SUITABILITY OF PHOTOMARVL FOR MEASURING CROWN STRUCTURE

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EXECUTIVE SUMMARY

PhotoMARVL consists of geometrical equations that allow tree features to be measured on a photographic image. It can provide quantitative information on both stem shape and crown variables.

Crown variables that could be measured using PhotoMARVL are examined in the first section of this report. A practical use of PhotoMARVL is illustrated in the second section.

When the photographic image covered at least 20 m of the stem it was difficult to identify small features, such as branches less that 2 cm, on the photographic image.

For over half the trees examined, PhotoMARVL predictions of mean internode length (below 12 m) and mean branch diameter (averaged over largest branch per cluster) were not significantly different from field measurements. There was generally no trend in the difference between field and PhotoMARVL measurements of branch diameter with cluster height indicating that PhotoMARVL is suitable for examining trends in branch diameter with cluster height.

PhotoMARVL was used to examine trends in branch diameter with cluster height for selected trees from a thinning experiment. PhotoMARVL is considered suitable for identifying which branches on which trees can respond to a thinning, and at what height this response occurs.

SECTION1

Examination of crown variables that can be measured using PhotoMARVL

INTRODUCTION

Rawley and Hayward (1990) suggested that improved estimation of stand log outturn could be achieved by developing:

> A methodology for projecting to a future age, a list of trees complete with quality attributes, and producing a compatible tree list with biologically consistent quality attributes.

It was considered that three steps were needed to achieve this objective (SGMC Report No. 28):

- develop a realistic description of the tree crown at any point in time
- develop methods to predict crown development through time
- convert subjective inventory data into an input file for the branch model developed

A detailed branch model (BLOSSIM) has been developed which incorporates our current knowledge of branch development. This model predicts:

- the location of branch clusters within annual shoots
- the number of branches and cones in each cluster
- the azimuthal location of each branch and cone
- diameter for each branch through time
- angle for each branch through time
- when branches become bark-encased due to mortality
- the occurrence of bark trapped above branches

Prototype rules to predict changes in branch diameter recorded during a mid-rotation inventory have been developed (SGMC Report No. 94).

Detailed descriptions of the tree crown derived using BLOSSIM can be passed through a sawing simulator such as AUTOSAW (e.g. Todoroki, 1997) to investigate the potential products which could be obtained (SGMC Report No. 82).

This pathway will be important for investigating:
- the influence of alternative branching patterns on sawn outturn
- the effect of different silviculture (e.g. small dead versus larger live branches)

For BLOSSIM to become a practical tool for forest managers, it is important that we can realistically predict branching patterns on a given site. Currently we have been using destructive sampling of near-rotation-age trees to understand the branching patterns of radiata pine and to develop model functions. Several of the functions have been found to vary with site. To be able to cover the range of sites, a modified and quicker sampling scheme is needed. PhotoMARVL was seen as a possible practical tool for such a modified sampling scheme.

In this study, we consider:

1. Which model coefficients can be estimated using PhotoMARVL data?
2. How do PhotoMARVL results compare with measured data?

METHODS AND RESULTS

The data used in the current analyses are field measurements and PhotoMARVL measurements from 4 trees at Taringatura (Southland) and 8 trees at Woodhill. The photographs are shown in SGMC Report No. 76. The distance between the camera and the tree was at least 15 m. This distance was chosen so that at least the lower 20 m of the stem (which represents approx. 90% of the stem value) is visible in the photograph.
The Taringatura photographs were analysed twice. In the first analysis, only the obvious branch clusters were digitised. In the second analysis an attempt was made to digitise every cluster.

1. Which functions can PhotoMARVL be used to obtain?

At the start of the project we knew that PhotoMARVL could be used to give stem shape, cluster position and diameter of the largest branch in a cluster on the visible half of the stem. We needed to know whether more information could be obtained from the photographic image, specifically:

- could the position of side branches be observed (to aid identification of annual shoots)
- was it feasible to count the number of branches in a cluster
- was it feasible to measure the diameter of all branches in a cluster
- was it feasible to record cones
- was it feasible to see bark patterns for recording branch angle

These are small features that required examining the photographic image more carefully than was needed to identify larger features. It was not feasible to identify bark patterns or side branches. It was possible to count branches and cones and record branch diameters for more than the largest branch. However recording these features was not considered practical for an operational tool. Based on this analysis, Table 1 summarises which branch model functions could be developed using PhotoMARVL or MARVL data. From this table it is clear that neither technique will give us any information on branch shape within the stem. PhotoMARVL gives more precise information than a MARVL inventory on cluster position however annual shoots cannot be identified. PhotoMARVL gives more precise information that MARVL on branch diameter and is considered suitable for obtaining the diameter of the largest branch in a cluster.

Table 1. Branch model functions that could be developed using PhotoMARVL or MARVL inventory.

Function	Relative importance for premium products (SGMC Report 82)	PhotoMARVL	MARVL Inventory
Annual Shoot Level			
Number of branch clusters	Very High	Gives actual positions of clusters. Cannot identify morphological annual shoots.	Does not routinely give cluster position
Relative position of clusters	Medium low	Gives actual positions.	Not considered
Cluster Level			
Number of branches in a cluster	High	Difficult to count	Does not routinely give number of branches per cluster
Reproductive maturity (really tree level)	High	Difficult to observe cones	Not considered
Number of cones in a cluster	High	Difficult to observe cones	Not considered
Arrangement of branches in a cluster	Low	Not feasible	Not feasible
Azimuth angle of largest branch in a cluster	Low	Not feasible	Not feasible
Diameter of largest branch in a cluster	High	Diameter of largest branch visible can be measured. Tests suggest that it should be within 1 cm of true value.	Only a maximum value for a particular portion of the stem
Diameter of other branches in a cluster	High	Difficult to measure more than the largest branch	Not feasible

Table 1 cont. **Branch model functions that could be developed using PhotoMARVL or MARVL inventory.**

Function	**Relative Importance for premium products (SGMC Report 82)**	**PhotoMARVL**	**MARVL Inventory**
Branch level			
Diameter of branch at any age	Could not be tested	Not feasible	Not feasible
"Branch angle"	Low	Difficult to observe bark patterns which would give an estimate of angle equivalent to destructive sampling. Could estimate current angle from branch and stem positions	Not feasible
Occurrence of bark encasement due to mortality	High	Not feasible	Not feasible
Occurrence of bark trapped above a branch (not due to branch mortality)	High	Not feasible	Not feasible

2. How do PhotoMARVL results compare with measured data?

There are several options for comparing PhotoMARVL data with actual field measurements, namely:

- differences in actual measurements
- differences in summary variables
- trends in differences between field and PhotoMARVL measurements

From the testing of PhotoMARVL during the development phase, it was concluded that PhotoMARVL provided unbiased measurements of dimensions. This was carried out on a clearly visible standing tower, and carefully tagged trees with branches removed (Brownlie *et al*, 1999). This study is the first comparison of its use in a field situation with detailed branch measurements.

We started to investigate the feasibility of carrying out a 1-1 reconciliation of PhotoMARVL estimates with field data from the half of the tree visible in the photograph. This proved to be difficult and was not pursued very far as it did not tell us whether the information obtained from PhotoMARVL would be useful in a management situation. To show this we compared summary variables such as mean internode length and diameter of largest branch in a cluster.

Differences in actual measurements

It is wrong to say that PhotoMARVL estimates are incorrect because they do not agree with field measurements. We are comparing two different measurement techniques. In the field, the stem was carefully scrutinised to identify all clusters. Field measurements of cluster position were obtained using a length tape on a felled stem. In reality these positions may be less accurate than the PhotoMARVL estimates. PhotoMARVL estimates of branch diameter may be less accurate than field measurements above 15 m due to "light flare".

A comparison of cluster identification was carried out by assuming that there was no bias in either set of data, and finding the field cluster closest to each cluster identified using PhotoMARVL. This was achieved by calculating the minimum value for:

(difference in height between PhotoMarvl cluster top – field cluster top)^2 +
(difference between PhotoMARVL cluster depth – field cluster depth)^2

This approach was not totally successful. Sometimes two PhotoMARVL clusters would be matched to one field cluster. Sometimes the analysis indicated that a very small cluster had been measured and the adjacent larger cluster had been missed. This is one reason for the large branch diameters in the last column of table 2. Another reason is that for some trees, there was a systematic trend in differences that made it difficult to decide what had been observed. For Taringatura, Tree 7 it appeared that field and PhotoMARVL measurements of cluster heights differed by about 1 m at 14 m. This was picked up from the position an extra large branch.

Some manual re-assessments were needed to produce the results in Table 2.

For Taringatura, the results of the 1st assessment (recording only obvious clusters) are shown. In the 2nd assessment, where a deliberate effort was made to identify small clusters, some of the smaller clusters were picked up, but spurious clusters were digitised as well.

Table 2. Comparison of clusters identified by PhotoMARVL with field data.

Tree	PhotoMARVL Identified all observed clusters to:	PhotoMARVL Identified clusters on photograph up to:	Number of clusters missed using PhotoMARVL	Diameter of largest visible branch in field clusters which matching program suggested were missed
Taringatura Tree 3	11.45 m	15.21 m	3 clusters	5 mm 12 mm 25 mm
Taringatura Tree 5	12.50 m	16.42 m	3 clusters	21 mm 35 mm 10 mm
Taringatura Tree 6	3.21 m	18.01 m	6 clusters	11 mm 13 mm 19 mm 5 mm 60 mm 14 mm
Taringatura Tree 7	14.05 m	27.3 m	Probably 6 clusters below 19 m	31 mm 21 mm 36 mm 35 mm 55 mm 44 mm

Note: the large branch diameters are more likely to be the result of mis-matched clusters than large clusters not identified.

Table 2 cont. Comparison of clusters identified by PhotoMARVL with field data.

Tree	PhotoMARVL Identified all observed clusters to:	PhotoMARVL Identified clusters on photograph up to:	Number of clusters missed using PhotoMARVL	Diameter of largest visible branch in field clusters which matching program suggested were missed
Woodhill Tree 1	8.8 m**	18.4 m	9	17 mm 22 mm 5 mm 29 mm 15 mm 9 mm 17 mm 10 mm 11 mm
Woodhill Tree 2	13.4 m**	15.9 m	3	10 mm 37 mm 3 mm
Woodhill Tree 3	8.1 m	17.8 m	3 (below 15.7 m)	17 mm 11 mm 14 mm
Woodhill Tree 4	7.8 m	20.6 m	2 (below 15.6 m)	28 mm 22 mm
Woodhill Tree 5	11.2 m **	15.7 m	4	68 mm 8 mm 28 mm 58 mm
Woodhill Tree 6	17.6 m	19.2 m	1	38 mm
Woodhill Tree 7	8.6 m	18.6	9	16 mm 14 mm 9 mm 16 mm 4 mm 4 mm 12 mm 22 mm 4 mm
Woodhill Tree 8	17.3 m	17.3 m	-	-

Notes:
** Woodhill, Tree 1 (1 cluster), Tree 2 (2 clusters) and Tree 5 (2 clusters) have been identified as two separate clusters. These clusters were towards the base of the tree.

In PhotoMARVL, the position of all branch clusters was measured first, then all branch diameters were measured. To determine which branches were identified, it was first necessary to assign branches to clusters. This was achieved by assigning branches to the closest cluster below the branch position as branch diameter was generally measured close to, but above, the top of the cluster. Field and PhotoMARVL branch diameters were compared by finding the actual cluster which gave the minimum value for:

$$(\text{difference in height between PhotoMarvl cluster top} - \text{field cluster top})^2 +$$
$$(\text{difference between PhotoMARVL branch diameter} - \text{field cluster branch diameter})^2$$

The field cluster branch diameter was the largest branch on the half of the tree visible to the camera.

