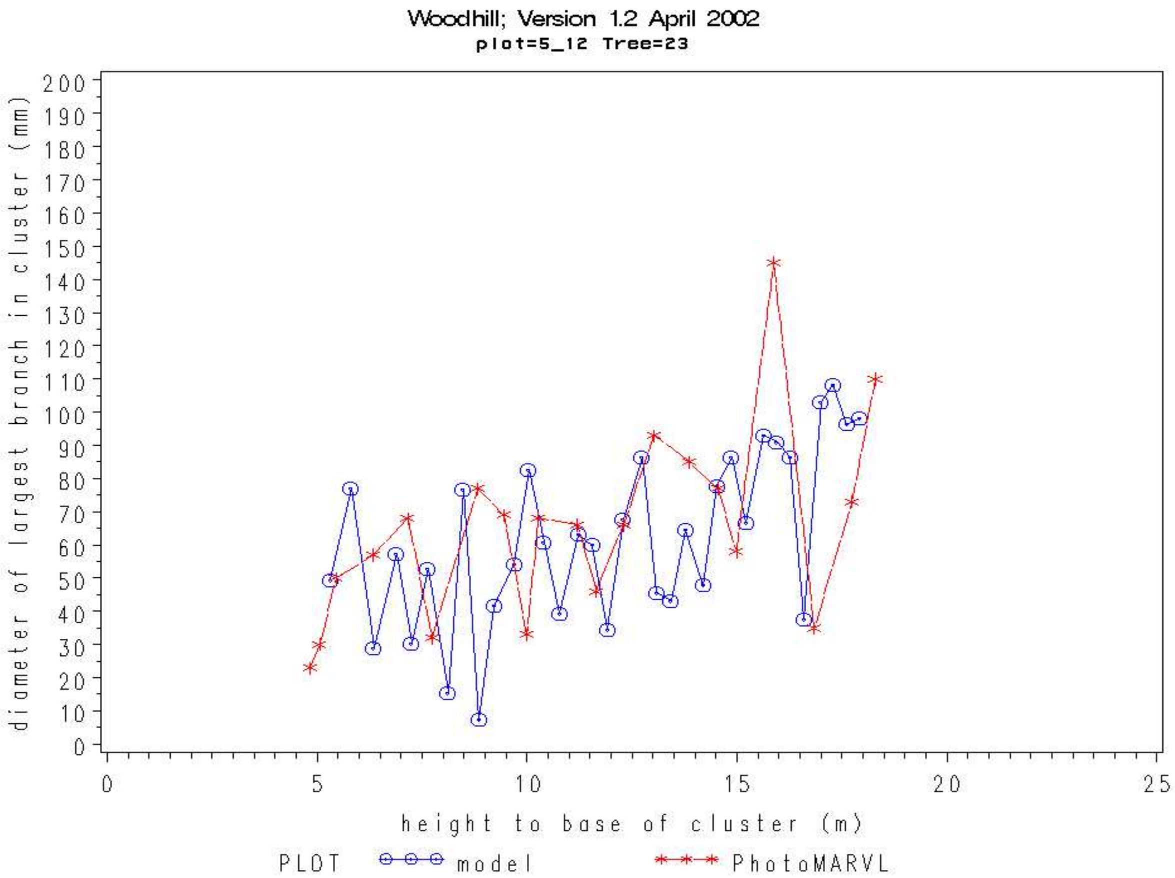


Figure 13. Tree at 100th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

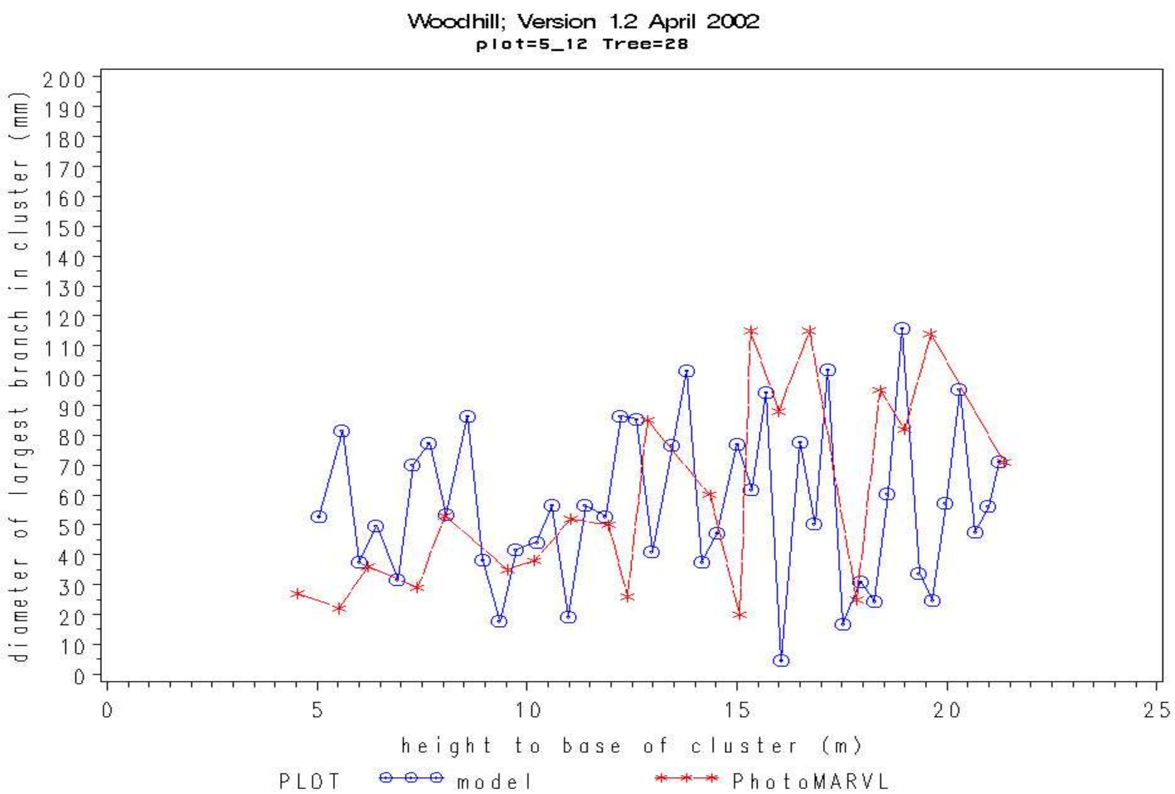


Figure 14. Tree at 10th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

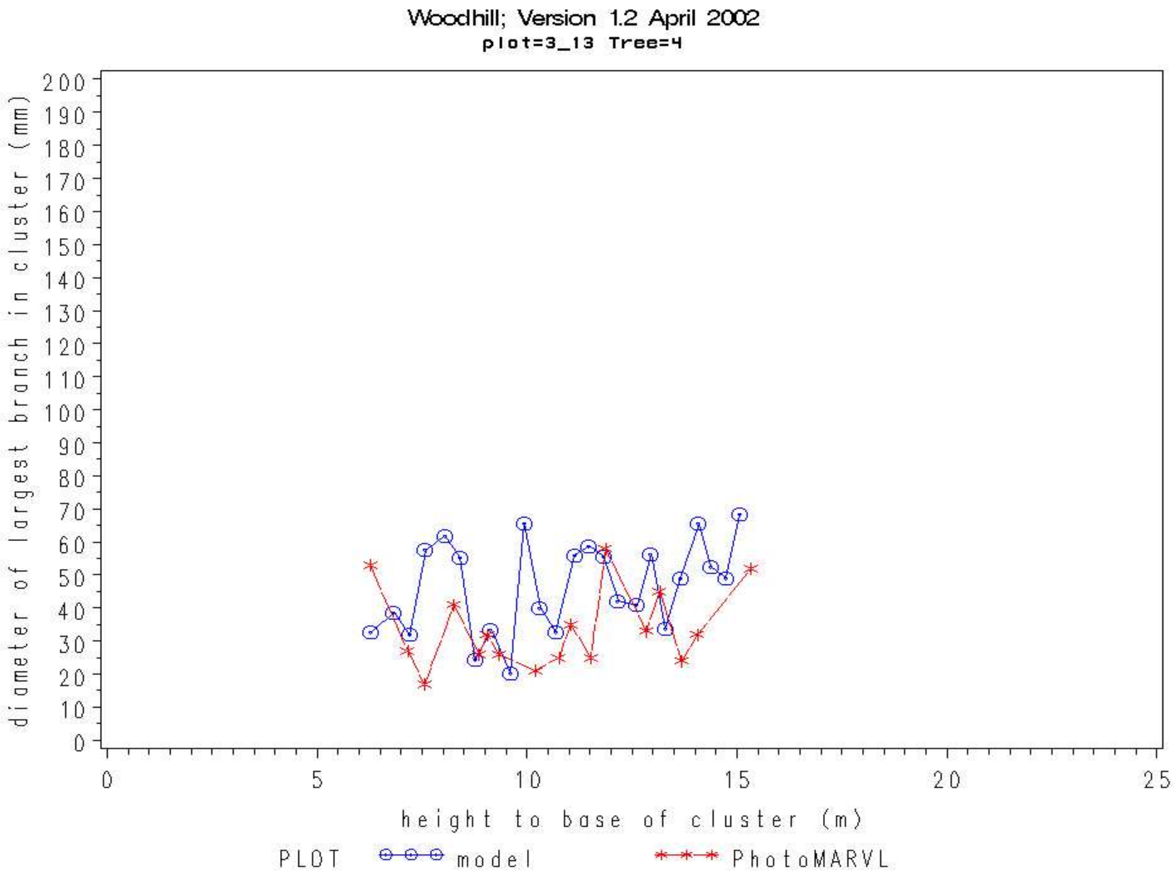


Figure 15. Tree at 40th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

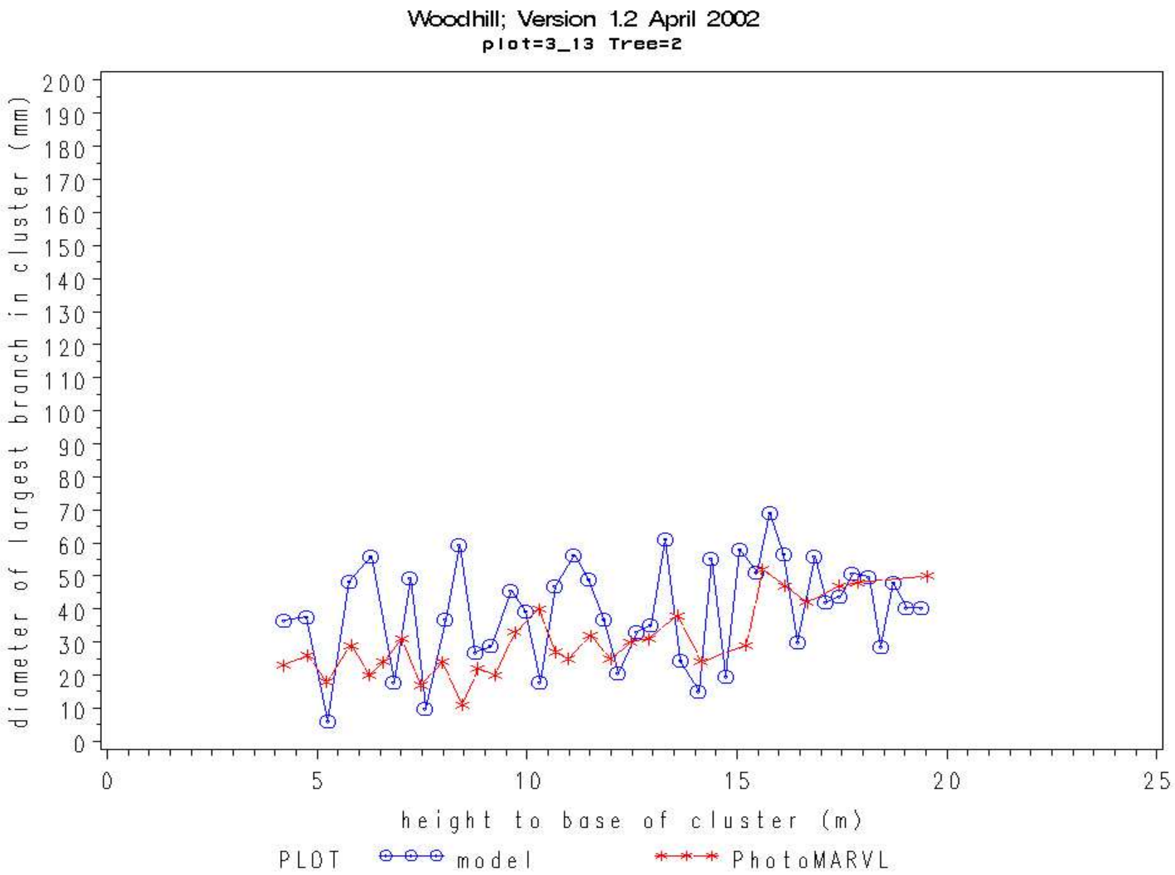


Figure 16. Tree at 70th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

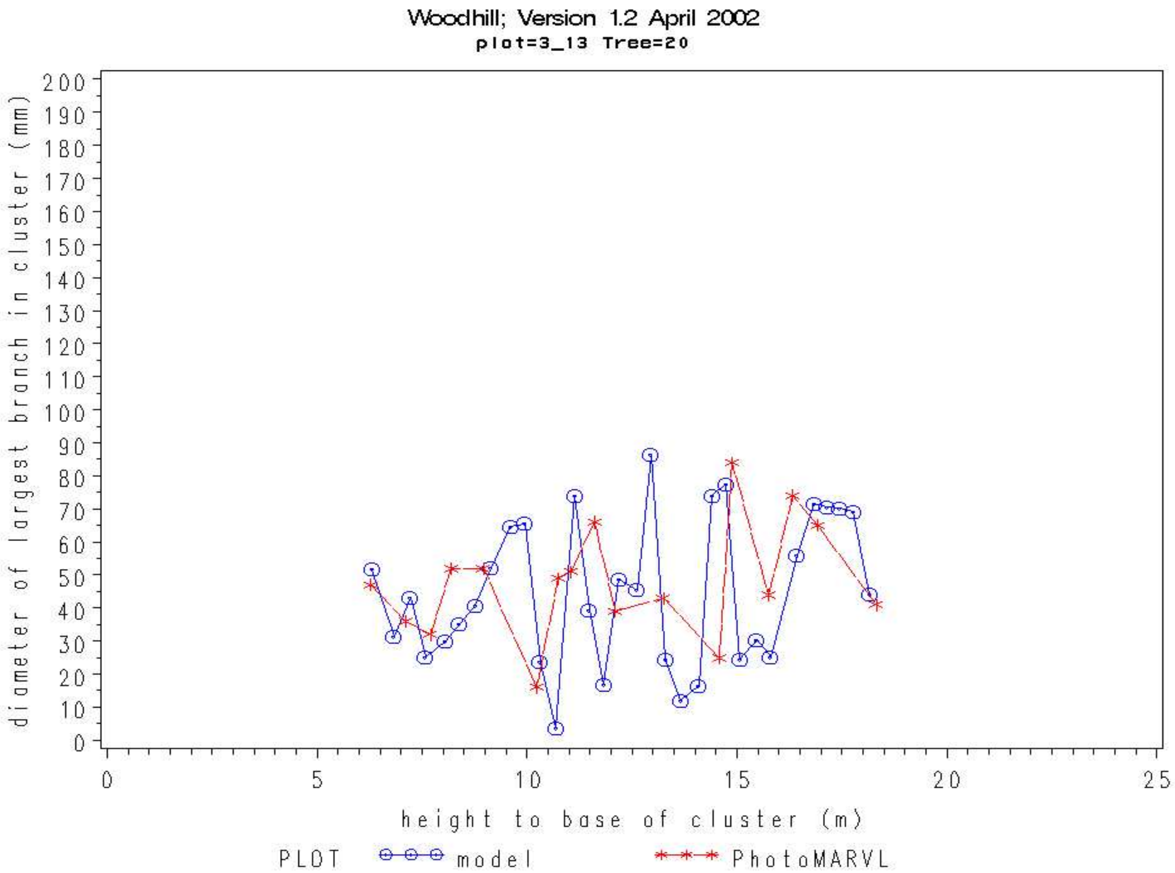


Figure 17. Tree at 100th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

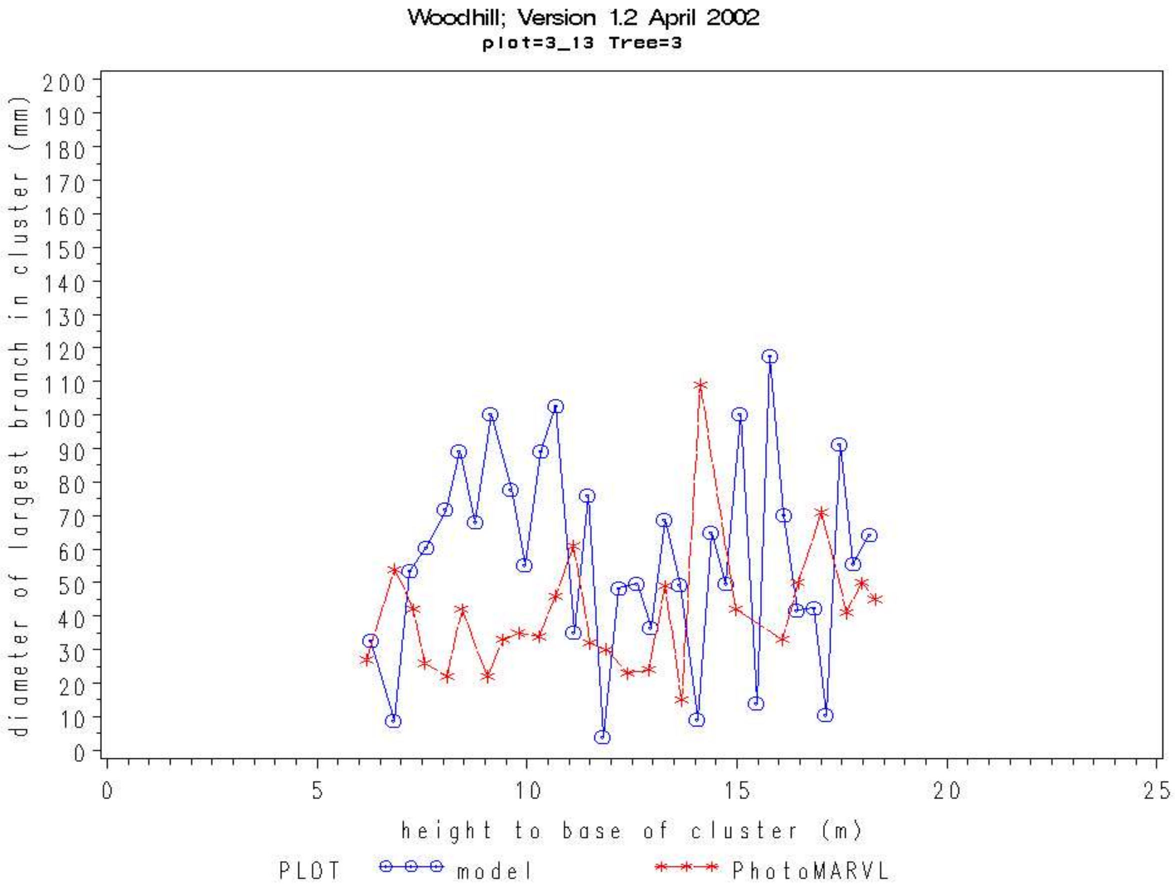


