EXPANDING MARVL BRANCH CODES TO PROVIDE A MORE COMPLETE DESCRIPTION OF THE TREE CROWN

J.C. GRACE

REPORT No 94. **August 2000**

EXECUTIVE SUMMARY

Using the knowledge and functions built into the branch model, BLOSSIM, methods have been developed to enable subjective MARVL branching codes to be expanded into a more detailed description of the tree's branching.

These methods were used to assign branch diameters to a set of 23 trees from a mid-rotation MARVL inventory. The trees and branches were grown forward from 14 years to 28 years. The results, predicted branch diameters at mid-rotation and at 28 years, appeared realistic when compared with tree DBH and MARVL codes.

Further testing of the approach is required using trees for which there are both mid-rotation and pre-harvest MARVL codes.

EXPANDING MARVL BRANCH CODES
TO A PROVIDE A MORE COMPLETE DESCRIPTION OF THE TREE CROWN

J.C. GRACE

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 model developed

To be able to address the original objective, the branch model, BLOSSIM was developed. This model incorporates our understanding of how tree crowns develop through time. With the knowledge gained, we are now in a position to develop routines to convert subjective inventory data into an input file for the branch model and grow the branches forward in time.

In this report, methods to convert subjective inventory codes on branching into a more complete description of the crown are described.

While working on this project it was realised that there were two possible research strategies:
- develop a full description of the crown from the MARVL data, that could feed through a sawing simulator and give possible sawn products.
- develop a simplified crown description, sufficient to grow MARVL codes forward in time which could then be reanalysed using MARVL to give possible log products.

The first approach provides and uses more detailed information about the tree's branching characteristics and is suitable for understanding the influence of different crown structures on products obtained.

In this report, only the second approach has been considered.

The following terms are used in this report:
- "primary age" means the tree age when a particular section of the stem was formed

METHODS AND RESULTS

J. Schnell (P.F. Olsen & Co. Ltd.) offered to provide a MARVL dataset for the project. At the outset, he consulted with J. Grace (***Forest Research***) to determine whether any other variables should be measured during the inventory. From the information provided in Appendix 1, it was decided to record the following additional information for the height trees:

- the number of branches in the lowest cluster
- the diameter of the largest branch in the lowest cluster
- the number of branch clusters in a given stem section (top of pruning to 10 m)

because the pertinent branch model functions had a large influence on timber value (SGMC Report No. 82).

The MARVL dataset, from Putawa Forest in the Waikato, contained 5 stands (see Appendix 2 for stand histories). The data for the stand 1/01 was provided first and used to develop the initial procedures outlined below.

Part 1. Assigning branches and growing branches forward in time

Step 1. Determine the height growth for the stand

The height growth must be calculated to determine annual extension (annual shoot length) as branch cluster positions are assigned within annual shoots.

MicroMARVL version 2.5 was used to determine mean top height of the stand.

The height growth model for Hawkes Bay (No. 26) was considered to be the most appropriate and was used to determine the mean top height for each year up to and including the present age of the stand (14.6 years).

Tree height at age A was calculated as follows:

tree height at inventory × mean top height at age A / mean top height at inventory

Step 2. Determine number of branch clusters in an annual shoot

The number of branch clusters in an annual shoot was found to have a large influence on timber value. This was the main reason for obtaining a count of clusters in a given stem length.

Approach 1

As no count was made in stand 1/01, it was necessary to select a value based on current knowledge. The number of clusters per annual shoots tends to increase on warmer sites for a given genetic material. Woodhill is the only site measured to date that has a similar climate to the Waikato (New Zealand Meteorological Service, 1983). Therefore a value of 4 clusters per year was used (SGMC Report No. 92).

Approach 2

For the other stands, cluster counts were provided by counting the number of clusters between the pruned height and 10 m.

The tree age at the prune height and at 10 m were calculated.
The number of clusters recorded was divided by the difference in two tree ages.

For stand 3/01, the site average for number of clusters in an annual shoot was estimated as 3.89. This very close to the estimated value used for stand 1/01.

<u>Step 3. Determine relative position of clusters in the annual shoot</u>

The relative position of clusters in the annual shoot only had a small influence on timber value. Therefore it is appropriate to use the current table incorporated in BLOSSIM (SGMC Report No. 92).

In the initial implementation for Stand 1, the relative positions for the 4 clusters were assumed to be 0.25, 0.50, 0.75 and 1.0.

<u>Step 4. Mean branch diameter by averaging the diameter of the largest branch in each cluster</u>

In stands where the crown has not been affected by thinning, and for that part of the crown where branches have stopped growing, there was generally no significant correlation between primary age 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).

Approach 1

If diameter of the largest branch in the lowest cluster is recorded, develop a relationship between this branch diameter and tree DBH, and use this relationship to give an average diameter for the largest branch in each cluster for the tree.

Adjustments may need to be made if the stand has received any thinning treatment.

Approach 2

In the situation where only the MARVL codes are available another approach will be required. One possible approach, yet to be tried, is outlined below.

The MARVL codes give an estimate of largest branch diameter for a given stem section. Excluding that part of the crown that is considered to be actively growing, an estimate of "average" branch diameter for each tree could be obtained by:

$$\Sigma \text{ (MARVL branch code diameter * stem section length) / (stem length of all sections)}$$

and then developing a regression equation between this value and DBH.

If the largest branch diameter for each code is used, then this approach will overestimate the mean diameter for the largest branch in each cluster over the whole tree. A closer estimate may be obtained using the mean branch diameter for each code.

Step 5. Limits for largest branch diameter in each cluster

The largest branch diameter in a cluster is extremely variable. The MARVL codes only capture the broad trends for the very largest branch clusters. The first step is to use these codes to set limits for the largest branch diameter in each cluster.