This approach was not successful at matching clusters. Several PhotoMARVL clusters were matched to the same field cluster; and the best-matched clusters were out of sequence. A more sophisticated pattern-matching algorithm might achieve a better result. However this line of research is not considered worth pursuing further as the accuracy of PhotoMARVL has been tested previously (Brownlie *et al*, 1999) and it does not tell us about the usefulness of PhotoMARVL for forestry applications.

Differences in summary variables

Two summary variables were chosen for comparison:

- mean internode length
- mean diameter averaged over largest branch /cluster

Mean internode length - Taringatura

Mean internode length was calculated in two ways. Firstly mean internode length was calculated for that section of the stem where all clusters were identified. Here we should expect no significant difference in mean internode length. Secondly mean internode length was calculated for that section of the stem where clusters could be identified using PhotoMARVL. As PhotoMARVL missed some clusters we could expect a difference in this case. The results are summarised in Table 3. The means were compared using a Student's t-test for small samples assuming that the variances were not equal (Bailey, 1959). For all trees equal stem lengths were compared. For tree 7, this resulted in a difference in number of observations because of the error in predicting cluster height.

Table 3. Comparison of internode length from PhotoMARVL and field data at Taringatura.

Tree	Mean Internode length (m) PhotoMARVL	Sample Size	Mean Internode Length (m) Measured	Sample Size	Significantly Different
Section where all clusters identified					
Tarintatura Tree 3	1.28	5	1.26	5	ns
Taringatura Tree 5	0.51	11	0.40	11	at 5%
Taringatura Tree 7	0.44	17	0.30	18	ns
Section of stem where some clusters not identified					
Tarintatura Tree 3	1.40	7	0.94	10	ns
Taringatura Tree 5	0.57	16	0.36	19	at 5%
Taringatura Tree 6	0.55	21	0.34	27	at 1%
Taringatura Tree 7	0.57	22	0.29	30	at 1%

Where equal stem sections were compared, the PhotoMARVL estimate of internode length tends to be slightly larger but within 15 cm of the field data. One reason for this may be the ability to distinguish the base of the cluster. In the field the branch bark patterns can be examined to identify the base of the cluster. This is not obvious on the photograph, and branch angle must be utilised.

As expected the PhotoMARVL estimate of internode length was generally significantly larger when a longer section of stem was considered.

Mean Internode Length – Woodhill

Mean internode length was calculated using all clusters that were initiated below 12 m. The stem length was approximately 6 m as the trees had been pruned (Table 4).

Table 4. Comparison of internode length from PhotoMARVL and field data at Woodhill.

Tree	Mean Internode length (m) PhotoMARVL	Sample Size	Mean Internode Length (m) Measured	Sample Size	Significantly Different
1	0.33	15	0.18	18	at 5%
2	0.19	17	0.19	15	ns
3	0.36	13	0.24	15	at 5%
4	0.27	14	0.21	16	ns
5	0.30	13	0.31	11	ns
6	0.55	7	0.47	7	ns
7	0.32	13	0.14	19	at 1%
8	0.47	10	0.37	11	ns

The number of clusters vary between PhotoMARVL and the field measurements for three reasons:

- missed clusters
- 1 cluster identified as 2
- a cluster initiated close to 12 m in one set of data but not the other (tree 8).

The mean internode length predicted by PhotoMARVL was generally slightly longer than that predicted from the field measurements. For 5 of the 8 trees, the difference in mean internode length was less than or equal to 10 cm and was not significant. The significant difference for trees 1, 3, and 7 was due to several small branch clusters not being identified using PhotoMARVL. The difference in mean internode length was greater than 15 cm for only 1 of these trees.

Mean branch diameter averaged over largest branch /cluster

The mean diameter was calculated by averaging over the largest branch in each cluster. For PhotoMARVL and field data, the same stem length was considered – the length of stem measured using PhotoMARVL. For PhotoMARVL the number of observations is smaller because it was not feasible to measure a branch diameter for every cluster. The mean diameter for the field data was calculated in two ways:

- by averaging over the largest branch in each cluster on the half of the tree visible in the photograph (this compares observations on the same half of the tree).
- by averaging over the largest branch in each cluster regardless of whether it was visible in the photograph (to know whether PhotoMARVL predictions are realistic for a whole tree).

For Taringatura, branch diameters from the 2nd assessment have been used. The results are shown in Tables 5 and 6. The means were compared using a Student's t-test for small samples assuming that the variances were not equal (Bailey, 1959).

The mean branch diameter using PhotoMARVL was generally slightly larger but within 1.5 cm of that observed in the field on the half of the tree visible in the photograph. This is considered to be because the minimum branch diameter observed using PhotoMARVL is about 2 cm, while the minimum value for the field measurements is less as we scrutinised the stem to identify all clusters including very small clusters. The maximum branch diameter observed using PhotoMARVL was within 1 cm of the field observation for 10 of the 12 trees. A large branch, not observed in the field, was identified on one of these trees at a height of approx 20m.

When the whole crown was considered, there was generally no significant difference in the mean branch diameter for a given tree.

Table 5. Comparison of branch diameter from PhotoMARVL and field data.

Tree		PhotoMARVL data	Field data (whole crown)	Significantly different	Field data (1/2 crown)	Significantly different
Taringatura Tree 3	No. obs.	10	12	ns	11	ns
	Mean (cm)	3.4	3.3		3.2	
	Min (cm)	1.2	0.5		0.5	
	Max (cm)	5.7	6.4		5.6	
Taringatura Tree 5	No. obs.	15	20	ns	20	ns
	Mean (cm)	3.9	4.4		3.3	
	Min (cm)	2.3	1.5		1.0	
	Max (cm)	7.4	8.2		6.7	
Taringatura Tree 6	No. obs.	18	29	ns	28	ns
	Mean (cm)	4.4	4.5		3.6	
	Min (cm)	2.5	0.5		0.5	
	Max (cm)	7.2	7.5		7.5	
Taringatura Tree 7	No. obs.	21	31	ns	31	ns
	Mean (cm)	4.8	5.3		4.7	
	Min (cm)	2.1	1.5		1.0	
	Max (cm)	8.2	9.3		9.3	

Table 6. Comparison of branch diameter from PhotoMARVL and field data.

Tree		PhotoMARVL data	Field Data (whole crown)	Significantly different	Field data (1/2 crown)	Significantly different
Woodhill Tree 1	No. obs.	18	36	ns	36	ns
	Mean (cm)	3.9	3.5		3.2	
	Min (cm)	1.9	1.0		0.5	
	Max (cm)	5.7	5.7		5.7	
Woodhill Tree 2	No. obs.	14	27	ns	27	at 5%
	Mean (cm)	4.4	4.1		3.3	
	Min (cm)	2.2	1.0		0.3	
	Max (cm)	5.7	6.6		6.6	
Woodhill Tree 3	No. obs.	14	37	at 5%	35	at 5%
	Mean (cm)	3.9	2.8		2.6	
	Min (cm)	1.5	0.5		0.8	
	Max (cm)	7.1	6.4		6.4	
Woodhill Tree 4	No. obs.	25	43	at 1%	43	at 1%
	Mean (cm)	3.8	2.9		2.6	
	Min (cm)	2.4	1.0		0.7	
	Max (cm)	8.1	5.5		4.9	
Woodhill Tree 5	No. obs.	13	21	ns	21	ns
	Mean (cm)	5.9	5.9		5.8	
	Min (cm)	2.0	0.8		0.8	
	Max (cm)	8.4	8.8		8.8	
Woodhill Tree 6	No. obs.	17	21	ns	21	ns
	Mean (cm)	5.2	4.8		4.5	
	Min (cm)	2.6	1.3		1.0	
	Max (cm)	7.5	7.6		7.6	
Woodhill Tree7	No. obs.	27	45	ns	44	ns
	Mean (cm)	4.1	4.2		3.4	
	Min (cm)	2.4	0.8		0.4	
	Max (cm)	6.4	6.7		6.7	
Woodhill Tree 8	No. obs.	20	24	ns	24	ns
	Mean (cm)	4.6	4.9		4.9	
	Min (cm)	2.6	2.1		2.1	
	Max (cm)	7.9	8.6		8.6	

Trends in differences between field and PhotoMARVL measurements

PhotoMARVL estimates of branch diameter were compared to field estimates of branch diameter by assuming clusters were correctly matched. It is suspected that this is not correct in some instances.

The difference between field and PhotoMARVL estimates of branch diameter were compared with measured cluster height for the Woodhill trees. (Table 7 and Figure 1). For 6 of the 8 trees there was no significant correlation between the difference in branch diameter and cluster height. Apart from tree 8 (Figure 1), there was no obvious bias between the two measurement techniques. Some of the variability in the difference in branch diameter can be attributed to incorrect cluster matching.

Table 7. Correlation between field –PhotoMARVL estimate of branch diameter and field measurement of cluster position.

Tree	Correlation	Signifcant
1	0.09	ns
2	-0.54	p=0.04
3	0.38	ns
4	-0.38	ns
5	-0.67	p=0.01
6	0.35	ns
7	-0.34	ns
8	-0.02	ns

DISCUSSION

PhotoMARVL is a non-destructive technique that can be used for measuring stem shape, cluster position and branch diameter. In this study we considered whether PhotoMARVL could provide more detailed information on branching needed for parameterising the branch model BLOSSIM.

PhotoMARVL was excellent for identifying the larger branches / branch clusters, but it proved difficult to see the small scale features on the photographs such as small branches, cones, bark patterns (for identifying branch angle).

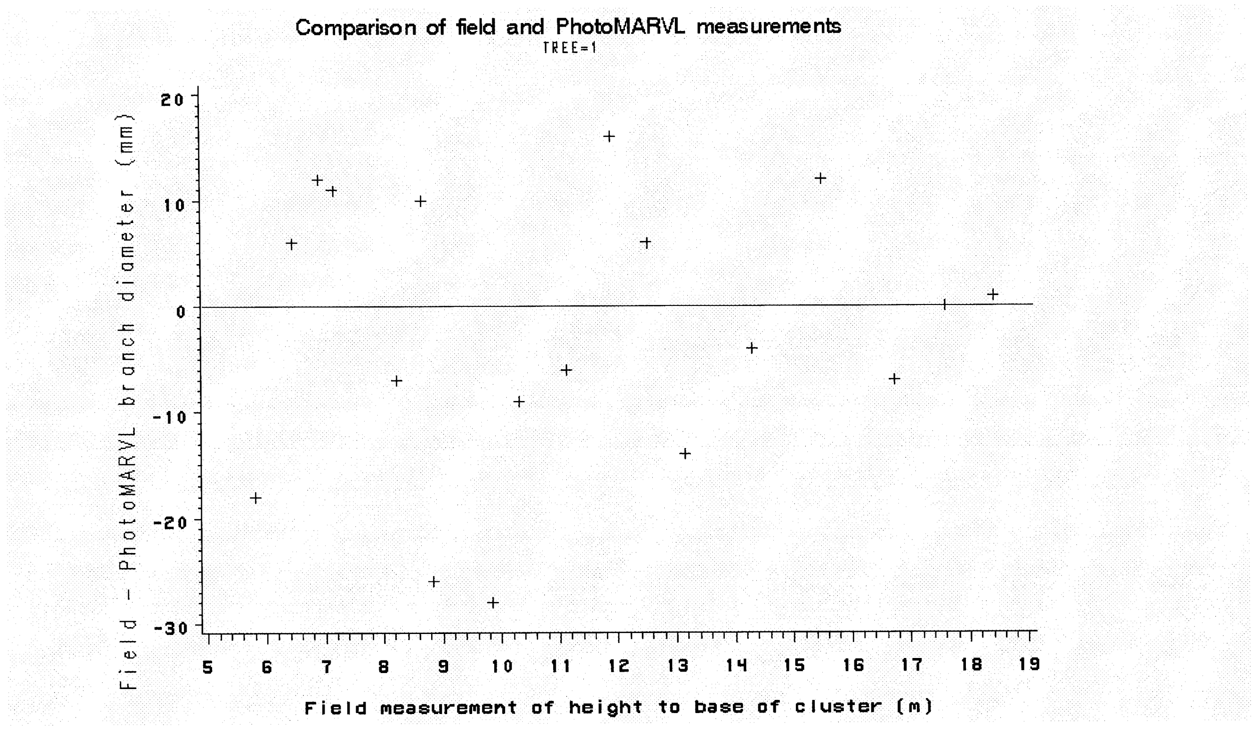
In the first analyses of the photographs, only the obvious clusters were recorded and a number of small branch clusters missed. When the photographs were reanalysed, taking care to record all clusters, there was interpretation problems – it was difficult to decide what was a cluster, and some spurious clusters were recorded. It is considered better just to record the obvious clusters and know that small clusters are likely to have been missed, than know that there may be spurious clusters in the data. Small branch clusters are of minor importance for structural timber but are likely to be of major importance for premium products as these small branches are likely to be bark-encased.