Figure 18. Tree at 10th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

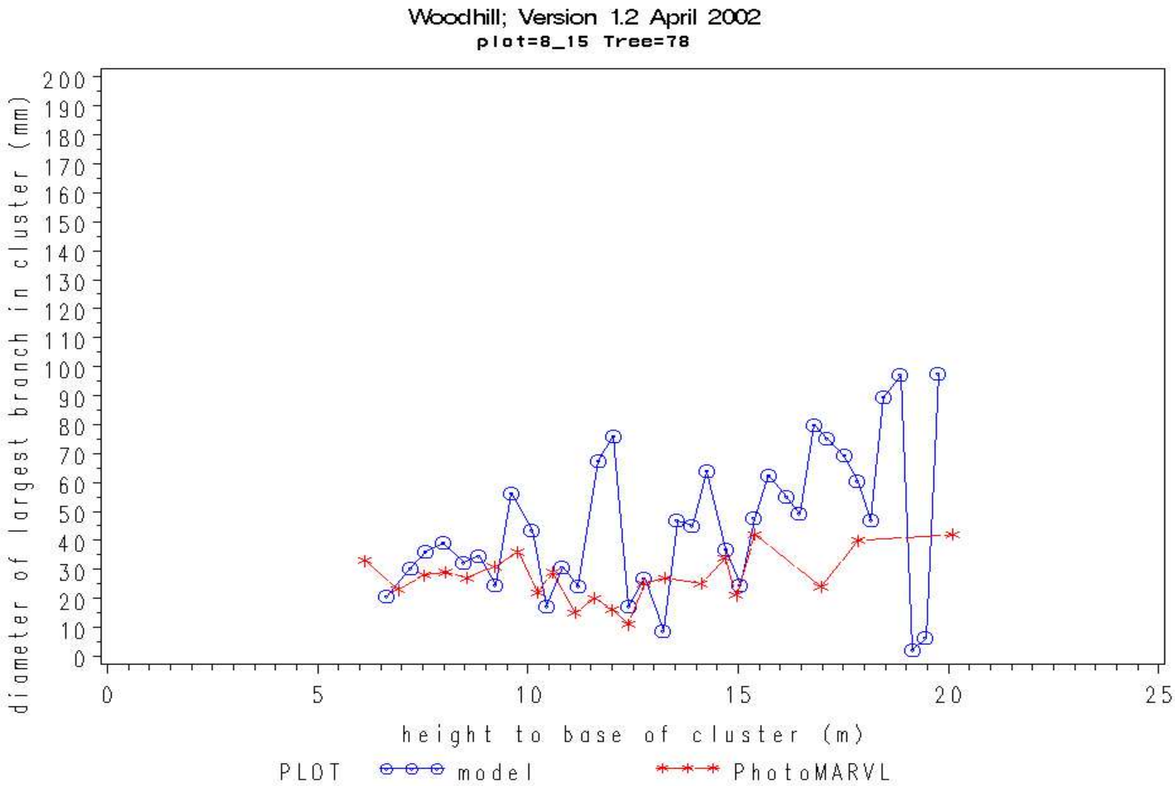


Figure 19. Tree at 40th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

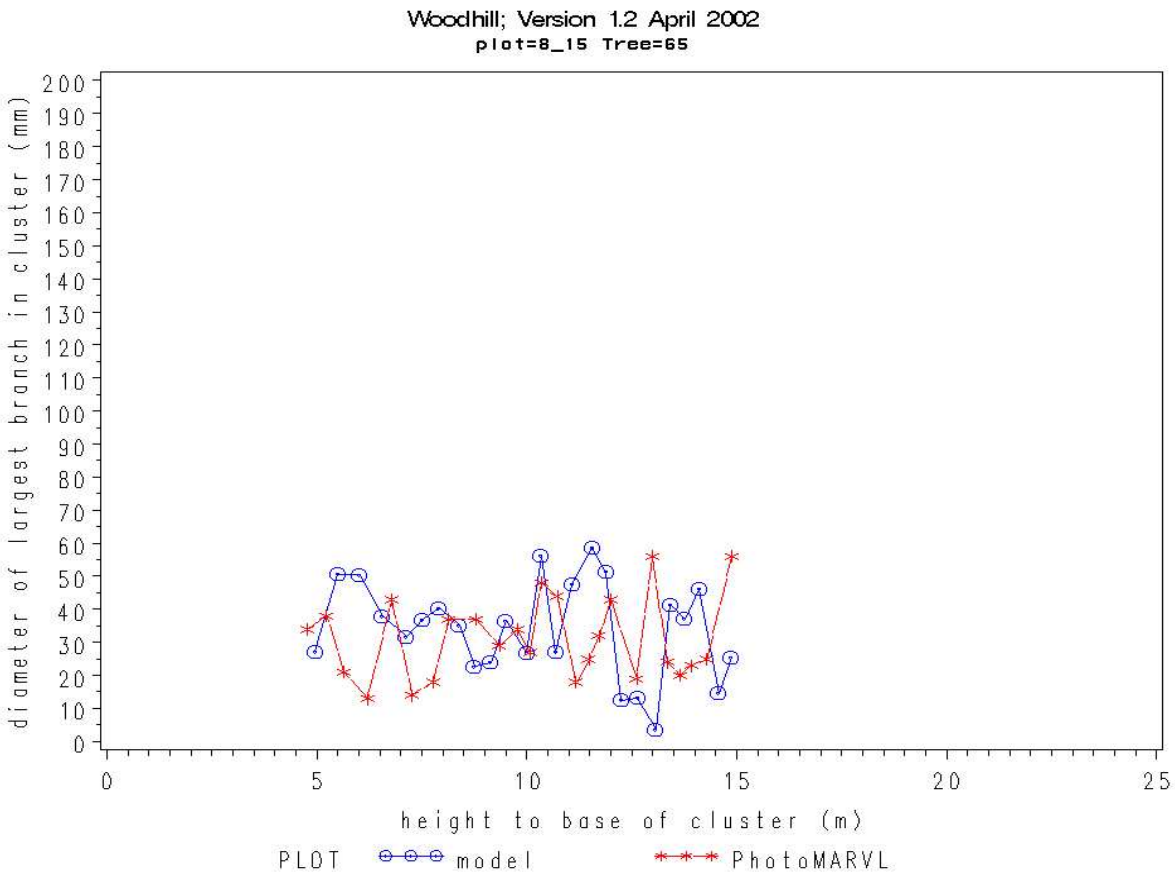


Figure 20. Tree at 70th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

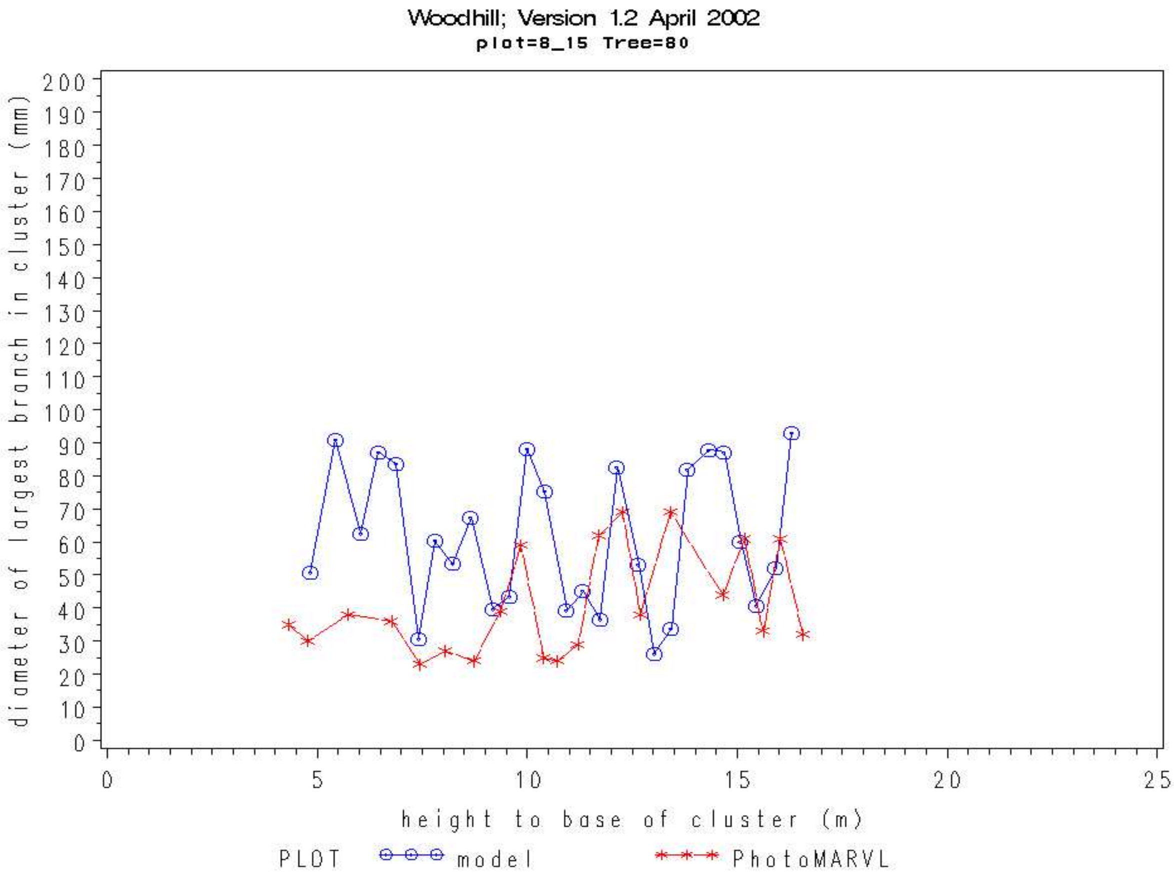


Figure 21. Tree at 100th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

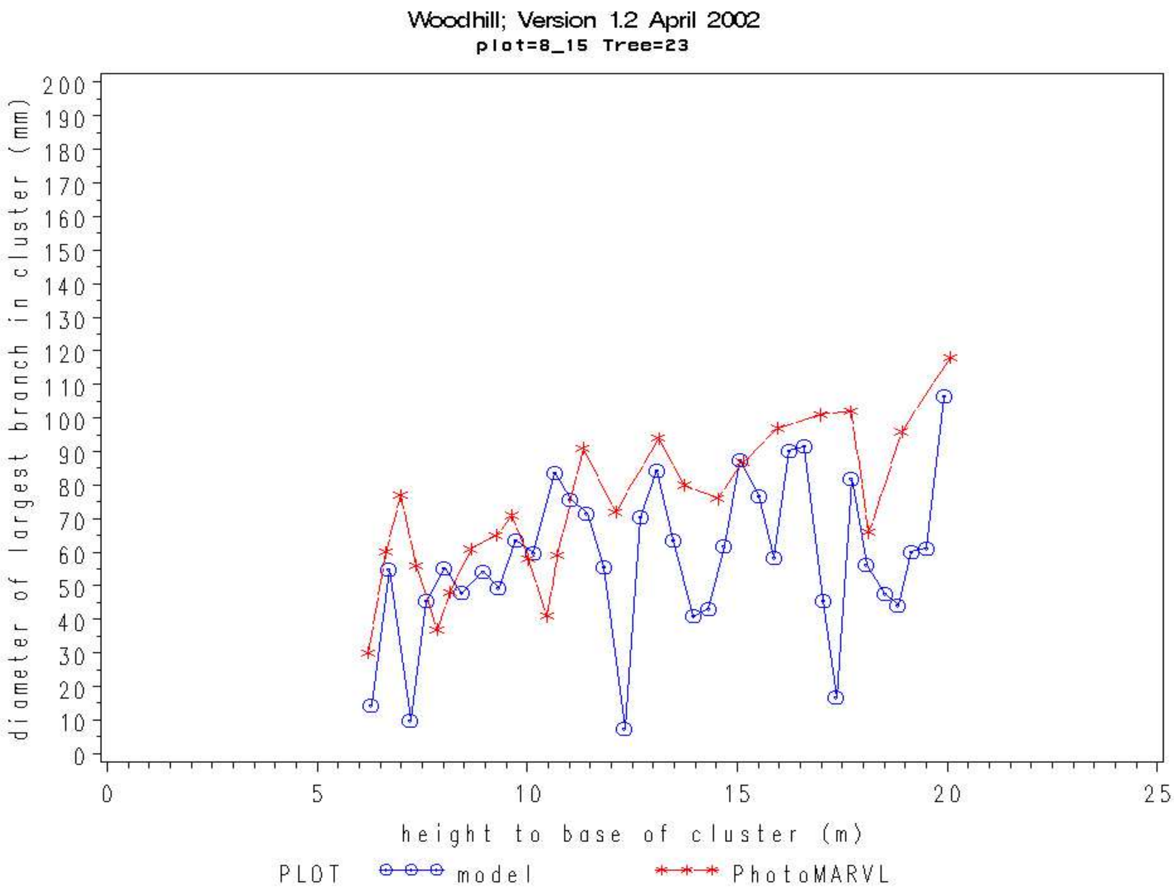


Figure 22. Tree at 10th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

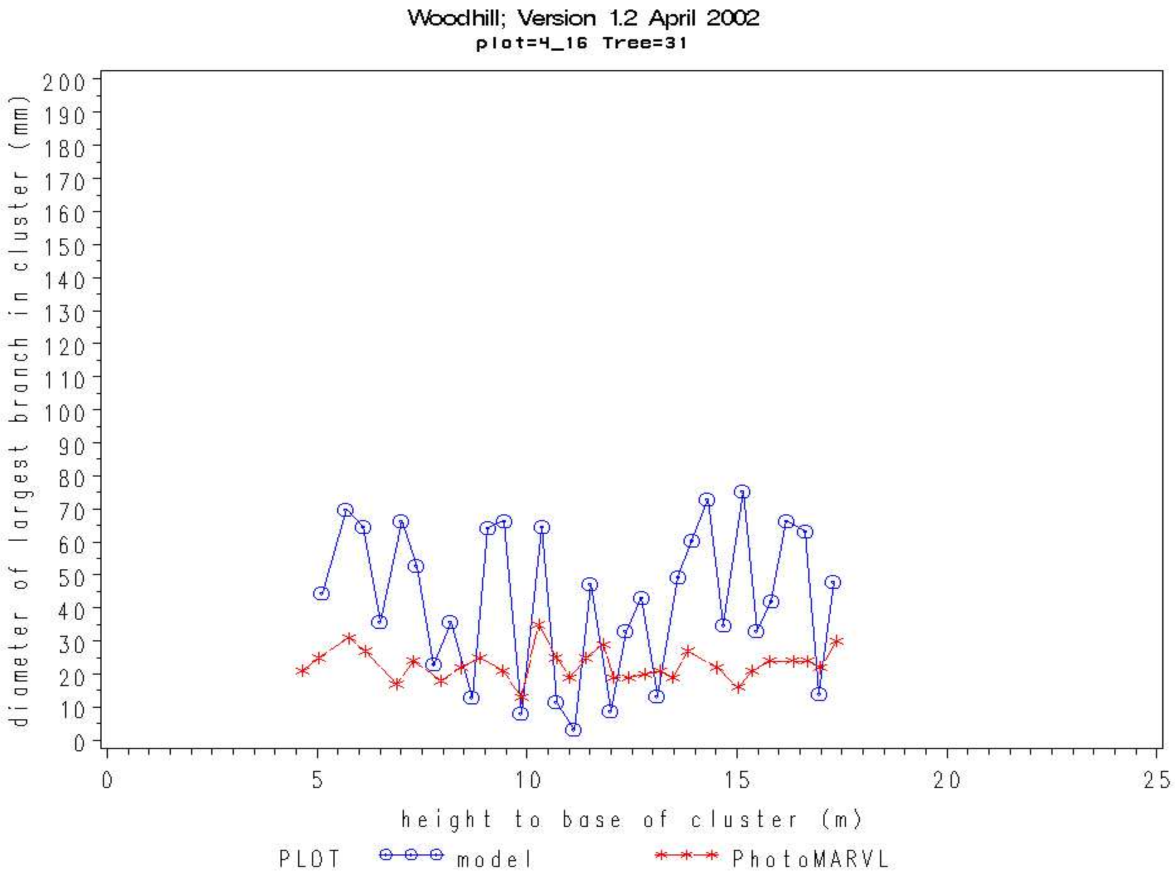


Figure 23. Tree at 40th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