The branch zone codes applied during the inventory were:

0: 0 cm (pruned)
7: less than 7 cm
10: 7 to 10 cm
15: 10 to 15 cm

The following rules were applied to limit the largest branch diameter in each cluster:

1. branch diameter must be less than the maximum allowed in that zone
2. branch diameter is further constrained where there is a change in zone as outlined below:

A. 1^{st} cluster above pruning:
If code is 7, branch diameter must be less than 7 cm
If code is 10, branch diameter must be between 7 and 10 cm
If code is 15, branch diameter must be between 10 and 15 cm

B. 1^{st} cluster above change from 7 to 10
branch diameter must be between 7 and 10 cm

C. 1^{st} cluster above change from 7 to 15
branch diameter must be between 10 and 15 cm

D. 1^{st} cluster above change from 10 to 15
branch diameter must be between 10 and 15 cm

E. Cluster immediately below change from 15 to 10
branch diameter must be between 10 and 15 cm

F. Cluster immediately below change from 15 to 7
branch diameter must be between 10 and 15 cm

G. Cluster immediately below change from 10 to 7
branch diameter must be between 7 and 10 cm

Step 6. Estimate largest branch diameter in each cluster

Initial analyses suggest that the frequency distribution for diameter of largest branch in a cluster / tree average of diameter of largest branch in a cluster varies little between trees on a site and between sites. One such distribution is illustrated in Appendix 3, Fig. 1.

Given the mean branch diameter from step 4, the largest branch diameter for each cluster was calculated as follows:

- select a random number from the frequency distribution (Appendix 3, Fig. 1) and multiply it by the mean branch diameter.

If the estimated diameter is within the limits set in Step 5, it is selected. If not the process is repeated until an acceptable diameter is found.

This approach was not practical where the branch diameter was constrained to be a large value because very few random observations fell into these zones. For these zones, a random value between the zone limits was selected.

Step 7. Assign branch potentials

In SGMC Report 90, the concept of a branch potential was introduced. This potential depended on the branch position in the cluster, the cluster position in the tree, the relative tree size, stocking, site and genetics. Using these potentials, realistic predictions of branch growth in response to thinning were obtained for unimproved radiata pine in the Central North Island. This model has been used here. A disadvantage of the model equation that emerged was that was not possible to solve for branch potential from knowing age and branch diameter. In this case, the potential for each branch was determined using a look-up table. Further research is needed to develop a branch growth function that can be solved to give potential.

In the lower part of the crown, branches were close to or at their maximum diameter and the estimated potentials seemed realistic. In the upper part of the crown (younger branch age), estimated potentials increased with decreasing age and were considered unrealistic. The potentials were considered to be realistic for branches older than 6 years (Appendix 3, Fig. 2).

The average potential was calculated for the branches older than 6 years. As the stand had been thinned, it was necessary to remove the stocking effect from the potential. In this instance it was assumed that branches older than 1 year at the time of thinning continued to grow at the old stocking, while branches that were 1 year or younger grew at the new stocking. Further research is needed to improve the incorporation of a thinning response.

Step 8. Reassign branch potentials in the growing part of the crown

More realistic branch potentials were calculated for the growing part of the crown as follows:

The random number, derived in step 6, was used to estimate the diameter of the largest branch in the cluster. This diameter and the potential, calculated in step 7, were clearly wrong.

A more realistic branch potential, and hence diameter was obtained by multiplying the random number by the average potential derived in Step 7.

Step 9. Estimate maximum diameter for branch and age at which it occurs

These values were derived from the look-up table used previously.

In these 9 steps we have estimated cluster locations, assigned a largest branch diameter to each cluster based on the MARVL codes and determined its growth trajectory. This information is sufficient to reassign MARVL codes at a later age and determine product outturn.

Further steps are needed to derive a complete description of the crown. The current functions in BLOSSIM would be used though an alternative approach has been developed for determining the number of branches in a cluster (Appendix 4).

Part 2. Implications of growing branches forward in time.

The procedures developed in Part 1 were applied to the 23 height trees from stand 1/01. The following steps were then carried out to determine how growing branches forward would influence the logs cut from the trees.

<u>Step 1. Growing trees forward in time</u>

The individual tree growth model was used to grow the trees forward from age 14 to age 28 years to give new heights and diameters.

<u>Step 2. Deriving MARVL codes for grown branches.</u>

To be able to determine changes in MARVL output from growing branches forward in time, the detailed description of largest branch in a cluster was converted back into MARVL format. A general mid-rotation MARVL dictionary used, not one created especially for this project (Table 1). As a first attempt this was done manually, using the original MARVL codes except where branches have "grown" into a new code. At some stage a program needs to be written to do this automatically. At this stage the following questions need to be addressed and will required feedback from industry:

- How is the growing part of the crown coded in practice?

    In this example, I assumed that the growing part of the crown had not been coded separately. Jeff Schnell confirmed this was correct. If the growing part of the crown was coded separately then the procedures developed above would need to be modified.

- How frequently should codes be changed when a program is written to do this automatically e.g. every cluster, every metre?