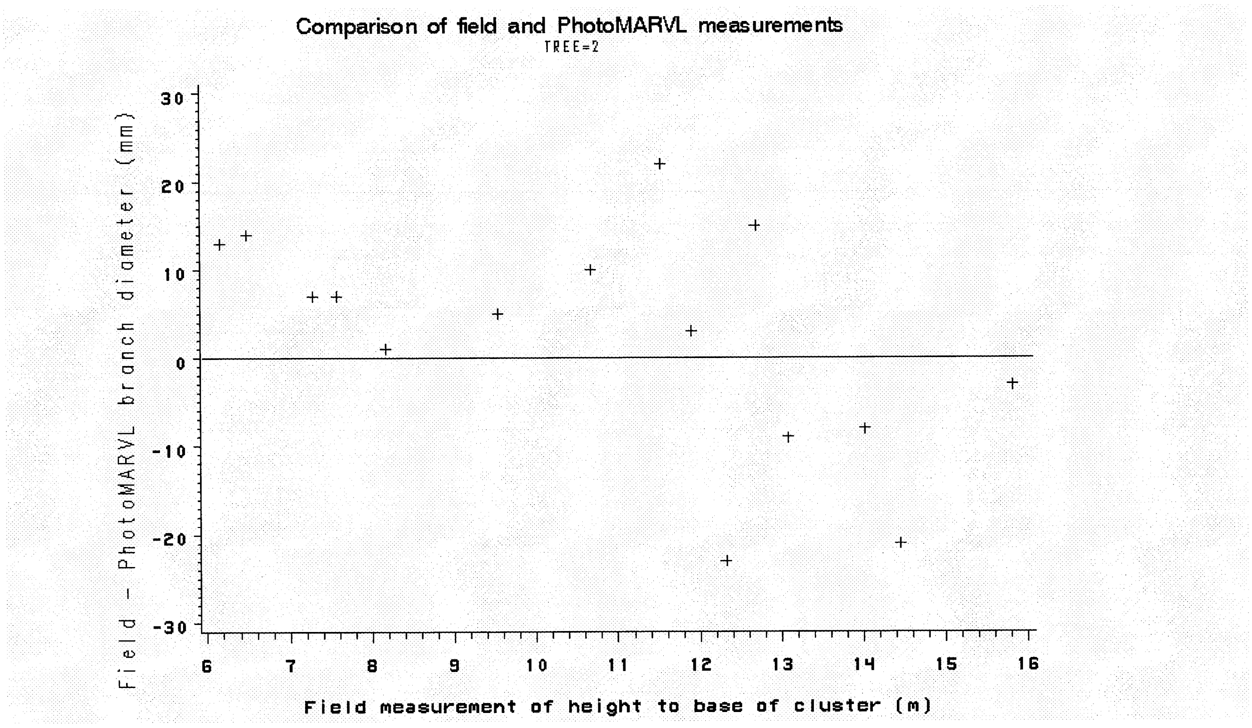
PhotoMARVL estimates of internode length in the lower part of the crown were generally not significantly different from the field measurements. PhotoMARVL could therefore be used to gain an indication of internode length without climbing or felling trees. If the estimates of internode length indicated that the timber would be suitable for premium products, it would be necessary to fell some trees to confirm whether there were no small branch clusters between the larger clusters.

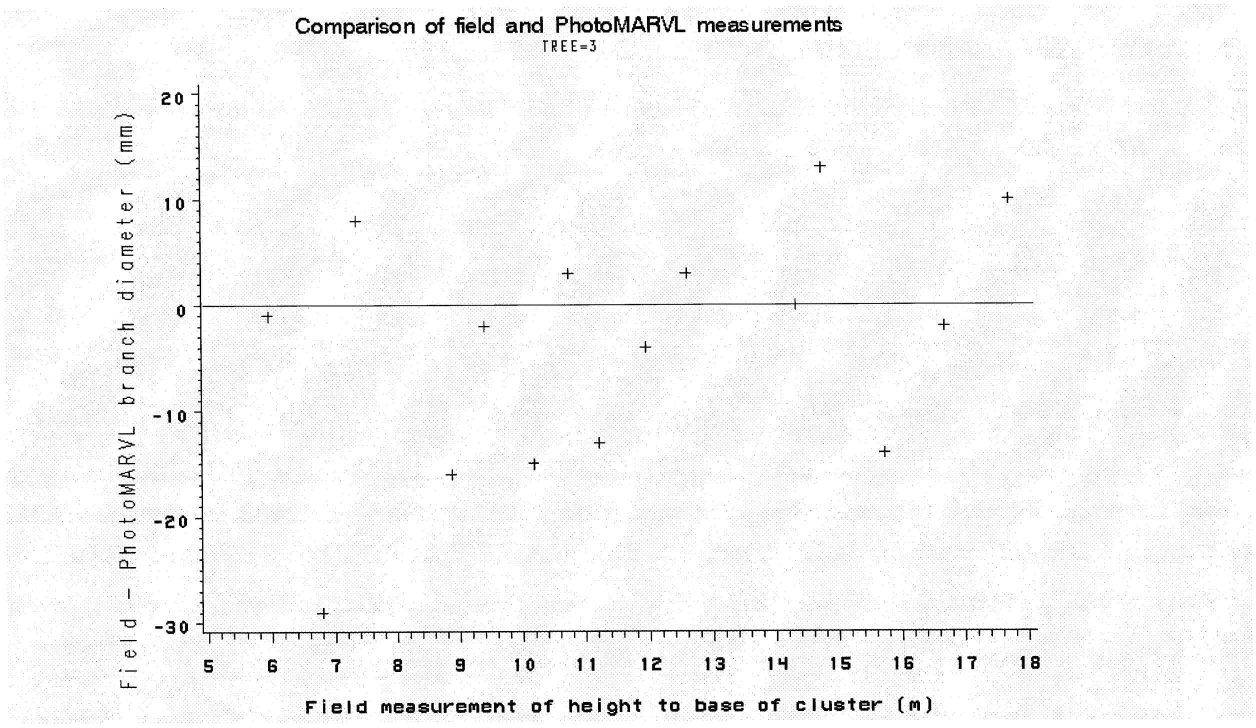
PhotoMARVL estimates of mean diameter averaged over the largest branch per cluster were generally not significantly different from the field measurements for either the visible half or the whole crown. One reason why PhotoMARVL results were applicable for the whole crown is that these crowns were reasonably symmetrical. If a crown was obviously asymmetrical then care should be taken in choosing the camera position to avoid asymmetry between the two sides of the crown. There was generally no trend in the difference between field and PhotoMARVL estimates of branch diameter. PhotoMARVL could therefore be a suitable tool for quantifying trends in branch diameter with height in the crown.

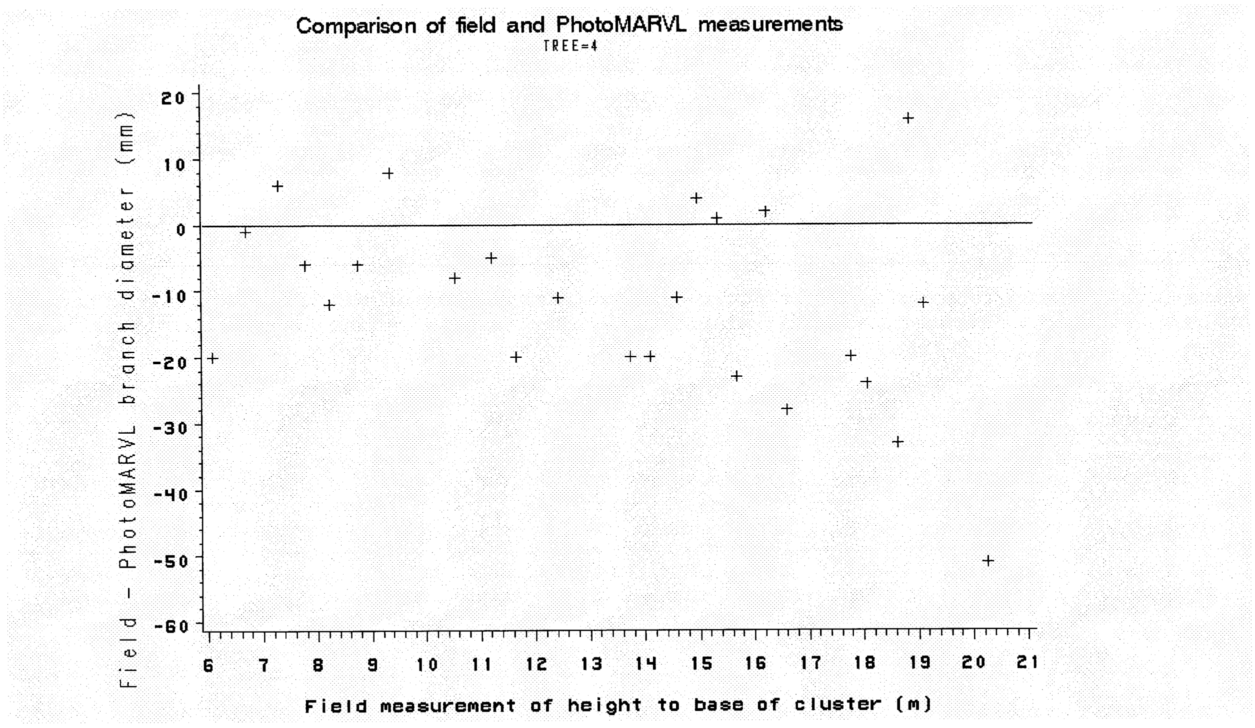
In terms of developing BLOSSIM, PhotoMARVL is seen as being useful for quantifying variation in branch diameter within tree crowns and between trees. In particular, this will enable us to expand our knowledge of which trees and which branches within a tree crown can respond to a thinning.