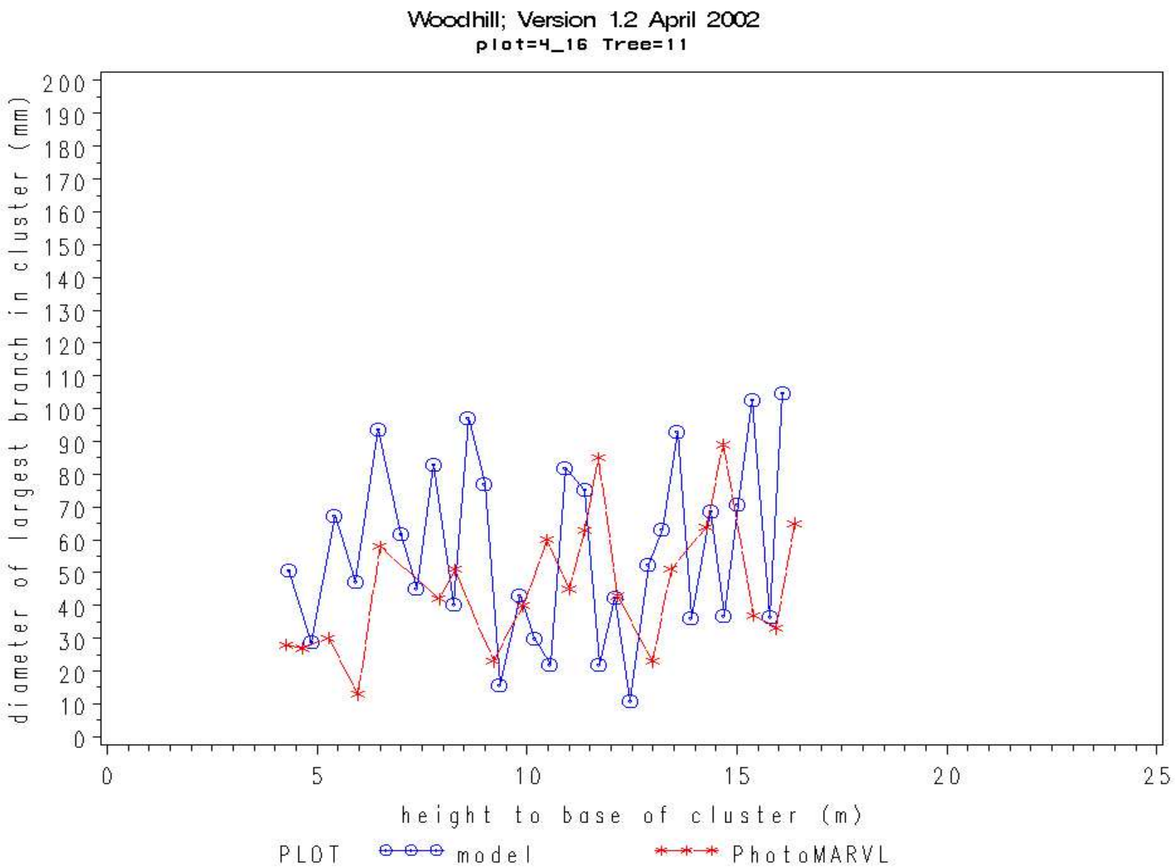


Figure 24. Tree at 70th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

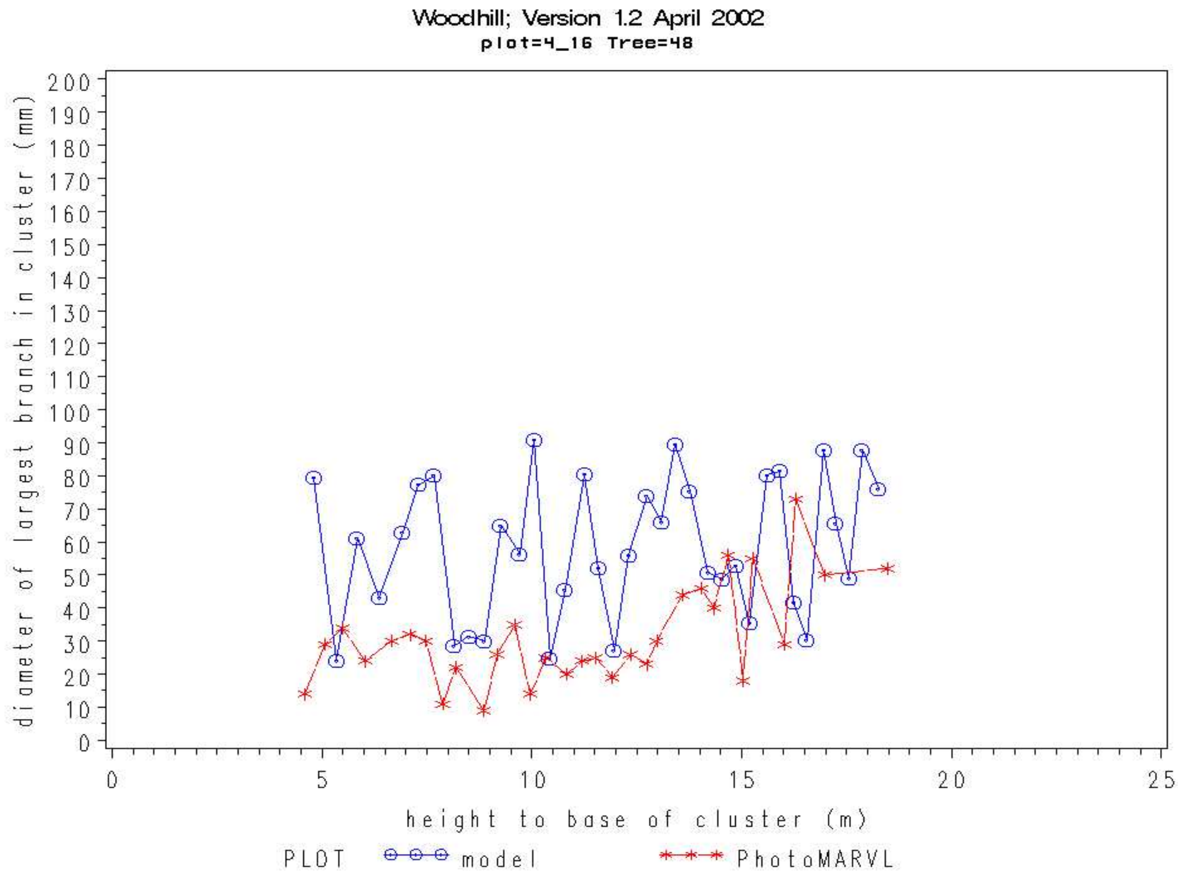


Figure 25. Tree at 100th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

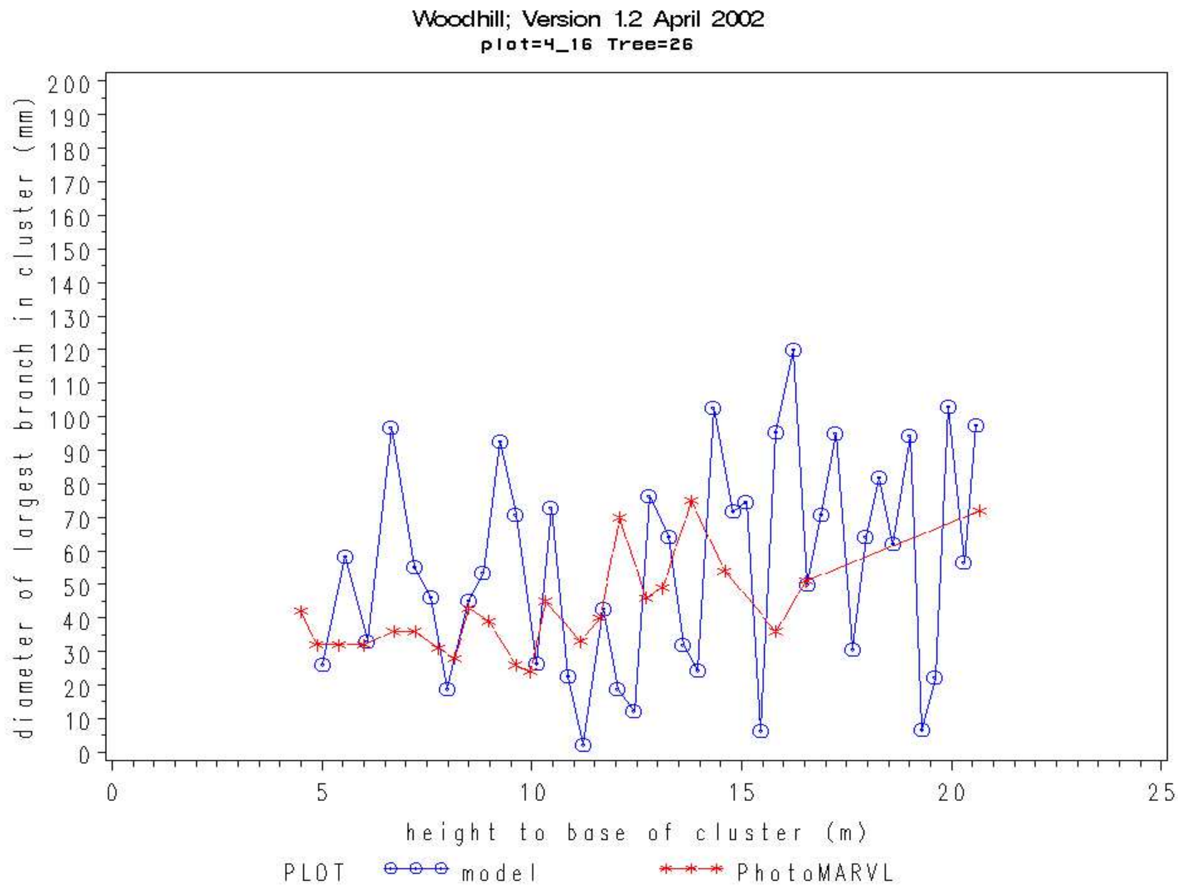


Figure 26. Tree at 10th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

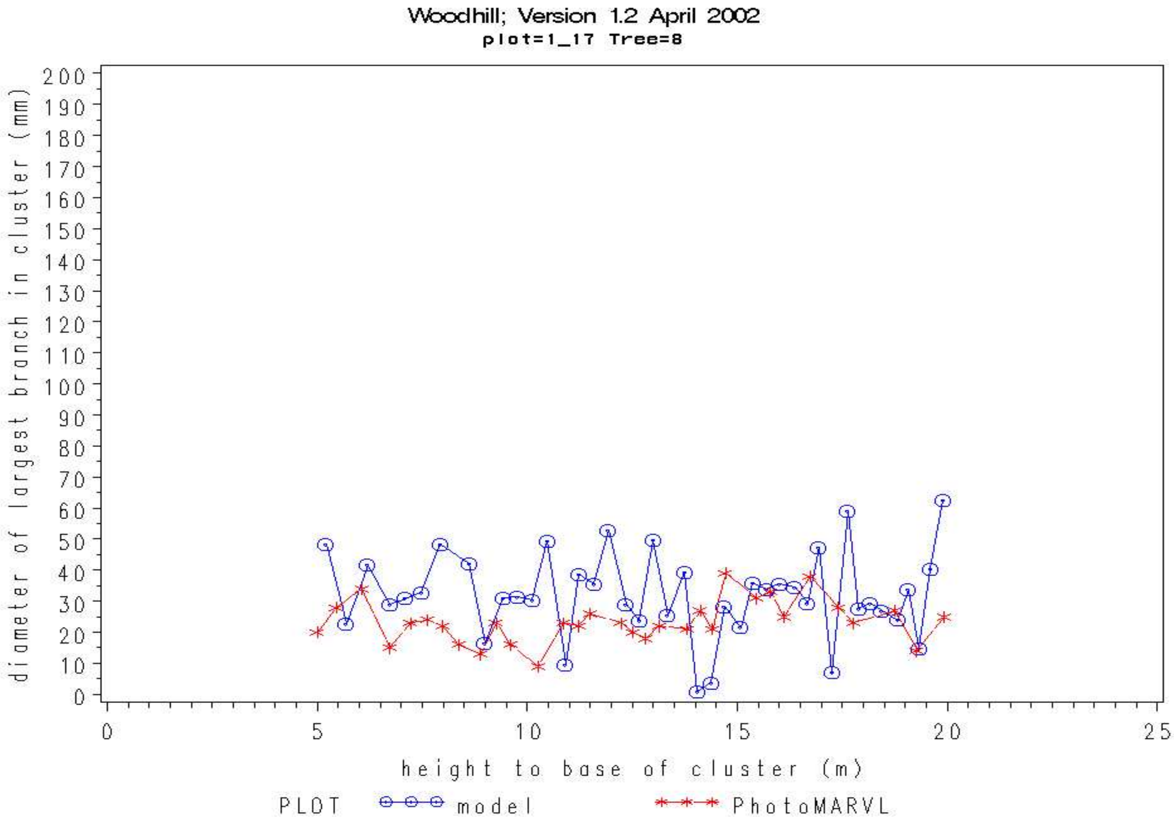


Figure 27. Tree at 40th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

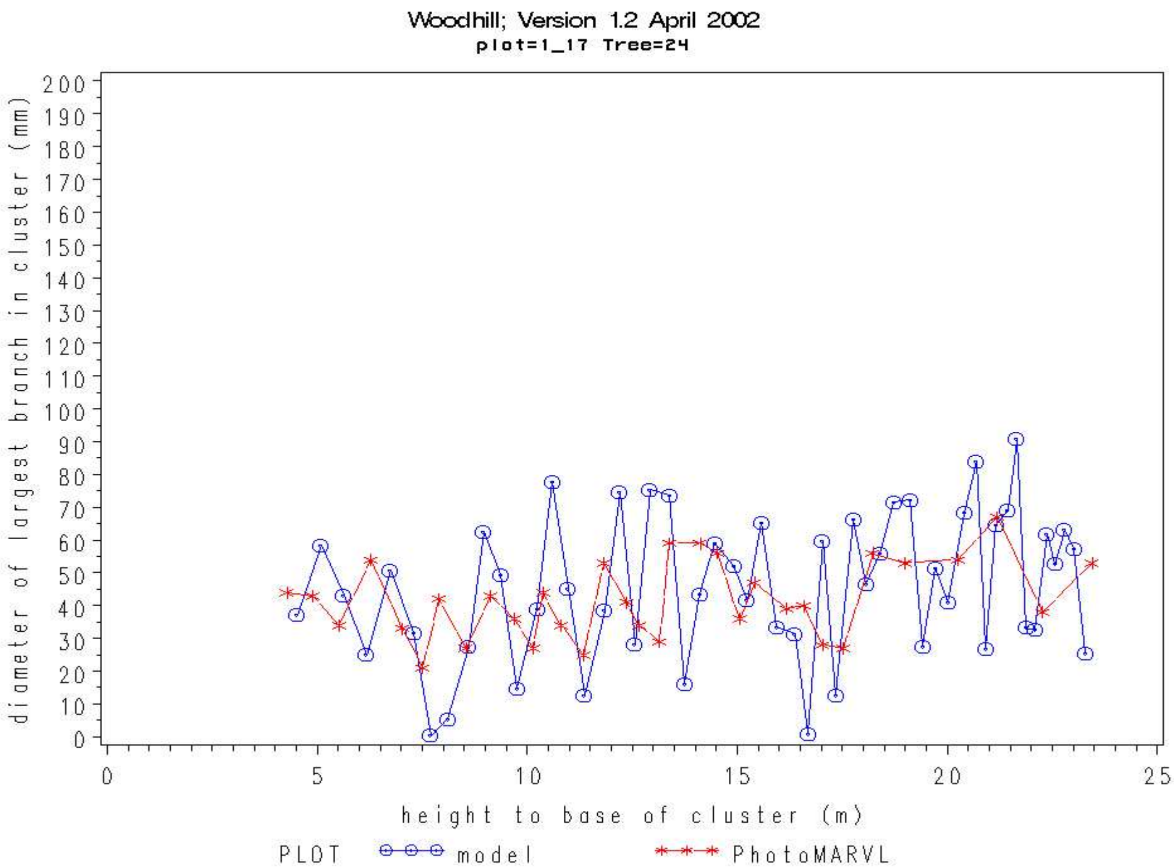


Figure 28. Tree at 70th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

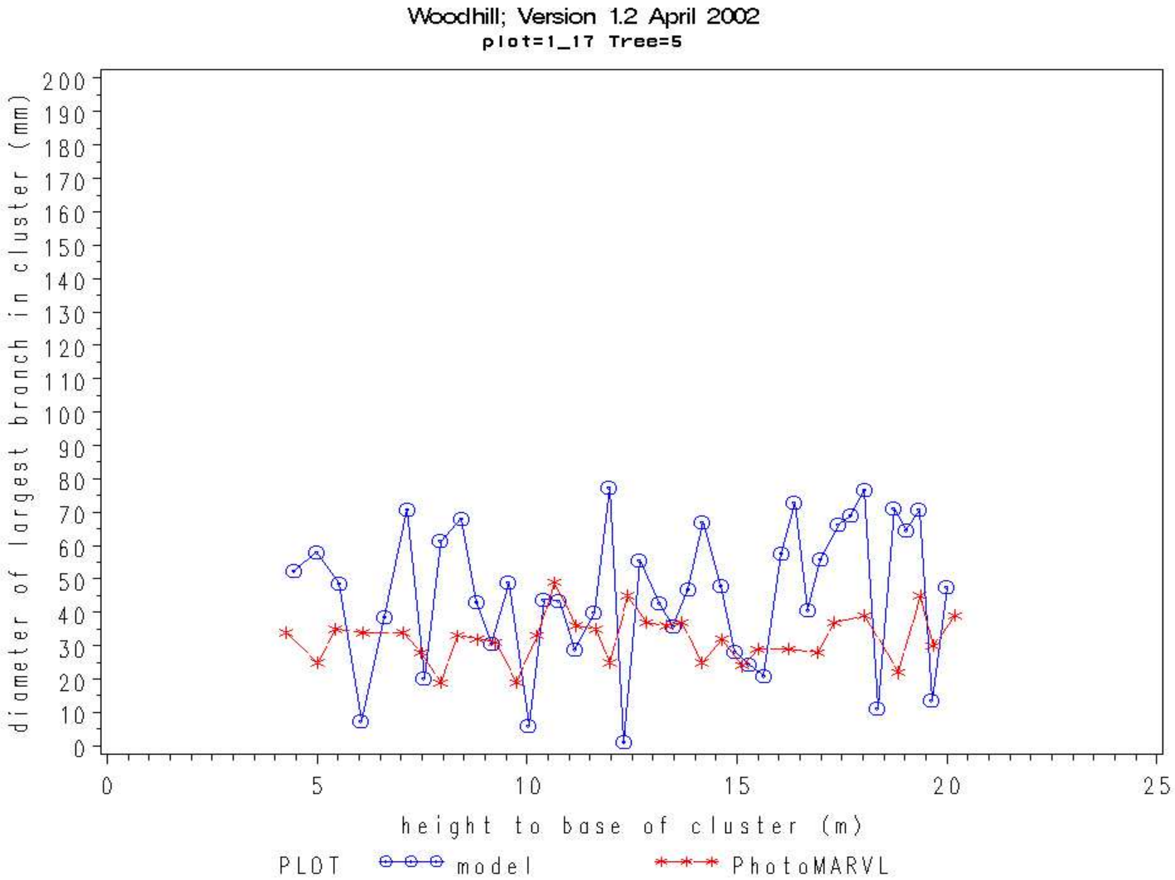
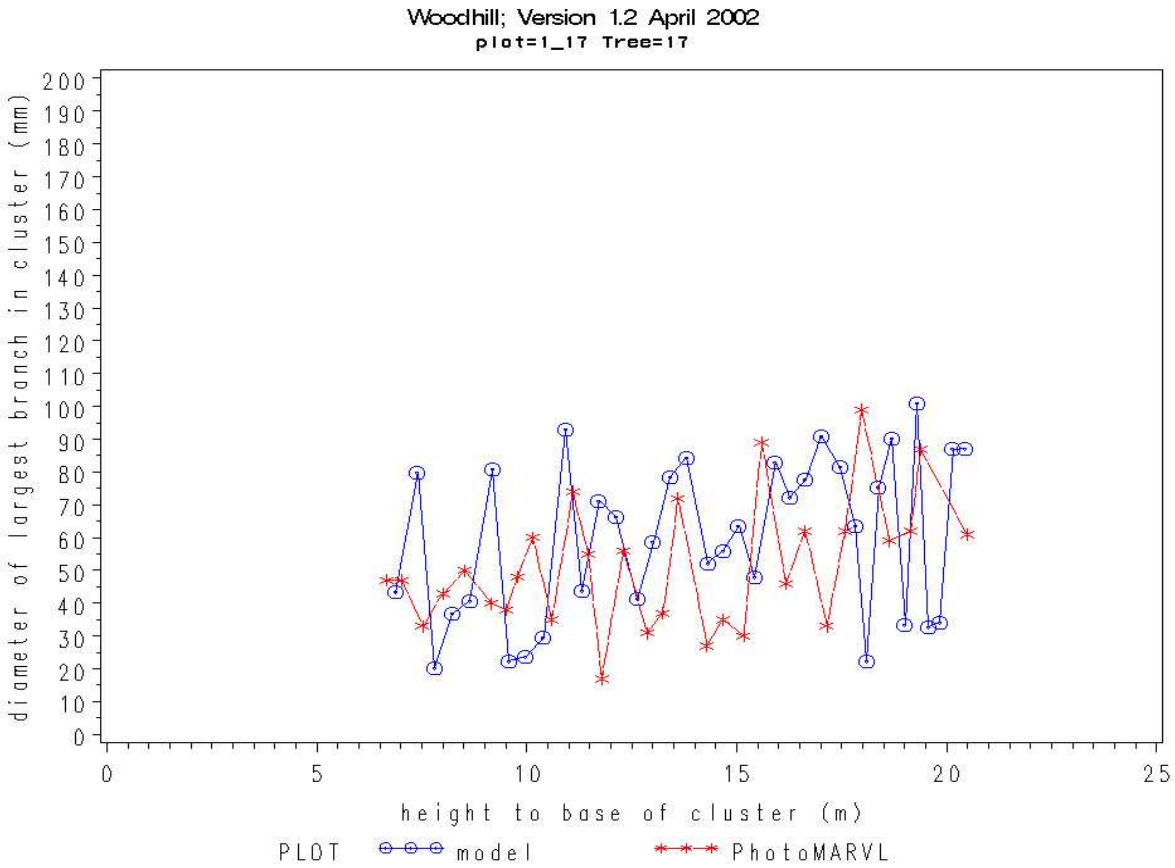