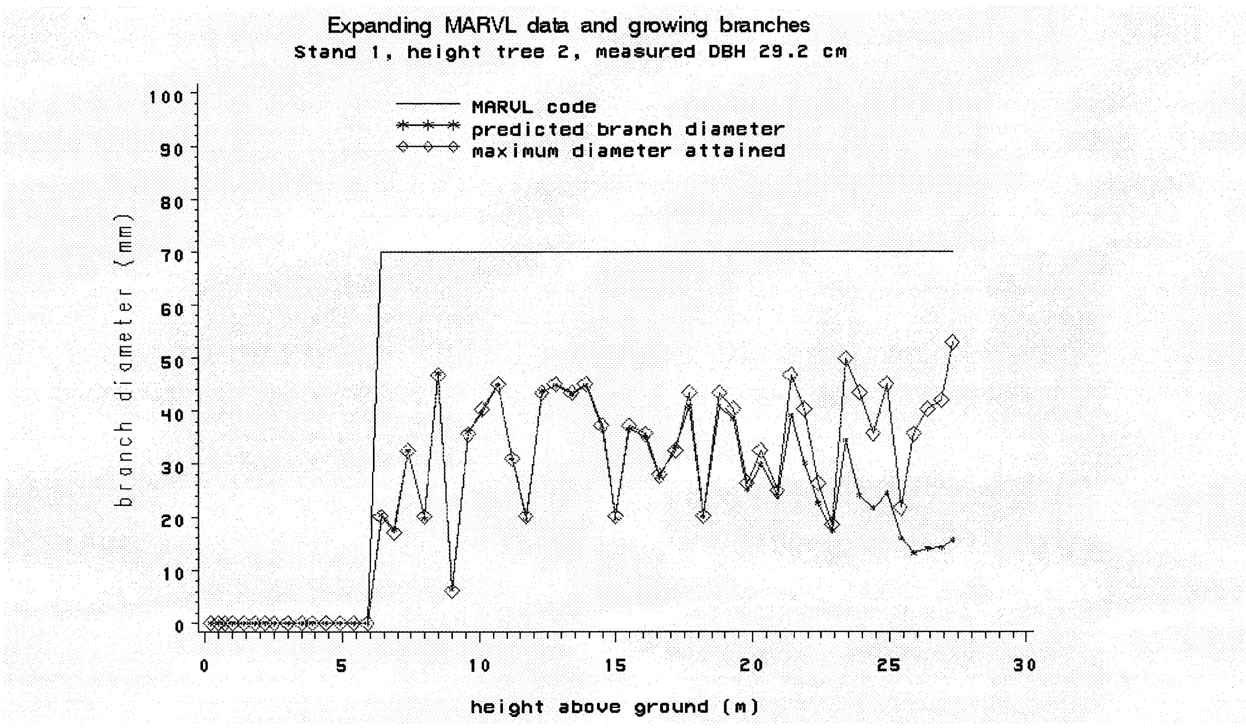
After growing the branches forward in time, the MARVL description remained the same for 11 of the 23 trees. To determine whether this was realistic, trees were ranked in terms of diameter and the new and old MARVL descriptions compared visually. The changes in MARVL codes appeared logical. The original MARVL codes, the initial predicted branch diameters and grown branch diameters are shown in Figs 1-5 for 5 trees selected to cover the range of measured DBH and patterns observed. The growing part of the crown at time of measurement can be seen in all the figures.

Table 1. MARVL dictionary used.

```
$ Mid-rotation dictionary;  Created Oct 1999
$   Pruned plus 3 branch size classes
$   3 sweep classes
A pruned              sweep < D/4
B pruned               sweep D/4 - D/2
C pruned               sweep D/2 - D
D branch < 7           sweep < D/4
E branch 7-10          sweep < D/4
G branch 10-15         sweep < D/4
H branch < 7           sweep D/4 - D/2
I branch 7-10          sweep D/4 - D/2
J branch 10-15         sweep D/4 - D/2
K branch < 7           sweep D/2 - D
L branch 7-10          sweep D/2 - D
M branch 10-15         sweep D/2 - D
P pulp    branch > 15  or  sweep > D
W waste (malformation)
[ABC] PRUNED
```

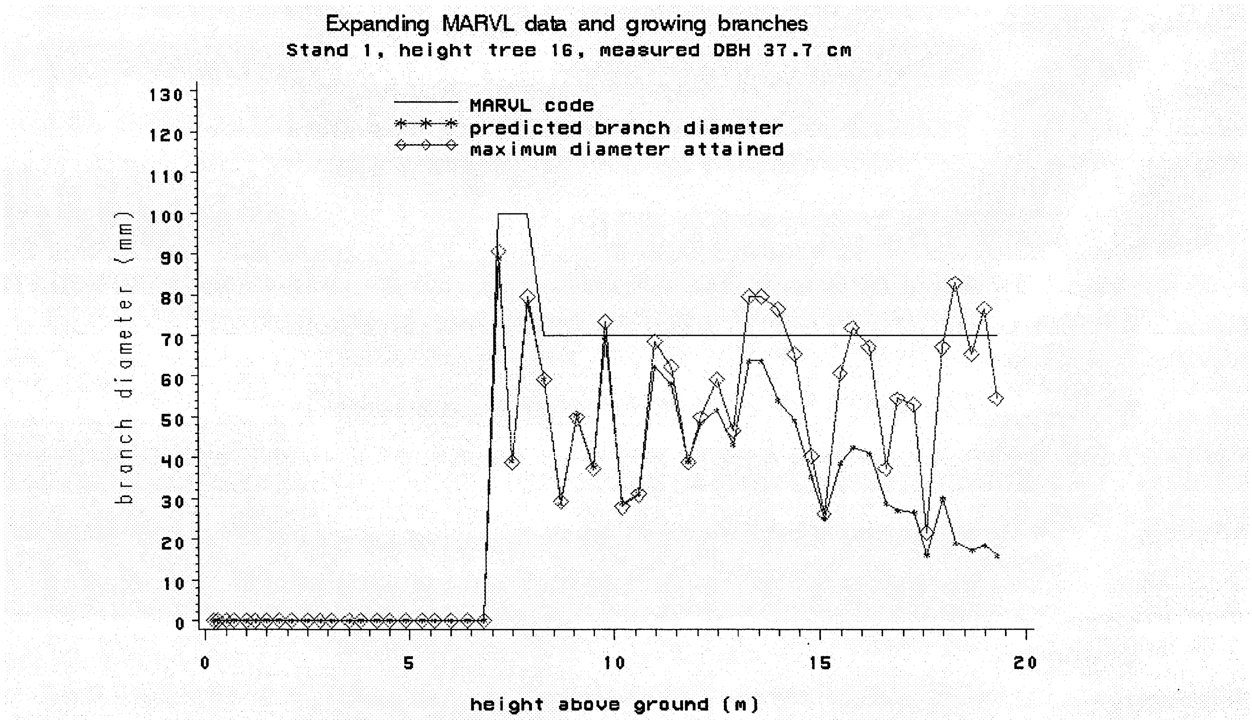
Tree 2 (Fig. 1) was the smallest tree measured. The initial branch diameters were way below the zone maximum of 7 cm, and still did not reach 7 cm when grown forward in time.

Figure 1. Predicted branch data for tree 2.



