FOREST & FARM PLANTATION
MANAGEMENT COOPERATIVE

VALIDATION AND IMPROVEMENT OF MODELS TO PREDICT "DIAMETER-OVER-STUBS"

R.L. Knowles and H McElwee

Report No. 61 March 1999

FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

EXECUTIVE SUMMARY

VALIDATION AND IMPROVEMENT OF MODELS TO PREDICT "DIAMETER-OVER-STUBS"

R.L. Knowles and H. McElwee

Report No. 61 **March 1999**

ABSTRACT

Please note that this report is a compilation of three separate papers that address the validation and improvement of models to predict "diameter over stubs".

PART 1: Development of a new function to predict 'diameter over stubs' (1999 DOS function).

Data was obtained from 143 pruned stands in 41 forests across New Zealand and was compared with predicted values for "diameter over stubs" (DOS) and maximum branch diameter on the DOS whorl obtained using existing national models. It was found that the existing (1987) functions tended to slightly overestimate DOS and maximum branch diameter on the DOS whorl for first lift pruning, but provided relatively unbiased estimates for second, third and fourth lift pruning.

Using this data set, new (1994) functions to predict DOS and maximum branch diameter on the DOS whorl were estimated using the same functional forms as the 1987 models. The new functions removed the prediction errors for first lift pruning in this data set, and provided relatively unbiased estimates of DOS and maximum branch diameter for all four pruning lifts. However the 1994 DOS prediction model predicted decreasing DOS with increasing maximum branch diameter at branch diameters greater than about 50 mm. Therefore a further (1999) DOS prediction function was estimated, using a linear mixed model and the same data set as the 1994 function. This model removed the prediction errors found in the 1987 model, but did not predict a decrease in DOS with increasing maximum branch diameter within the normal range of maximum branch diameter. The 1999 DOS prediction function also provided unbiased estimates for all four pruning lifts if predicted maximum branch data (from the 1994 maximum branch diameter function) is used rather than actual maximum branch data. The difference in DOS between regions was found to be quite small, with less than 1 cm difference between the region with the smallest DOS (East Coast) and the region with the largest DOS (Waikato).

PART 2: Validation of DOS prediction functions for Wenita Forest Products Ltd's Otago forests.

Measured DOS data from pruned stands in Otago Coast, Berwick and Mount Allan forests was compared with predicted DOS calculated using the 1987 and 1999 DOS prediction models for radiata pine. Measurements of maximum branch diameter on the DOS whorl from the same data set were compared with predicted values from the 1987 and 1994 maximum branch diameter

models. The 1987 DOS model appeared to produce better DOS predictions than the 1999 model for Otago Coast, Berwick and Mount Allan Forests. The 1987 function provided good estimates for all pruning lifts in Otago Coast and Berwick Forests and at DOS heights less than 4 m in Mount Allan Forest, but tended to over-predict DOS in Mount Allan Forest by about 0.9 cm at DOS heights greater than 4 m (third and fourth lift pruning). The prediction error for third and fourth lift pruning in Mount Allan Forest was only reduced slightly (0.1 - 0.2 cm) by using the 1999 model instead of the 1987 model. In general, the 1994 maximum branch diameter model gave better predictions than the 1987 model for all three forests. The 1987 model tended to over-predict maximum branch diameter, whereas the predictions from the 1994 model were relatively unbiased. When DOS was calculated using predicted maximum branch diameter (using the 1987 DOS model and the 1994 max branch model) the errors were small (less than 0.5 cm) for all DOS height classes in Otago Coast and Berwick Forests. In Mount Allan Forest, the errors were small for DOS heights less than 4 m, but the model again over-predicted DOS by about 0.8 cm at DOS heights greater than 4 m (third or fourth lift pruning).

PART 3: Validation of DOS prediction functions for Rayonier New Zealand Ltd's forests.
Predicted DOS from the 1987 and 1999 DOS prediction models and predicted maximum branch diameter from the 1987 and 1994 maximum branch prediction models were compared with measured data from 45 pruned stands in nine forests managed by Rayonier New Zealand Limited. When actual maximum branch diameter data was used, the 1987 DOS prediction model provided better estimates of DOS than the 1999 model for the first pruning lift, but the 1999 model provided slightly better estimates for subsequent pruning lifts. The 1987 and 1994 maximum branch models both consistently overestimated maximum branch diameter on the DOS whorl, although the errors were smaller for the 1994 function for all pruning lifts and regions. Therefore, if predicted rather than actual maximum branch data is used, it is recommended that the 1994 model be used to estimate maximum branch diameter. When predicted maximum branch diameter data was used (calculated from the 1994 maximum branch model), the 1999 DOS prediction model tended to provide better estimates of DOS than the 1987 model. The bias in the predictions from the 1999 DOS model and the 1994 maximum branch models worked in opposite directions for this data set and tended to cancel each other out. However, there is no reason to assume that this would necessarily be the case for other sets and where possible actual branch data should be used in preference to predicted maximum branch diameter, to prevent the possibility of compounding errors.

TABLE OF CONTENTS

PART 1. DEVELOPMENT OF ALTERNATIVE FUNCTIONS FOR PREDICTING "DIAMETER OVER STUBS" AND MAXIMUM BRANCH DIAMETER ON THE DOS WHORL FOR RADIATA PINE

1.1 Summary

Data was obtained from 143 pruned stands in 41 forests across New Zealand and was compared with predicted values for "diameter over stubs" (DOS) and maximum branch diameter on the DOS whorl obtained using existing national models. It was found that the existing (1987) functions tended to slightly overestimate DOS and maximum branch diameter on the DOS whorl for first lift pruning, but provided relatively unbiased estimates for second, third and fourth lift pruning.

Using this data set, new (1994) functions to predict DOS and maximum branch diameter on the DOS whorl were estimated using the same functional forms as the 1987 models. The new functions removed the prediction errors for first lift pruning in this data set, and provided relatively unbiased estimates of DOS and maximum branch diameter for all four pruning lifts. However the 1994 DOS prediction model predicted decreasing DOS with increasing maximum branch diameter at branch diameters greater than about 50 mm. Therefore a further (1999) DOS prediction function was estimated, using a linear mixed model and the same data set as the 1994 function. This model removed the prediction errors found in the 1987 model, but did not predict a decrease in DOS with increasing maximum branch diameter within the normal range of maximum branch diameter. The 1999 DOS prediction function also provided unbiased estimates for all four pruning lifts if predicted maximum branch data (from the 1994 maximum branch diameter function) is used rather than actual maximum branch data. The difference in DOS between regions was found to be quite small, with less than 1 cm difference between the region with the smallest DOS (East Coast) and the region with the largest DOS (Waikato).

1.2 Introduction

A single diameter over stubs (DOS) prediction function was developed to estimate DOS in pruned radiata pine stands across New Zealand (Knowles *et al.*, 1987). This function was developed for all sites and validated with data from all regions in New Zealand, across a wide range of silvicultural regimes. Mean plot values for each variable were used to estimate the model.

The model estimates DOS using DADOS, maximum branch diameter on the DOS whorl and DOS height:

$$DOS = b_o + b_1\ DADOS + b_2\ MAXBR + b_3\ MAXBR^2 + b_4\ DOS\ Ht + b_5\ DOS\ Ht^2$$

where:

bo = 1.1731
b1 = 0.935
b2 = 0.1351
b3 = -0.0007031

b4 = -0.2513
b5 = 0.0451

and:

DADOS = DBH (TREE Ht - DOS Ht)/(TREE Ht - 1.4)

Subsequent validation work (West, 1994) indicated that the 1987 DOS function was under-predicting DOS by 1.0 - 1.5 cm for first lift pruning on some low site index sites; in particular, southern Kaingaroa and Otago Coast. In contrast however, data from 41 forests managed by Tasman Forestry Limited appears to indicate that the 1987 DOS function consistently *over-*predicts DOS by up to about 1.0 cm for first lift pruning.

DOS may be estimated using either actual measurements of maximum branch diameter on the DOS whorl or predicted maximum branch diameter, as estimated by the following function:

MAXBR = 0.9358*X1 + 9.537*X2

where:

X1 = (TREE HT - DOS HT)*(DBH/(TREE HT - 1.4))^2
X2 = (DOS HT)$^{0.5}$

DOS prediction errors are likely to be greater if predicted maximum branch diameter data is used rather than actual maximum branch diameter, as errors in branch diameter prediction may be carried through to give DOS prediction errors.

The objective of this exercise is to document the development of new models to predict DOS and maximum branch diameter, which were estimated in 1994 using data from 41 forests managed at that time by Tasman Forestry Limited. It is also intended to develop a third (1999) DOS prediction function, as the 1994 model in its current form predicts that DOS will *decrease* as maximum branch diameter increases for maximum branch diameters greater than 50 mm.

1.3 Method

The Tasman data set consisted of measured DOS data from 143 pruned stands in 41 forests across New Zealand (Table 1). First, second, third and fourth lift pruning were represented in the data set (Table 2). All measurements were recorded from 1990-1992, from forests that were owned at that time by Tasman Forestry Limited. The number of trees measured from each stand ranged from 9-100, with a mean of 36 trees per stand. Mean values for each stand were used for the estimation of the 1994 DOS prediction function and the 1994 maximum branch diameter prediction function. The full data set is listed in Appendix 1.

Table 1. Forests included in data set for estimation of 1994 DOS prediction and maximum branch diameter prediction functions

Forest	Number of stands measured
Findlays	2
Gammons	1
Golden Downs	7
Huanui	8
Kainui	1
Kaitangata	1
Korere	1
Lilburns	2
Manawahe	3
Mangaorewa/Kaharoa T/C	1
Matahina	2
Mt Allan	5
Ngamanawa	1
Ngaruru	2
Nobleburn	3
Omanawa	2
Opepe Trust	1
Pahautea	1
Pinnacles	1
Rai	4
Rainy	3
Rerewhakaitu	4
Rotoiti	5
Serpentine	1
SF 28	1
Sun Valley	5
Tahorakuri	7
Takeke	1
Tarawera	3
Tauhara	12
Te Marunga	9
Te Matai	4
Tuararangaia	4
Tuhoe	2
Waimanu	6
Wainui	1
Waipapa 2A	1
Wairau	5
Waitahanui	1
Wakaroa	17
Wharetoto	2
Total	**143**

Table 2. Number of stands included in data set by pruning lift

Lift number	Number of stands
1st lift	39
2nd lift	45
3rd lift	41
4th lift	18
Total	**143**

1.4. Results

1.4.1. Prediction errors from 1987 DOS and maximum branch diameter functions

Predicted values of DOS and maximum branch diameter on the DOS whorl were calculated using the 1987 functions, and compared with the actual DOS and maximum branch diameter data. DOS prediction errors were plotted against predicted DOS for first, second, third and fourth pruning lifts (Figures 1-4), and maximum branch prediction errors were plotted against predicted maximum branch diameter (Figures 5-8). Mean prediction errors by pruning lift for DOS and maximum branch diameter on the DOS whorl are displayed in Table 3.

These results indicate that, on average, the 1987 DOS prediction function tends to overestimate DOS for the first pruning lift by nearly 1 cm, but provides reasonable predictions for second, third and fourth pruning lifts. The 1987 maximum branch diameter prediction function over-predicts maximum branch diameter for the first pruning lift by an average of nearly 7mm. Maximum branch diameter is also over-predicted for second, third and fourth pruning lifts, although the mean error is small in each case.

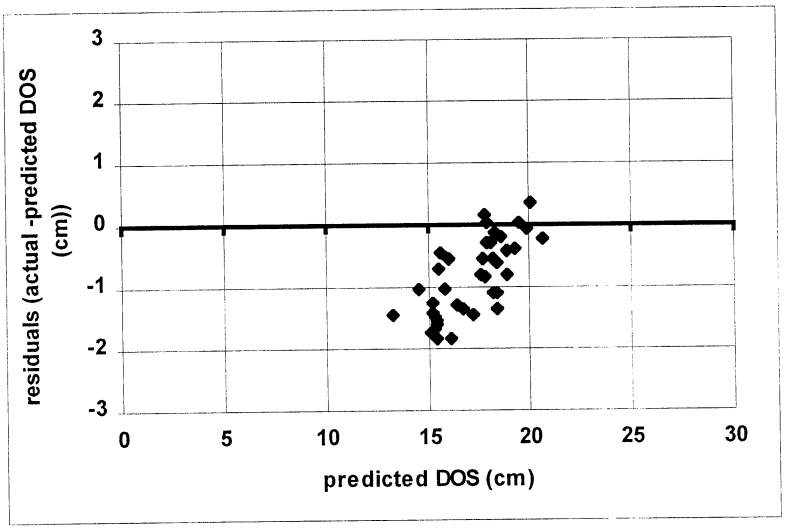

Figure 1. Residuals versus predicted DOS for first lift pruning (using 1987 DOS prediction function, and actual max branch diameter)

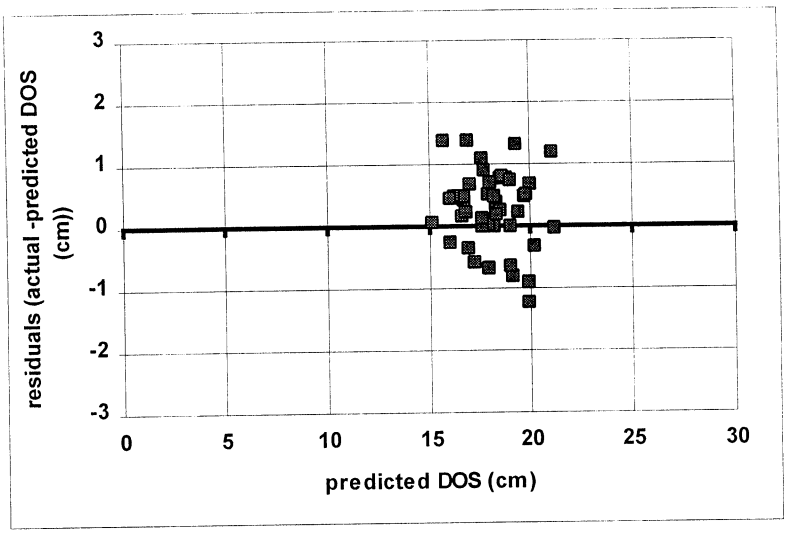

Figure 2. Residuals versus predicted DOS for second lift pruning (using 1987 DOS prediction function, and actual max branch diameter)

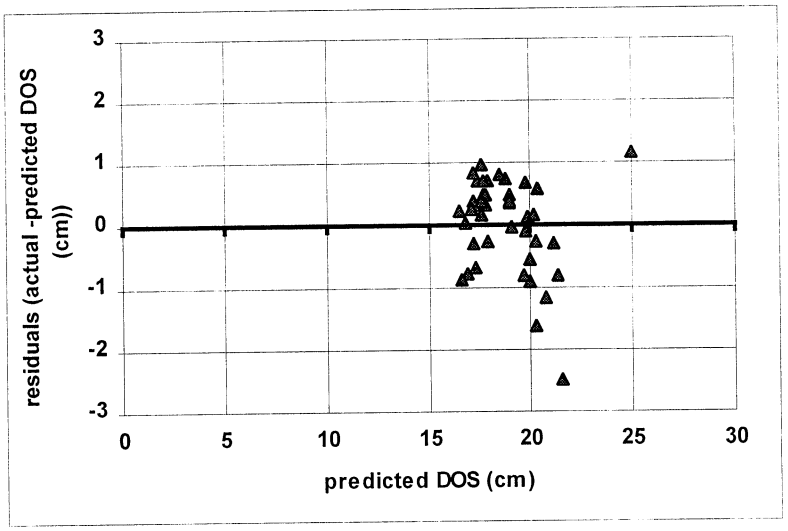

Figure 3. Residuals versus predicted DOS for third lift pruning (using 1987 DOS prediction function, and actual max branch diameter)