Figure 29. Tree at 100th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years



APPENDIX 2: Golden Downs (NN529/1) - Diameter of largest branch in a cluster - *PhotoMARVL* measurements and TreeBLOSSIM predictions

Figure 30. Tree at 10th percentile of DBH distribution in unthinned plot

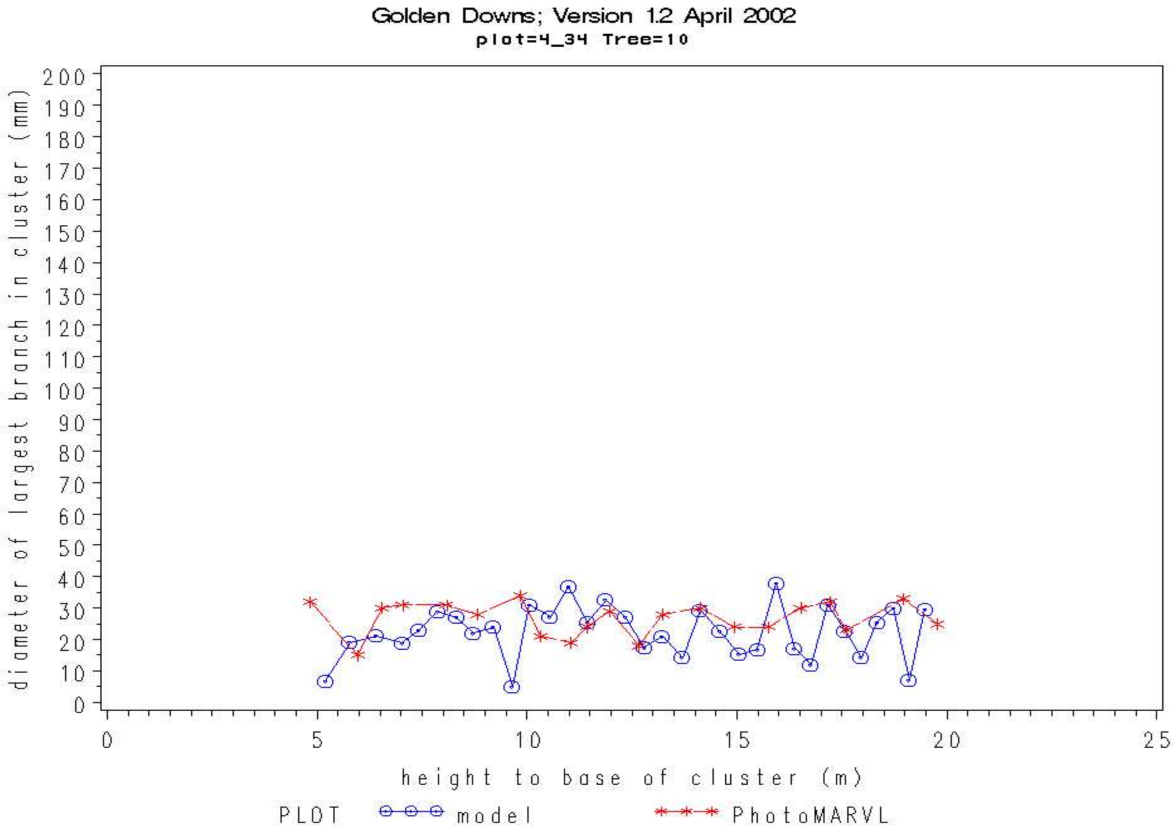


Figure 31. Tree at 40th percentile of DBH distribution in unthinned plot

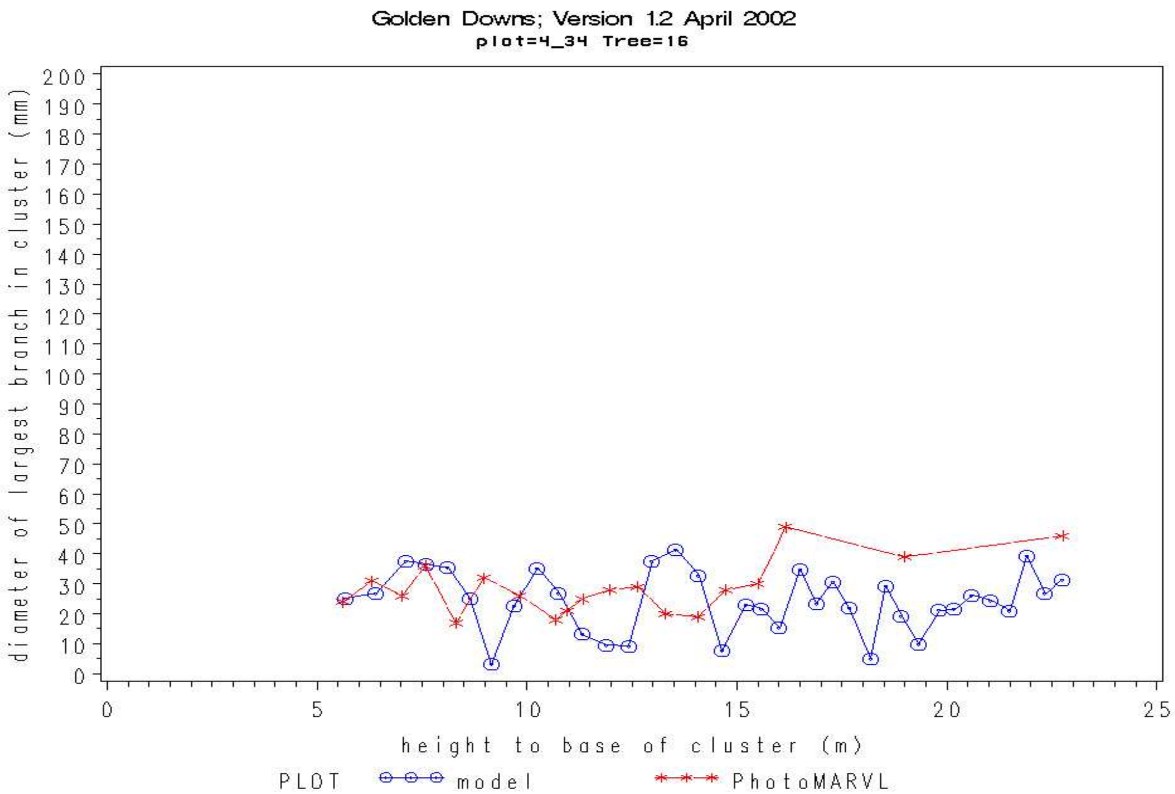


Figure 32. Tree at 70th percentile of DBH distribution in unthinned plot

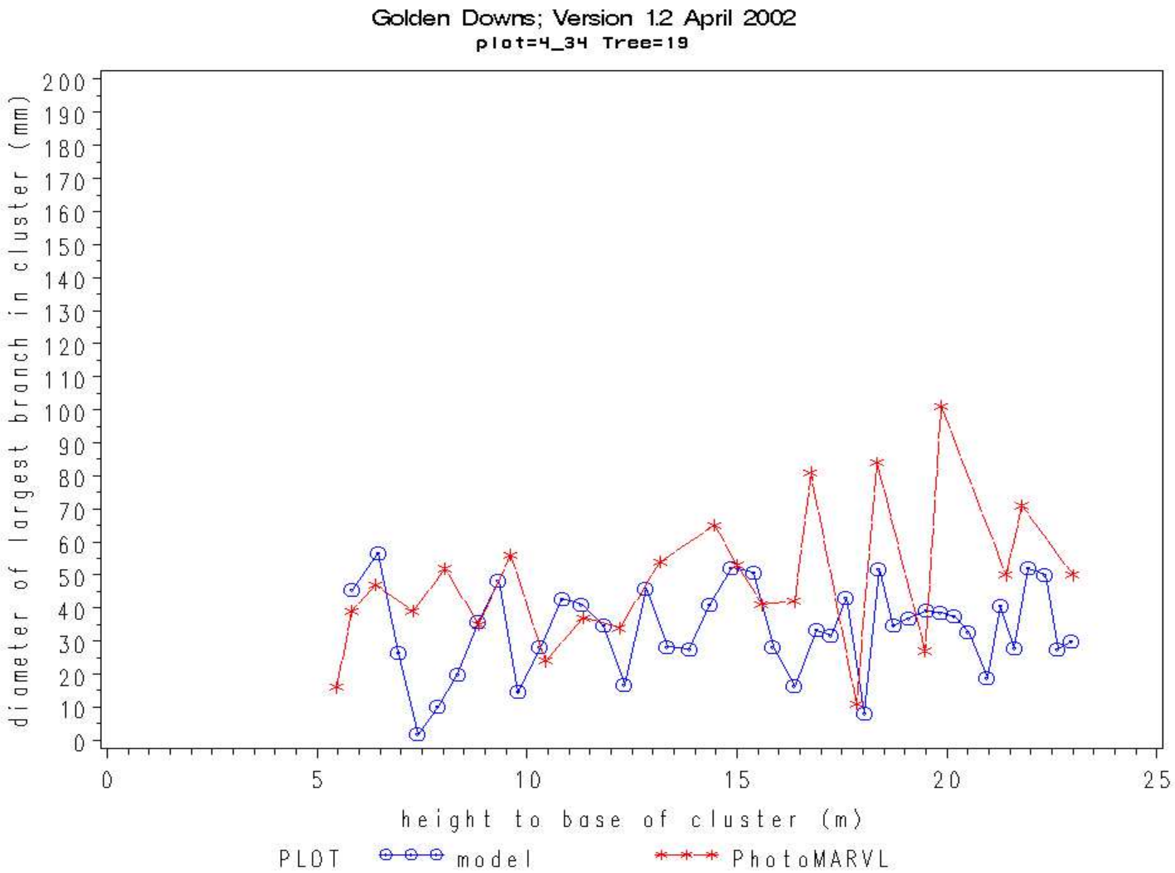


Figure 33. Tree at 100th percentile of DBH distribution in unthinned plot

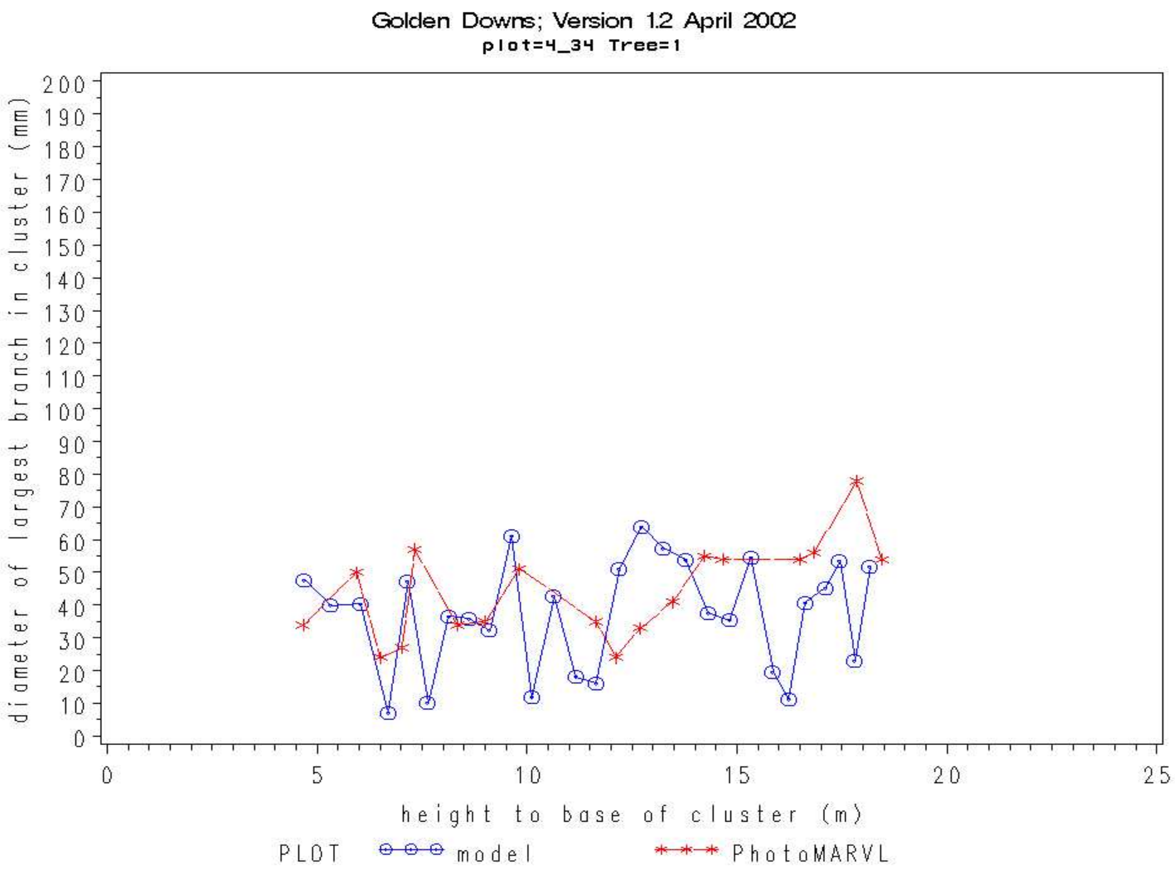


Figure 34. Tree at 10th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

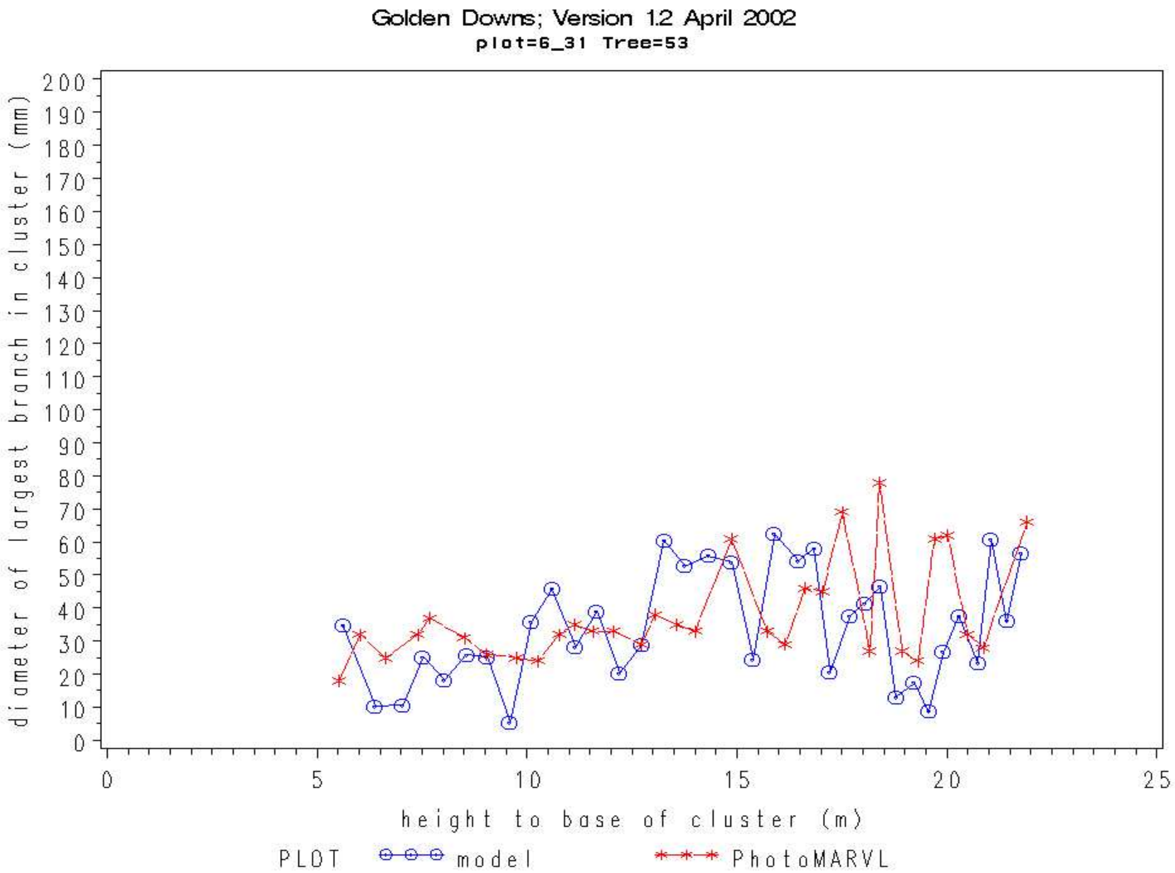