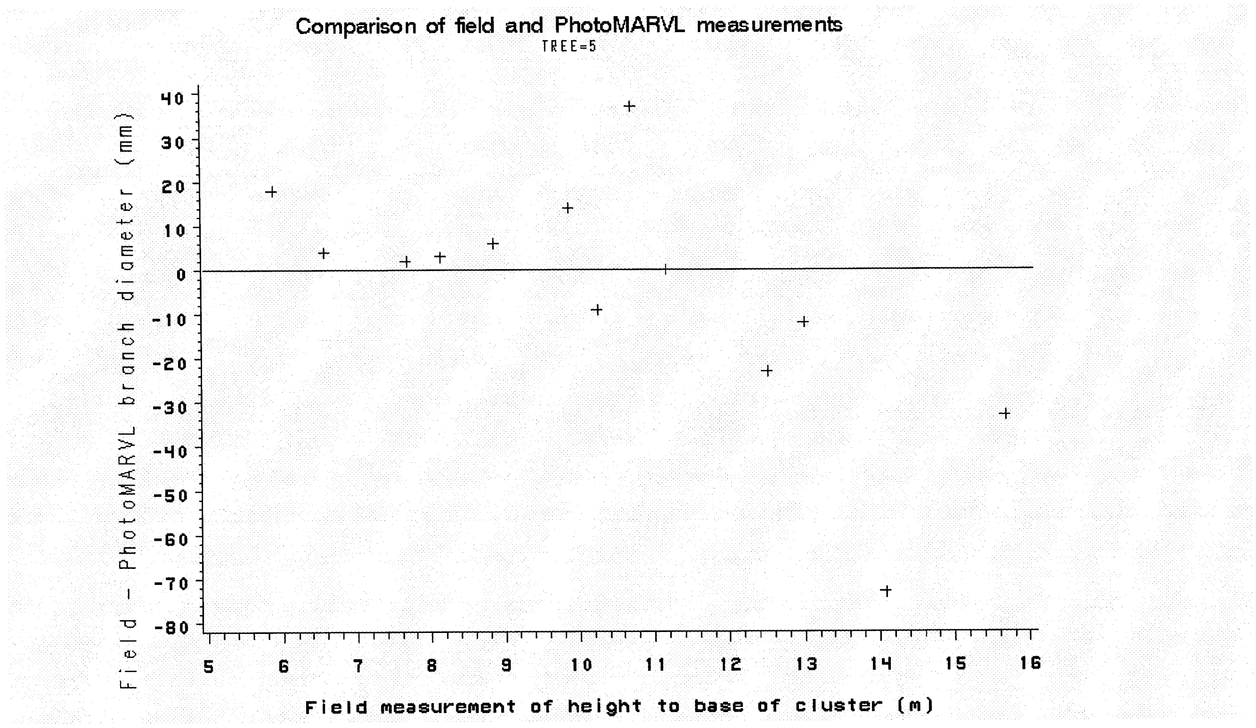
Figure 1. Comparison of field and PhotoMARVL estimates of branch diameter



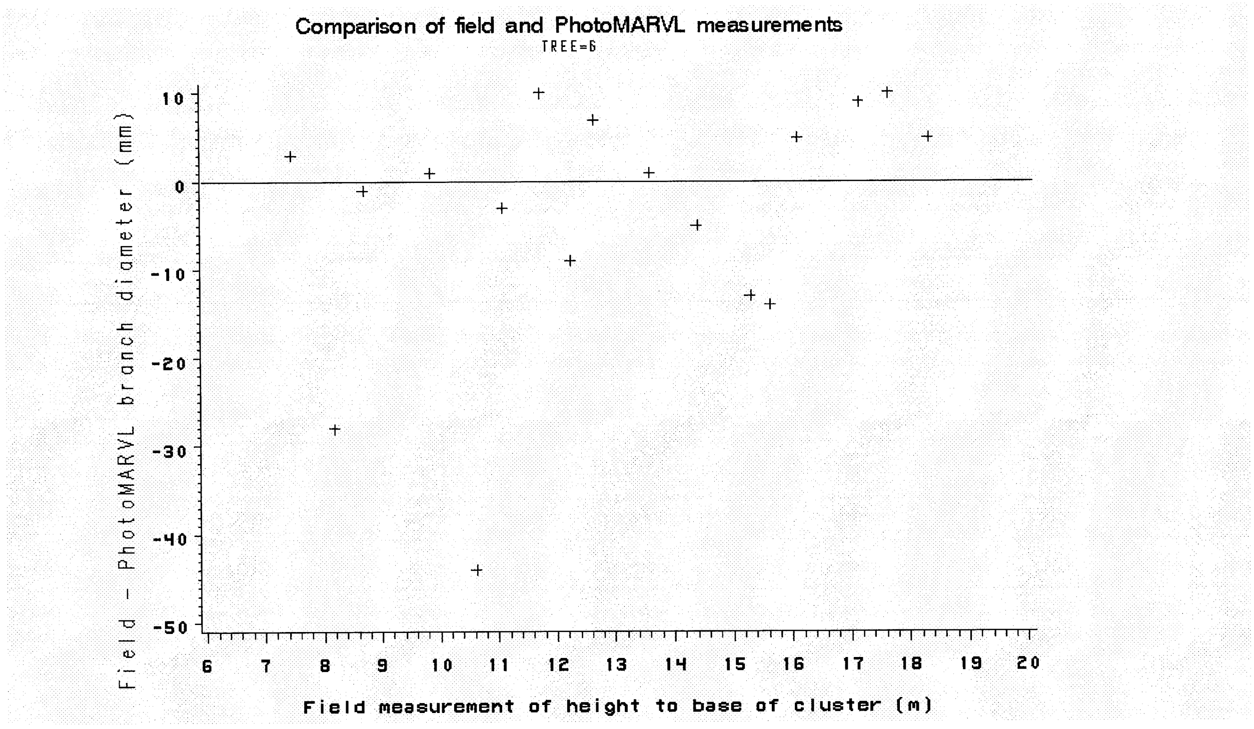



Comparison of field and PhotoMARVL measurements
TREE=3
Field - PhotoMARVL branch diameter (mm)
20
10
0
-10
-20
-30
5 6 7 8 9 10 11 12 13 14 15 16 17 18
Field measurement of height to base of cluster (m)

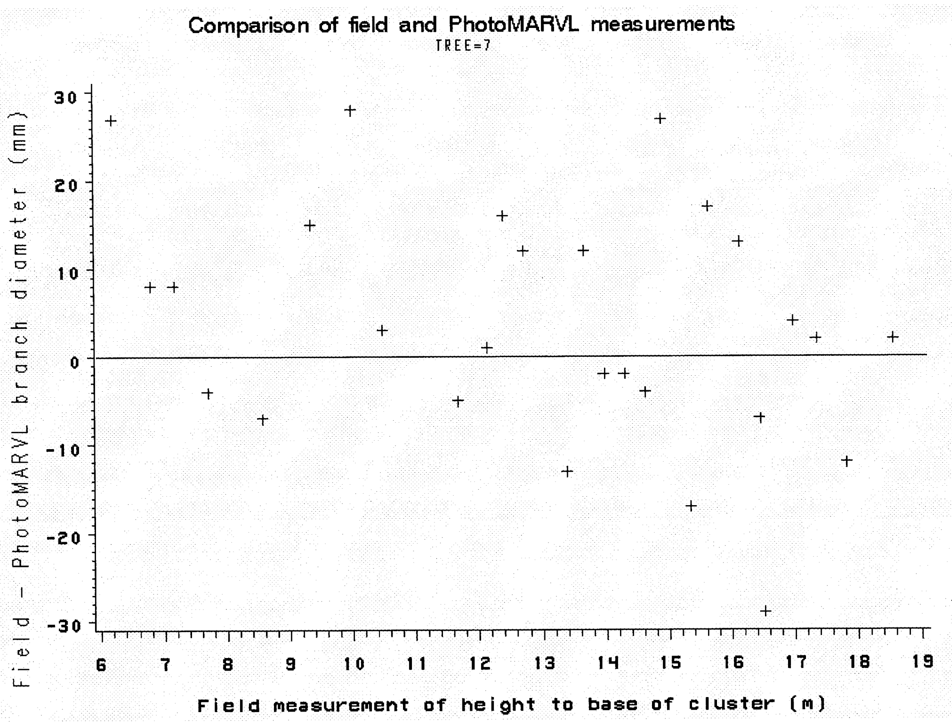

Comparison of field and PhotoMARVL measurements
TREE=4
Field - PhotoMARVL branch diameter (mm)
20
10
0
-10
-20
-30
-40
-50
-60
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Field measurement of height to base of cluster (m)

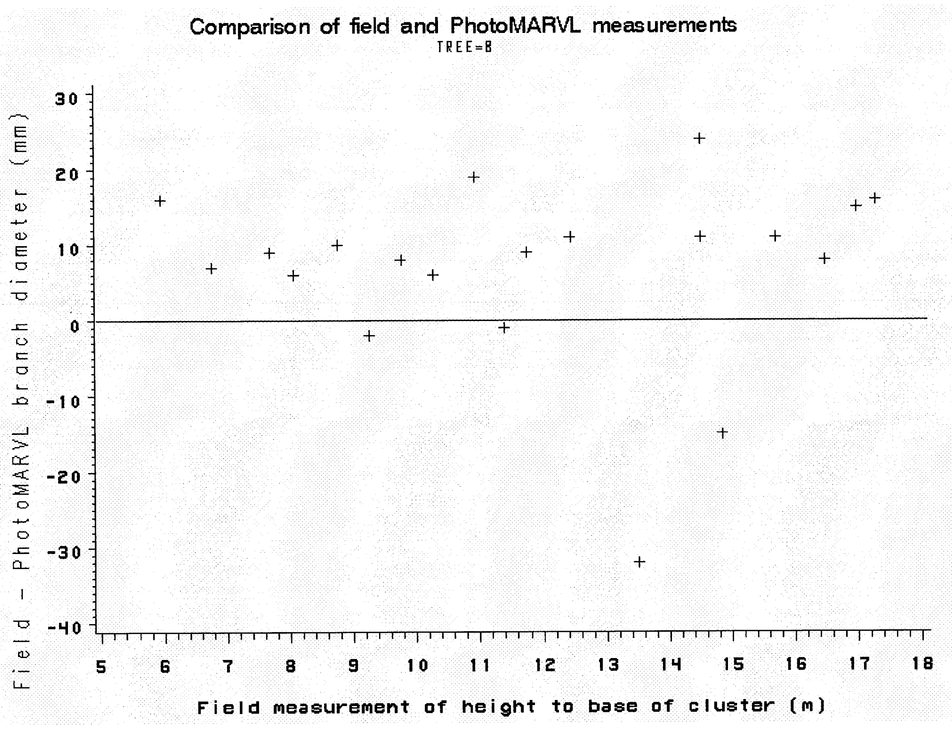


Comparison of field and PhotoMARVL measurements
TREE=5
Field - PhotoMARVL branch diameter (mm)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
5
6
7
8
9
10
11
12
13
14
15
16
Field measurement of height to base of cluster (m)



Comparison of field and PhotoMARVL measurements
TREE=6
Field - PhotoMARVL branch diameter (mm)
10
0
-10
-20
-30
-40
-50
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Field measurement of height to base of cluster (m)


Comparison of field and PhotoMARVL measurements
TREE=7
Field - PhotoMARVL branch diameter (mm)
30
20
10
0
-10
-20
-30
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Field measurement of height to base of cluster (m)


Comparison of field and PhotoMARVL measurements
TREE=8
Field - PhotoMARVL branch diameter (mm)
30
20
10
0
-10
-20
-30
-40
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Field measurement of height to base of cluster (m)

SECTION 2

A practical use of PhotoMARVL - visual assessment and PhotoMARVL to determine tree and branch response to thinning

INTRODUCTION

To be able to model the response to thinning in a stand situation, we need to quantify on which trees (in terms of DBH), branches would be able respond to the thinning, and at what height this response occurs.

The spacing experiment, RO696, was established in a naturally regenerated stand that was thinned once to the nominal stockings when the tallest tree was 6.1 m. The trees were pruned to 6.1 m, hence all branches were formed and developed at the nominal stocking. For that part of the crown where branches had stopped growing, there was generally no significant correlation between height of the cluster and diameter of the largest branch in the cluster. The mean branch diameter, considering only the largest branch in each cluster, was highly correlated with tree DBH (SGMC Report No. 50).