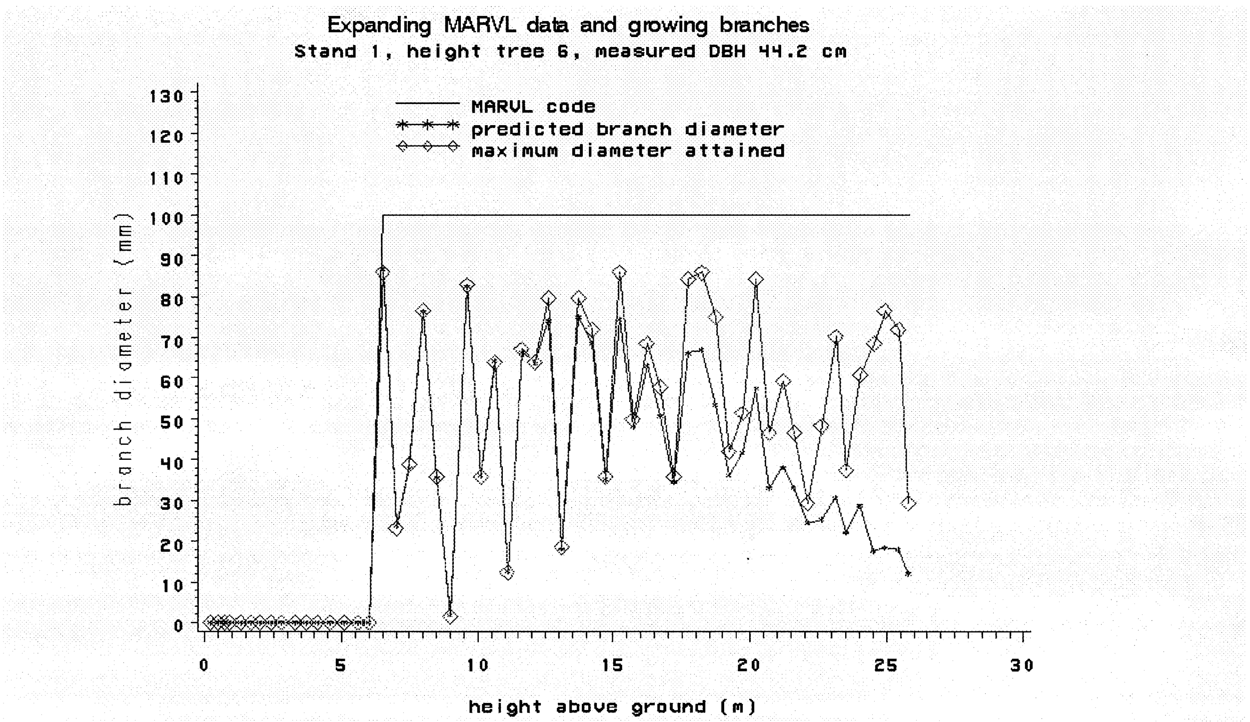
Tree 16 (Fig. 2) was slightly larger. Initially a few branches were over 7 cm, and others were close to 7 cm. When the branches were grown forward, several branches exceeded 7 cm.

Figure 2. Predicted branch data for tree 16.



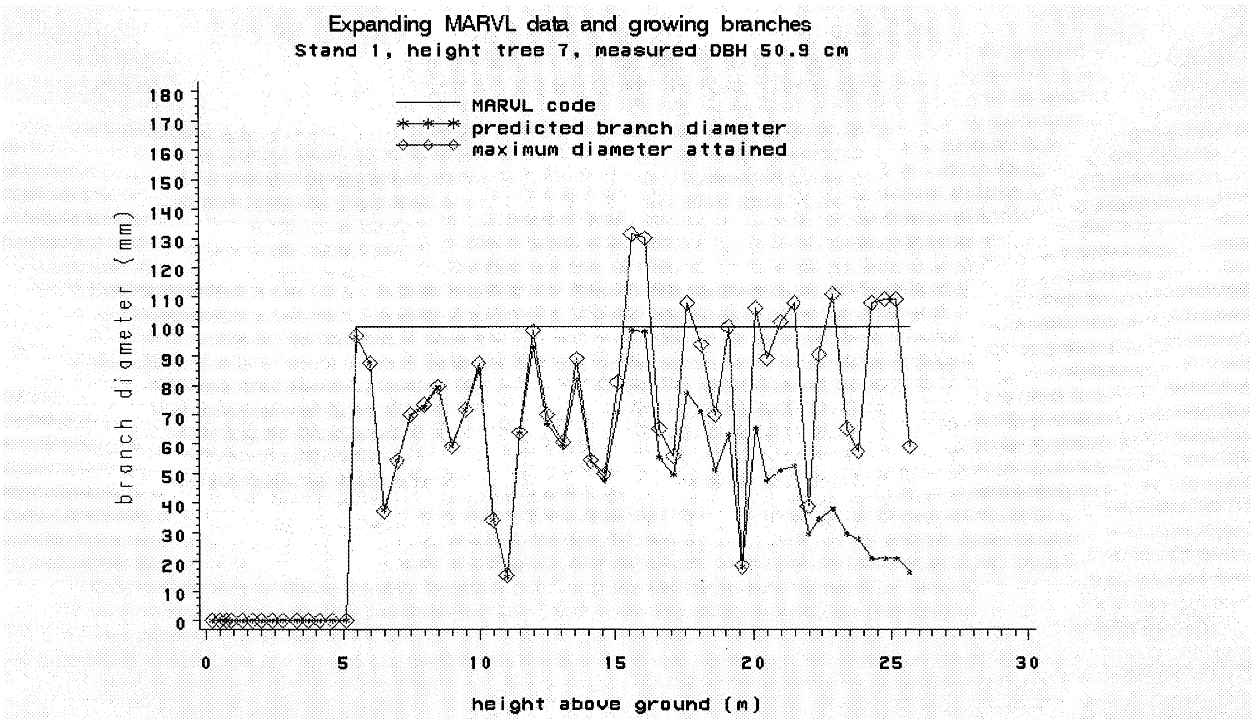
Tree 6 (Fig. 3) was coded as having branches between 7 and 10 cm. The initial branch diameters were closer to 7 cm, and when grown forward did not exceed 10 cm.

Figure 3. Predicted branch data for tree 6.