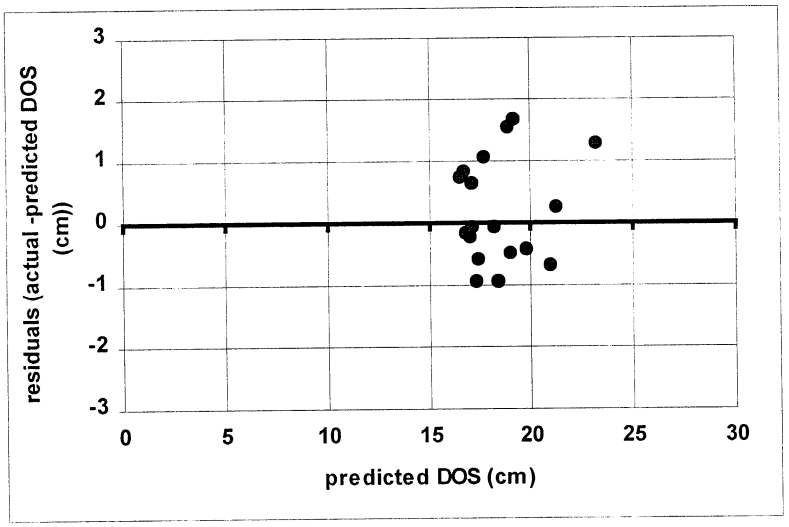

Figure 4. Residuals versus predicted DOS for fourth lift pruning (using 1987 DOS prediction function, and actual max branch diameter)

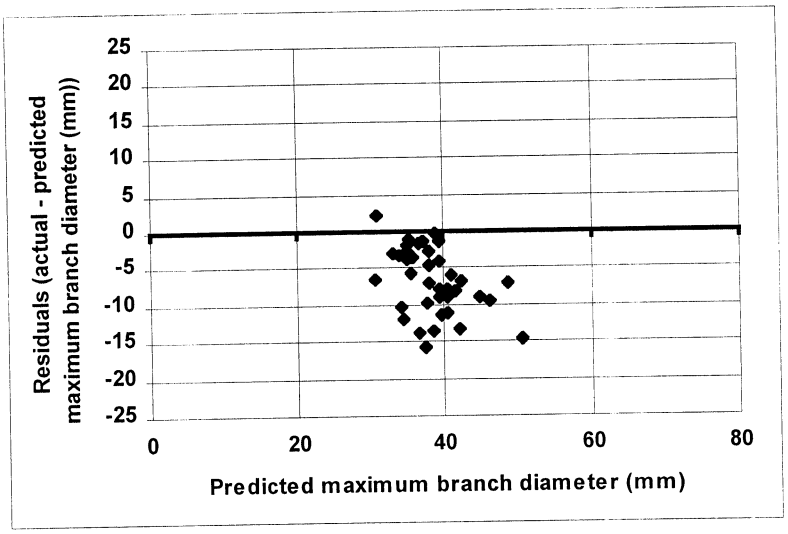

Figure 5. Residuals versus predicted maximum branch diameter for first lift pruning (using 1987 maximum branch prediction function)

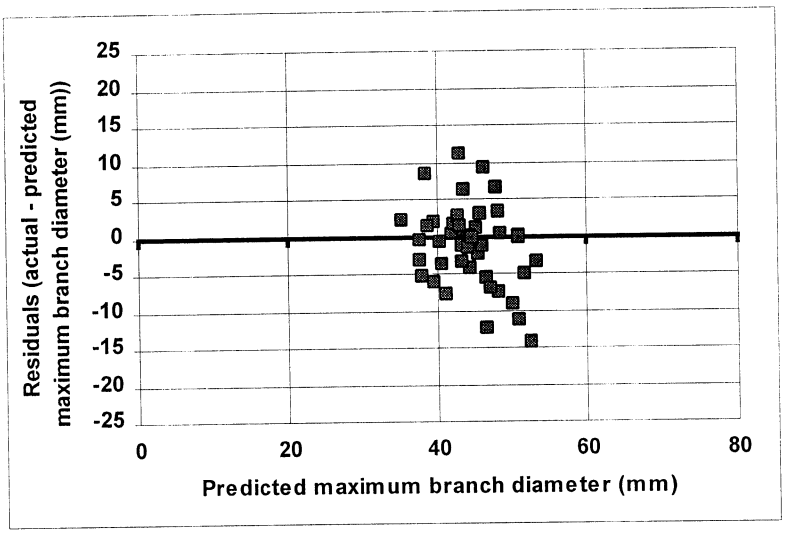

Figure 6. Residuals versus predicted maximum branch diameter for second lift pruning (using 1987 maximum branch prediction function)

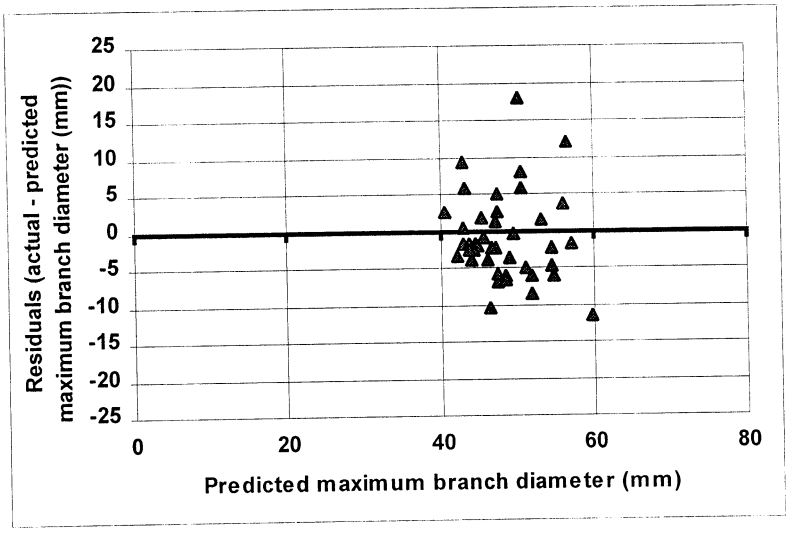

Figure 7. Residuals versus predicted maximum branch diameter for third lift pruning (using 1987 maximum branch prediction function)

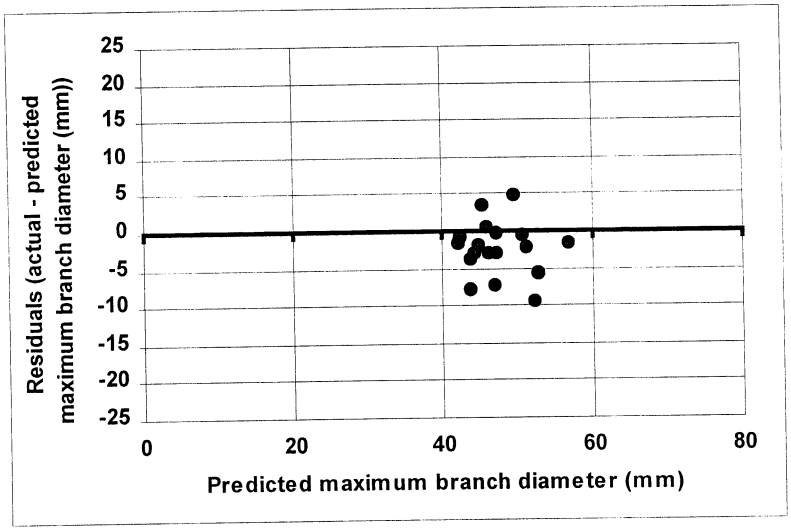

Figure 8. Residuals versus predicted maximum branch diameter for fourth lift pruning (using 1987 maximum branch prediction function)

Table 3. Mean DOS and maximum branch prediction errors by pruning lift (using 1987 DOS and maximum branch prediction functions)

Lift number	Mean DOS prediction error (cm)	Mean maximum branch prediction error (mm)
1st lift	-0.86	-6.7
2nd lift	0.28	-1.0
3rd lift	0.01	-0.9
4th lift	0.19	-2.4
All lifts	**-0.12**	**-2.7**

1.4.2. Estimation of 1994 DOS and maximum branch diameter prediction functions

The Tasman data set was used to re-estimate the DOS prediction function using the same functional form that was used for the 1987 function:

$$DOS = b_0 + b_1\ DADOS + b_2\ MAXBR + b_3\ MAXBR^2 + b_4\ DOS\ Ht + b_5\ DOS\ Ht^2$$

where:

bo = -4.0649
b1 = 1.0797
b2 = 0.2386
b3 = -0.002381
b4 = 0.9256
b5 = -0.09679

The R^2 for this model was 0.92

The Tasman data set was also used to re-estimate the maximum branch prediction function:

MAXBR = 0.7011*X1 + 12.122*X2

where:

X1 = (TREE HT - DOS HT)*(DBH/(TREE HT - 1.4))^2

X2 = (DOS HT)$^{0.5}$

The R^2 for the model was 0.63.

Plots of the DOS prediction errors against predicted DOS (Figures 11-14), and maximum branch prediction errors against predicted maximum branch diameter (Figures 15-18) indicate that the new functions provide relatively unbiased estimates for all four pruning lifts. Mean prediction errors by pruning lift for DOS and maximum branch diameter on the DOS whorl are displayed in Table 4.

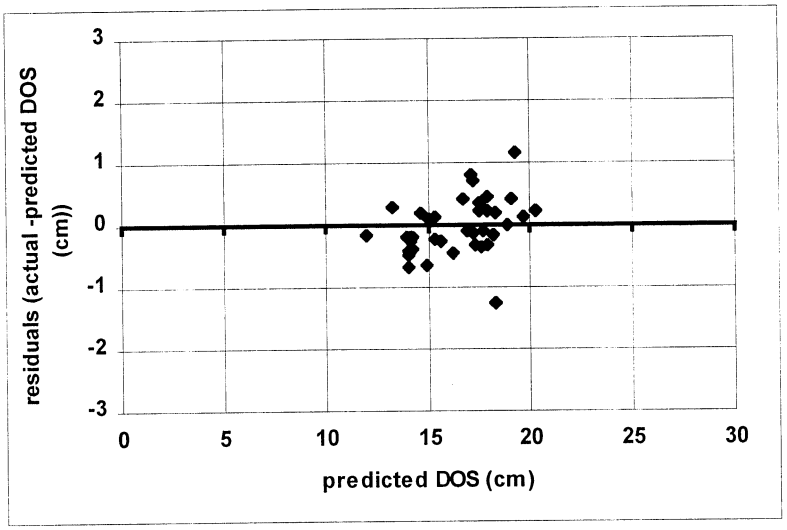

Figure 9. Residuals versus predicted DOS for first lift pruning (using 1994 DOS prediction function, and actual max branch diameter)

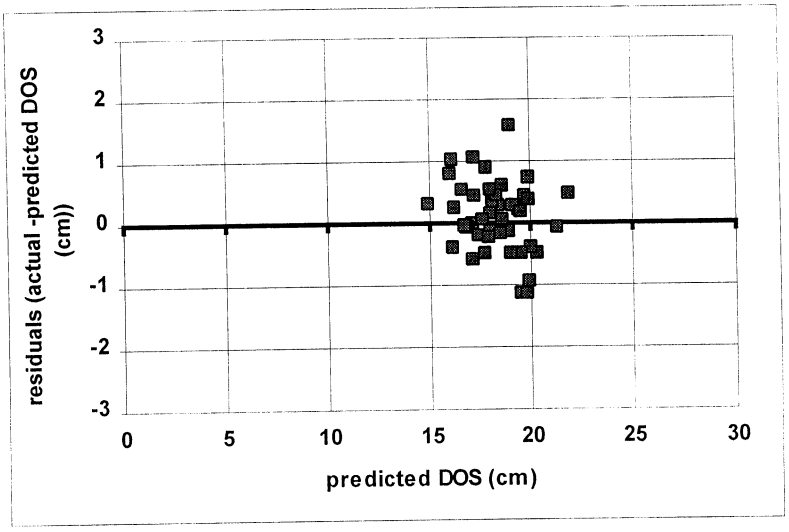

Figure 10. Residuals versus predicted DOS for second lift pruning (using 1994 DOS prediction function, and actual max branch diameter)

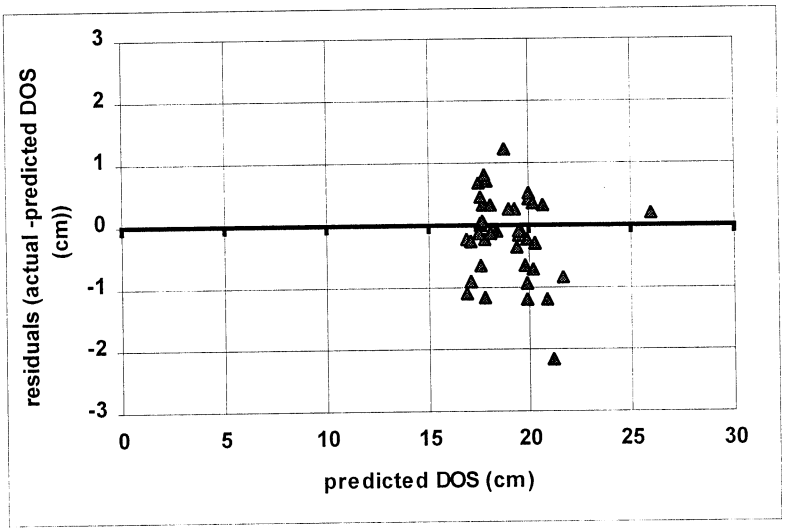

Figure 11. Residuals versus predicted DOS for third lift pruning (using 1994 DOS prediction function, and actual max branch diameter)

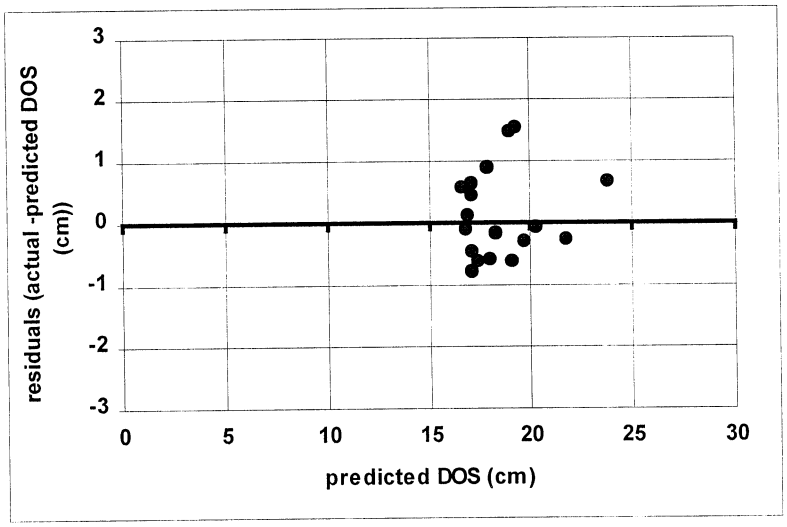

Figure 12. Residuals versus predicted DOS for fourth lift pruning (using 1994 DOS prediction function, and actual max branch diameter)

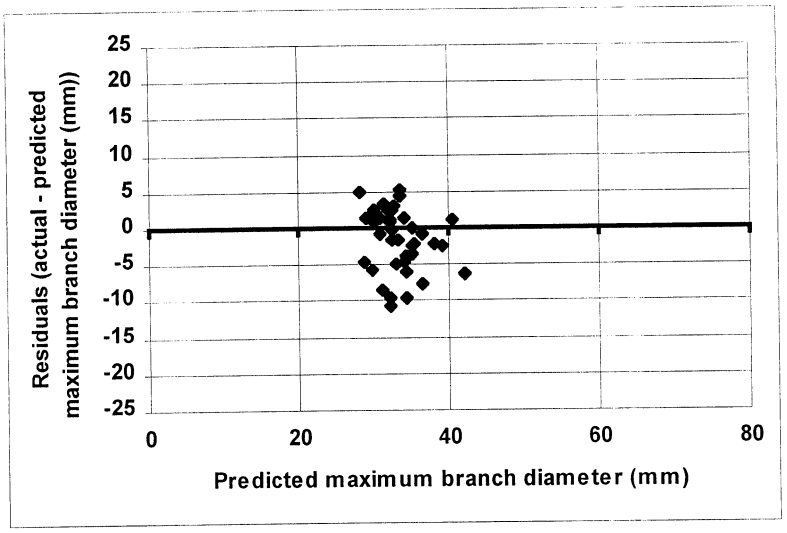

Figure 13. Residuals versus predicted maximum branch diameter for first lift pruning (using 1994 maximum branch prediction function)