Figure 35. Tree at 40th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

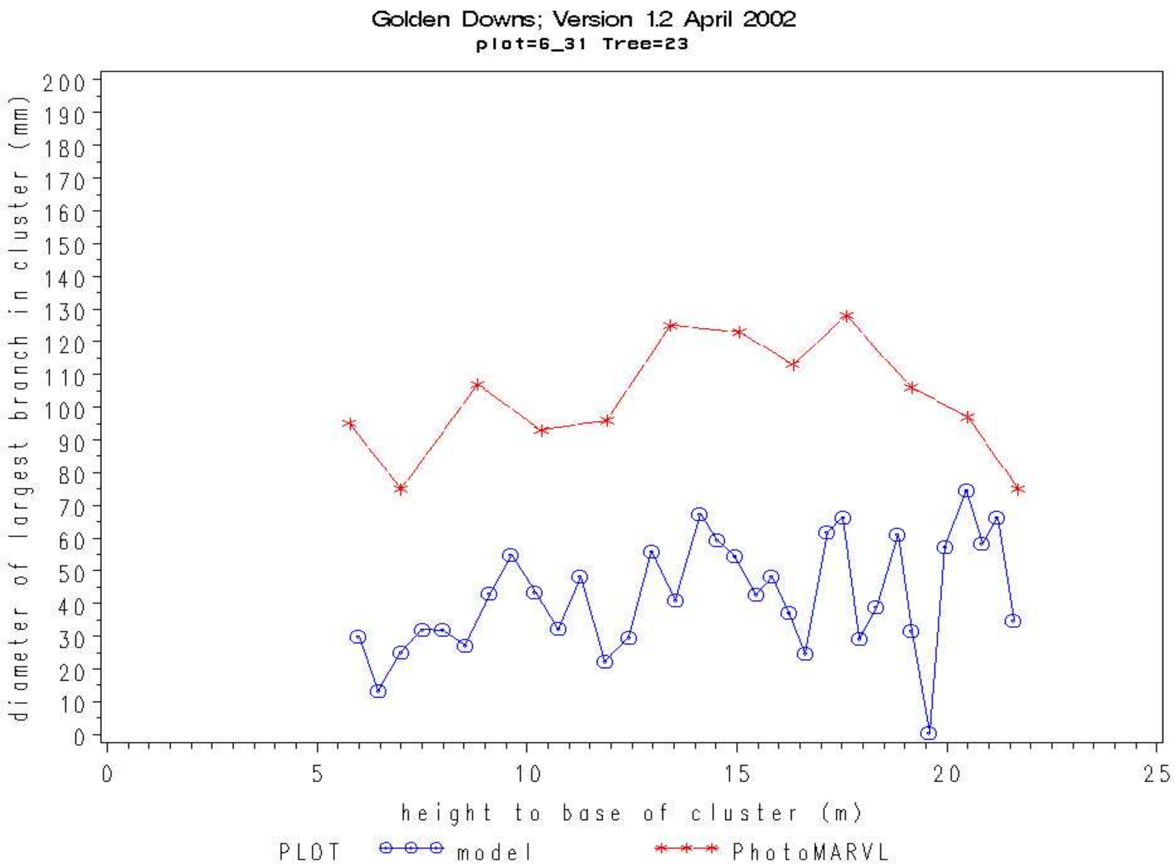


Figure 36. Tree at 70th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

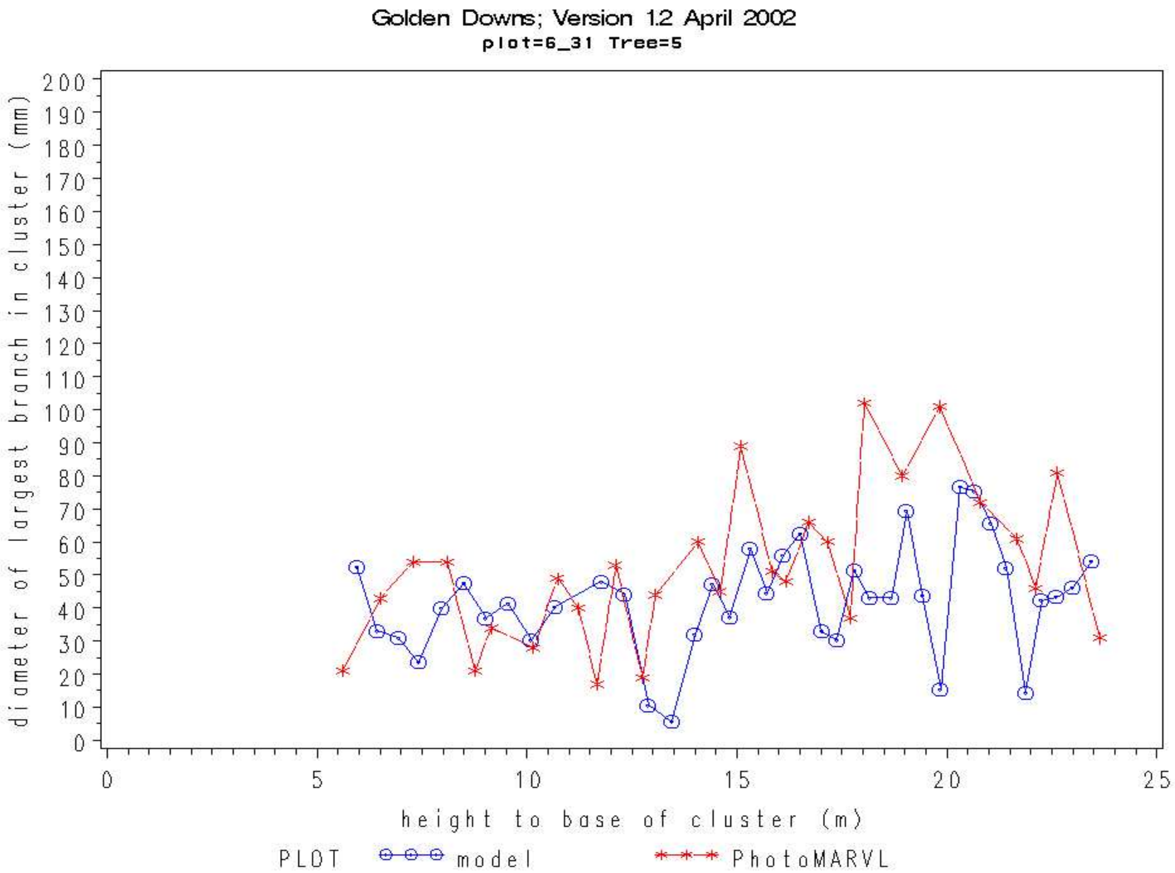


Figure 37. Tree at 100th percentile of DBH distribution in plot thinned to 100 stems/ha at age 11 years

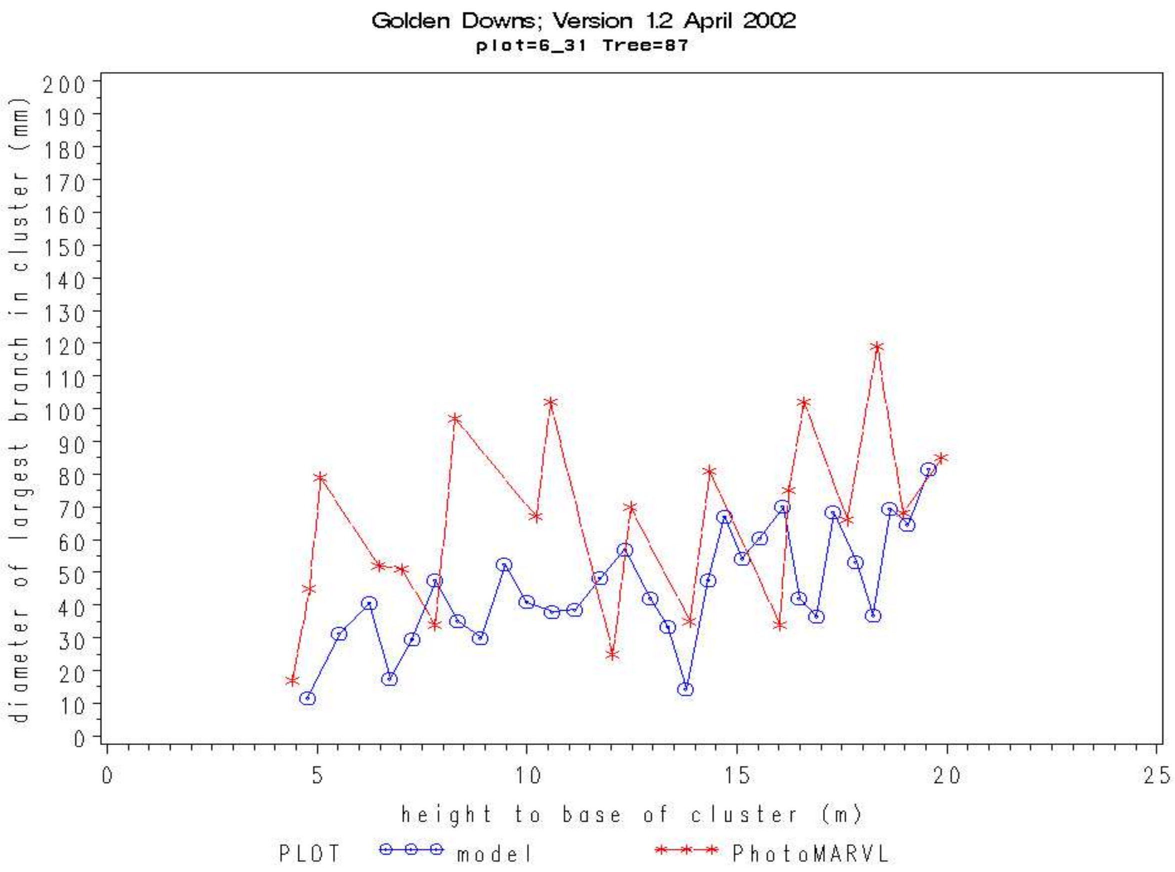


Figure 38. Tree at 10th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

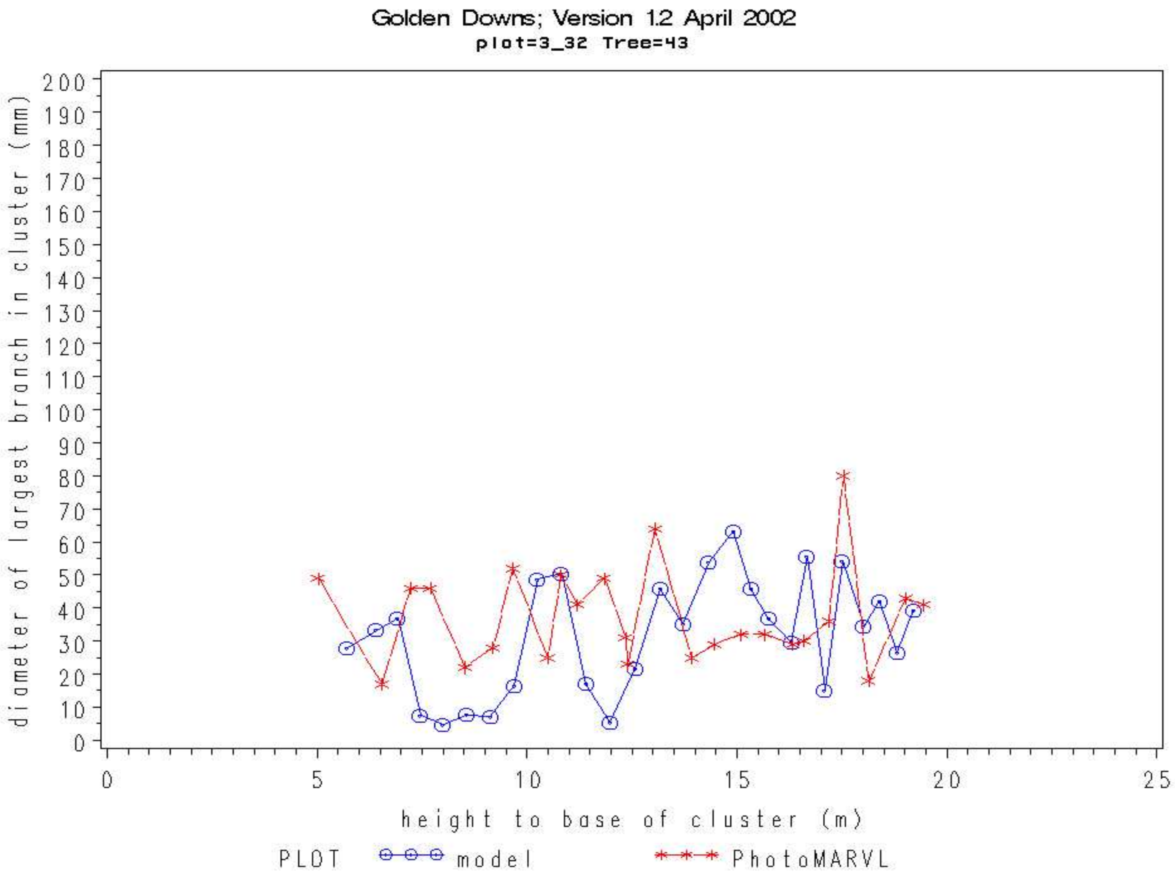


Figure 39. Tree at 40th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

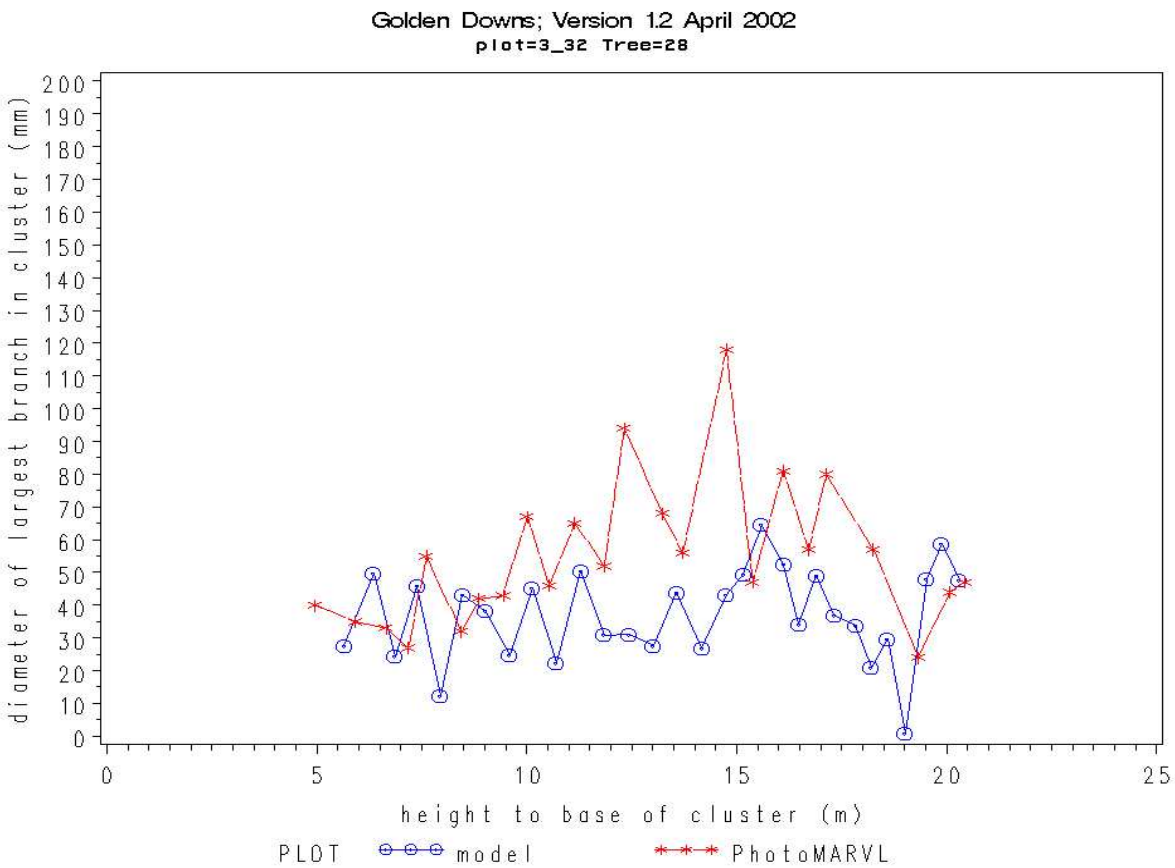


Figure 40. Tree at 70th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

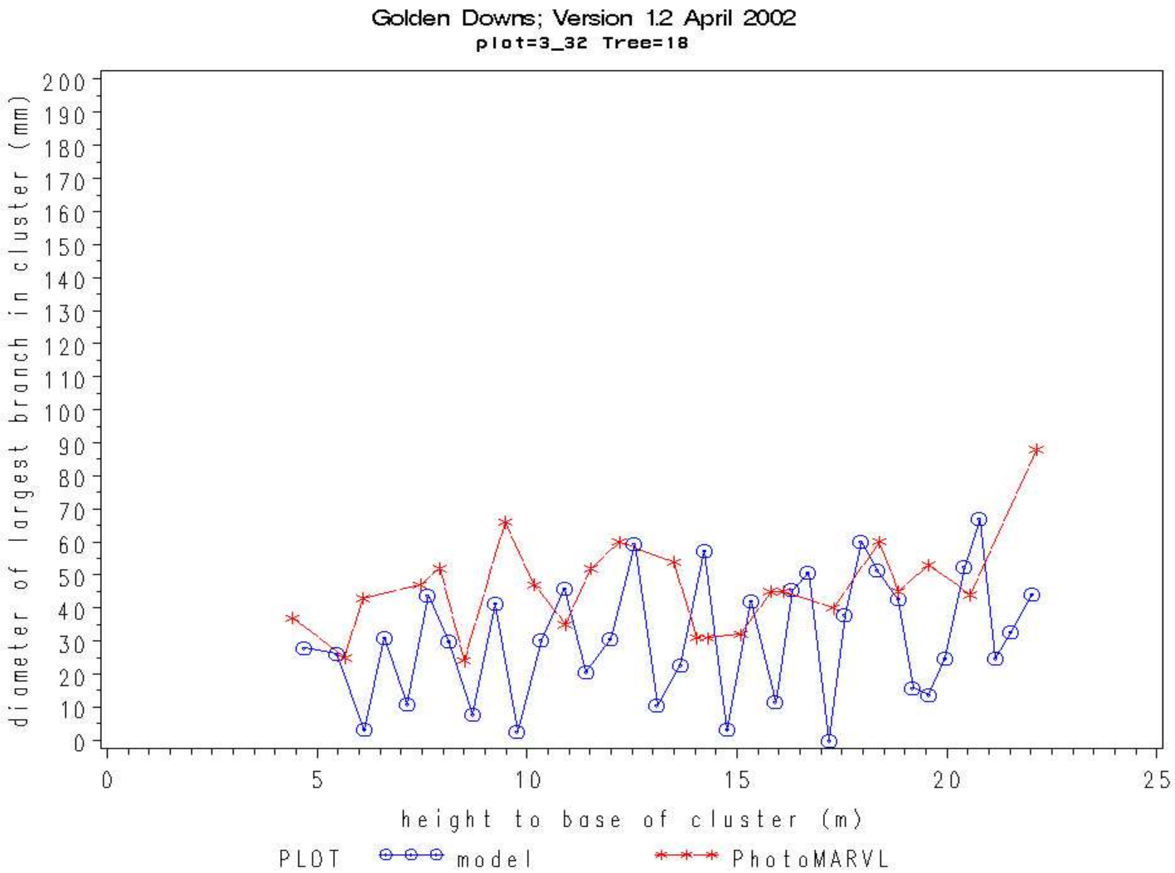


Figure 41. Tree at 100th percentile of DBH distribution in plot thinned to 200 stems/ha at age 11 years