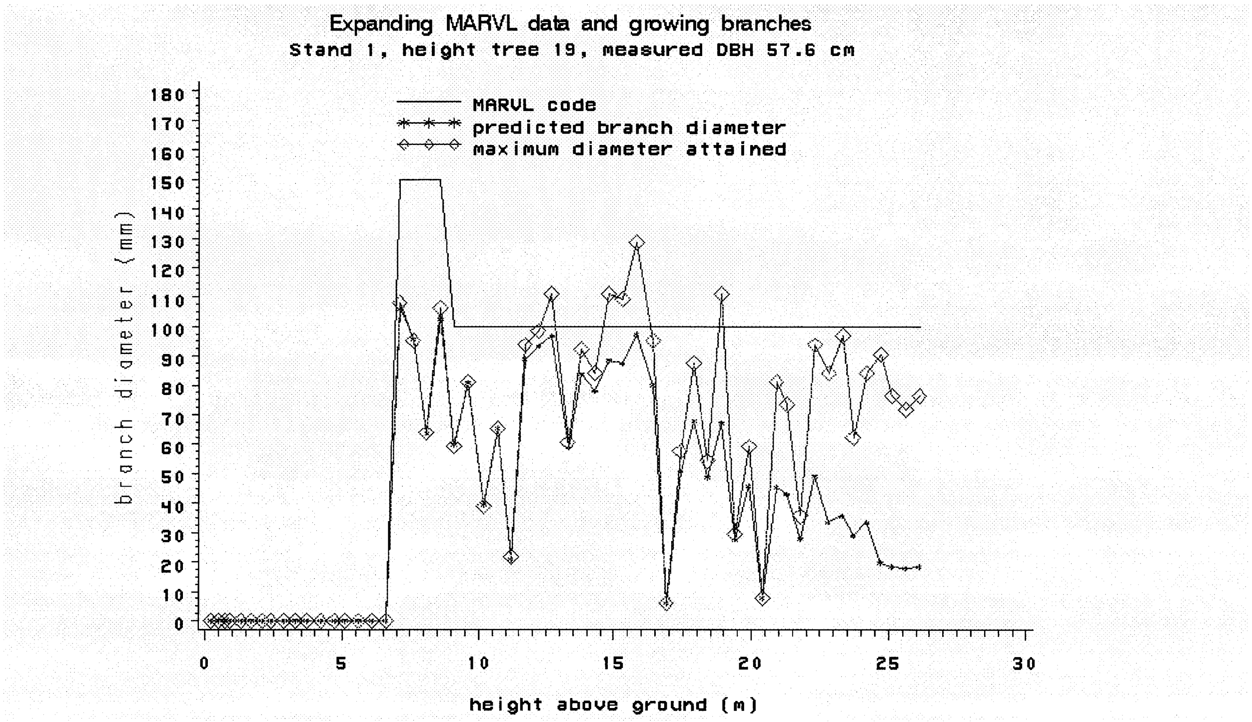
Tree 7 (Fig. 4) was also coded as having branches between 7 and 10 cm. It was a slightly larger than tree 6, and the initial branch diameters were closer to 10 cm. When the branches were grown forward several exceeded 10 cm in the upper half of the crown.

Figure 4. Predicted branch data for tree 7.



Tree 19 (Fig. 5) was the largest tree measured. Initially a few branches were over 10 cm. When the branches were grown forward other branches exceeded 10 cm.

Figure 5. Predicted branch data for tree 19.



Step 3. Comparison of output

Two MARVL runs were carried out:

- trees grown to age 28 years but not branches, i.e. no change in quality coding
- trees grown to age 28 years and branches grown forward as outlined above, stems recoded.

The trees were cut into logs using the following cutting strategy which was generated to highlight the effects changes in branching:

```
 0.2500 0.877270  0.500 PFOMR.DIC
"PRUNED PEELER        "    40.00    30.0    99.9    99.9 A
      5.40       5.40
      2.70       2.70
"PRUNED SAWLOG        "    30.00    30.0    99.9    99.9 ABC
      5.40       5.40
      2.70       2.70
"UNPRUNE SAWLOG SMALL"     20.00    25.0    99.9   120.0 ABCDHK
      3.50       6.00
"UNPRUNE SAWLOG LARGE"     15.00    25.0    99.9   120.0 ABCDHKEIL
      3.50       6.00
"PULP                 "    10.00    15.0    99.9   120.0 ABCDHKEILGJMP
      3.50       6.00
```

The products cut using the two approaches are shown for 3 of the trees where MARVL codes changed (Tables 2 and 3).

For tree 16 (Fig. 2), large branches sawlogs were cut instead of small branched sawlogs.

For tree 7 (Fig. 4) and tree 19 (Fig. 5), pulp logs were cut instead of large branched sawlogs.

Considering the 23 trees together, the products cut changed as follows:

small-branched sawlogs,	-10%
large-branched sawlogs,	-13%
pulp,	+125%

Table 2. Logs cut using original MARVL codes.

TREE	DBH	BASE	TOP	BREAK	TYPE	LENGTH	SED	VOLUME	$
7	682	0.0	46.1	24.9	_Breakage	21.1m	0.0	0.716	
					UNPRUNE SAWLOG LARGE	3.5m	34.1	0.367	5.50
					UNPRUNE SAWLOG LARGE	3.5m	38.7	0.459	6.89
					UNPRUNE SAWLOG LARGE	6.1m	42.8	1.020	15.30
					UNPRUNE SAWLOG LARGE	6.1m	48.9	1.280	19.21
					PRUNED PEELER	2.6m	54.2	0.643	25.71
					_PRUNED SAWLOG	2.6m	57.7	0.785	23.54
					Stump	0.3m	67.3	0.091	
	Ht 46.1 BA 0.365 Recov 4.554/ 6 logs						Totals:	5.362	96.15
16	513	0.0	39.0	25.9	_Breakage	13.2m	0.0	0.159	
					PULP	4.4m	20.2	0.185	1.85
					UNPRUNE SAWLOG SMALL	6.1m	26.0	0.425	8.49
					UNPRUNE SAWLOG SMALL	6.1m	33.0	0.620	12.39
					UNPRUNE SAWLOG LARGE	3.5m	38.4	0.436	6.54
					PRUNED SAWLOG	2.6m	41.1	0.371	11.14
					_PRUNED PEELER	2.6m	43.9	0.456	18.24
					Stump	0.3m	51.8	0.054	
	Ht 39.0 BA 0.207 Recov 2.493/ 6 logs						Totals:	2.707	58.66
19	759	0.0	47.1	29.2	_Breakage	17.5m	0.0	0.523	
					UNPRUNE SAWLOG LARGE	3.5m	31.7	0.327	4.91
					UNPRUNE SAWLOG LARGE	4.4m	37.1	0.559	8.38
					UNPRUNE SAWLOG LARGE	6.1m	43.2	1.068	16.03
					UNPRUNE SAWLOG LARGE	6.1m	50.5	1.386	20.80
					PULP	3.5m	56.5	0.930	9.30
					_PRUNED PEELER	5.3m	59.8	1.737	69.46
					Stump	0.3m	74.1	0.110	
	Ht 47.1 BA 0.452 Recov 6.007/ 6 logs						Totals:	6.640	128.87