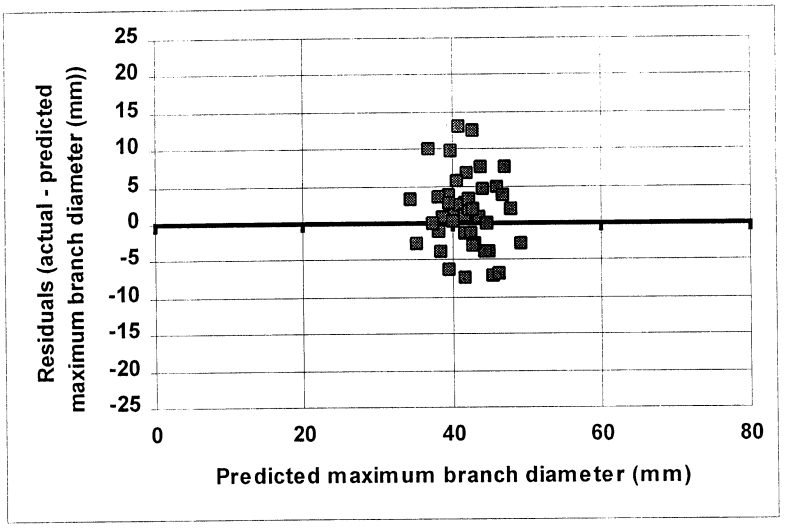

Figure 14. Residuals versus predicted maximum branch diameter for second lift pruning (using 1994 maximum branch prediction function)

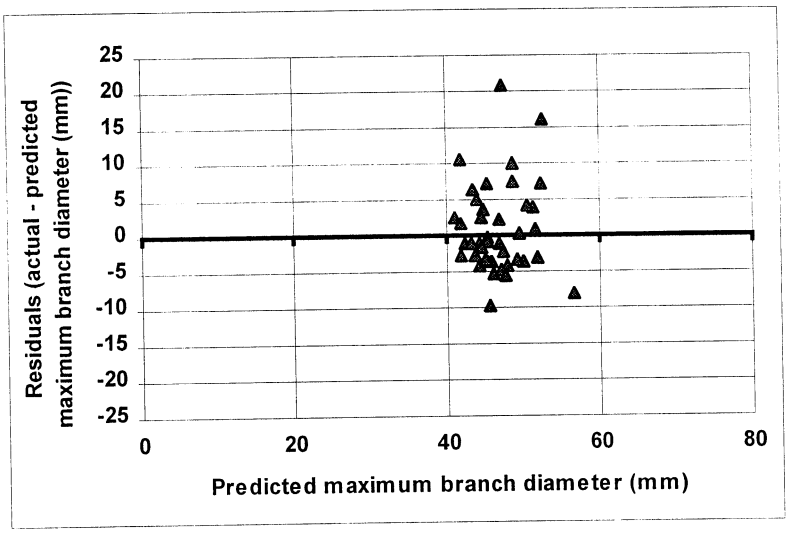

Figure 15. Residuals versus predicted maximum branch diameter for fourth lift pruning (using 1994 maximum branch prediction function)

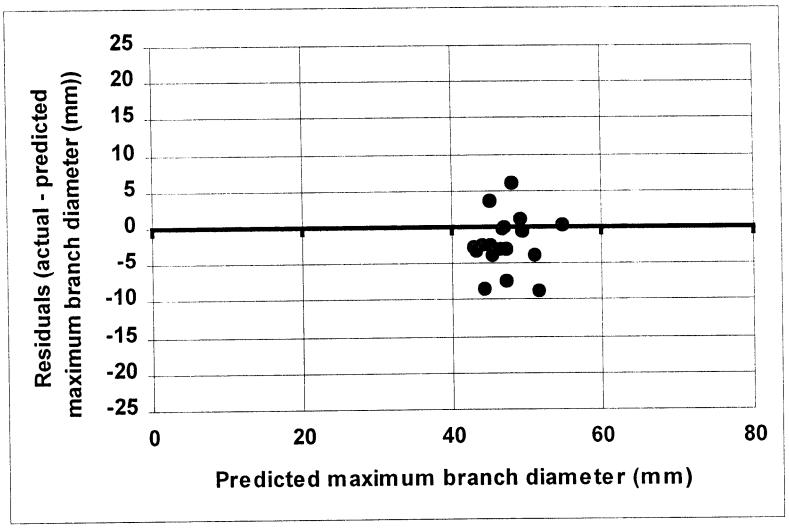

Figure 16. Residuals versus predicted maximum branch diameter for fourth lift pruning (using 1994 maximum branch prediction function)

Table 4. Mean DOS and maximum branch prediction errors by pruning lift (using 1994 DOS and maximum branch prediction functions)

Lift number	Mean DOS prediction error using actual max branch (cm)	Mean maximum branch prediction error (mm)
1st lift	-0.04	-1.6
2nd lift	0.11	1.5
3rd lift	-0.17	0.8
4th lift	0.14	-2.2
All lifts	**0.00**	**0.0**

1.4.3. Estimation of 1999 DOS prediction function

It was found that despite the good fit of the 1994 DOS prediction function, the model predicts that DOS will *decrease* as maximum branch diameter increases for maximum branch diameters greater than 50 mm (Figure 17). This appears to be illogical, as larger branches on the DOS whorl should lead to increased nodal swelling, and hence greater DOS. Note that DOS height, DBH and tree height were held constant at 0.8 m, 12 cm and 6.5 m respectively in Figure 17.

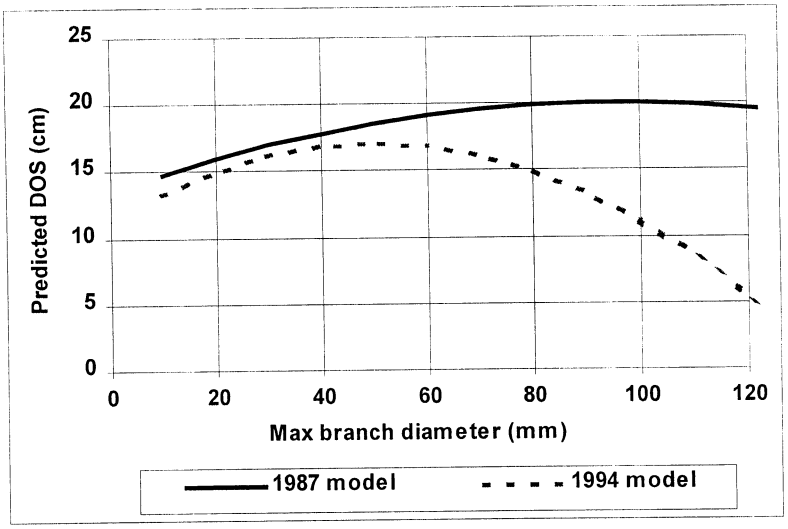

Figure 17. Predicted DOS versus maximum branch diameter for 1987 DOS prediction model and 1994 DOS prediction model

Because of the effect of maximum branch diameter on predicted DOS in the 1994 model, the DOS prediction model was re-estimated using a linear mixed model of the same functional form used for the 1987 and 1994 models:

$$DOS = b_0 + b_1\ DADOS + b_2\ MAXBR + b_3\ MAXBR^2 + b_4\ DOS\ Ht + b_5\ DOS\ Ht^2$$

where:

bo = 0.6787
b1 = 0.8597
b2 = 0.1439
b3 = -0.0007354
b4 = 0.4777
b5 = -0.03793

The mixed model uses individual tree data rather than plot mean data, with separate intercept parameters calculated for each plot. The intercept parameter for the model as a whole is a weighted average of the individual plot parameters, based on the sample size for each plot.

Predicted DOS versus maximum branch diameter using the 1999 model is illustrated in Figure 18, indicating that predicted DOS increases with increasing maximum branch diameter across the entire range of values likely to be encountered (mean maximum branch diameter on the DOS whorl is rarely greater than 60 mm for any stand).

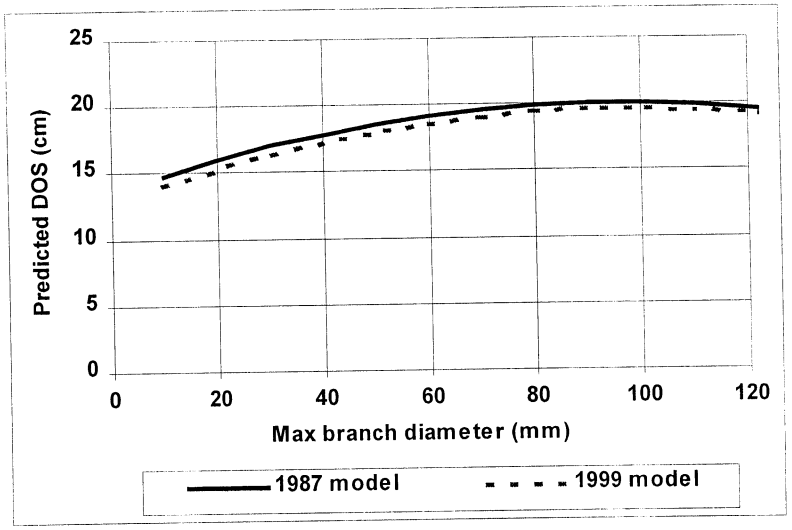

Figure 18. Predicted DOS versus maximum branch diameter for 1987 DOS prediction model and 1999 DOS prediction model

Plots of the DOS prediction errors against predicted DOS for the 1999 model are displayed in Figures 19-22, indicating that the function provides relatively unbiased estimates for all four pruning lifts. Table 5 shows that the mean DOS prediction error using plot mean data to estimate DOS is smaller than 4 mm for all four pruning lifts, regardless of whether actual or predicted maximum branch diameter data is used. Note that the mean residual for "all lifts" is not exactly equal to zero as individual tree data was used to estimate the model, while plot mean data was used to generate the values of predicted DOS in Table 5.

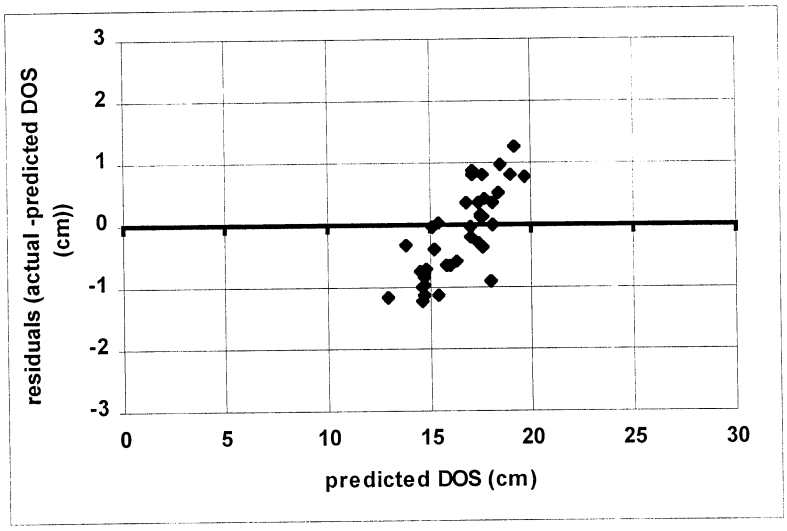

Figure 19. Residuals versus predicted DOS for first lift pruning (using 1999 DOS prediction function, and actual max branch diameter)

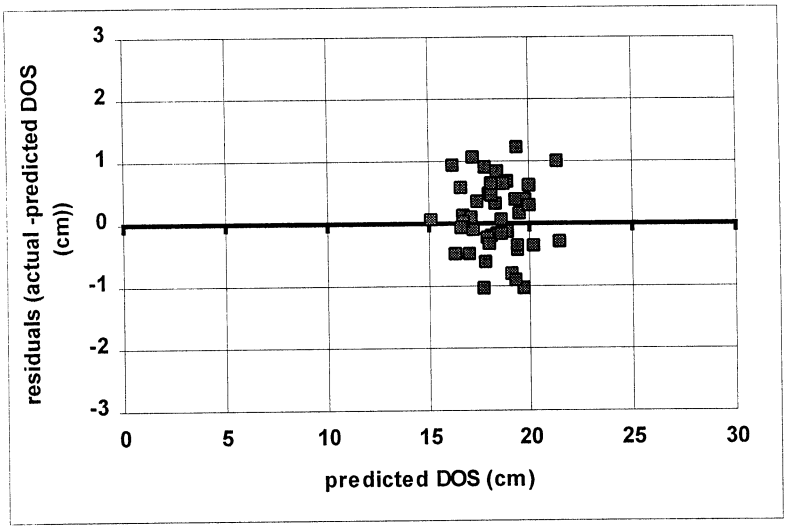

Figure 20. Residuals versus predicted DOS for second lift pruning (using 1999 DOS prediction function, and actual max branch diameter)

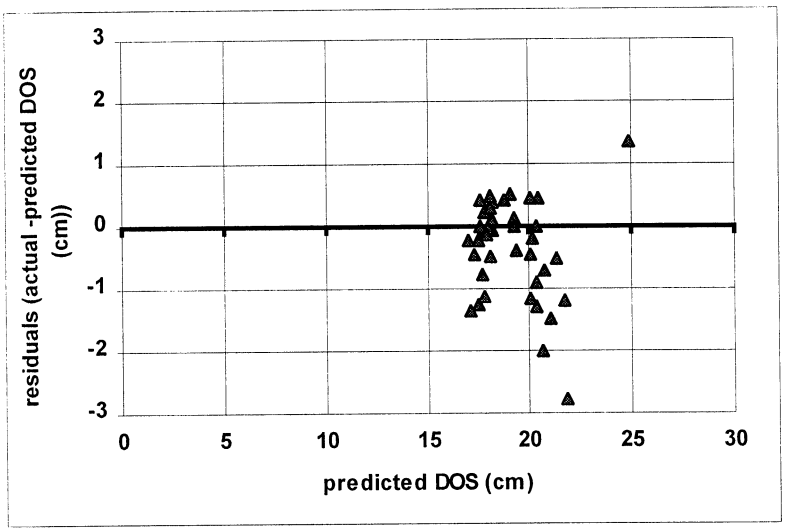

Figure 21. Residuals versus predicted DOS for third lift pruning (using 1999 DOS prediction function, and actual max branch diameter)

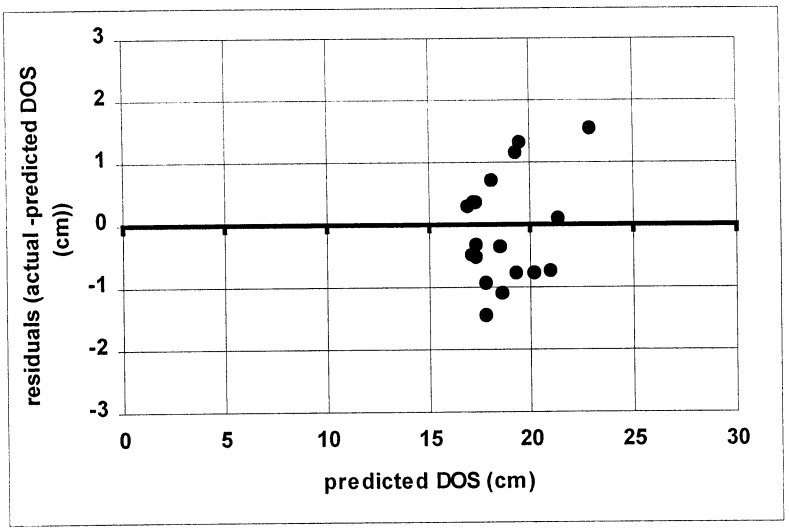

Figure 22. Residuals versus predicted DOS for fourth lift pruning (using 1999 DOS prediction function, and actual max branch diameter)

Table 5. Mean DOS prediction errors by pruning lift (using 1999 DOS prediction function)

Lift number	Mean DOS prediction error using actual max branch (cm)	Mean DOS prediction error using predicted max branch (cm)
1st lift	-0.16	-0.32
2nd lift	0.09	0.19
3rd lift	-0.34	-0.31
4th lift	-0.08	-0.27
All lifts	**-0.12**	**-0.15**

1.4.4. Regional differences in DOS

In order to test whether there were any regional differences in DOS, the forests in the data set were divided into 5 general regions; Waikato, Bay of Plenty, Taupo, East Coast, and the South Island (Table 6).