In order to determine how branches respond to a thinning, 13 trees were destructively sampled from a thinning experiment, RO905. At most 2 trees were sampled from a particular thinning treatment (SGMC Report No. 52). The study indicated that the larger branches on the larger trees would show increased diameter growth following a thinning (SGMC Report No. 62), i.e. one would expect a correlation between primary age of the cluster and diameter of the largest branch in the cluster.

To expand the database on branch growth response to thinning, further detailed data were collected on 3 trees in another thinning experiment (RO2098). In order to explore options for determining which trees show a response to thinning, all trees in one sample plot per treatment were visually assessed. As the previous section of this report indicated that PhotoMARVL should be suitable for estimating diameter of the largest branch in a cluster, PhotoMARVL photographs were taken of four trees per plot to quantify branch diameters before and after thinning and the height at which the response to thinning occurred.

METHODS

Experiment RO2098 was established in the "850" polycross trial, planted in 1975 at 625 stems/ha. Six thinning treatments and a control were applied (Table 1). All the trees in one sample plot per treatment were assessed visually to determine whether branches had responded to the thinning. The sample plot assessed was the one where the stocking remained closest to the prescribed treatment.

Table 1. RO2098, treatments and plots examined.

Treatment	Number of plots	Plot examined
Unthinned	6	10/24
Thinned to 100 sph at 12m	3	7/11
Thinned to 200 sph at 12 m	3	5/12
Thinned to 400 sph at 12m	3	6/13
Thinned to 100 sph at 20 m	3	9/25
Thinned to 200 sph at 20m	3	19/36
Thinned to 400 sph at 20 m	3	15/27

The visual assessment consisted of examining the tree to see how the branch diameter varied within the crown. Notes were made for each tree, if there appeared to be a change in branch size, and at what height it occurred. Branch diameters were not estimated. Based on these notes, a subjective branch response score was assigned to each tree. The scoring system used was:

0: no response
1: possible response
2: obvious response
3: large branches all way up stem, implying response from base of crown

The subjective branch response scores were then plotted against tree DBH at time of thinning.

PhotoMARVL photographs were taken of 4 trees per plot on the basis of the diameter distribution in the plot at the time of the last measurement (June 1999). The trees selected were at the 100, 70, 40 and 10 percentiles of the diameter distribution. For the plots thinned at 20 m and for the plots thinned at 12m, one of the trees was leaning, and another forked. In these cases, the next closest tree in the diameter distribution was selected.

The photographs taken of the trees thinned to 100 stems/ha (plots 7/11 and 9/25) were enlarged and measurements of cluster position and branch diameters recorded using PhotoMARVL procedures on the AP190 analytical stereoplotter (Firth *et al.* 2000). Base and top of all clusters were measured prior to branch diameters. The position where branch diameters are measured is generally close to but above the top of the cluster. Hence each branch was assigned to the nearest cluster below its recorded position. The diameter of the largest branch measured in each cluster was plotted against the height to the base of the cluster.

Previous research indicated that there was generally no significant correlation between diameter of the largest branch in a cluster and cluster height when there was no change in nominal stocking (SGMC Report No. 50). When a thinning occurs, it is suggested that a sigmoid curve would be appropriate for describing the relationship between diameter of the largest branch in a cluster and cluster height. It is suggested that the lower and upper asymptotes give the average diameter of the largest branch at the before and after thinning respectively; and the sloping part of the curve represents the zone where branches respond to the thinning . If there was no response to thinning then the asymptotes would be the same. A 4-parameter Gompertz equation, which is asymmetrical about the point of inflection (Eqn. 1), was fitted to each tree individually

$$D = \alpha + \beta \exp(-\exp(\gamma - \delta \times H)) \qquad (1)$$

D is the branch diameter
H is the height of the cluster above the base of the crown
α, β, γ, δ are model parameters
α gives the mean branch diameter prior to the thinning
β gives the change in branch diameter after the thinning
$\alpha+\beta$ gives the mean branch diameter after the thinning
the ratio γ/δ gives the point of inflection

RESULTS

Visual Assessment

There were no obvious changes in branch diameter with height in the crown in the unthinned plot (10/24). This agrees with previous results and indicates that any changes observed in thinned plots are most likely to be a result of the thinning. Plots of the branch response code versus DBH at time of thinning are shown in Figure 1. The number of trees that showed a possible or obvious response to the thinning increased with the severity of the thinning (Table 2). The time of thinning had little effect on the percentages at 100 or 200 stems/ha. In the plot thinned to 400 stems/ha at 12 m, 50% of the trees showed a response to thinning whereas when the thinning was at 20 m only 1 tree showed a response.

Table 2. Percentage of trees showing possible or obvious response to the thinning.

Stems/ha	Thinned at 12 m	Thinned at 20 m
100	87%	100%
200	68%	69%
400	50%	1%

PhotoMARVL Assessment

Plots of largest branch diameter versus height to the base of the cluster are shown in Figure 2. Superimposed on the graph is the fitted curve (Eqn. 1). It proved difficult to obtain realistic parameter estimates for Eqn. 1 due to the large variability in branch diameter between clusters. It was necessary to fix one parameter (δ) to obtain realistic estimates and asymptotic standard errors for the other parameters. Initially δ was fixed at 10, which seemed reasonable from an initial analysis. δ was also set to 15, and 13, and for one tree 17, in order to find a realistic solution. It was not possible to obtain a realistic solution for tree 10/5 in plot 7/11. A straight line was fitted instead as there was no obvious trend in branch diameter. Estimates of branch diameter from fitting Eqn. 1 together with the visual assessment for each tree are shown in Table 3. It can be seen that the PhotoMARVL assessment corresponds reasonably well with the visual assessment as well as providing estimates of branch diameter and the height of the response. The mean branch diameter in the two plots before thinning was similar. The larger the branch diameter before thinning, the larger the increase in branch diameter (Fig. 3). For a given initial branch diameter, the increase in branch diameter appears to be slightly larger in the plot thinned at 12 m compared with the plot thinned at 20 m (Fig. 3).

Table 3. Estimates of changes in branch diameter using PhotoMARVL.

Plot	Tree	Visual assessment	Mean branch diameter before thinning (cm)	Change in branch diameter (cm)	Significant	Height of inflection (m)
7/11	10/5	maybe larger branches above about 15 m	3.7	-	no	-
7/11	11/3	possibly larger branches above about 9 m	4.1	3.5	yes	11.2
7/11	16/5	larger branches above about 12 m	3.9	2.3	yes	14.8
7/11	18/2	larger branches above about 10 m	4.8	3.4	yes	10.2
9/25	3/3	increase in branch diameter at about 15 m	4.9	3.3	yes	13.9
9/25	16/1	larger branches above about 12 m	4.3	1.6	yes	12.3
9/25	17/5	possibly larger branches above about 15 m	4.0	1.0	no	-
9/25	19/5	possibly larger branches above about 15 m	2.6	1.6	no	7.0

DISCUSSION

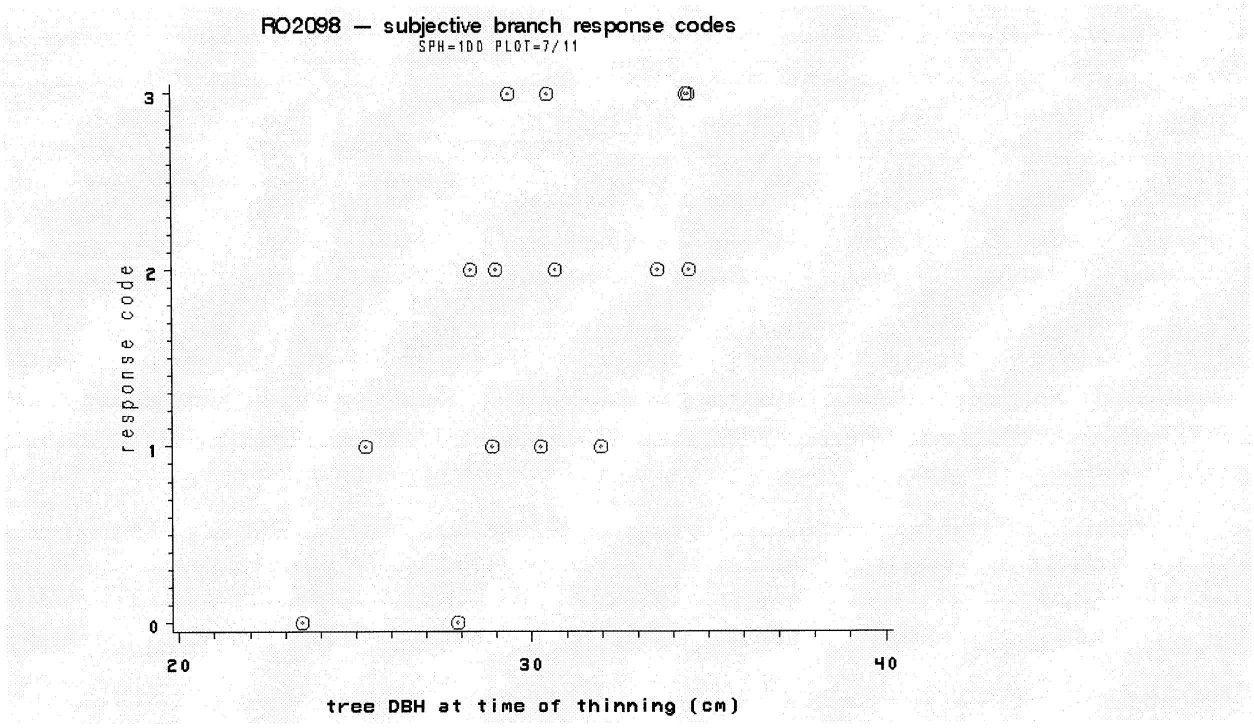
Visual assessment supported by detailed measurements from photographic images is an appropriate technique for determining on which trees (in terms of DBH), branches would be able respond to the thinning, and at what height this response occurred.

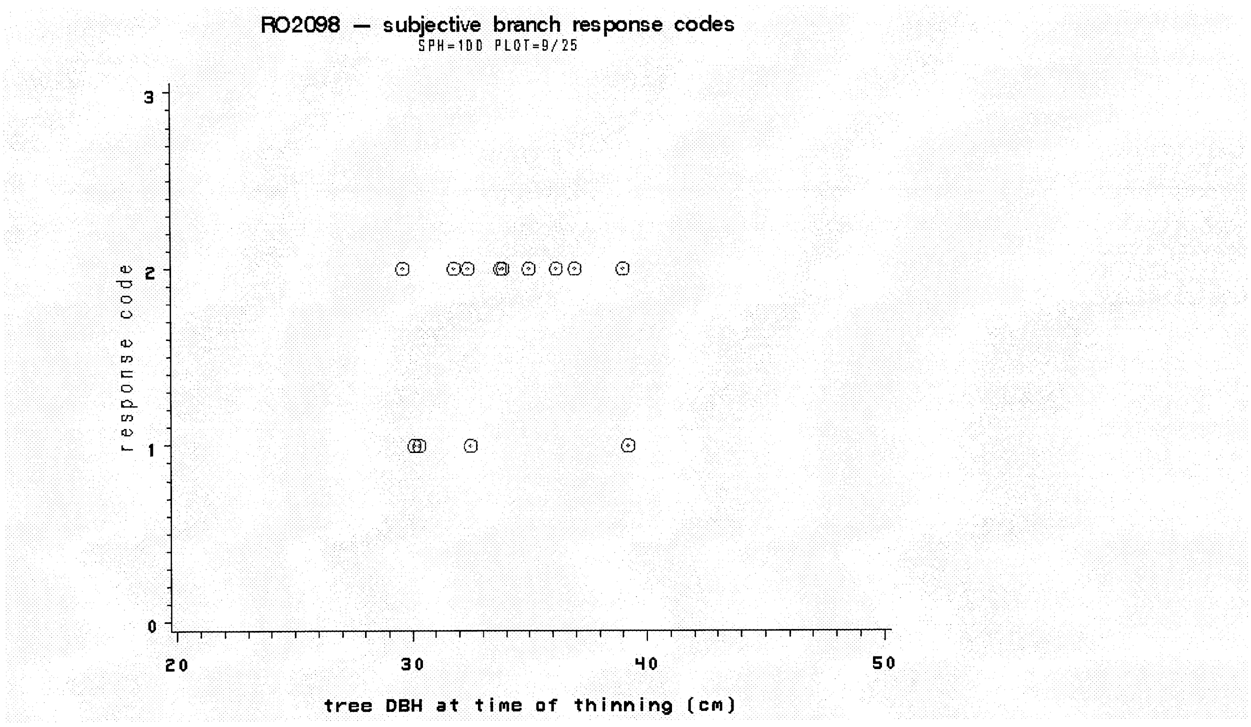
Visual assessment was quick and provided qualitative information on which trees showed a response to the thinning. In this study, the percentage of trees where branches could respond to the thinning varied with the severity of the thinning. The percentage of trees where branches responded to the thinning varied little with timing of thinning when the final stocking was 100 or 200 stems/ha but was very different when the final stocking was 400 stems/ha (Table 2).