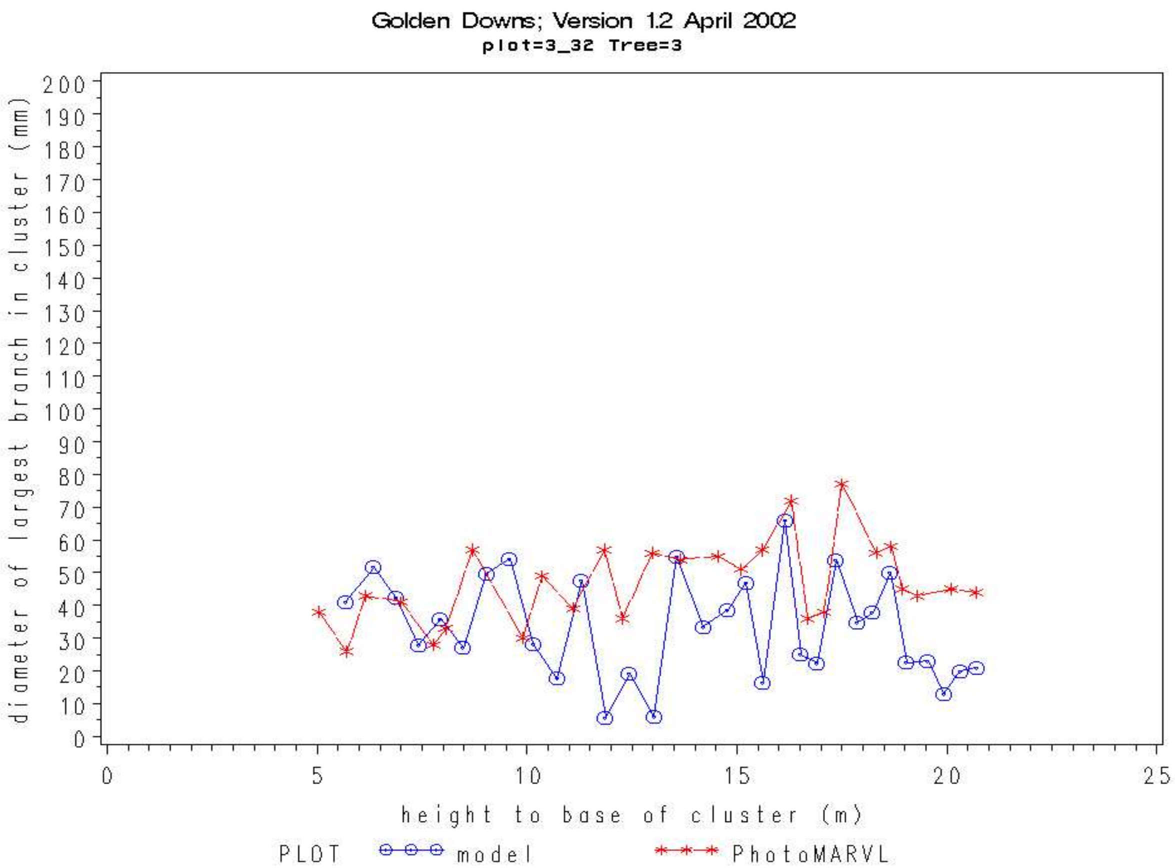


Figure 42. Tree at 10th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

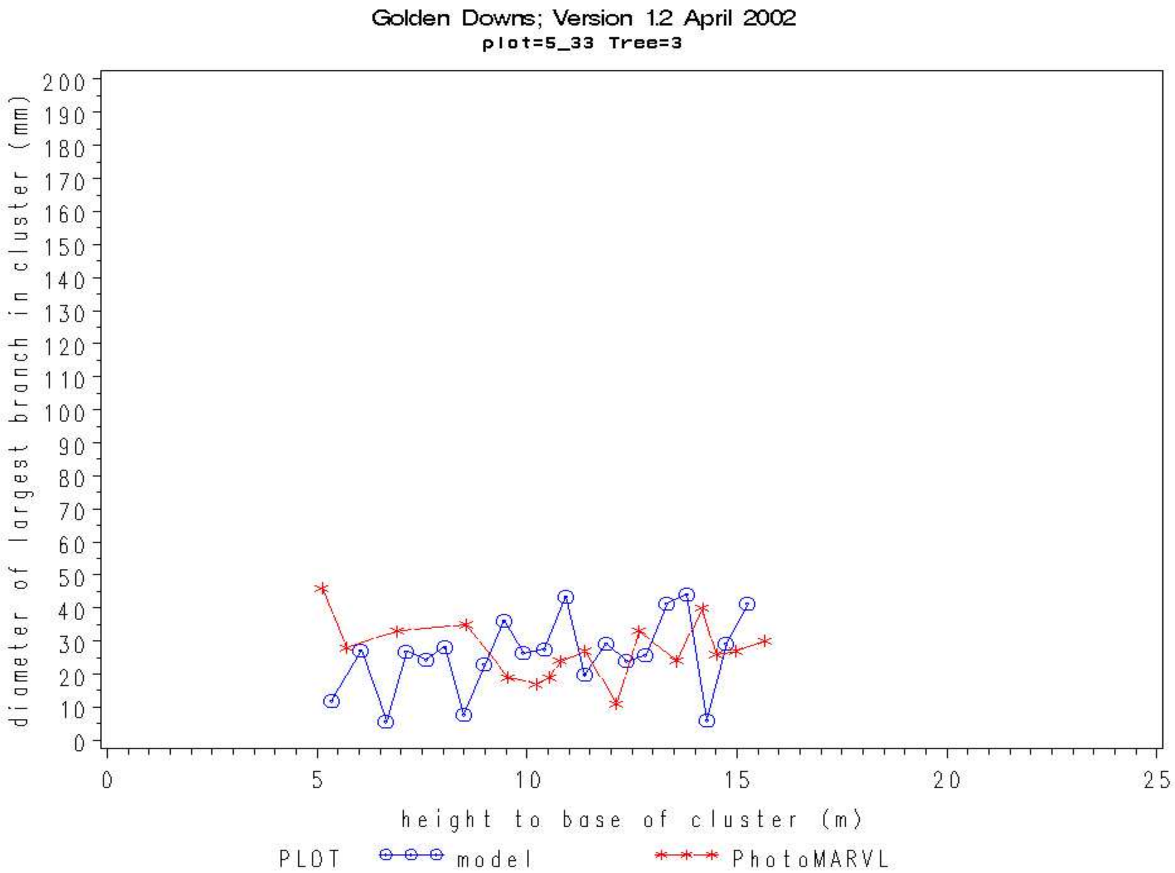


Figure 43. Tree at 40th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

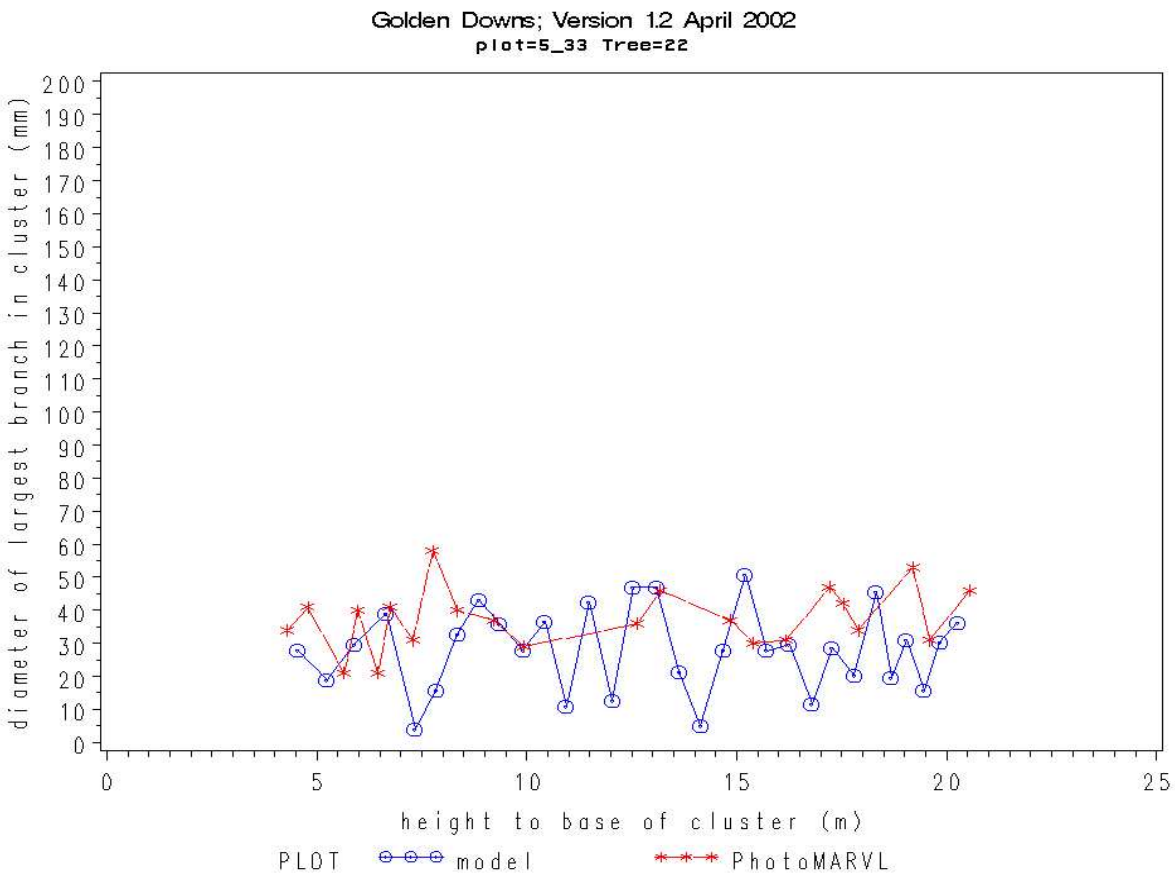


Figure 44. Tree at 70th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

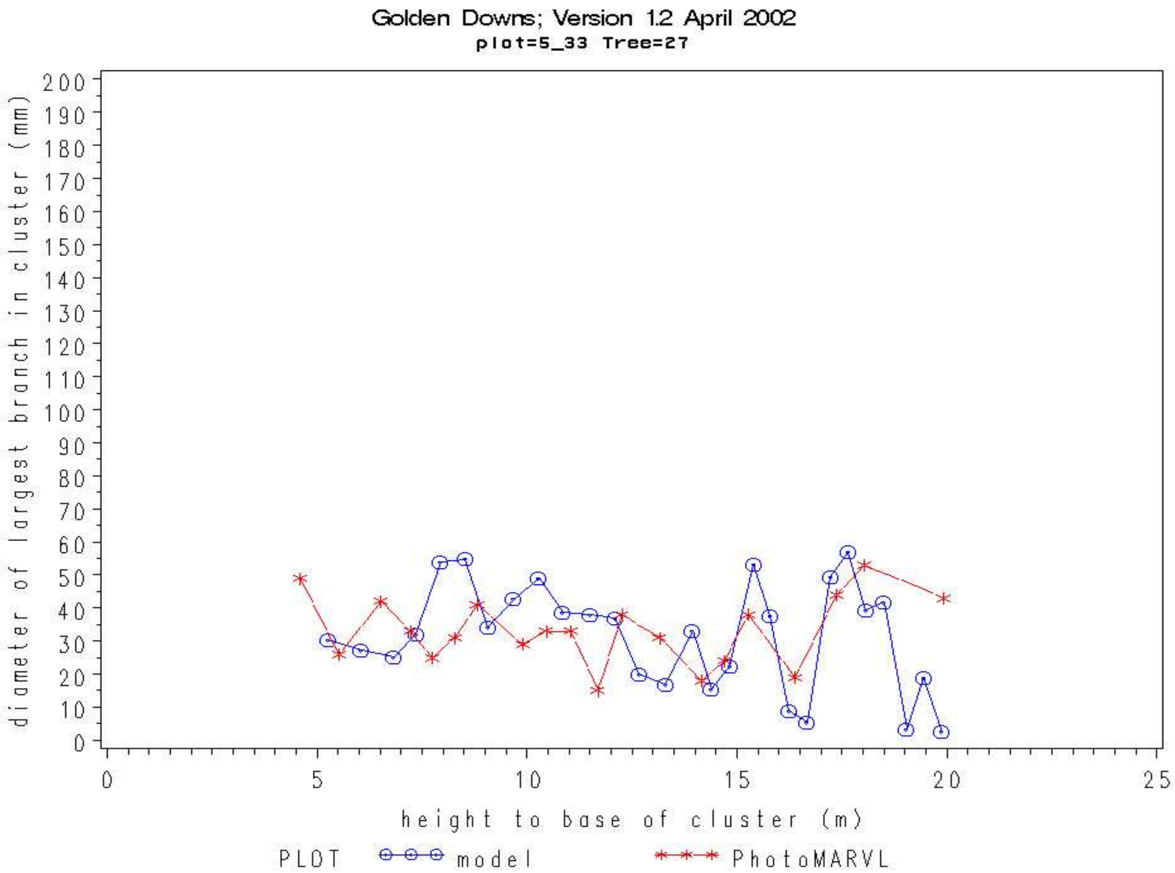


Figure 45. Tree at 100th percentile of DBH distribution in plot thinned to 400 stems/ha at age 11 years