Table 6. Aggregation of individual forests into regions

Region	Forest
Waikato	Gammons Mangaorewa/Kaharoa T/C Ngamanawa Omanawa Pinnacles SF 28 Sun Valley Takeke Te Matai Waipapa 2A
Bay of Plenty	Manawahe Matahina Rerewhakaitu Rotoiti Tarawera Tuararangaia Tuhoe
Taupo	Lilburns Opepe Trust Pahautea Tahorakuri Tauhara Wainui Waitahanui Wharetoto

Table 6. (continued) Aggregation of individual forests into regions

Region	Forest
East Coast	Findlays Huanui Te Marunga Waimanu Wakaroa
South Island	Golden Downs Kainui Kaitangata Korere Mt Allan Ngaruru Nobleburn Rai Rainy Serpentine Wairau

The mean of the intercept values for all plots in each region was calculated, effectively giving an estimate of a separate intercept for each region. Table 7 illustrates the difference between the intercept for each region and the intercept for the National 1999 model.

Table 7. Variation in mean intercept values by region for 1999 DOS prediction model

Region	Deviation of regional intercept from national intercept (cm)
Waikato	+ 0.57 cm
Bay of Plenty	- 0.26 cm
Taupo	+ 0.36 cm
East Coast	- 0.27 cm
South Island	- 0.04 cm
All regions	**+ 0.00 cm**

These results indicate that the difference in mean DOS between the region with the smallest DOS (East Coast) and the region with the largest DOS (Waikato) is only about 0.8 cm. It appears that there may be differences in DOS between some of the regions represented in the data set, but the magnitude of these differences is small.

1.5. Recommendations and conclusions

In general, it is recommended that the 1999 DOS prediction model be used to predict DOS for the 41 forests used in this data set, especially for first lift pruning. However in cases where the mean DOS prediction error for the forest is greater than 1.0 cm using the 1999 model, it is advisable to use the 1987 DOS prediction model if the mean error is smaller for the 1987 model than the 1999 model. As a guideline, Appendix 2 outlines the mean DOS prediction error for the 1987 and 1999 models by pruning lift and by forest. It should be noted however, that in many cases only a single plot was measured for a given pruning lift in a given forest and hence the mean errors in Appendix 2 should be interpreted with caution. The use of the 1994 DOS prediction model should generally be avoided, especially if the mean value of maximum branch diameter on the DOS whorl is greater than 50 mm.

It is also recommended that the 1994 maximum branch diameter prediction model be used in preference to the 1987 model for these 41 forests, again particularly for first lift pruning. As a guide, Appendix 3 outlines the mean maximum branch diameter prediction errors for the 1987 and 1994 models by pruning lift and by forest. It should be noted that where possible, measured data for maximum branch diameter should be used to avoid the possibility of maximum branch diameter prediction errors being carried through to give DOS prediction errors.

PART 2. EVALUATION OF ALTERNATIVE FUNCTIONS FOR PREDICTING "DIAMETER OVER STUBS" AND MAXIMUM BRANCH DIAMETER ON THE DOS WHORL FOR RADIATA PINE IN OTAGO COAST, BERWICK AND MOUNT ALLAN FORESTS

2.1. Summary

Measured DOS data from pruned stands in Otago Coast, Berwick and Mount Allan forests was compared with predicted DOS calculated using the 1987 and 1999 DOS prediction models for radiata pine. Measurements of maximum branch diameter on the DOS whorl from the same data set were compared with predicted values from the 1987 and 1994 maximum branch diameter models. The 1987 DOS model appeared to produce better DOS predictions than the 1999 model for Otago Coast, Berwick and Mount Allan Forests. The 1987 function provided good estimates for all pruning lifts in Otago Coast and Berwick Forests and at DOS heights less than 4 m in Mount Allan Forest, but tended to over-predict DOS in Mount Allan Forest by about 0.9 cm at DOS heights greater than 4 m (third and fourth lift pruning). The prediction error for third and fourth lift pruning in Mount Allan Forest was only reduced slightly (0.1 - 0.2 cm) by using the 1999 model instead of the 1987 model. In general, the 1994 maximum branch diameter model gave better predictions than the 1987 model for all three forests. The 1987 model tended to over-predict maximum branch diameter, whereas the predictions from the 1994 model were relatively unbiased. When DOS was calculated using predicted maximum branch diameter (using the 1987 DOS model and the 1994 max branch model) the errors were small (less than 0.5 cm) for all DOS height classes in Otago Coast and Berwick Forests. In Mount Allan Forest, the errors were small for DOS heights less than 4 m, but the model again over-predicted DOS by about 0.8 cm at DOS heights greater than 4 m (third or fourth lift pruning).

2.2. Introduction

In Part 1 of this report a new DOS prediction model (1999 model) was developed as an alternative to the 1987 DOS prediction model. A new model to predict maximum branch diameter on the DOS whorl (1994 model) was also developed, as an alternative to the 1987 maximum branch prediction model. The objective of Part 2 of the report is to compare measured DOS data from pruned stands in Otago Coast, Berwick and Mount Allan forests with predicted DOS using the 1987 and 1999 models. It is also intended to compare actual measurements of maximum branch diameter on the DOS whorl with predicted values from the 1987 and 1994 maximum branch diameter models.

2.3. Data set

The validation data set was comprised of 1527 trees from Otago Coast Forest, 2029 trees from Mount Allan Forest and 1110 trees from Berwick Forest. Some 12 trees were omitted from the analysis (one from Otago Coast, four from Berwick and seven from Mount Allan) due to missing DOS height measurements or obvious errors in the recorded data.

The data set included first, second and third lift pruning (DOS height ranged from 0.10 m to 6.80 m). Tree height ranged from 2.8 m to 18.6 m and DBH ranged from 3.9 cm to 33.7 cm.

2.4. Results

2.4.1. Validation of DOS models

The measured data from recently pruned stands in Otago Coast, Berwick and Mount Allan forests was compared with predicted DOS using the 1987 and 1999 DOS prediction functions. The mean DOS prediction errors were small for both models in all three forests (Table 8)

Table 8. Mean prediction errors (measured as actual DOS - predicted DOS) using 1987 and 1999 DOS prediction models

	Otago Coast	Berwick	Mount Allan
1987 DOS model	-0.11cm	0.03cm	-0.28cm
1999 DOS model	0.02cm	0.20cm	-0.05cm

In order to test for any correlation between prediction errors and DOS height, mean errors for each 0.5 m DOS height class were calculated using both models for all three forests (Figures 23-28).

The 1987 model appears to accurately predict DOS for all DOS height classes in Otago Coast and Berwick forests, whereas the 1999 model under-predicts DOS by about 0.5-1.1 cm for DOS height classes less than 1.5m. That is, the 1987 model provides good predictions for all pruning lifts, while the 1999 model under-predicts DOS for first lift pruning.

The results for Mount Allan forest indicate that the 1987 model over-predicts DOS by an average of about 0.9 cm when DOS height is greater than 4 m (ie., third or fourth lift pruning) but only has small errors (<0.5 cm) when DOS height is less than 4 m. The 1999 model under-predicts DOS by about 1 cm for DOS height classes less than 1.5m (ie. first lift pruning) and over-predicts DOS by an average of about 0.7 cm when DOS height is greater than 4 m. Thus prediction error for third and fourth lift pruning in Mount Allan Forest is only reduced slightly (0.1 - 0.2 cm) by using the 1999 model instead of the 1987 model.

In general therefore, it appears that the 1987 DOS prediction function provides better estimates than the 1999 function for Otago Coast, Berwick and Mount Allan Forests, particularly for first lift pruning.

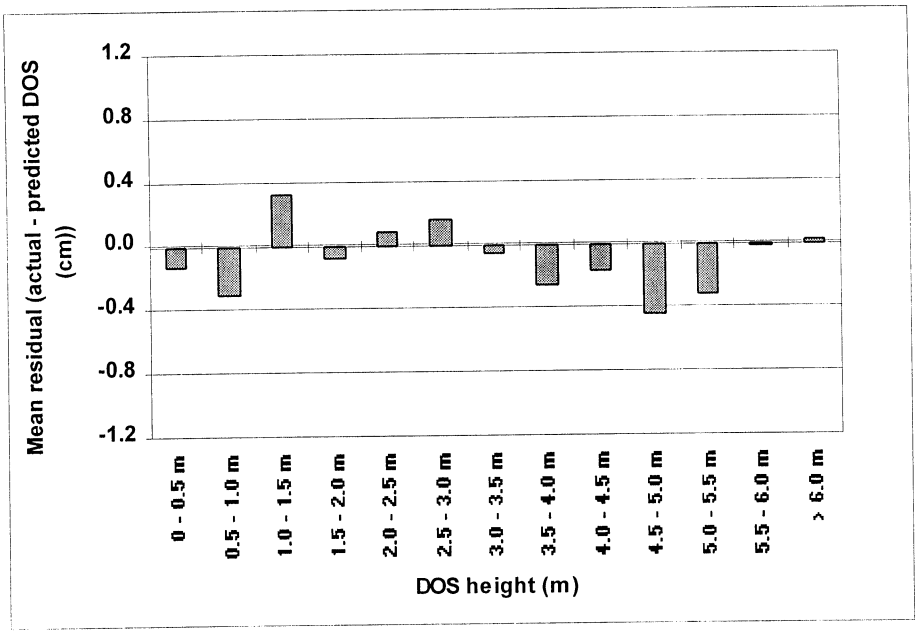

Figure 23. Mean DOS prediction errors by DOS height class for Otago Coast Forest (using 1987 DOS prediction model)

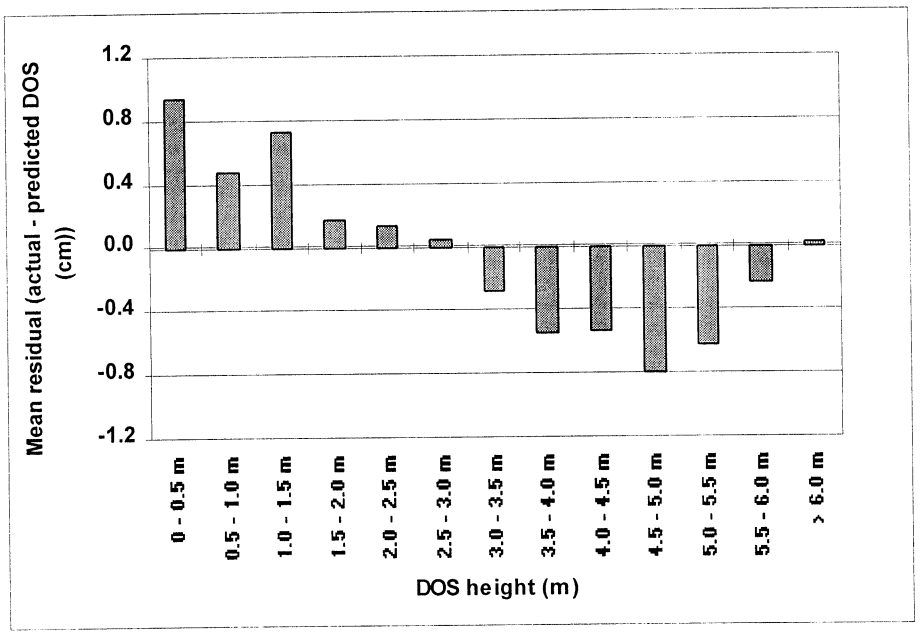

Figure 24. Mean DOS prediction errors by DOS height class for Otago Coast Forest (using 1999 DOS prediction model)

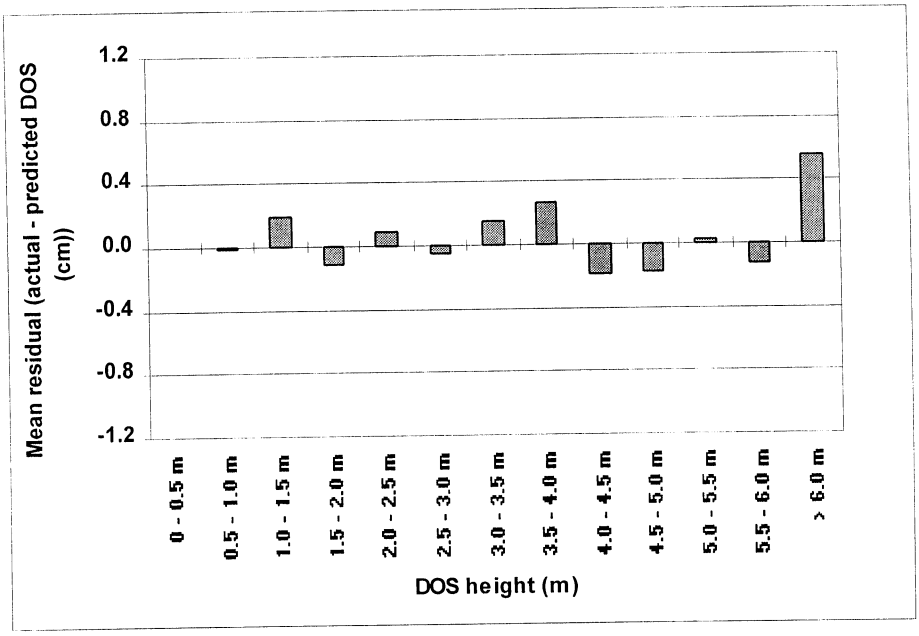

Figure 25. Mean DOS prediction errors by DOS height class for Berwick Forest (using 1987 DOS prediction model)

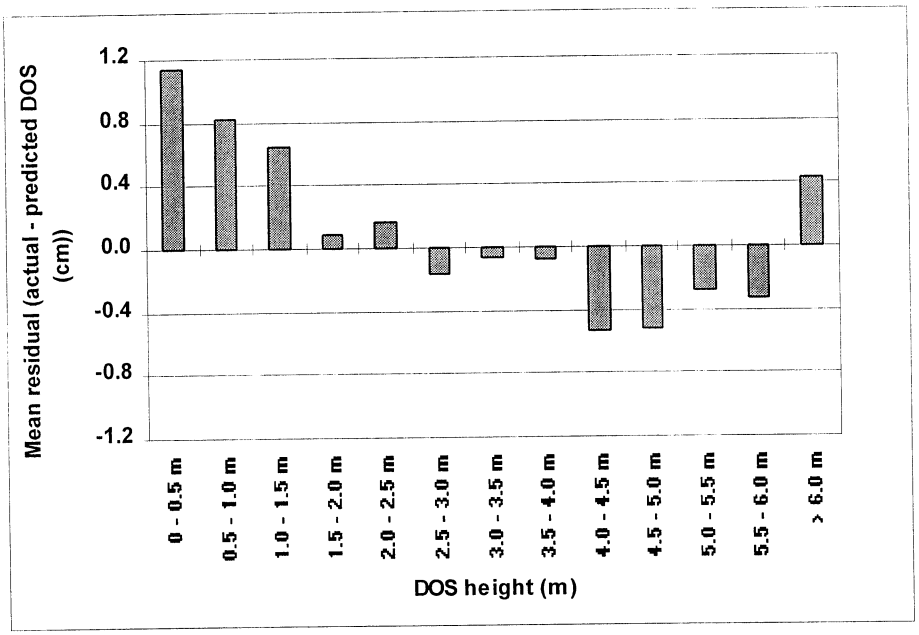

Figure 26. Mean DOS prediction errors by DOS height class for Berwick Forest (using 1999 DOS prediction model)

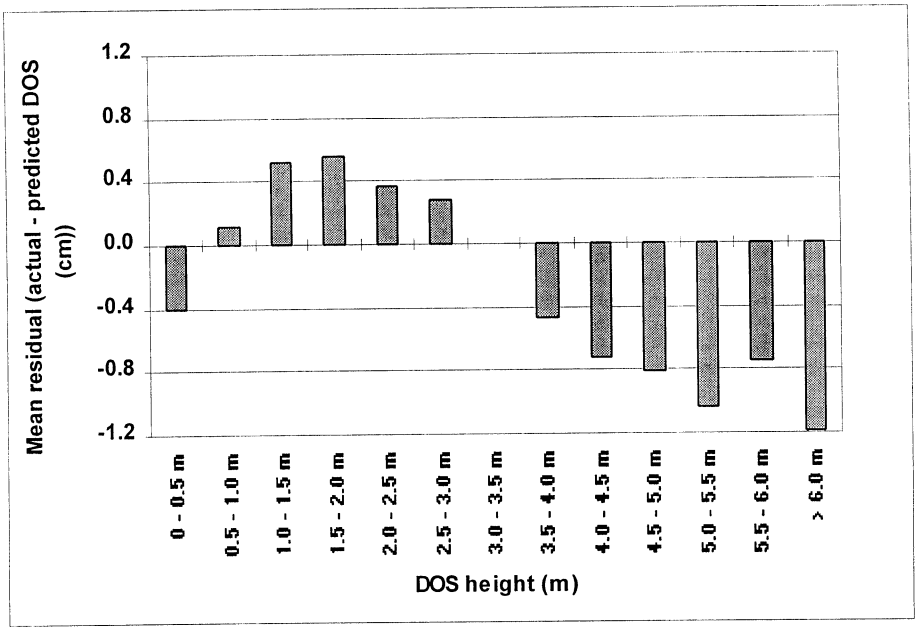

Figure 27. Mean DOS prediction errors by DOS height class for Mount Allan Forest (using 1987 DOS prediction model)