Table 3. Logs cut using modified MARVL codes

TREE	DBH	BASE	TOP	BREAK	TYPE	LENGTH	SED	VOLUME	$
7	682	0.0	46.1	24.9	_Breakage	21.1m	0.0	0.716	
					PULP	3.5m	34.1	0.367	3.67
					PULP	6.1m	38.7	0.864	8.64
					UNPRUNE SAWLOG LARGE	3.5m	45.6	0.616	9.24
					UNPRUNE SAWLOG LARGE	6.1m	48.9	1.280	19.21
					PRUNED PEELER	2.6m	54.2	0.643	25.71
					_PRUNED SAWLOG	2.6m	57.7	0.785	23.54
					Stump	0.3m	67.3	0.091	
	Ht 46.1	BA 0.365	Recov	4.554/	6 logs		Totals:	5.362	90.00
16	513	0.0	39.0	25.9	_Breakage	13.2m	0.0	0.159	
					PULP	4.4m	20.2	0.185	1.85
					UNPRUNE SAWLOG LARGE	3.5m	26.0	0.218	3.27
					UNPRUNE SAWLOG LARGE	6.1m	30.2	0.538	8.06
					UNPRUNE SAWLOG LARGE	6.1m	36.3	0.725	10.87
					PRUNED SAWLOG	2.6m	41.1	0.371	11.14
					_PRUNED PEELER	2.6m	43.9	0.456	18.24
					Stump	0.3m	51.8	0.054	
	Ht 39.0	BA 0.207	Recov	2.493/	6 logs		Totals:	2.707	53.44
19	759	0.0	47.1	29.2	_Breakage	17.5m	0.0	0.523	
					UNPRUNE SAWLOG LARGE	3.5m	31.7	0.327	4.91
					UNPRUNE SAWLOG LARGE	6.1m	37.1	0.830	12.45
					PULP	3.5m	45.5	0.624	6.24
					PULP	4.4m	49.6	0.928	9.28
					PULP	6.1m	54.0	1.562	15.62
					_PRUNED PEELER	5.3m	59.8	1.737	69.46
					Stump	0.3m	74.1	0.110	
	Ht 47.1	BA 0.452	Recov	6.007/	6 logs		Totals:	6.640	117.96

DISCUSSION

In this project, the knowledge gained from developing the branch model, BLOSSIM, and some of the model functions have been used to develop a prototype model that will enable MARVL branch codes to be converted into branch diameters, and then grown forward in time. New MARVL descriptions were manually created. The trees were also grown forward using the individual-tree growth model (SGMC Report No. 77). The grown trees were run through MARVL using both the old and new descriptions to determine the changes in terms of log products.

The comparisons were made on an individual tree basis as MARVL cannot process stand level (per ha) plot data where trees have had their weighting altered as is the case when tree growth is predicted using an individual tree growth model.

The results seemed logical and realistic, but as the data was from a recently MARVLed stand, it is not possible to determine the accuracy of the results at present.

The study brought to light several issues which require further research, in particular:

- a simpler mathematical form is required for predicting branch growth
- a method is needed to obtain the branch potential (excluding stocking) for branches which have already had the ability to respond to a thinning.

These methods need to be tested on other data sets prior to a prototype version being released for testing. Trees which have been MARVLed twice would be particularly suitable.

The other issue that this project has raised in my mind, is the wealth of information on branching habits contained in MARVL descriptions. I wonder whether these data could be used in the further development of BLOSSIM.

ACKNOWLEDGMENTS

I would like to thank Jeff Schnell (P.F. Olsen & Co. Ltd.) and Evergreen Forests Ltd. for allowing me to use the MARVL data set from Putawa Forest; and Andy Gordon for many useful discussions and help in running MARVL.

REFERENCES

New Zealand Meteorological Service, 1983: New Zealand Climatic Regions. Miscellaneous Publication No. 175 Part 2.

Rawley, B.; Hayward, W. 1990: A new paradigm for growth models – Discussion paper. Stand Growth modelling Cooperative (unpublished).

APPENDIX 1. Initial Notes on updating inventory data to a full description of the crown

To be able to generate a detailed description of branching, suitable for input into logmaking or sawing simulators, a detailed description of a tree's branching characteristic is required. The 13 functions in the branch model, BLOSSIM, are outlined below. A "first cut" detailing how the relevant information would be obtained from MARVL and PhotoMARVL are summarised.