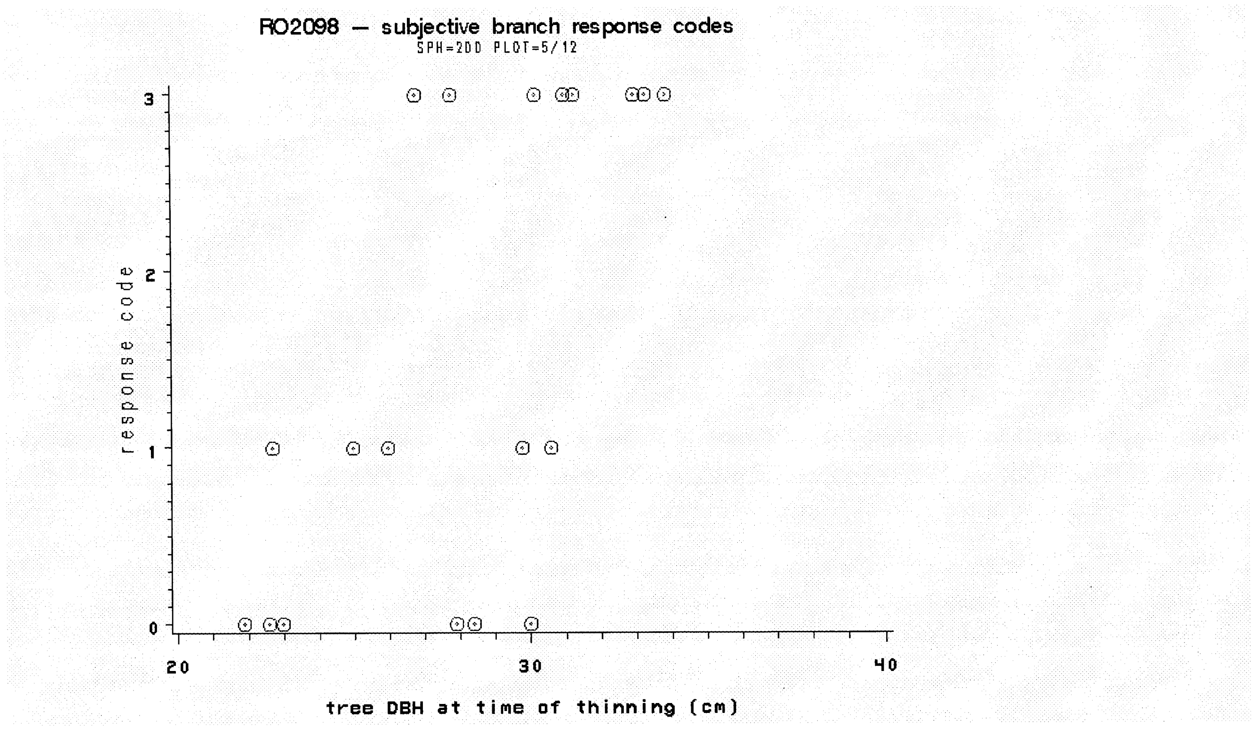
PhotoMARVL provided a quantitative estimate of "average" branch diameter before and after and the height at which a response to thinning occurred. The visual assessment of response height agreed reasonably well with the measurements obtained using PhotoMARVL confirming that the visual assessment was realistic.

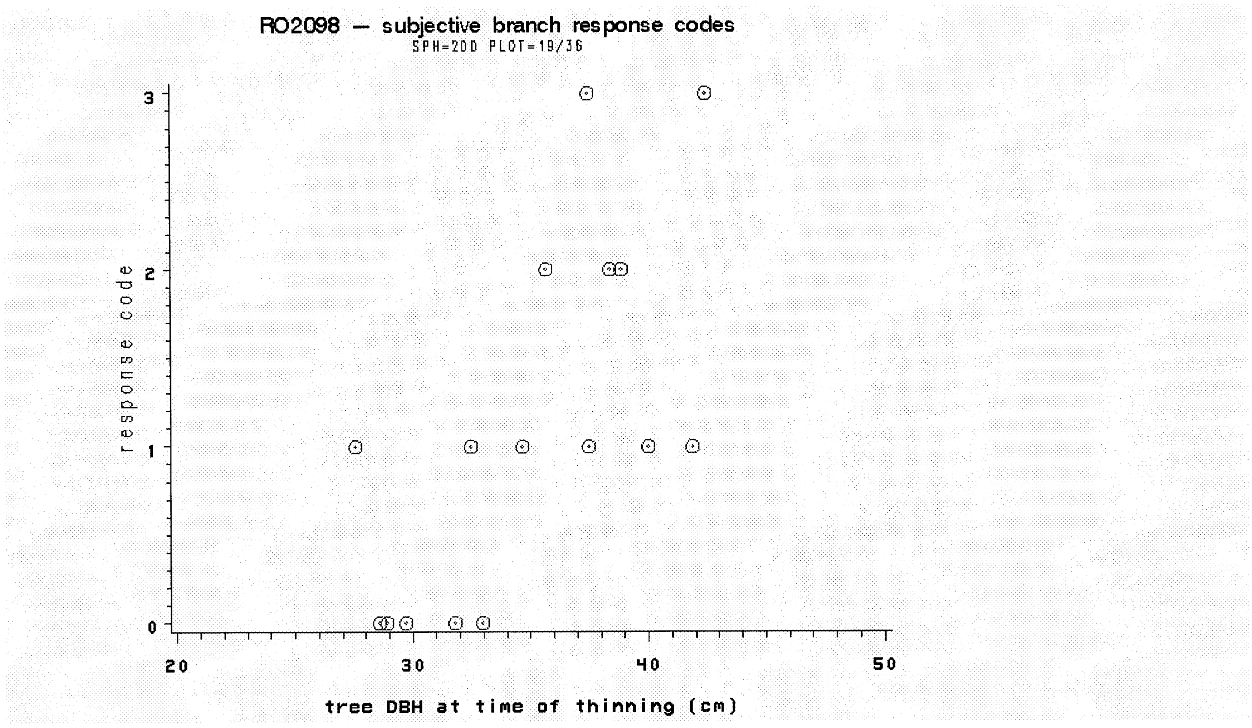
The results illustrate the potential of visual assessment and PhotoMARVL for determining response to thinning. More information on branch growth in response to thinning will be obtained when photographs taken in the other plots are analysed. The results will be compared with predictions from the current version of the branch model BLOSSIM, and if necessary the information used to modify the functions within BLOSSIM.

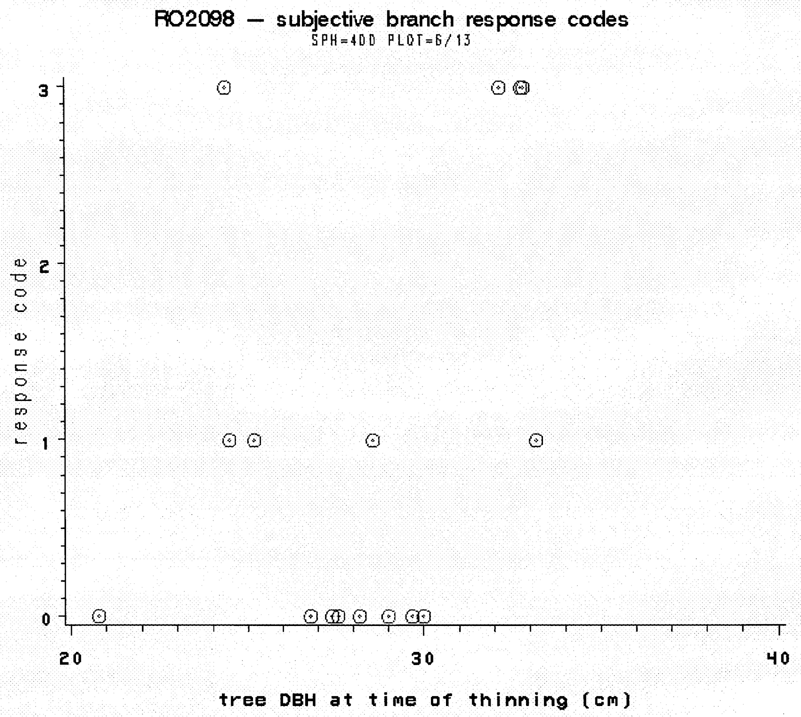
Figure 1. Subjective response of branches to thinning.






RO2098 — subjective branch response codes
SPH=200 PLOT=5/12
response code
0
1
2
3
20
30
40
tree DBH at time of thinning (cm)


RO2098 — subjective branch response codes
SPH=200 PLOT=19/36
response code
0
1
2
3
20
30
40
50
tree DBH at time of thinning (cm)


RO2098 — subjective branch response codes
SPH=400 PLOT=6/13
response code
0
1
2
3
20
30
40
tree DBH at time of thinning (cm)