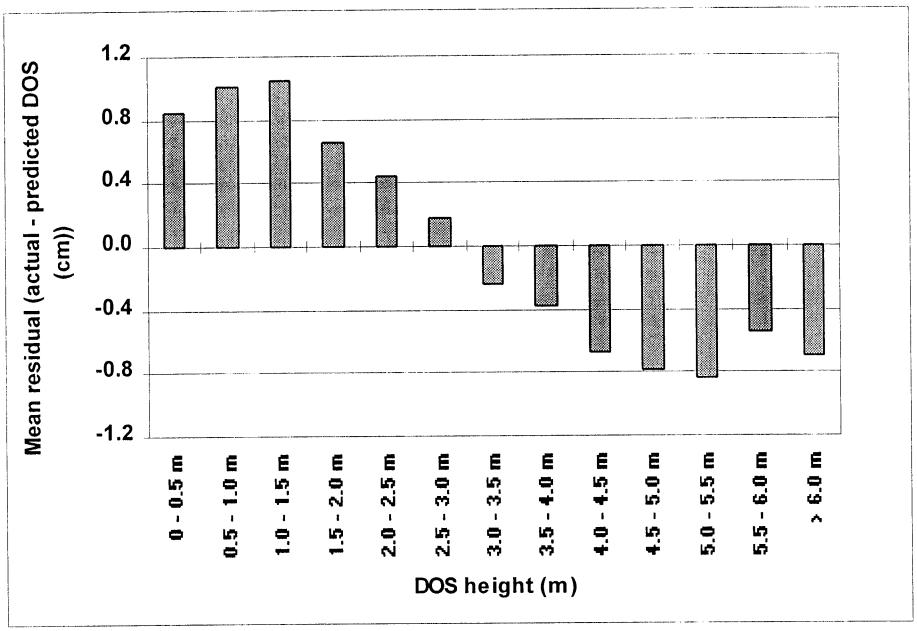

Figure 28. Mean DOS prediction errors by DOS height class for Mount Allan Forest (using 1999 DOS prediction model)

Mean DOS prediction errors were also calculated for a range of DADOS classes and maximum branch diameter classes. No correlation was found between DOS prediction error and DADOS in any of the three forests. In Otago Coast and Berwick Forests, no correlation was found between DOS prediction error and maximum branch diameter, but in Mount Allan forest there was a tendency to over-predict DOS by about 1 cm when maximum branch diameter was less than 30 mm.

2.4.2 Validation of maximum branch diameter models

The measured data was also compared with predicted maximum branch diameter using the 1987 and 1994 max branch prediction models. The 1987 model tended to slightly over-predict maximum branch diameter, while the 1994 model, on average, provided good predictions of maximum branch diameter, particularly for Berwick and Mount Allan Forests (Table 9).

Table 9. Mean prediction errors (measured as actual max branch - predicted max branch) using 1987 and 1994 maximum branch diameter prediction models

	Otago Coast	Berwick	Mount Allan
1987 max branch model	-1.3mm	-3.7mm	-4.3mm
1994 max branch model	2.4mm	-0.5mm	-0.3mm

Mean errors for each 0.5 m DOS height class were also calculated, in order to test for any correlation between prediction errors and DOS height (Figures 29-34).

In Berwick and Mount Allan forests, the 1987 model appears to over-predict maximum branch diameter across a range of DOS heights, whereas the 1994 model generally over-predicts maximum branch diameter only at DOS heights greater than 5 m. In Otago Coast Forest, the 1987 model over-predicts maximum branch diameter for DOS heights less than 1 m, while the 1994 model under-predicts maximum branch diameter by about 3-6 mm at DOS heights from 1.5 - 4.5 m.

In general therefore, it appears that the 1994 DOS maximum branch diameter model provides better estimates than the 1987 function for these forests.

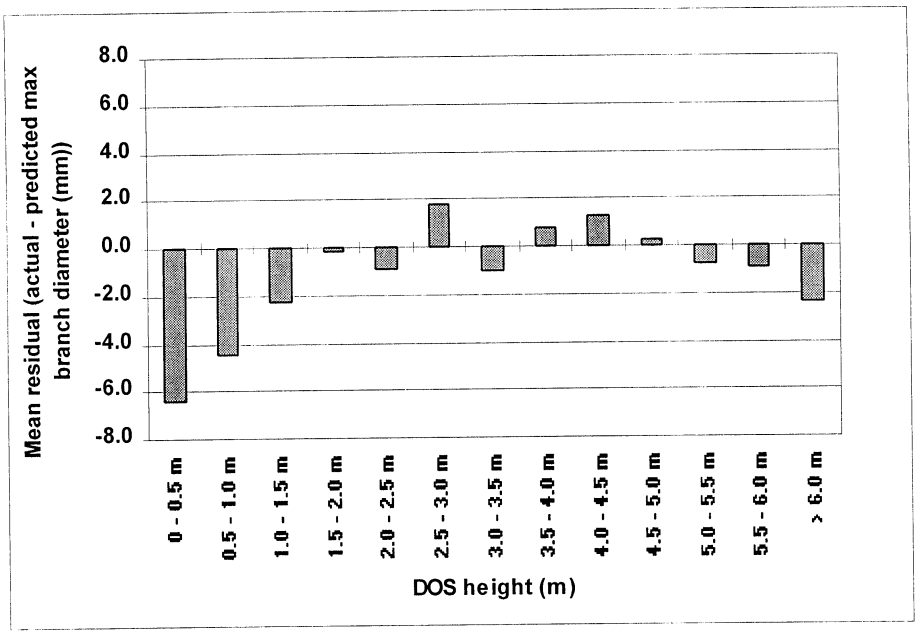

Figure 29. Mean maximum branch diameter prediction errors by DOS height class for Otago Coast Forest (using 1987 max branch prediction model)

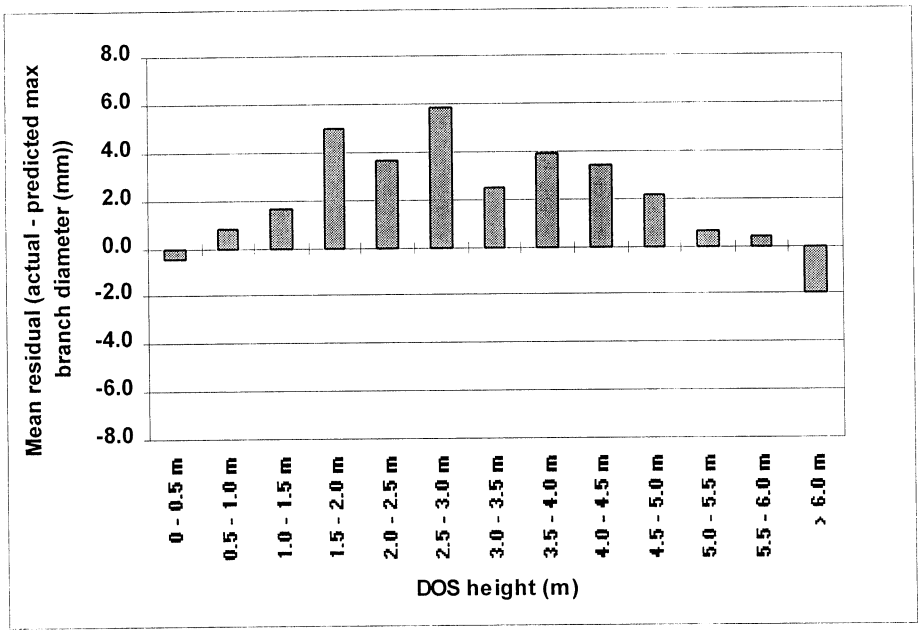

Figure 30. Mean maximum branch diameter prediction errors by DOS height class for Otago Coast Forest (using 1994 max branch prediction model)

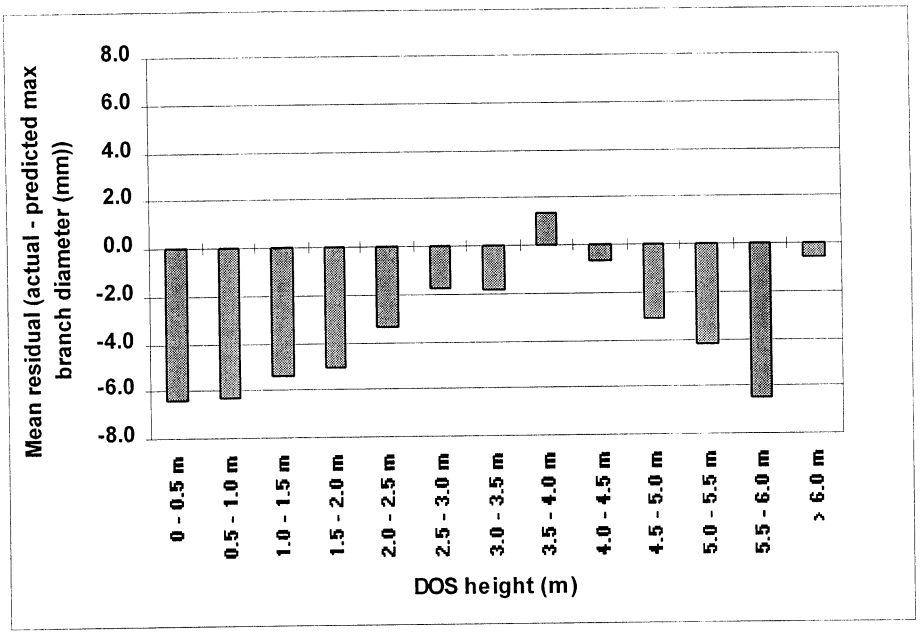

Figure 31. Mean maximum branch diameter prediction errors by DOS height class for Berwick Forest (using 1987 max branch prediction model)

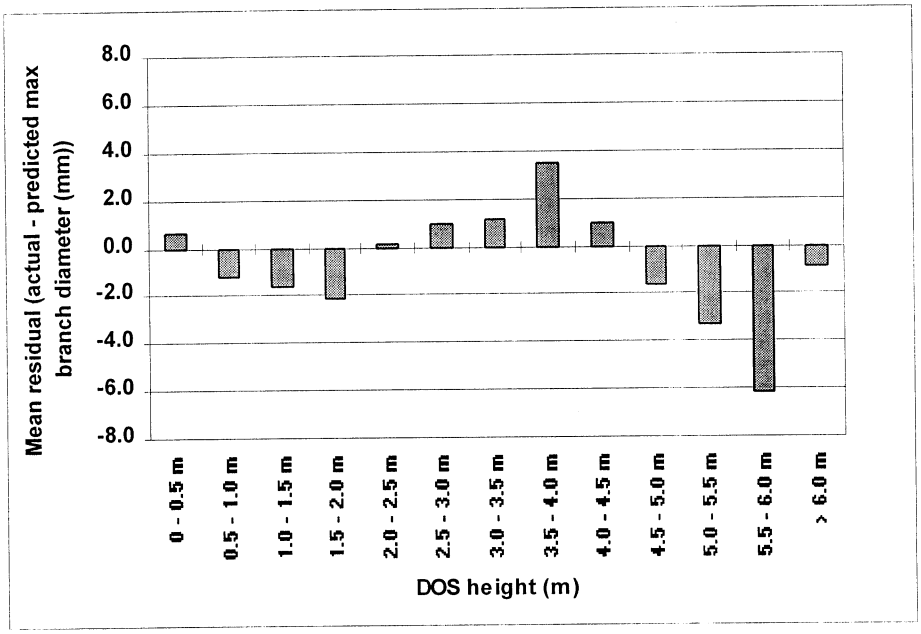

Figure 32. Mean maximum branch diameter prediction errors by DOS height class for Berwick Forest (using 1994 max branch prediction model)

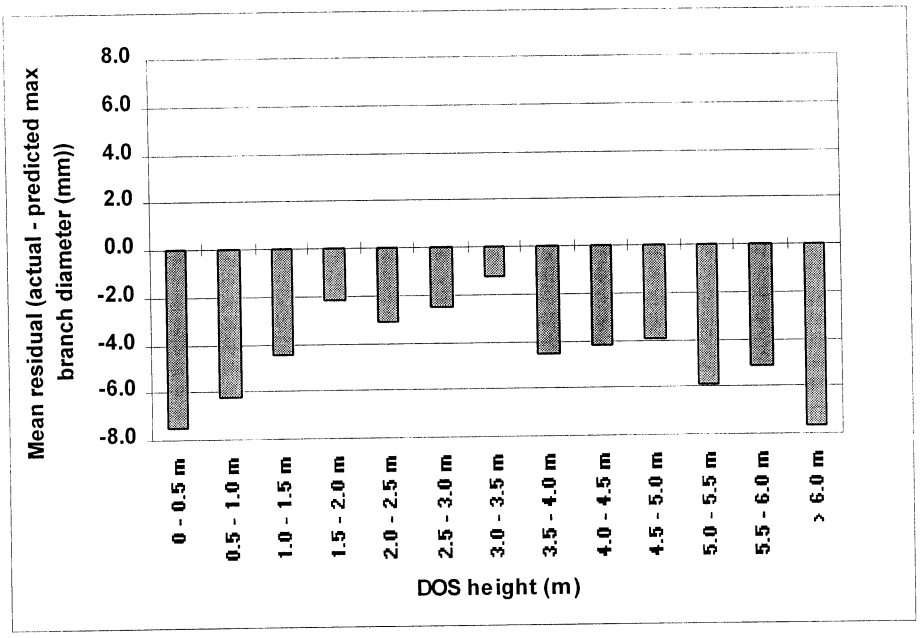

Figure 33. Mean maximum branch diameter prediction errors by DOS height class for Mount Allan Forest (using 1987 max branch prediction model)

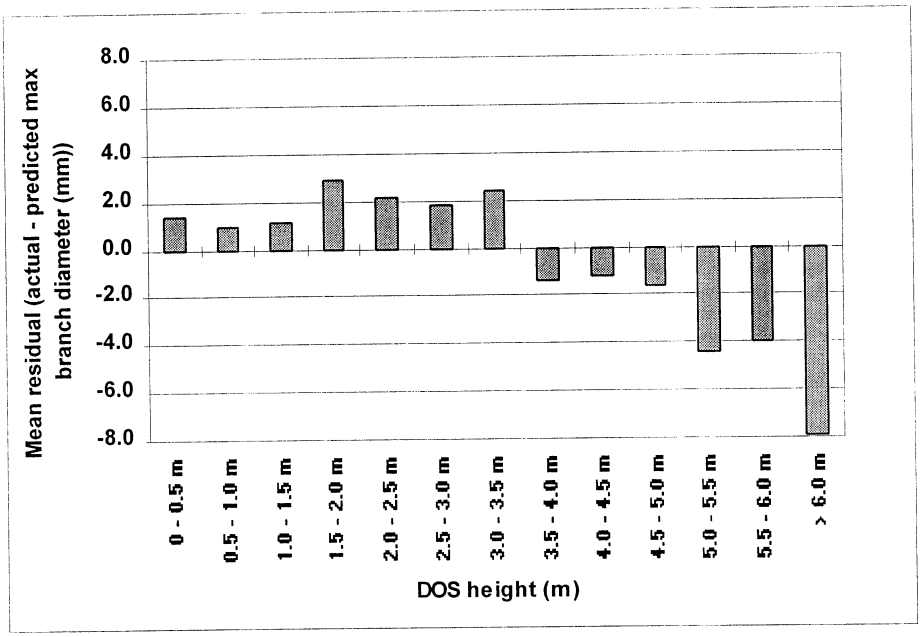

Figure 34. Mean maximum branch diameter prediction errors by DOS height class for Mount Allan Forest (using 1994 max branch prediction model)

2.4.3 Predicting DOS using predicted maximum branch diameter

Predicted DOS was also calculated using the 1987 DOS model and predicted maximum branch diameter data. The 1994 max branch model was used to provide the predicted maximum branch diameter data. This represents the best combination of DOS and max branch models based on the analysis above. The mean DOS prediction errors were again small for all three forests (Table 10)

Table 10. Mean prediction errors (measured as actual DOS - predicted DOS) using the 1987 DOS model, and using predicted max branch from the 1994 max branch model

	Otago Coast	Berwick	Mount Allan
Mean DOS prediction error	0.11cm	-0.09cm	-0.22cm

The DOS prediction errors for each DOS height class are also small (less than 0.5 cm) for Otago Coast and Berwick Forests (Figures 35 and 36). In Mount Allan Forest, the DOS prediction errors are small for DOS heights less than 4 m, but the model over-predicts DOS by an average of about 8 mm at DOS heights greater than 4 m (that is, third or fourth lift pruning) (Figure 37).