Function	How function would be derived using MARVL data	How function would be derived using PhotoMARVL data	Importance of function in terms of effect on sawing (visual grading) from SGMC Report 82.
Number of branch clusters in an annual shoot	Height growth models would be used to predict annual shoot lengths. A count of number of branch clusters in a given stem section would provide an estimate of average clusters/annual shoot. Otherwise, number of clusters/ annual shoot would have to be based on best available knowledge from current data.	Photographs would provide the actual position of clusters within a given stem section. Using the relevant height model, an estimate of clusters/annual shoot could be obtained.	Number of clusters in an annual shoot has a major influence on log value. Log value can vary by up to 50% depending on the number of clusters in the annual shoot
Relative position of clusters within an annual shoot	Relative positions of clusters within an annual shoot would need to be calculated using best available functions	Photograph would provide actual positions for a given stem section. For rest of tree, positions would have to be estimated using best available knowledge	Error likely to be less than 6%

Function	How function would be derived using MARVL data	How function would be derived using PhotoMARVL data	Importance of function in terms of effect on sawing (visual grading) from SGMC Report 82.
Number of branches in each cluster	Would need to be estimated using best available functions	Number of branches on half the stem in each cluster can be counted	Error likely to be significant, perhaps up to 20%
Probability a tree has reached reproductive maturity	Would need to be estimated using best available functions	Can see where cones are on the stem	A cone has to be modelled as a branch in AUTOSAW. The actual age is probably of minor importance.
Number of stem cones in a cluster	Would need to be estimated using best available functions	Number of cones on half the stem in each cluster can be counted	Error likely to be significant. (Cones are modelled as branches; and number of branches is significant)
Arrangement of branches in each cluster (phyllotaxy)	Will need to assume most frequent phyllotaxy	It may be feasible to obtain phyllotaxy from the photograph. Most likely scenario will be to assume most frequent phyllotaxy.	Error likely to be very small (less than 2%)
Azimuth angle of the largest branch in a cluster	Assume random at present (incorrect for edge trees, probably realistic otherwise)	May be able to obtain some information from photograph. Most likely scenario, assume random.	Error, slightly more important than phyllotaxy, but still likely to be less than about 5%
Diameter of the largest branch in a cluster	Largest branch for stem sections will need to be used. Rules to modify this value for other clusters will need to be developed from current data	Photograph will give largest or second largest branch in each visible cluster.	Quite important – error could be up to 10%
Diameter of other branches in a cluster	Estimate from best available function	Could be measured on photograph for half the stem	Error likely to be very small (less than 3%)

Function	How function would be derived using MARVL data	How function would be derived using PhotoMARVL data	Importance of function in terms of effect on sawing (visual grading) from SGMC Report 82.
Branch diameter at any age	Will need to be estimated using best available function	Will need to be estimated using best available function	This function provided shape of branch within the stem which could not be tested within AUTOSAW
Vertical distance between branch and stem piths (branch angle)	Will need to be estimated using best available function	Some estimate of branch angle could be obtained from a photograph	Error likely to be very small (less than 3%)
Bark encasement due to mortality	Will need to be estimated using best available function	Will need to be estimated using best available function	Branch shape in AUTOSAW does not match well with observed patterns. Appears that errors could be quite large (5-10%) if not modelled correctly.
Bark inclusion	Will need to be estimated using best available function	Will need to be estimated using best available function	Bark inclusion not considered in AUTOSAW. Tests assuming bark encasement, rather than bark inclusion suggests errors could be quite large if not modelled correctly (5-10%)

Appendix 2. Putawa 1985 P.rad stand histories

Stand 1/01 NSA (ha): 70.2

Operation	Area treated ha	date	Total stocking s/ha	Pruned stocking s/ha	Pruned height m	Mean Crop Ht m	Mean Crop DBH cm
Planting	70.2	Jun-85	1167				
Prune 1	45.2	Dec-89		424	2.4	6.2	12.8
Waste thin 1	45.2	Dec-89	424			6.2	
Prune 1	25.0	Sep-91		316	4.5	10.6	18.8
Waste thin 1	25.0	Sep-91	316			10.6	
Prune 2	45.2	Feb-92		337	5.0		21.5
Prune 3	70.2	Aug-94		291	6.4	15.1	28.9
Waste thin 2	70.2	May-96	300				

Stand 3/01 NSA (ha): 62.2

Operation	Area treated ha	date	Total stocking s/ha	Pruned stocking s/ha	Pruned height m	Mean Crop Ht m	Mean Crop DBH cm
Planting	62.6	Jun-85	1167				
Prune 1	62.6	Jan-90		405	2.5	6.2	12.5
Waste thin 1	62.6	Jan-90	405			6.2	
Prune 2	62.6	Jul-91	326	254	4.3	7.3	18.2
Prune 3	62.6	Mar-94	306	244	6.6	14.8	25.8
Waste thin 2	62.6	May-96	244			14.8	25.8

Stand 4/01 NSA (ha): 60.8

Operation	Area treated ha	date	Total stocking s/ha	Pruned stocking s/ha	Pruned height m	Mean Crop Ht m	Mean Crop DBH cm
Planting	60.8	Jun-85	1167				
Prune 1	54.7	May-89		360	2.5	6.1	12.5
Prune 2	54.7	Apr-91			4.5		
Prune 1	6.1	May-91		300	4.9		17.7
Waste thin 1	60.8	May-91	375				
Prune 3	60.8	May-94	355	291	6.7	16.1	29.3
Waste thin 2	60.8	May-95	300				

Stand 6/01 NSA (ha): 10.4

Operation	Area treated ha	date	Total stocking s/ha	Pruned stocking s/ha	Pruned height m	Mean Crop Ht m	Mean Crop DBH cm
Planting	10.4	Jun-85	1167				
Prune 1	10.4	Oct-89		290	3.5	6.7	13.7
Waste thin 1	10.4	Oct-89	290			6.7	
Prune 2	10.4	Apr-92	261	250	6.1	10.1	24.5

Stand 6/02 NSA (ha): 14.4

Operation	Area treated ha	date	Total stocking s/ha	Pruned stocking s/ha	Pruned height m	Mean Crop Ht m	Mean Crop DBH cm
Planting	14.4	Jun-85	1852				
Prune 1	14.4	Jul-91		282	4.6		17.6
Waste thin 1	14.4	Nov-91	375				
Prune 2	7.3	Apr-92	261	250	6.1	10.1	24.5
Prune 2	7.1	Mar-94	292	273	6.8	16.7	30.1

Appendix 3.