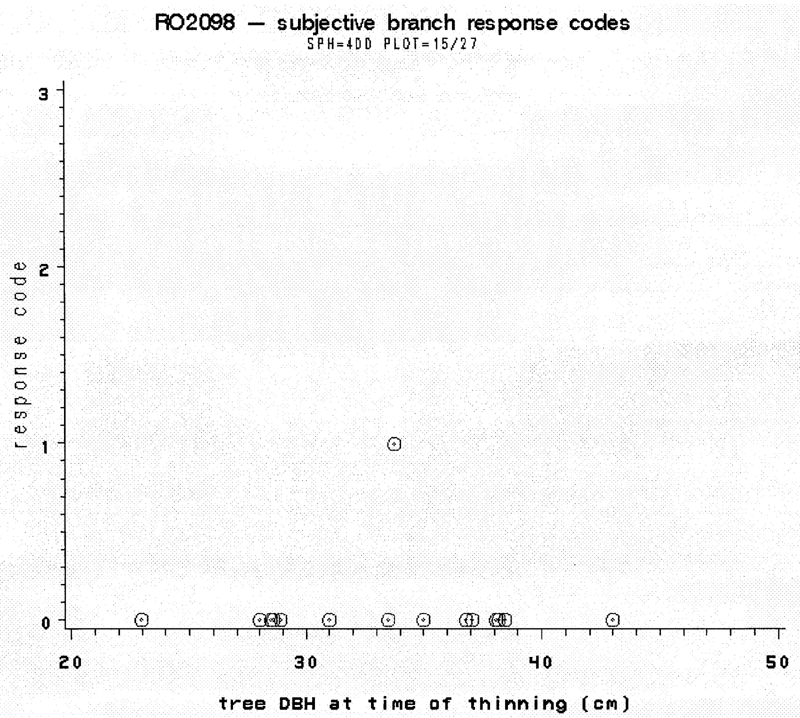
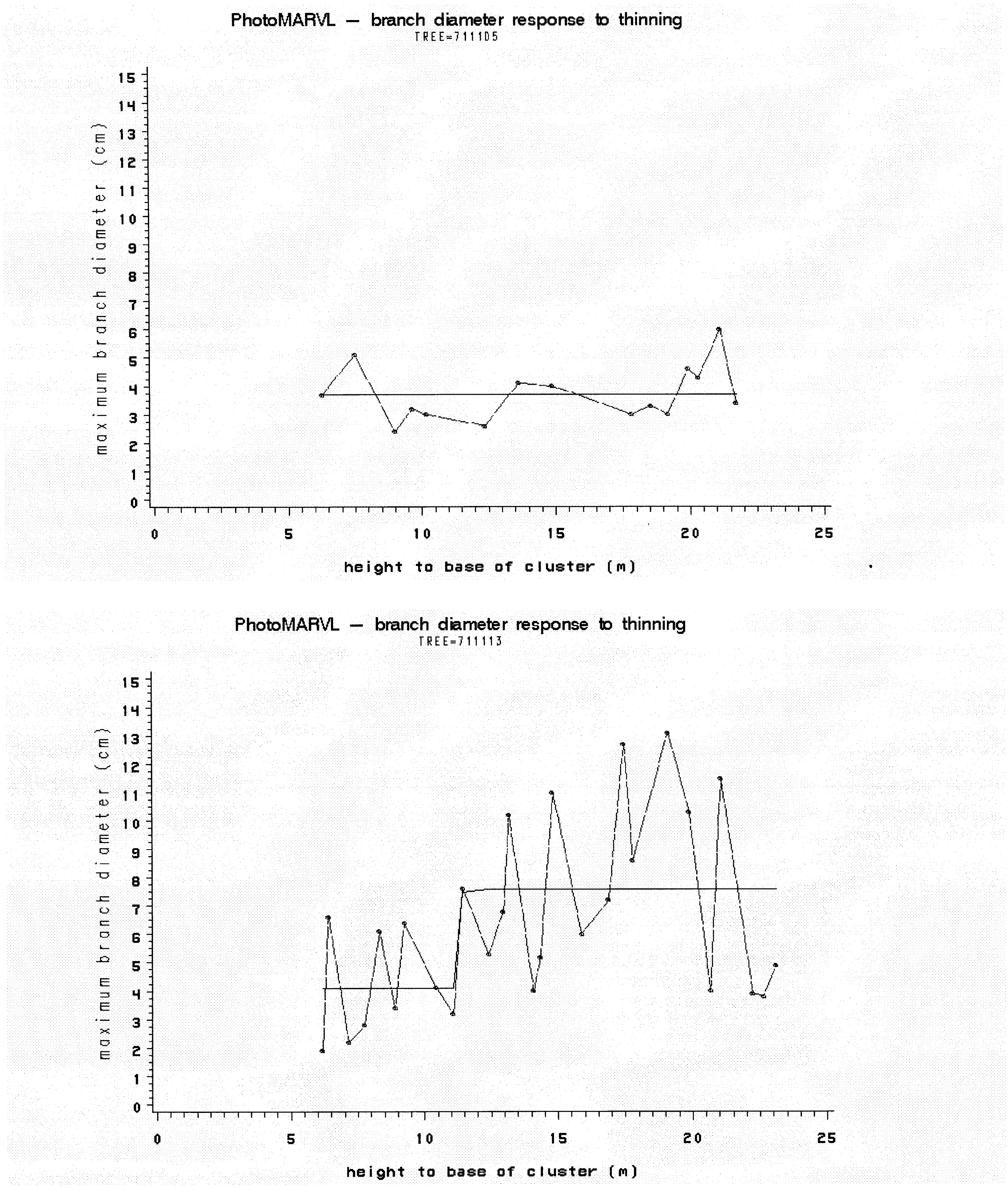
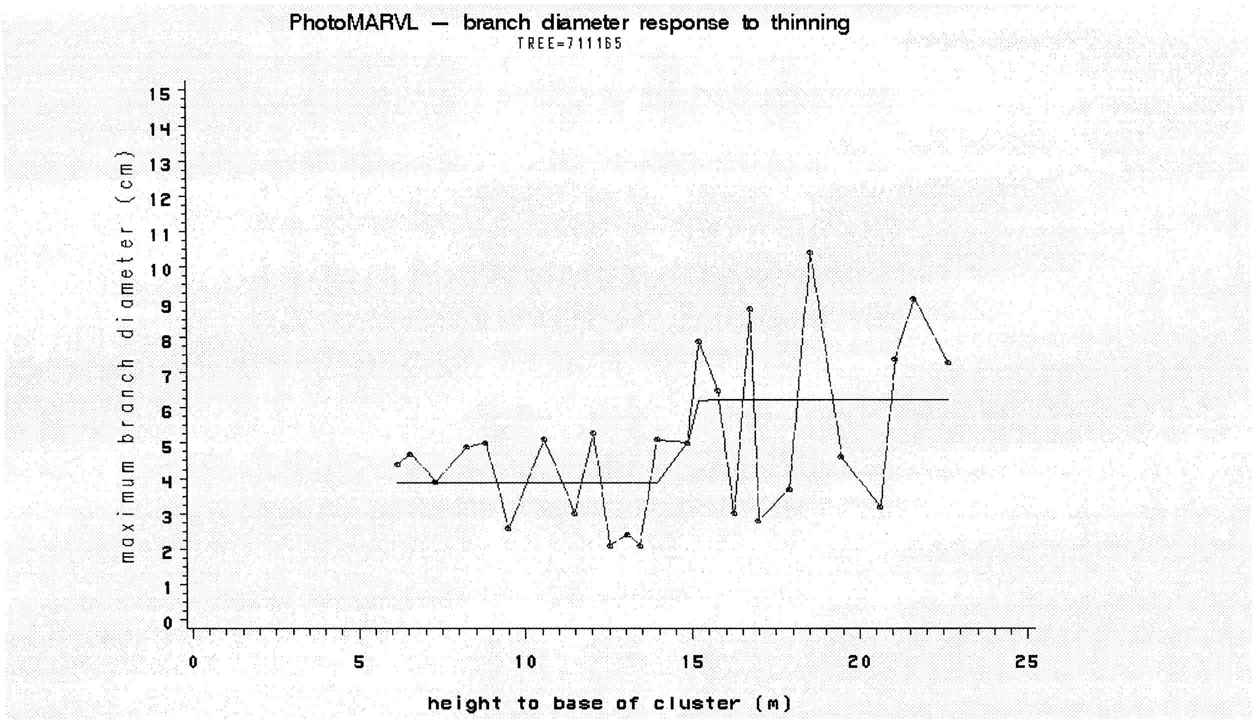
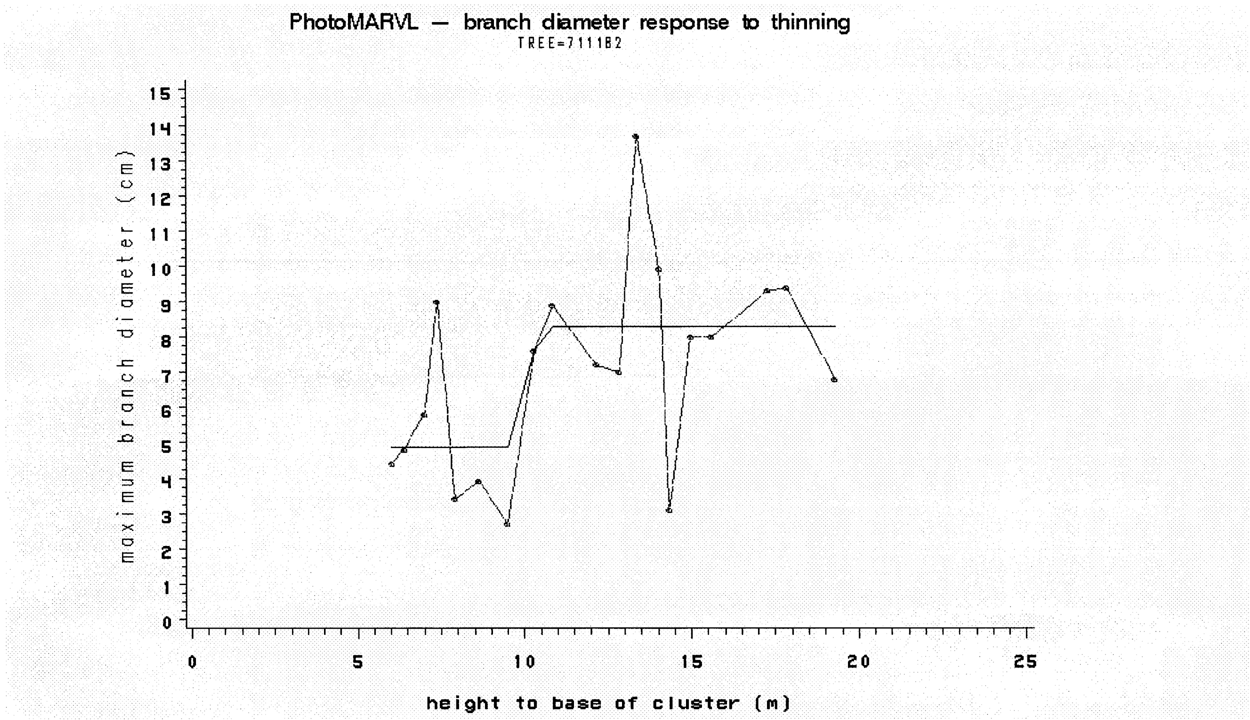
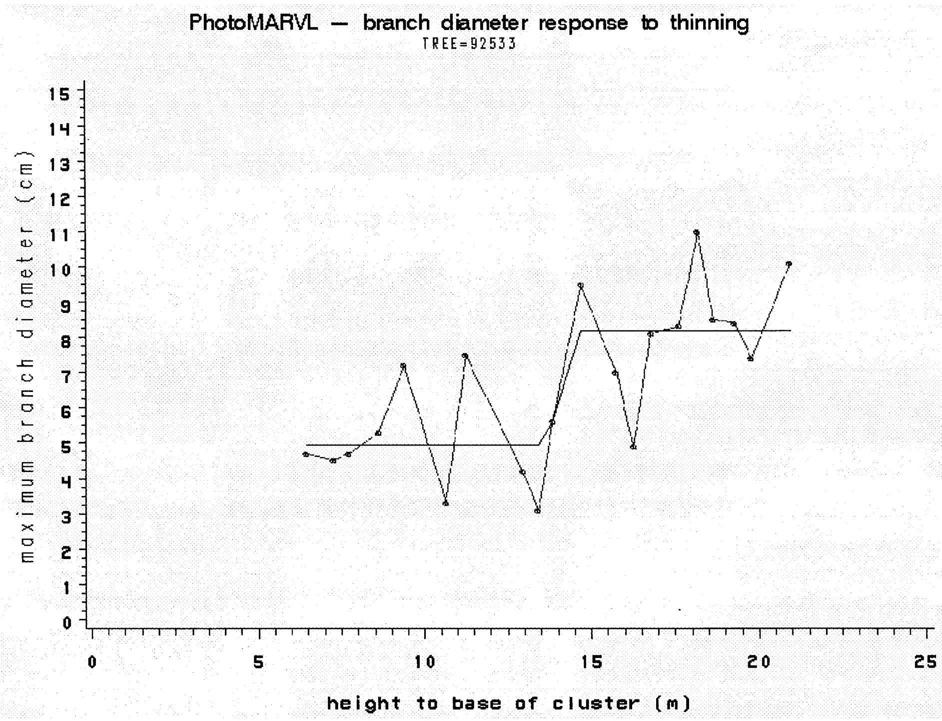