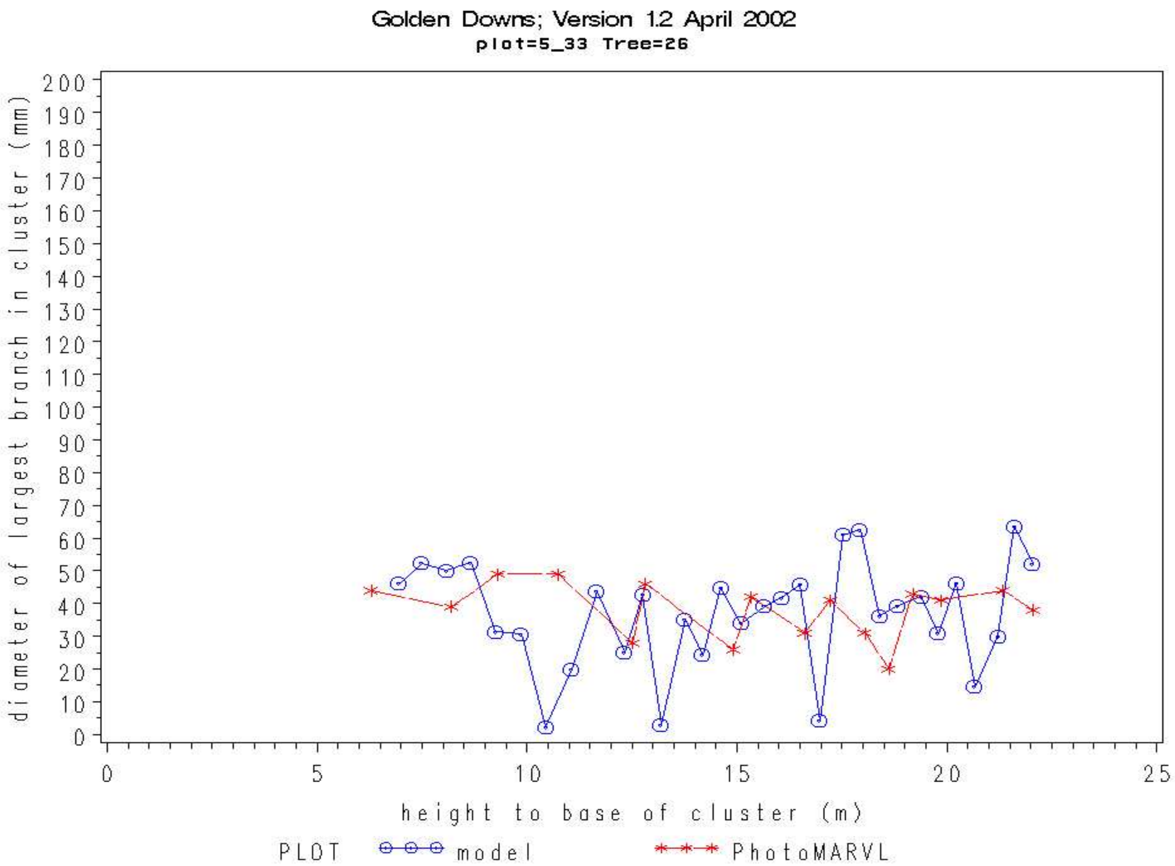


Figure 46. Tree at 10th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

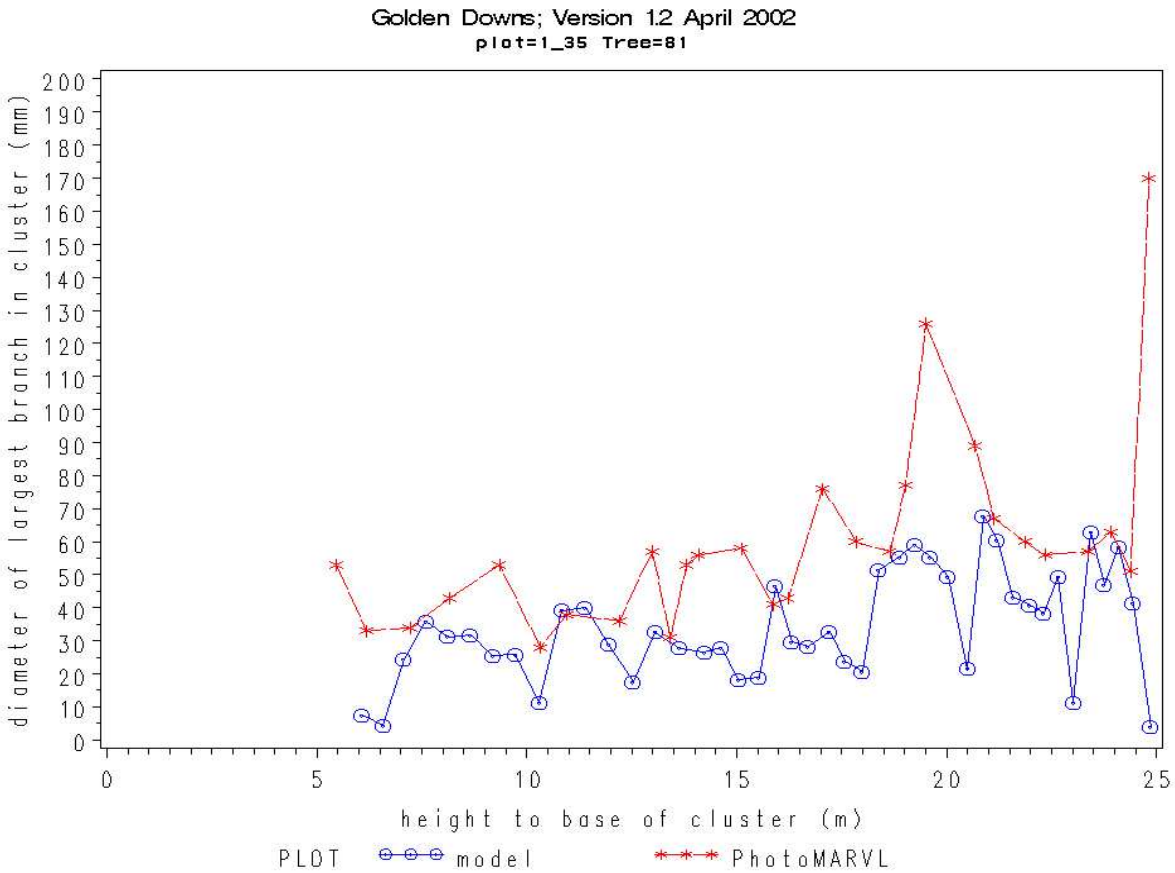


Figure 47. Tree at 40th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

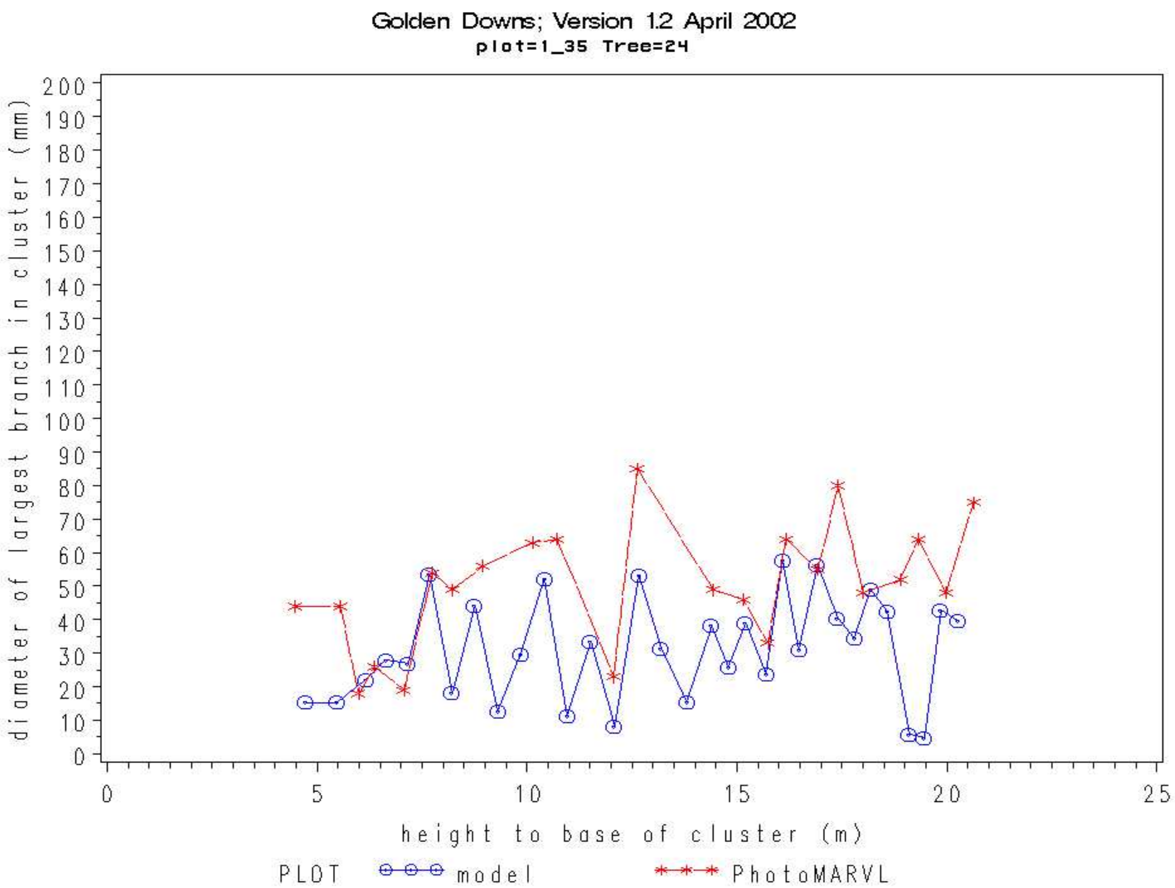


Figure 48. Tree at 70th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

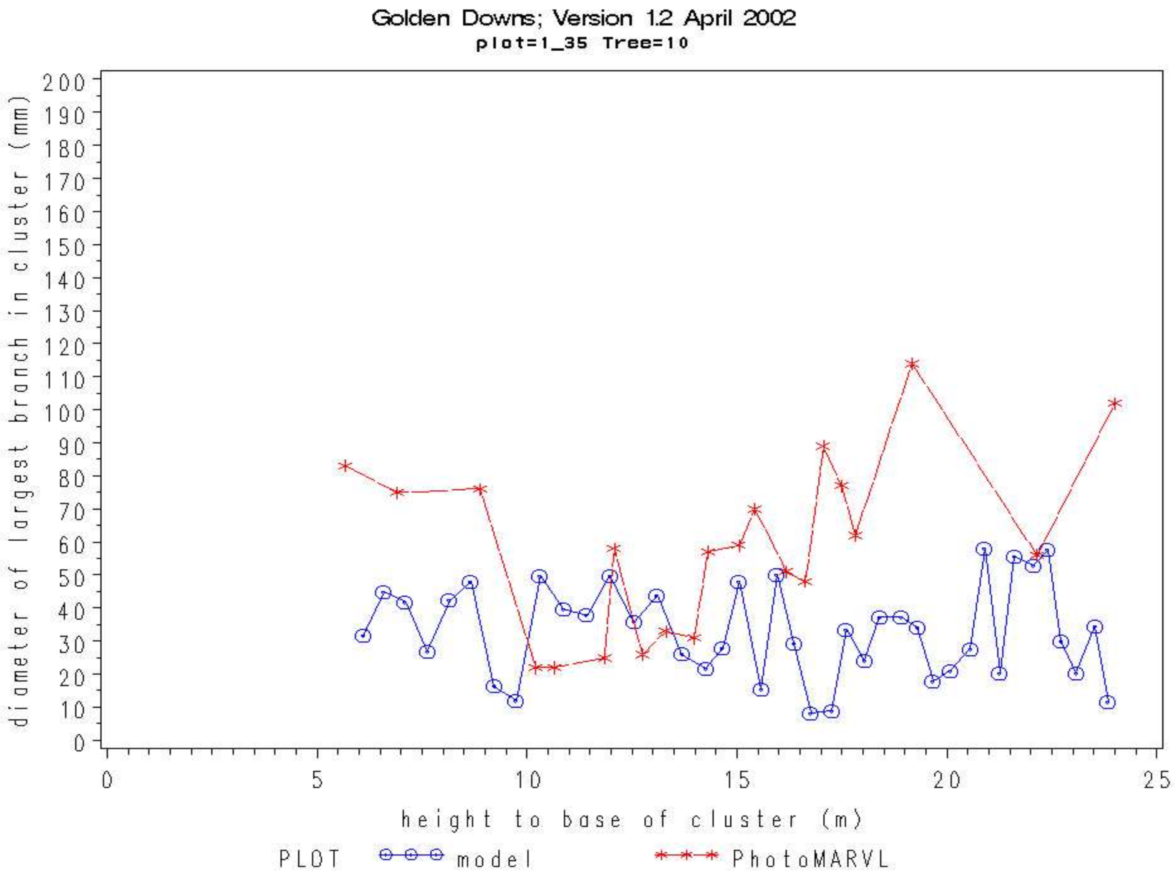


Figure 49. Tree at 100th percentile of DBH distribution in plot thinned to 100 stems/ha at age 14 years