Figure 1. Frequency distribution for relative branch diameter

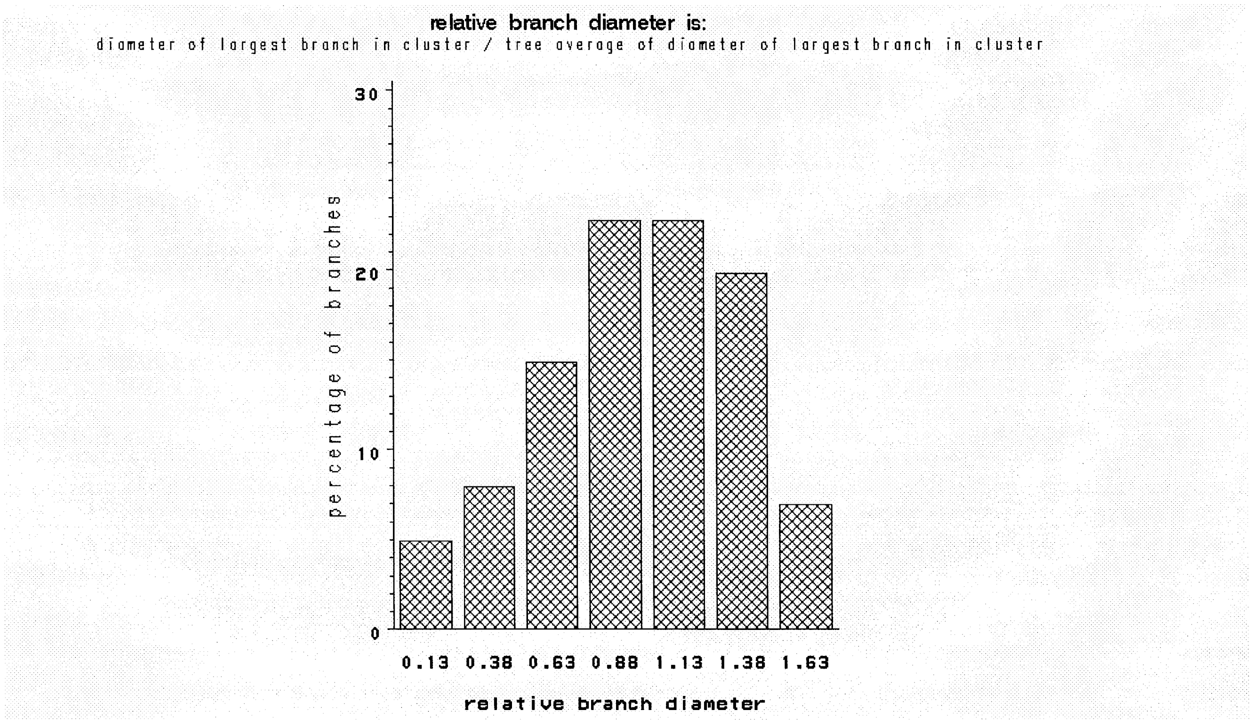
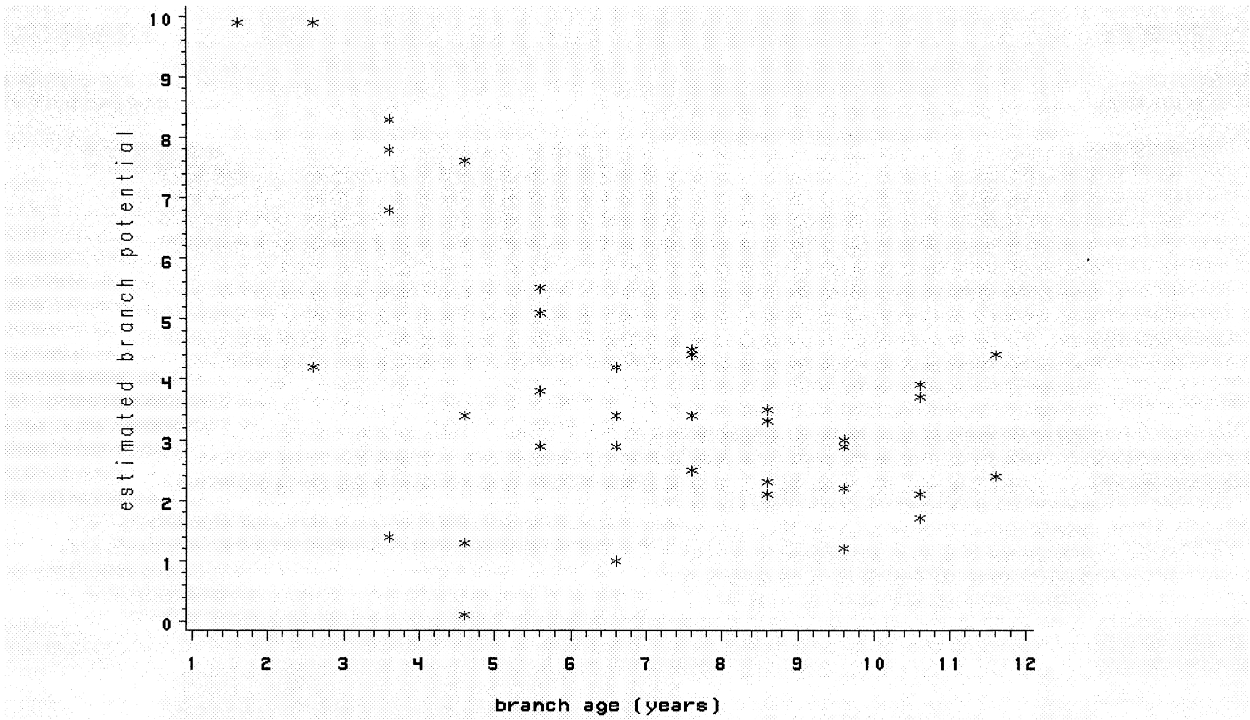


Figure 2. Estimated branch potential versus branch age



Appendix 4. Procedure for calculating number of branches in a cluster from field counts

The number of branches in a cluster had a high influence on timber value (SGMC Report 82) but was not affected by the primary age of the tree (SGMC Report No. 68). It is therefore reasonable to derive a distribution for branches per cluster using a branch count from the first cluster in each tree.

A SAS routine was used to calculate the coefficients for a polya-aeppeli distribution (SGMC Report No. 68), and a FORTRAN program used to calculate the cumulative distribution. The number of branches in each cluster was calculated by choosing a random value from the derived distribution.