RO2098 — subjective branch response codes
SPH=400 PLOT=15/27
response code
0
1
2
3
20
30
40
50
tree DBH at time of thinning (cm)

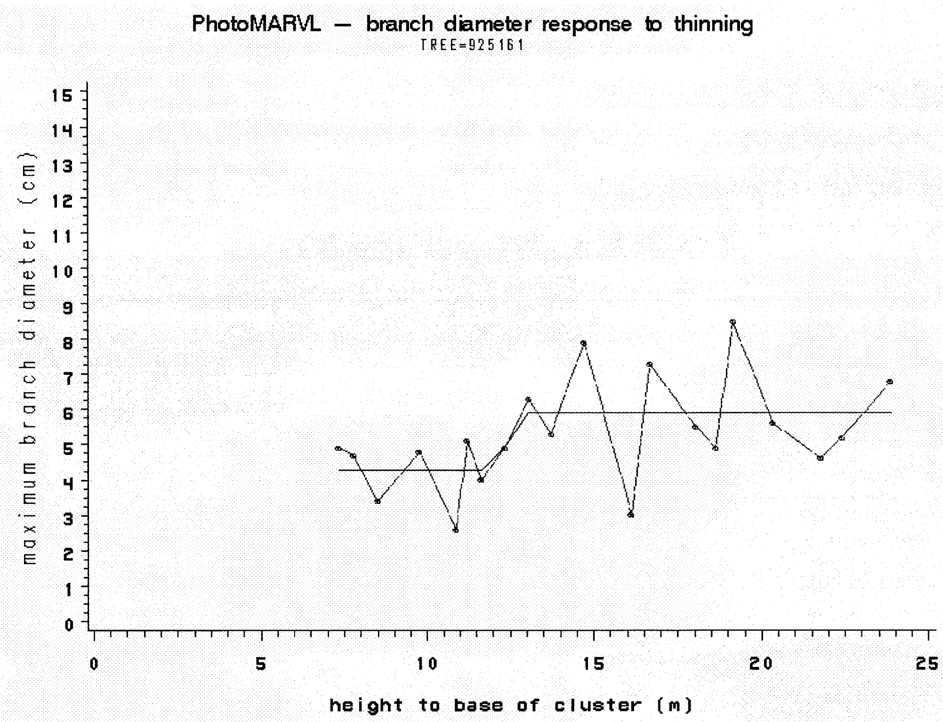
Figure 2. PhotoMARVL assessment of branch diameter and fitted curve.

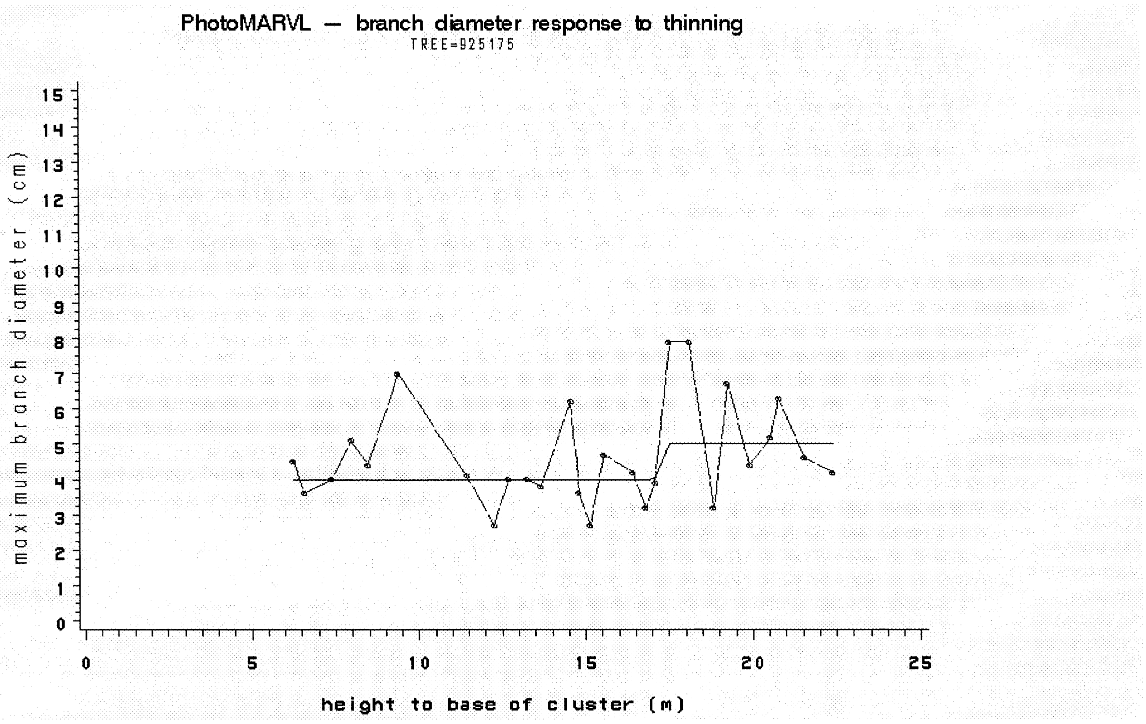



PhotoMARVL — branch diameter response to thinning
TREE=711165
maximum branch diameter (cm)
height to base of cluster (m)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


PhotoMARVL — branch diameter response to thinning
TREE=711182
maximum branch diameter (cm)
height to base of cluster (m)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


PhotoMARVL — branch diameter response to thinning
TREE=92533
maximum branch diameter (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
5
10
15
20
25
height to base of cluster (m)


PhotoMARVL — branch diameter response to thinning
TREE=925161
maximum branch diameter (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
5
10
15
20
25
height to base of cluster (m)


PhotoMARVL — branch diameter response to thinning
TREE=925175
maximum branch diameter (cm)
height to base of cluster (m)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

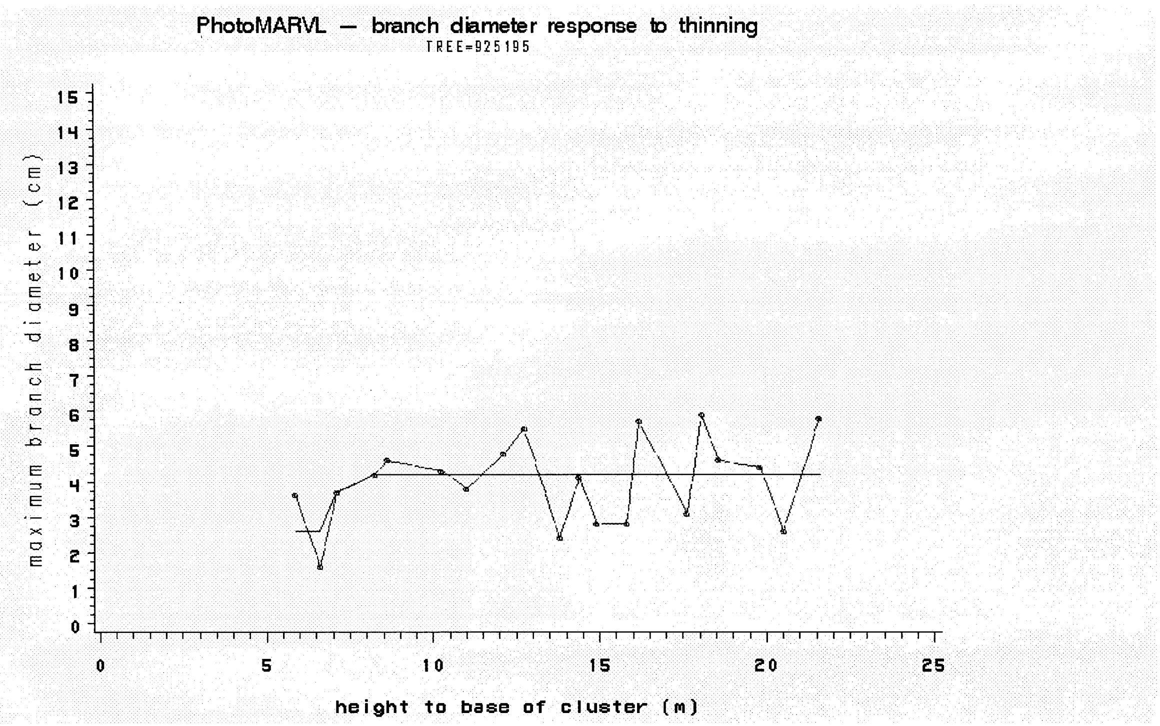
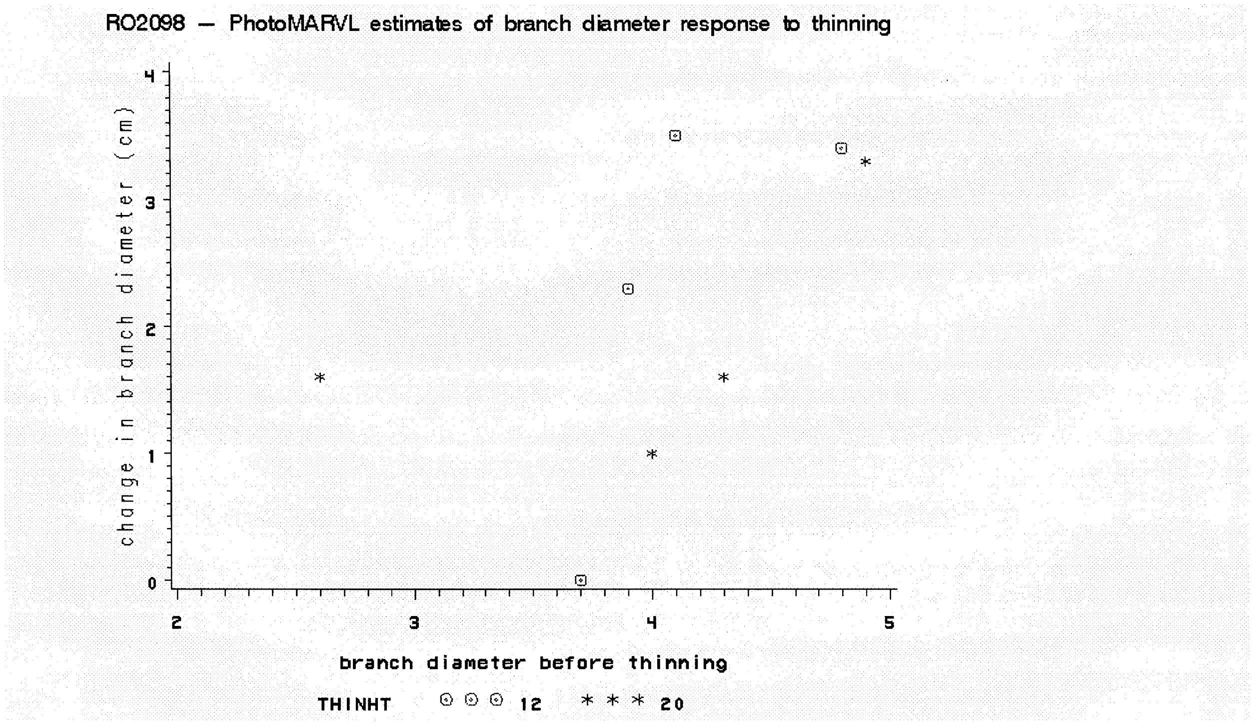

PhotoMARVL — branch diameter response to thinning
TREE=925195
maximum branch diameter (cm)
height to base of cluster (m)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 3. Increase in branch diameter due to thinning.



Note: THINHT is the height at time of thinning.

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