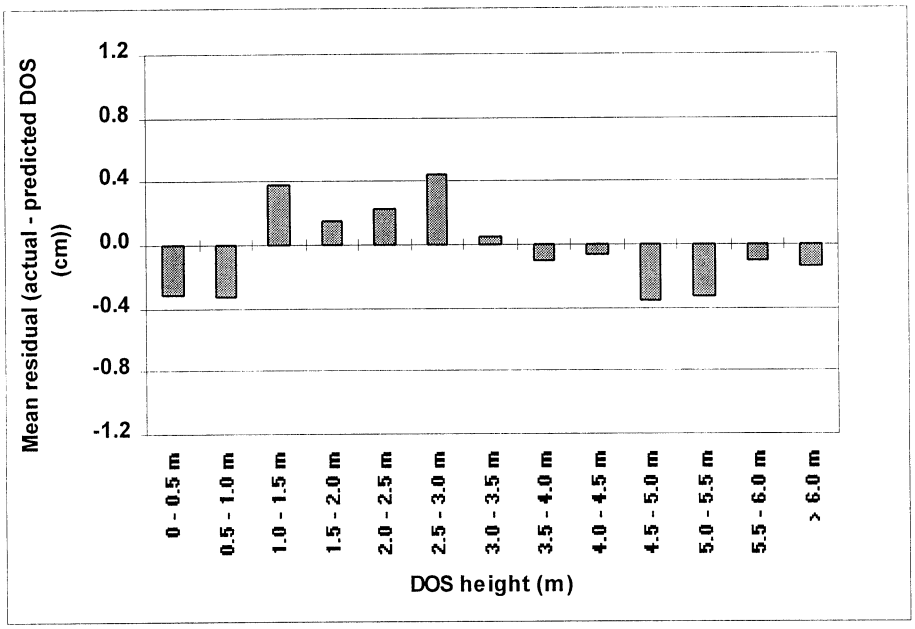

Figure 35. Mean DOS prediction errors by DOS height class for Otago Coast (using 1987 DOS model and 1994 max branch model)

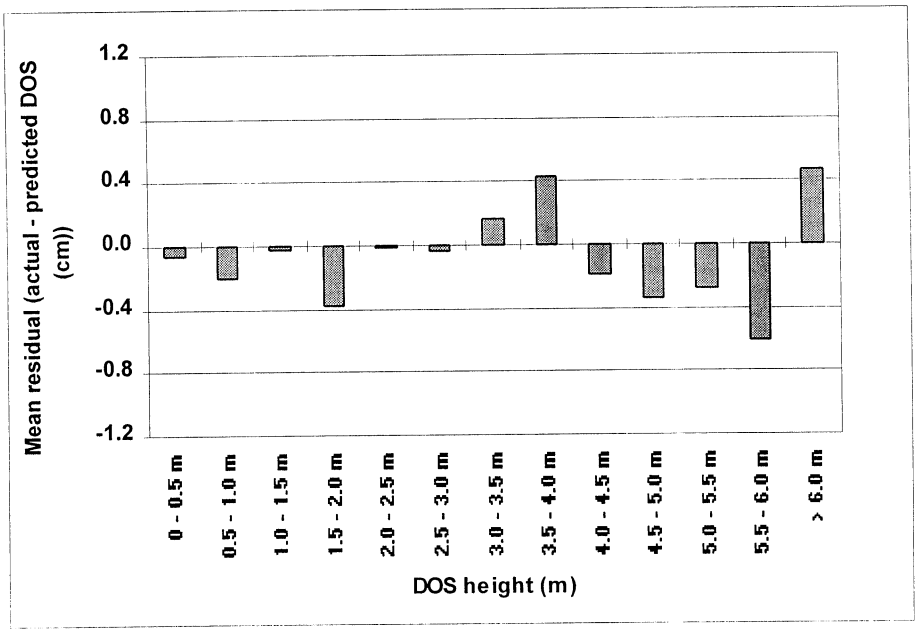

Figure 36. Mean DOS prediction errors by DOS height class for Berwick Forest (using 1987 DOS model and 1994 max branch model)

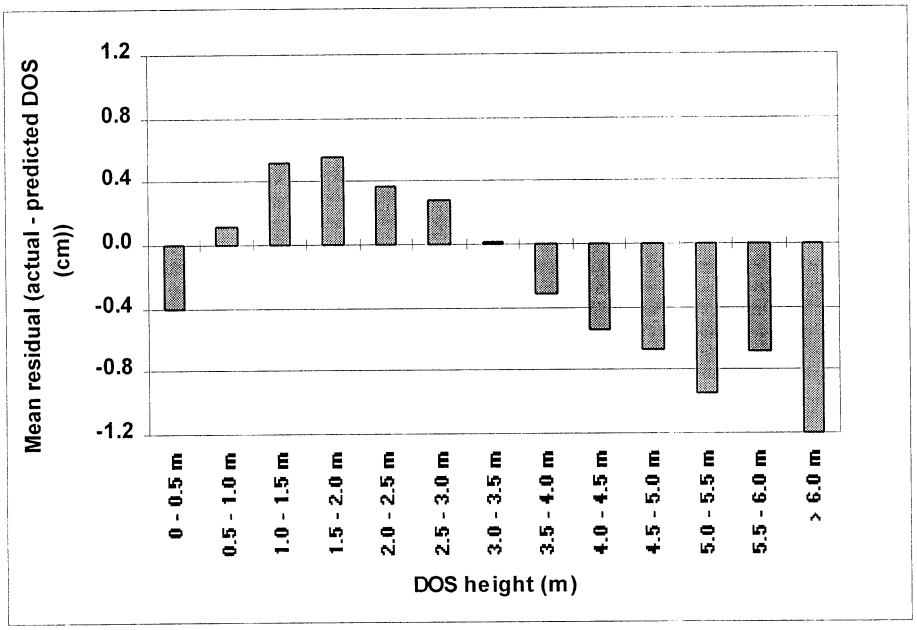

Figure 37. Mean DOS prediction errors by DOS height class for Mount Allan Forest (using 1987 DOS model and 1994 max branch model)

PART 3. EVALUATION OF ALTERNATIVE FUNCTIONS FOR PREDICTING "DIAMETER OVER STUBS" AND MAXIMUM BRANCH DIAMETER ON THE DOS WHORL FOR RADIATA PINE IN FORESTS MANAGED BY RAYONIER NZ LTD

3.1 Summary

Predicted DOS from the 1987 and 1999 DOS prediction models and predicted maximum branch diameter from the 1987 and 1994 maximum branch prediction models were compared with measured data from 45 pruned stands in nine forests managed by Rayonier New Zealand Limited. When actual maximum branch diameter data was used, the 1987 DOS prediction model provided better estimates of DOS than the 1999 model for the first pruning lift, but the 1999 model provided slightly better estimates for subsequent pruning lifts. The 1987 and 1994 maximum branch models both consistently overestimated maximum branch diameter on the DOS whorl, although the errors were smaller for the 1994 function for all pruning lifts and regions. Therefore, if predicted rather than actual maximum branch data is used, it is recommended that the 1994 model be used to estimate maximum branch diameter. When predicted maximum branch diameter data was used (calculated from the 1994 maximum branch model), the 1999 DOS prediction model tended to provide better estimates of DOS than the 1987 model. The bias in the predictions from the 1999 DOS model and the 1994 maximum branch models worked in opposite directions for this data set and tended to cancel each other out. However, there is no reason to assume that this would necessarily be the case for other sets and where possible actual branch data should be used in preference to predicted maximum branch diameter, to prevent the possibility of compounding errors.

3.2. Introduction

In Part 1 of this report a new DOS prediction model (1999 model) was developed as an alternative to the 1987 DOS prediction model. A new model to predict maximum branch diameter on the DOS whorl (1994 model) was also developed, as an alternative to the 1987 maximum branch prediction model. In Part 2, measured data from pruned stands in Otago Coast, Berwick and Mount Allan forests was used to compare the two sets of predictive models for both DOS and maximum branch diameter. The objective of Part 3 is to compare measured data from 45 pruned stands in nine forests managed by Rayonier New Zealand Limited with predicted DOS obtained from the 1987 and 1999 DOS models, and with predicted maximum branch diameter from the 1987 and 1994 maximum branch models.

3.3. Data set

The data set was comprised of measured data from 45 pruned stands in nine forests managed by Rayonier New Zealand Limited (Table 11). Six forests are in the Southern North Island, and the remaining three are in the Waikato/King Country.

Table 11. Number of stands in data set by Forest and Region

Region	Forest	Number of stands measured
Southern North Island	Kohitere	2
	Lismore	14
	Manakau	1
	Tawarau	5
	Te Wera	8
	Waitarere	3
Waikato/ King Country	Pirongia	1
	Pureora	5
	Waituhi	6
	Total	**45**

The data set included first, second and third lift pruning measurements, although most stands were measured at the time of first or third lift pruning (Table 12).

Table 12. Number of stands in data set by pruning lift and Region

	Pruning lift	Number of stands measured
Southern North Island	1st lift	12
	2nd lift	3
	3rd lift	18
Waikato/ King Country	1st lift	8
	3rd lift	4
	Total	**45**

Mean values for each stand were compared with predicted DOS obtained from the 1987 and 1999 functions, and with predicted maximum branch diameter obtained from the 1987 and 1994 functions.

The full data set is listed in Appendix 4.

3.4. Results

3.4.1 Validation of DOS models

The mean prediction errors for the 1987 and 1999 DOS prediction functions were calculated by region and pruning lift (Table 13). It appears that the mean DOS prediction error is smaller for the 1987 model than the 1999 model for the first pruning lift, but the mean error is smaller for the 1999 model for subsequent pruning lifts. The 1987 model provides reasonable DOS estimates for first lift pruning but under-predicts for second and third lift pruning, while the 1999 model under-predicts DOS by 0.5-1.0 cm for all three lifts. A full list of errors by forest and pruning lift is contained in Appendix 5.1.

Table 13. Mean prediction errors (actual - predicted DOS) by region and pruning lift for 1987 and 1999 DOS prediction models

Region	Pruning lift	Mean DOS prediction error using 1987 model (cm)	Mean DOS prediction error using 1999 model (cm)
Southern North Island	1st lift	0.25	0.79
	2nd lift	0.60	0.49
	3rd lift	0.79	0.56
Waikato/ King Country	1st lift	-0.14	0.64
	3rd lift	1.38	1.04
All regions/lifts		**0.52**	**0.67**

Figures 38 and 39 display the prediction errors for each function against DOS height, again indicating that the 1987 model slightly underestimates DOS for DOS heights above 2 metres (ie., second and third lift pruning), while the 1999 model underestimates DOS for all three lifts.

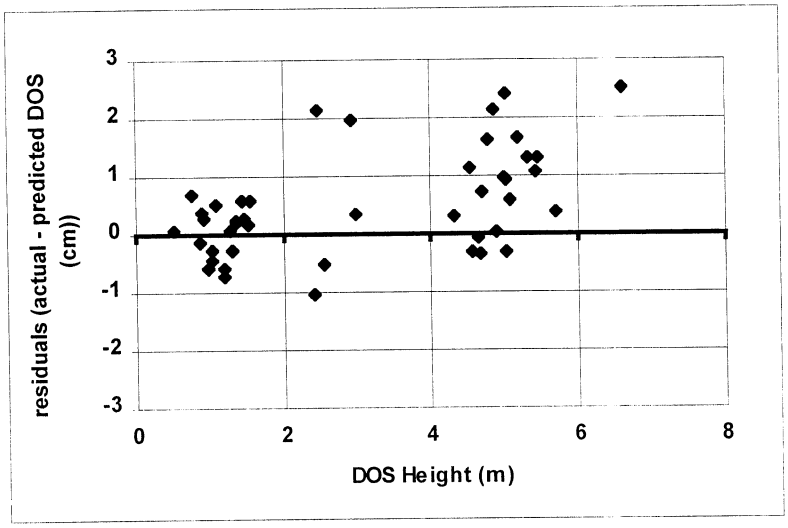

Figure 38. Errors from 1987 DOS prediction model versus DOS height

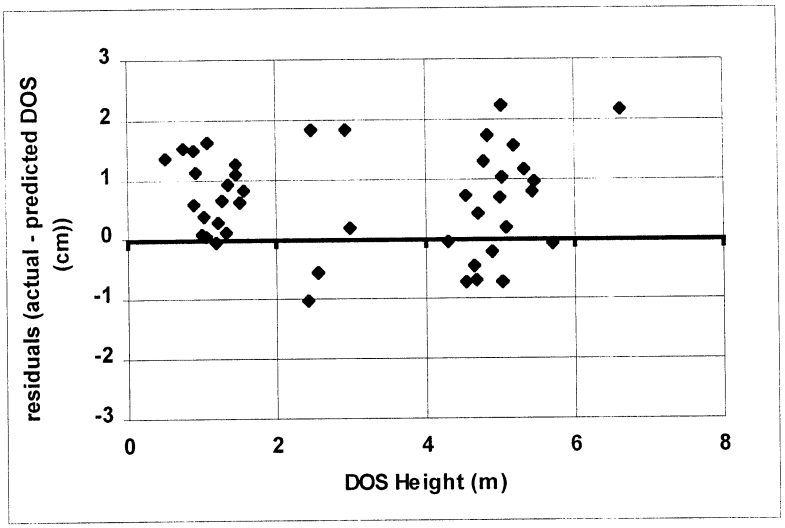

Figure 39. Errors from 1999 DOS prediction model versus DOS height

3.4.2 Validation of maximum branch diameter models

The mean errors from the functions for predicting maximum branch diameter on the DOS whorl were also calculated by region and pruning lift (Table 14). Maximum branch diameter on the DOS whorl is over-predicted by both functions, although the errors are smaller for the 1999 function than the 1987 function for all pruning lifts in all regions. The mean prediction error is similar for all three pruning lifts in the case of the 1994 function, while the error is larger for second and third lift pruning in the case of the 1987 function. A full list of errors by forest and pruning lift is contained in Appendix 5.2.

Table 14. Mean prediction errors (actual - predicted max branch diameter) by region and pruning lift for 1987 and 1994 maximum branch prediction models

Region	Pruning lift	Mean max branch prediction error using 1987 model (mm)	Mean max branch prediction error using 1994 model (mm)
Southern North Island	1st lift	-7.5	-2.0
	2nd lift	-10.8	-7.9
	3rd lift	-8.8	-7.5
Waikato/ King Country	1st lift	-13.4	-7.3
	3rd lift	-11.4	-10.1
All regions/lifts		**-9.7**	**-6.3**

Figures 40 and 41 display the prediction errors for each function against DOS height, again showing that maximum branch diameter is over-predicted by both functions across a range of DOS heights.