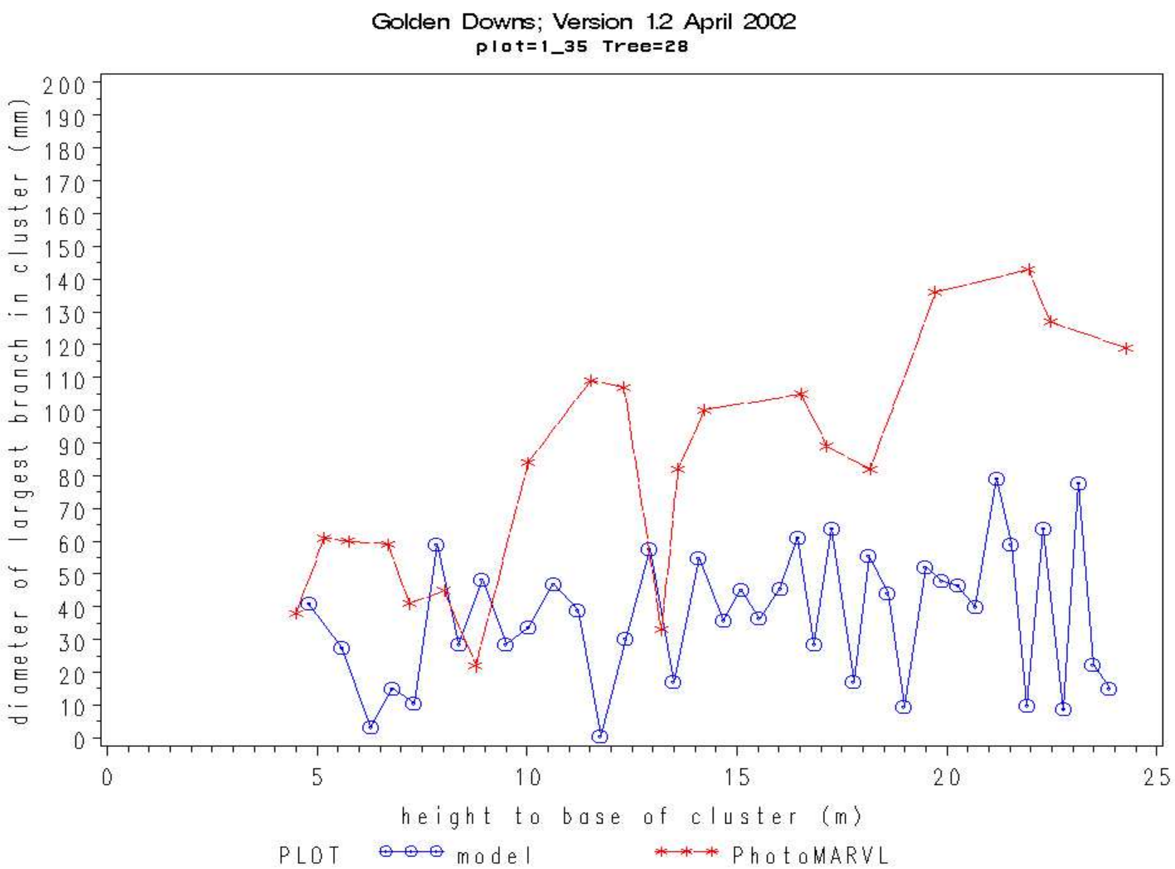


Figure 50. Tree at 10th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

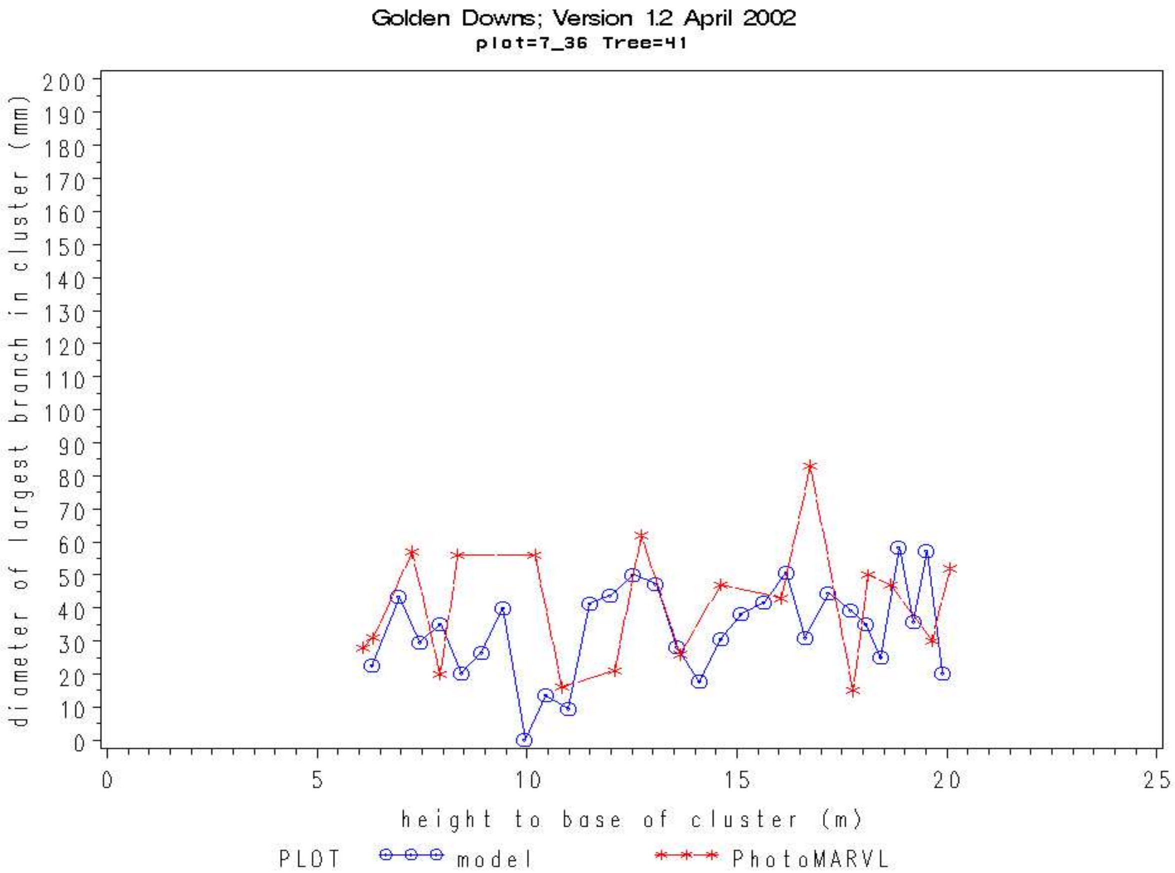


Figure 51. Tree at 40th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

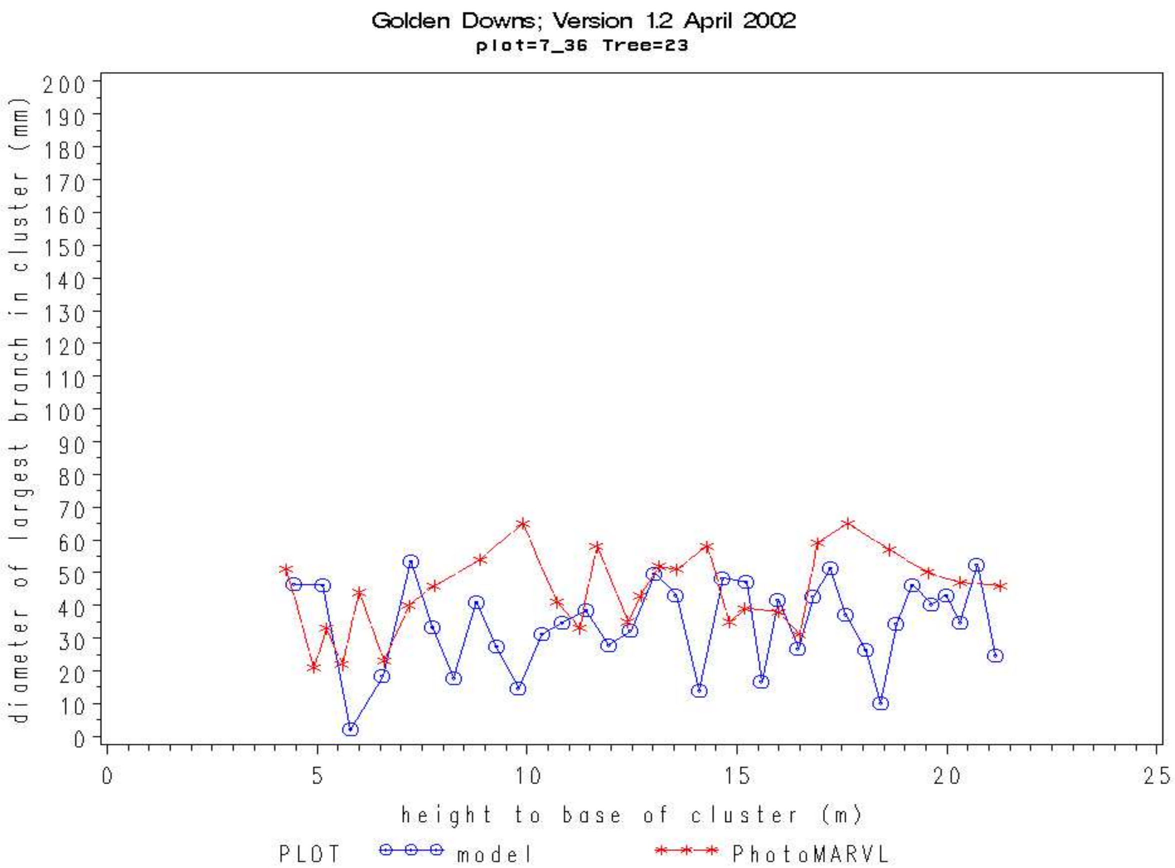


Figure 52. Tree at 70th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

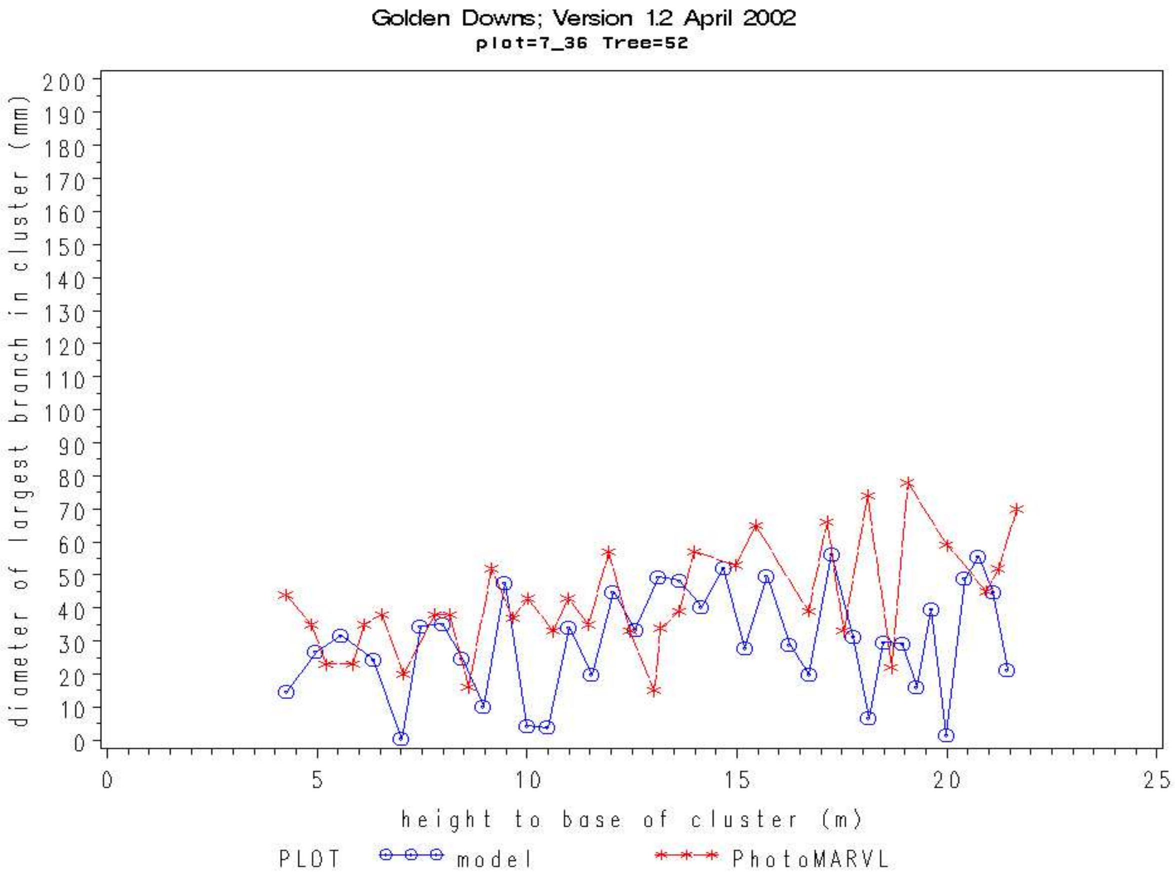


Figure 53. Tree at 100th percentile of DBH distribution in plot thinned to 200 stems/ha at age 14 years

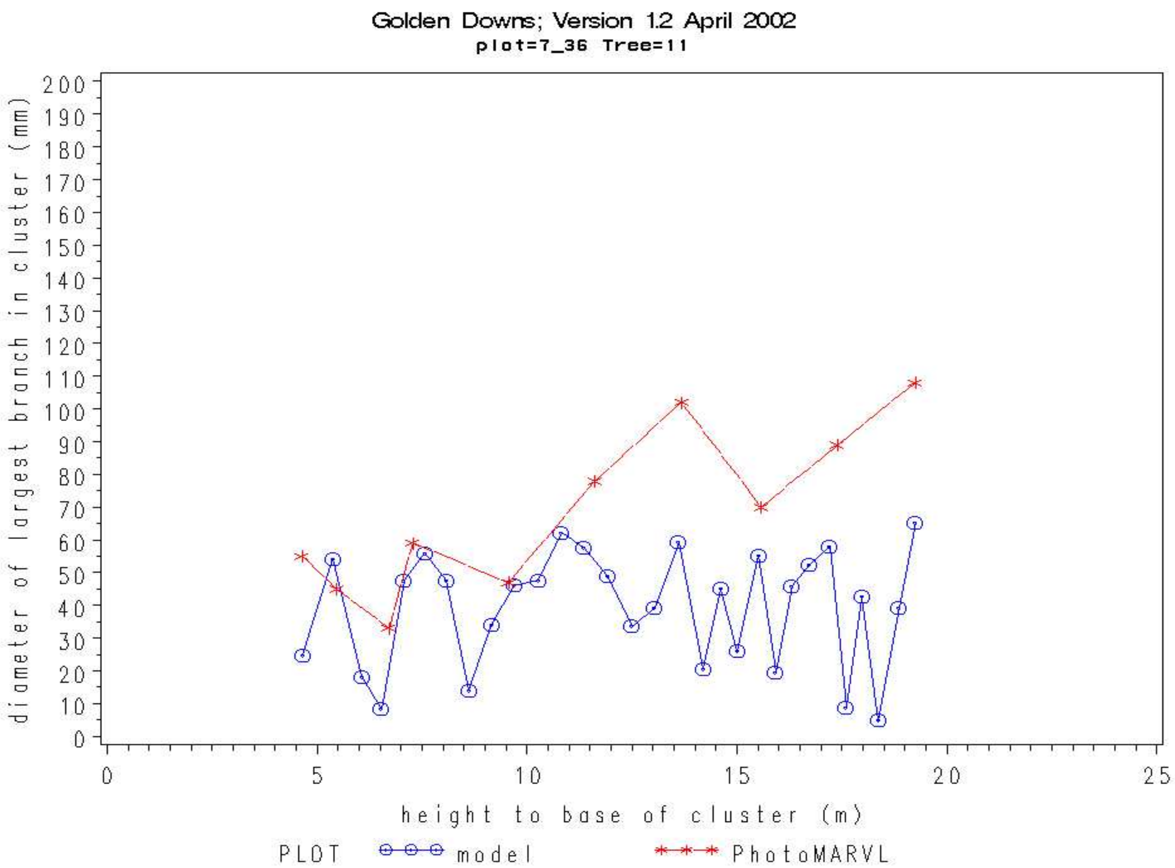


Figure 54. Tree at 10th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

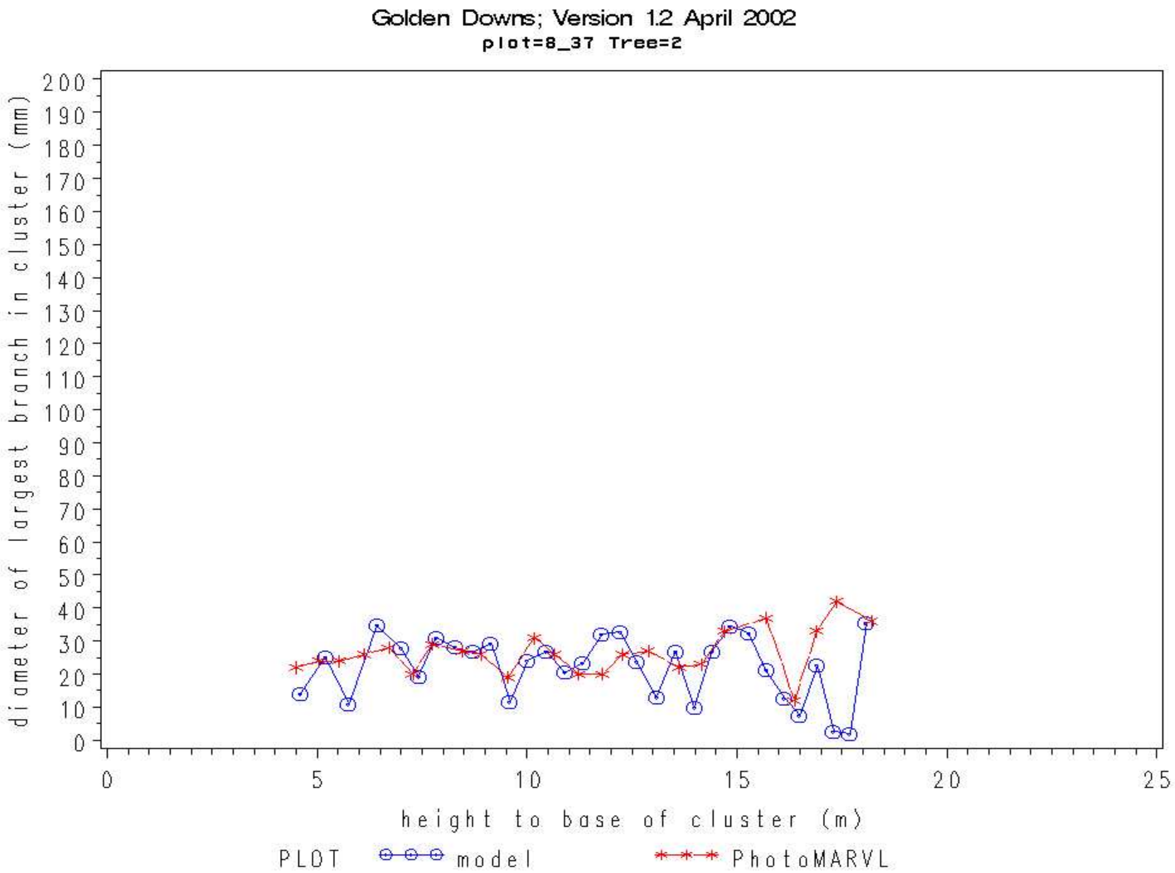


Figure 55. Tree at 40th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

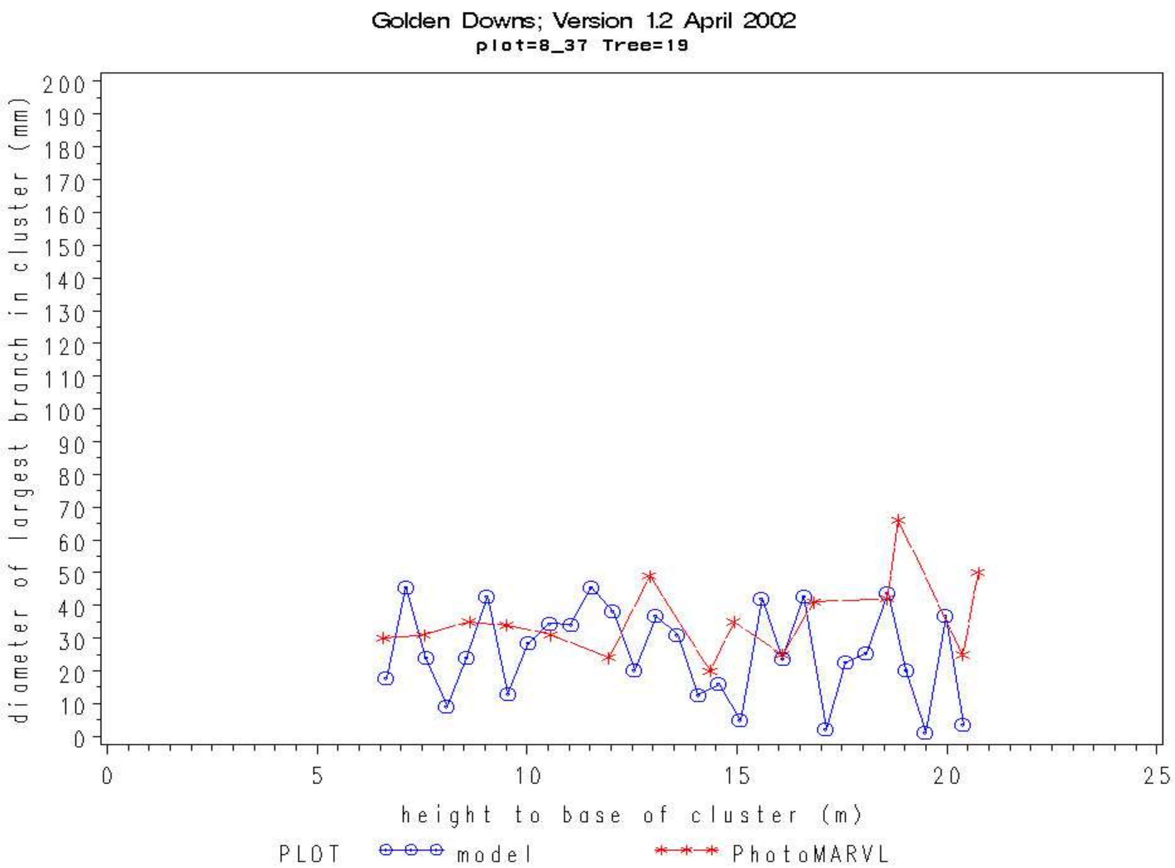


Figure 56. Tree at 70th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years

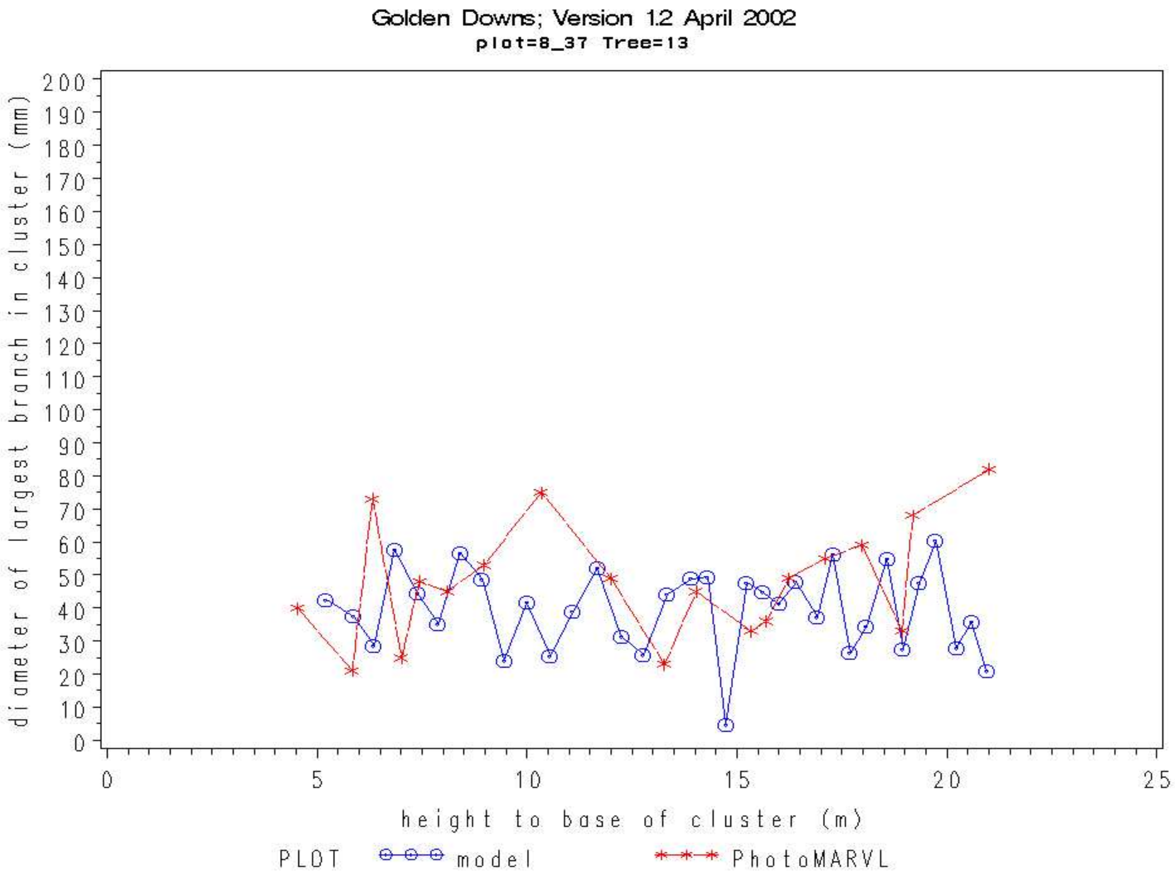


Figure 57. Tree at 100th percentile of DBH distribution in plot thinned to 400 stems/ha at age 14 years