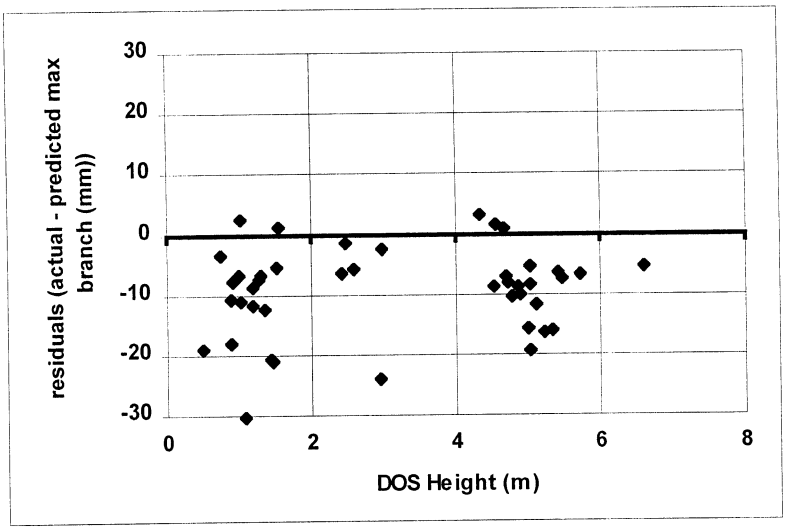

Figure 40. Errors from 1987 maximum branch diameter prediction function versus DOS height

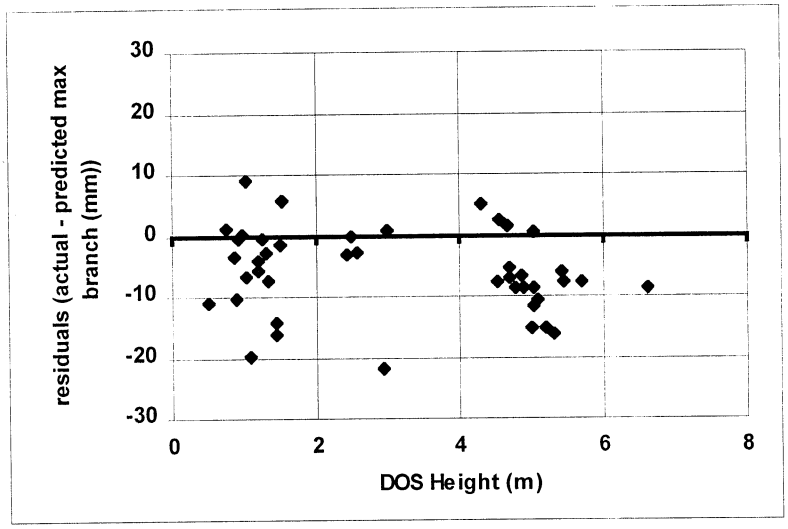

Figure 41. Errors from 1994 maximum branch diameter prediction function versus DOS height

3.4.3 Predicting DOS using predicted maximum branch diameter

If predicted DOS is calculated using predicted maximum branch data (from the 1994 max branch model), the mean DOS prediction errors are smaller for both functions than if actual maximum branch data is used (Table 15), as the errors from the DOS prediction functions and the maximum branch prediction functions tend to work in opposite directions for this data set. In general, the best combination of models appears to be the 1999 DOS model with the 1994 max branch model, except perhaps for first lift pruning in the Southern North Island where the 1987 DOS model with the 1994 max branch model gives a smaller mean error. A full list of errors by forest and pruning lift is contained in Appendix 5.3.

Table 15. Mean prediction errors (actual - predicted DOS) by region and pruning lift for 1987 and 1999 DOS prediction models (using predicted max branch data from 1994 max branch model)

Region	Pruning lift	Mean DOS prediction error using 1987 model (cm)	Mean DOS prediction error using 1999 model (cm)
Southern North Island	1st lift	0.08	0.60
	2nd lift	-0.13	-0.29
	3rd lift	0.20	-0.08
Waikato/ King Country	1st lift	-0.77	-0.04
	3rd lift	0.61	0.22
All regions/lifts		**0.01**	**0.12**

Figures 42 and 43 plot the prediction errors for each DOS prediction model against DOS height, where DOS is calculated using predicted maximum branch diameter from the 1994 maximum branch model.

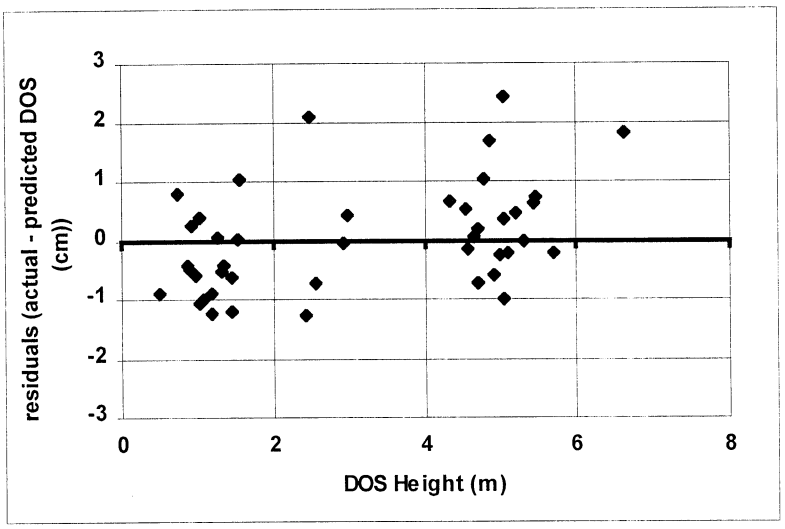

Figure 42. Errors from 1987 DOS prediction model (using predicted max branch data from 1994 max branch model) versus DOS height

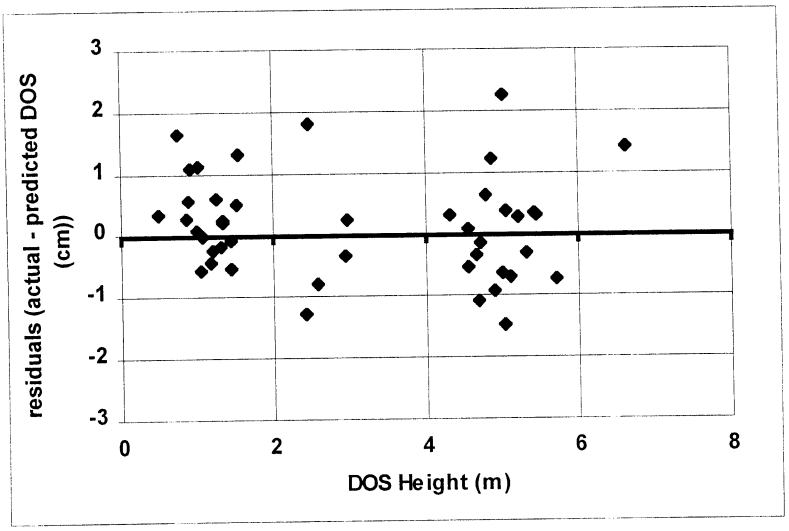

Figure 43. Errors from 1999 DOS prediction model (using predicted max branch data from 1994 max branch model) versus DOS height

References

Knowles R.L., West G.G. and A.R. Koehler, 1987: Predicting "diameter over stubs" in pruned stands of radiata pine. Ministry of Forestry, FRI Bulletin No. 12.

West G.G., 1994: Validation of diameter over stubs prediction function for genetically improved radiata pine. Forest and Farm Plantation Management Cooperative Report No. 7.

Appendix 1. Data set used for re-estimation of the DOS prediction and maximum branch diameter prediction functions

Lift	Forest	Number of trees in plot	DOS Ht (m)	DOS (cm)	Max branch (mm)	DBH (cm)	Tree Ht (m)
1	Findlays	30	0.79	17.74	38.67	12.69	6.92
1	Findlays	20	0.76	20.46	35.85	15.10	7.04
1	Golden Downs	29	0.87	19.48	28.38	15.17	8.87
1	Golden Downs	19	0.76	18.37	21.68	14.77	9.00
1	Golden Downs	43	1.38	17.63	32.26	14.29	9.21
1	Golden Downs	42	0.99	19.76	29.05	15.75	8.86
1	Huanui	29	0.97	16.80	35.97	12.63	7.14
1	Huanui	39	0.84	18.08	36.08	13.45	6.58
1	Kainui	50	1.46	17.06	33.28	14.86	10.10
1	Kaitangata	72	0.95	17.98	30.51	13.31	7.33
1	Korere	10	1.36	15.15	24.20	12.59	9.01
1	Mt Allan	20	0.59	17.18	31.65	12.02	6.29
1	Ngaruru	79	0.77	17.95	33.41	12.53	6.39
1	Ngaruru	31	0.86	18.43	35.48	13.74	7.65
1	Rai	37	1.00	16.96	22.65	14.35	8.90
1	Rai	32	1.15	15.46	22.66	12.73	7.85
1	Rainy	9	1.23	17.63	25.00	14.99	9.04
1	Te Marunga	11	0.95	17.81	35.82	12.99	6.57
1	Te Marunga	18	0.67	14.83	34.94	9.82	5.14
1	Waimanu	20	0.70	20.46	41.65	13.74	6.36
1	Wairau	55	1.19	18.12	34.40	14.06	9.01
1	Wairau	28	0.86	18.87	27.96	15.05	9.21
1	Wakaroa	24	0.68	14.12	30.88	10.04	5.61
1	Wakaroa	52	0.67	13.81	30.38	9.78	5.53
1	Wakaroa	59	0.67	13.84	32.29	9.66	5.13
1	Wakaroa	62	0.71	15.36	35.21	10.87	5.69
1	Wakaroa	40	0.65	13.67	30.93	9.47	4.78
1	Wakaroa	51	0.66	13.56	23.92	9.66	5.31
1	Wakaroa	16	0.79	15.13	35.31	10.59	5.13
1	Wakaroa	32	0.58	13.58	32.53	9.33	4.98
1	Wakaroa	61	0.67	13.92	29.92	9.87	5.28
1	Wakaroa	36	0.62	13.89	31.06	9.66	5.23
1	Wakaroa	36	0.61	15.79	29.39	11.70	5.95
1	Wakaroa	16	0.69	17.10	37.94	12.24	6.49
1	Wakaroa	79	0.62	14.30	33.32	10.10	5.18
1	Wakaroa	28	0.84	17.28	36.75	12.74	5.94
1	Wakaroa	28	0.90	13.96	32.75	9.82	4.70
1	Wakaroa	36	0.92	13.41	31.53	9.91	4.75
1	Wakaroa	16	0.99	11.78	33.13	8.14	4.64
2	Gammons	50	4.36	19.69	44.90	20.08	11.67
2	Golden Downs	41	4.49	17.71	44.10	18.53	11.52
2	Golden Downs	49	4.99	18.74	44.55	20.30	12.50
2	Golden Downs	33	4.34	19.02	45.73	19.32	12.68
2	Huanui	49	2.42	18.66	43.45	15.98	8.86

Lift	Forest	Number of trees in plot	DOS Ht (m)	DOS (cm)	Max branch (mm)	DBH (cm)	Tree Ht (m)
2	Irvines	32	4.14	17.22	33.47	17.50	11.92
2	Manawahe	33	2.54	18.22	48.79	16.12	8.01
2	Manawahe	35	2.45	18.33	42.29	16.96	9.63
2	Manawahe	35	1.93	18.64	46.49	16.42	8.71
2	Matahina	100	2.66	15.80	37.74	14.13	9.36
2	Mt Allan	48	2.82	18.33	55.44	17.05	8.65
2	Mt Allan	50	3.14	16.67	54.18	16.00	8.24
2	Omanawa	35	3.12	20.26	50.80	19.05	9.15
2	Omanawa	35	1.92	15.24	32.83	12.59	6.78
2	Rai	50	4.41	18.45	39.84	19.34	12.24
2	Rai	51	4.20	16.72	34.65	16.71	11.96
2	Rerewhakaitu	35	2.31	16.20	43.18	13.58	8.00
2	Rerewhakaitu	35	2.22	16.79	49.77	13.79	6.49
2	Rerewhakaitu	35	1.95	17.23	43.34	14.80	7.16
2	Rotoiti	50	2.86	17.90	44.58	16.61	8.66
2	Rotoiti	49	2.58	19.81	48.63	18.11	9.31
2	SF 28	49	4.62	22.29	46.65	22.96	12.68
2	Tahorakuri	22	3.48	17.14	37.32	15.40	9.84
2	Tahorakuri	23	2.90	19.37	40.17	17.51	9.79
2	Takeke	99	3.03	17.71	42.60	16.37	8.41
2	Tauhara	24	2.22	19.24	41.04	16.40	7.46
2	Tauhara	48	2.82	19.63	40.69	18.45	9.58
2	Tauhara	36	2.75	19.58	39.47	18.14	8.55
2	Tauhara	36	3.10	18.26	39.72	16.00	9.43
2	Te Marunga	40	2.68	20.16	50.00	18.30	8.14
2	Te Marunga	19	2.47	20.57	51.42	16.91	8.19
2	Te Marunga	30	2.58	20.61	51.10	18.01	8.50
2	Te Matai	35	3.21	16.87	33.49	16.35	9.49
2	Te Matai	35	4.21	18.57	44.43	18.80	10.48
2	Tuararangaia	35	3.03	17.08	41.66	15.64	9.32
2	Tuararangaia	33	2.69	18.67	42.36	15.90	8.84
2	Tuararangaia	35	2.73	17.67	47.03	15.38	9.55
2	Waimanu	10	1.51	18.97	38.30	16.17	7.28
2	Waimanu	50	2.49	16.54	37.06	15.20	8.57
2	Wainui	36	2.38	18.46	41.08	16.07	7.84
2	Wairau	20	5.06	21.12	54.50	22.38	13.95
2	Wairau	10	4.47	18.62	44.60	19.04	11.85
2	Wairau	30	4.97	16.52	40.33	17.31	11.98
2	Wharetoto	24	1.84	17.16	34.46	14.12	6.45
2	Wharetoto	36	2.42	18.73	40.17	16.36	7.96
3	Waipapa 2A	34	4.52	18.56	47.06	19.28	10.48
3	Serpentine	47	4.96	16.85	41.17	19.23	11.16
3	Huanui	10	4.96	16.19	44.90	19.78	10.52
3	Huanui	49	3.69	19.01	48.47	19.18	10.25
3	Irvines	32	5.74	17.83	41.88	20.62	12.91
3	Lilburns	20	4.74	17.63	35.90	20.10	11.04

Lift	Forest	Number of trees in plot	DOS Ht (m)	DOS (cm)	Max branch (mm)	DBH (cm)	Tree Ht (m)
3	Lilburns	20	3.87	17.99	41.60	18.92	9.55
3	Mt Allan	50	4.63	19.61	54.74	22.80	11.51
3	Mt Allan	49	4.73	18.67	58.73	21.98	11.50
3	Ngamanawa	50	5.48	26.18	48.32	28.36	15.72
3	Nobleburn	20	3.82	20.04	68.25	20.09	9.98
3	Nobleburn	10	4.49	19.02	59.80	23.40	11.19
3	Nobleburn	20	4.22	20.53	68.50	22.66	10.28
3	Opepe Trust	20	5.16	18.17	41.90	21.38	11.24
3	Pahautea	35	4.73	19.27	42.54	21.03	11.21
3	Pinnacles	34	4.84	18.41	42.79	19.76	11.51
3	Rerewhakaitu	49	2.62	17.59	49.90	16.11	7.47
3	Rotoiti	98	3.72	15.76	43.42	17.09	9.19
3	Sun Valley	25	4.31	17.33	42.08	18.50	10.40
3	Sun Valley	35	5.13	18.07	40.09	19.78	11.85
3	Tahorakuri	30	5.14	17.61	42.17	20.40	11.18
3	Tahorakuri	10	5.69	18.62	44.90	21.63	12.03
3	Tahorakuri	20	4.33	19.43	44.40	20.20	11.52
3	Tahorakuri	19	4.65	18.06	42.95	19.31	10.92
3	Tahorakuri	20	5.44	20.50	46.30	23.27	12.60
3	Tarawera	99	4.28	16.65	41.28	18.42	10.97
3	Tauhara	20	4.02	19.31	45.50	20.18	10.41
3	Tauhara	40	2.96	20.93	49.75	19.66	8.90
3	Tauhara	47	3.20	19.56	43.51	19.04	8.72
3	Tauhara	23	2.95	20.39	55.35	19.54	8.14
3	Tauhara	20	4.15	16.75	38.95	17.71	10.24
3	Tauhara	36	4.39	18.29	40.56	19.95	10.51
3	Te Marunga	30	3.85	19.66	52.47	19.80	10.88
3	Te Marunga	49	4.91	19.09	56.31	22.11	11.65
3	Te Matai	50	4.36	19.33	45.78	21.33	10.27
3	Tuararangaia	35	4.43	16.93	43.43	17.89	11.55
3	Tuhoe	35	3.76	18.90	52.37	18.87	11.97
3	Tuhoe	35	5.50	18.19	49.06	19.76	12.46
3	Waimanu	20	3.89	19.97	49.05	20.45	10.75
3	Waimanu	50	4.58	19.43	52.36	22.68	10.61
3	Waimanu	30	4.79	20.81	48.87	23.83	12.06
4	Huanui	30	5.23	16.33	48.73	20.01	11.03
4	Huanui	40	5.47	18.47	46.95	21.73	12.73
4	Huanui	28	6.28	20.24	55.14	26.49	12.89
4	Mang/Kah T/C	98	4.63	17.54	40.06	18.79	10.65
4	Matahina	35	6.17	17.01	41.60	20.04	13.49
4	Rotoiti	44	6.28	17.45	46.48	21.82	13.60
4	Rotoiti	50	5.57	16.63	35.94	20.06	12.44
4	Sun Valley	25	5.50	18.80	42.72	20.51	12.50
4	Sun Valley	25	4.98	20.45	50.32	21.96	10.95
4	Sun Valley	24	5.20	20.85	48.96	22.55	11.49
4	Tarawera	35	4.98	19.37	54.37	21.93	11.85

Lift	Forest	Number of trees in plot	DOS Ht (m)	DOS (cm)	Max branch (mm)	DBH (cm)	Tree Ht (m)
4	Tarawera	34	6.26	24.53	42.88	26.54	17.59
4	Tauhara	50	5.35	21.49	47.26	24.32	13.49
4	Tauhara	20	5.97	17.73	39.75	21.71	12.01
4	Te Marunga	49	6.00	16.76	41.49	20.65	12.50
4	Te Marunga	50	5.66	16.83	43.32	21.11	11.87
4	Te Matai	50	5.40	17.24	40.40	19.02	11.99
4	Waitahanui	30	5.66	18.17	44.27	21.73	12.37

Appendix 2. Mean DOS prediction errors (actual DOS minus predicted DOS) by pruning lift and by forest for the 1987 and 1999 DOS prediction models

Appendix 2.1. DOS prediction errors for first lift pruning

Forest	Number of plots	Mean error using 1987 DOS model (cm)	Mean error using 1999 DOS model (cm)
Wakaroa	17	-1.45	-0.78
Huanui	2	-0.80	-0.11
Waimanu	1	0.36	1.26
Te Marunga	2	-0.67	0.00
Findlays	2	-0.42	0.44
Kainui	1	-1.35	-0.89
Rainy	1	-0.56	0.12
Korere	1	-0.46	-0.04
Golden Downs	4	-0.14	0.69
Rai	2	-0.69	0.00
Ngaruru	2	-0.20	0.59
Wairau	2	-0.27	0.47
Mt Allan	1	-0.53	0.37
Kaitangata	1	0.15	0.87

Note that positive errors represent a smaller predicted DOS than actual DOS, and negative errors represent a larger predicted DOS than actual DOS

Appendix 2.2. DOS prediction errors for second lift pruning

Forest	Number of plots	Mean error using 1987 DOS model (cm)	Mean error using 1999 DOS model (cm)
Huanui	1	0.39	0.32
Waimanu	2	-0.64	-0.45
Te Marunga	3	0.83	0.74
Manawahe	3	-0.68	-0.66
Rotoiti	2	-0.14	-0.28
Rerewhakaitu	3	-0.21	-0.31
Tuararangaia	3	0.45	0.19
Matahina	1	-0.24	-0.49
Tauhara	4	0.79	0.69
Tahorakuri	2	1.09	0.80
Wainui	1	0.52	0.47
Wharetoto	2	0.57	0.61
Gammons	1	0.73	0.37
SF28	1	1.20	1.00
TeMatai	2	0.67	0.30
Omanawa	2	0.30	0.19
Takeke	1	0.67	0.35
Kainui	1	0.48	0.10
Golden Downs	3	0.13	-0.27
Rai	2	0.34	-0.06
Wairau	3	0.30	-0.10
Mt Allan	2	-0.61	-0.97

Note that positive errors represent a smaller predicted DOS than actual DOS, and negative errors represent a larger predicted DOS than actual DOS

Appendix 2.3. DOS prediction errors for third lift pruning

Forest	Number of plots	Mean error using 1987 DOS model (cm)	Mean error using 1999 DOS model (cm)
Huanui	2	-0.40	-0.82
Waimanu	3	-0.25	-0.54
Te Marunga	2	-0.51	-0.88
Tuhoe	2	-0.17	-0.55
Tarawera	1	-0.69	-1.14
Rotoiti	1	-0.86	-1.35
Rerewhakaitu	1	-0.26	-0.50
Tuararangaia	1	-0.29	-0.78
Tauhara	6	0.43	0.13
Tahorakuri	5	0.58	0.22
Pahautea	1	0.80	0.44
Opepe Trust	1	0.31	-0.06
Lilburns	2	0.38	-0.01
Ngamanawa	1	1.17	1.34
TeMatai	1	0.38	0.01
Waipapa 2A	1	0.96	0.47
Pinnacles	1	0.71	0.29
Sun Valley	2	0.54	0.10
Rainy	1	0.18	-0.12
Serpentine	1	0.03	-0.44
Nobleburn	3	-1.18	-1.56
Mt Allan	2	-1.38	-1.73

Appendix 2.4. DOS prediction errors for fourth lift pruning

Forest	Number of plots	Mean error using 1987 DOS model (cm)	Mean error using 1999 DOS model (cm)
Huanui	3	-0.71	-0.99
Te Marunga	2	-0.41	-0.73
Tarawera	2	0.44	0.39
Rotoiti	2	-0.55	-0.79
Matahina	1	-0.07	-0.31
Tauhara	2	0.44	0.23
Waitaha	1	-0.06	-0.36
Mang/Kah	1	0.84	0.36
TeMatai	1	0.73	0.29
Sun Valley	3	1.44	1.07

Note that positive errors represent a smaller predicted DOS than actual DOS, and negative errors represent a larger predicted DOS than actual DOS

Appendix 3. Mean prediction errors for maximum branch diameter on the DOS whorl (actual max branch diameter minus predicted max branch diameter) by pruning lift and by forest for the 1987 and 1994 models.

Appendix 3.1. Maximum branch diameter prediction errors for first lift pruning

Forest	Number of plots	Mean error using 1987 model (mm)	Mean error using 1994 model (mm)
Wakaroa	17	-5.3	-0.1
Huanui	2	-5.1	0.5
Waimanu	1	-7.0	1.1
Te Marunga	2	-4.2	1.3
Findlays	2	-7.4	-0.5
Kainui	1	-1.8	1.0
Rainy	1	-13.7	-9.5
Korere	1	-6.5	-4.6
Golden Downs	4	-11.0	-6.2
Rai	2	-13.0	-9.2
Ngaruru	2	-6.1	-0.4
Wairau	2	-5.4	-1.2
Mt Allan	1	-7.9	-1.8
Kaitangata	1	-8.9	-3.8

Note that positive errors represent a smaller predicted max branch than actual max branch, and negative errors represent a larger predicted max branch than actual max branch

Appendix 3.2. Maximum branch diameter prediction errors for second lift pruning

Forest	Number of plots	Mean error using 1987 model (mm)	Mean error using 1994 model (mm)
Huanui	1	0.9	3.9
Waimanu	2	-8.9	-4.2
Te Marunga	3	0.0	4.8
Manawahe	3	1.1	4.8
Rotoiti	2	0.2	3.7
Rerewhakaitu	3	3.4	6.7
Tuararangaia	3	3.7	5.4
Matahina	1	2.4	3.2
Tauhara	4	-7.1	-3.4
Tahorakuri	2	-2.2	-0.8
Wainui	1	-5.5	-1.4
Wharetoto	2	-9.5	-5.0
Gammons	1	-1.2	0.1
SF28	1	-5.1	-2.8
TeMatai	2	-4.0	-2.7
Omanawa	2	-2.7	0.6
Takeke	1	-1.5	1.0
Kainui	1	-6.1	-6.2
Golden Downs	3	1.5	1.7
Rai	2	-3.3	-3.4
Wairau	3	3.2	3.2
Mt Allan	2	10.2	12.8

Note that positive errors represent a smaller predicted max branch than actual max branch, and negative errors represent a larger predicted max branch than actual max branch

Appendix 3.3. Maximum branch diameter prediction errors for third lift pruning

Forest	Number of plots	Mean error using 1987 model (mm)	Mean error using 1994 model (mm)
Huanui	2	0.3	1.6
Waimanu	3	-2.9	0.0
Te Marunga	2	5.4	7.4
Tuhoe	2	7.7	7.8
Tarawera	1	-1.6	-1.1
Rotoiti	1	0.4	1.6
Rerewhakaitu	1	2.5	6.4
Tuararangaia	1	2.7	2.5
Tauhara	6	-4.8	-1.6
Tahorakuri	5	-3.1	-2.3
Pahautea	1	-6.1	-4.6
Opepe Trust	1	-6.6	-5.7
Lilburns	2	-8.2	-6.6
Ngamanawa	1	-11.6	-8.2
TeMatai	1	-6.1	-3.4
Waipapa 2A	1	1.6	2.5
Pinnacles	1	-2.0	-1.7
Sun Valley	2	-2.9	-2.6
Rainy	1	-2.5	-3.2
Serpentine	1	-2.6	-2.6
Nobleburn	3	11.2	14.7
Mt Allan	2	4.7	7.1

Appendix 3.4. Maximum branch diameter prediction errors for fourth lift pruning

Forest	Number of plots	Mean error using 1987 model (mm)	Mean error using 1994 model (mm)
Huanui	3	0.5	1.2
Te Marunga	2	-3.0	-3.5
Tarawera	2	-2.3	-1.3
Rotoiti	2	-3.6	-4.4
Matahina	1	-0.9	-2.6
Tauhara	2	-6.4	-5.7
Waitaha	1	-3.1	-3.0
Mang/Kah	1	-3.7	-3.4
TeMatai	1	-1.7	-2.6
Sun Valley	3	-1.6	-0.6

Note that positive errors represent a smaller predicted max branch than actual max branch, and negative errors represent a larger predicted max branch than actual max branch

Appendix 4. Data set used for evaluation of 1987 and 1999 functions for predicting DOS and maximum branch diameter on the DOS whorl for radiata pine

Lift	Forest	Number of trees measured	DOS height (m)	DOS (cm)	Max branch (mm)	DBH (cm)	Tree Ht (m)
1	Lismore	270	1.55	18.36	44.46	13.49	6.65
1	Lismore	48	0.99	18.58	40.63	13.70	6.40
1	Lismore	30	1.03	20.18	48.83	14.63	7.21
1	Lismore	66	2.42	17.54	38.26	16.80	9.02
1	Manakau	36	1.09	24.45	32.22	19.87	8.71
1	Pirongia	42	1.20	22.98	33.33	20.01	12.45
1	Pureora	48	1.04	14.94	27.29	11.14	5.78
1	Pureora	11	0.88	18.18	36.82	12.72	5.78
1	Pureora	36	1.19	16.71	32.36	13.08	6.79
1	Pureora	29	1.31	16.11	31.55	12.52	6.83
1	Tawarau	90	1.52	19.14	34.09	15.51	9.41
1	Te Wera	24	1.35	20.34	30.42	16.72	9.67
1	Te Wera	24	1.35	20.34	30.58	16.71	9.67
1	Te Wera	12	2.48	16.30	34.50	12.57	7.13
1	Waitarere	6	0.75	18.60	31.67	12.93	7.83
1	Waitarere	42	0.92	21.04	41.02	15.26	7.33
1	Waitarere	42	1.27	20.16	42.81	15.32	7.10
1	Waituhi	12	0.51	21.30	27.50	16.09	8.29
1	Waituhi	30	0.90	23.16	31.17	18.45	9.81
1	Waituhi	142	1.45	20.47	28.35	16.91	8.48
2	Kohitere	12	2.94	16.74	18.75	15.94	8.48
2	Lismore	124	2.98	19.72	45.40	18.43	9.50
2	Lismore	60	2.57	18.11	38.33	17.08	9.46
3	Kohitere	8	1.46	20.85	21.88	18.34	11.38
3	Lismore	24	5.04	26.63	55.42	30.70	12.55
3	Lismore	24	5.03	25.80	62.92	28.05	11.31
3	Lismore	36	4.69	18.63	43.33	21.70	11.18
3	Lismore	143	4.71	19.38	39.50	21.01	11.85
3	Lismore	60	5.71	15.39	37.42	19.91	10.45
3	Lismore	180	5.46	18.11	37.89	20.48	11.62
3	Lismore	354	5.43	19.65	41.31	21.80	12.60
3	Lismore	66	6.62	15.23	33.03	17.71	10.98
3	Pureora	18	5.21	21.47	33.33	23.14	13.83
3	Tawarau	156	5.32	19.43	29.12	21.29	13.91
3	Tawarau	156	5.32	19.43	29.12	21.29	13.91
3	Tawarau	144	4.32	20.10	53.02	21.06	10.96
3	Tawarau	136	4.79	20.21	40.97	22.00	10.88
3	Te Wera	30	4.56	18.37	46.80	19.90	11.79
3	Te Wera	24	5.00	18.37	31.04	20.85	11.96
3	Te Wera	35	4.66	18.60	45.40	19.88	12.21
3	Te Wera	35	5.03	16.03	35.17	19.25	11.29
3	Te Wera	39	4.90	19.16	39.62	22.03	12.08
3	Waituhi	60	4.86	20.02	42.92	21.76	10.21
3	Waituhi	119	5.10	17.16	36.94	21.02	10.29
3	Waituhi	126	4.54	18.37	37.65	19.77	10.63

Appendix 5.1. Mean prediction errors (actual - predicted DOS) by forest and pruning lift for 1987 and 1999 DOS prediction models

Pruning lift	Forest	Number of plots	Mean DOS prediction error using 1987 model (cm)	Mean DOS prediction error using 1999 model (cm)
1st lift	Lismore	4	-0.32	0.07
	Manakau	1	0.51	1.62
	Pirongia	1	-0.73	0.28
	Pureora	4	-0.36	0.18
	Tawarau	1	0.17	0.64
	TeWera	3	0.86	1.22
	Waitare	3	0.35	1.09
	Waituhi	3	0.34	1.37
2nd lift	Kohitere	1	1.97	1.82
	Lismore	2	-0.08	-0.17
3rd lift	Kohitere	1	0.29	1.09
	Lismore	8	1.12	0.85
	Pureora	1	1.65	1.55
	Tawarau	4	1.15	0.89
	TeWera	5	0.07	-0.28
	Waituhi	3	1.29	0.87
All forests and lifts		**45**	**0.52**	**0.67**

Appendix 5.2. Mean prediction errors (actual - predicted maximum branch diameter) by forest and pruning lift for 1987 and 1994 maximum branch prediction functions

Pruning lift	Forest	Number of plots	Mean max branch prediction error using 1987 model (mm)	Mean max branch prediction error using 1999 model (mm)
1st lift	Lismore	4	-2.5	2.9
	Manakau	1	-30.4	-19.9
	Pirongia	1	-11.6	-5.8
	Pureora	4	-9.4	-4.2
	Tawarau	1	-5.3	-1.6
	TeWera	3	-8.8	-5.0
	Waitare	3	-6.2	0.1
	Waituhi	3	-19.2	-11.9
2nd lift	Kohitere	1	-23.9	-21.7
	Lismore	2	-4.3	-1.0
3rd lift	Kohitere	1	-21.0	-16.3
	Lismore	8	-8.3	-6.7
	Pureora	1	-16.4	-15.3
	Tawarau	4	-10.0	-9.0
	TeWera	5	-6.3	-5.7
	Waituhi	3	-9.7	-8.4
All forests and lifts		**45**	**-9.7**	**-6.3**

Appendix 5.3. Mean prediction errors (actual - predicted DOS) by forest and pruning lift for 1987 and 1999 DOS prediction models (using predicted max branch data from 1994 max branch model)

Pruning lift	Forest	Number of plots	Mean DOS prediction error using 1987 model (cm)	Mean DOS prediction error using 1999 model (cm)
1st lift	Lismore	4	0.30	-0.11
	Manakau	1	-0.01	-1.00
	Pirongia	1	-0.24	-1.22
	Pureora	4	-0.22	-0.73
	Tawarau	1	0.49	0.03
	TeWera	3	0.75	0.42
	Waitare	3	1.11	0.37
	Waituhi	3	0.27	-0.68
2nd lift	Kohitere	1	-0.36	-0.06
	Lismore	2	-0.26	-0.17
3rd lift	Kohitere	1	-0.53	-1.22
	Lismore	8	0.34	0.65
	Pureora	1	0.28	0.47
	Tawarau	4	0.09	0.40
	TeWera	5	-0.78	-0.39
	Waituhi	3	0.20	0.66
All forests and lifts		**45**	**0.12**	**0.01**