FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

VALIDATION OF A MODEL TO PREDICT CANOPY CLOSURE FOR RADIATA PINE

H McElwee

Report No. 62 March 1999

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EXECUTIVE SUMMARY

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Canopy closure can be used to describe rainfall interception losses from a forest and is therefore useful as a surrogate for water use, and an indicator of the contribution of trees to soil stability. Canopy closure is also directly related to understorey pasture production, and can therefore be used to predict changes in livestock carrying capacity of pastoral farmland planted into forestry. To validate an existing canopy closure model for radiata pine derived from the Bay of Plenty, canopy images from 30 plots, in four forests on the East Coast of the North Island, were digitised and assessed. The model provided relatively unbiased estimates of canopy closure in the East Coast plots. However, the variance of the residuals was larger than the variance of the residuals from the original data set of 79 plots. The model was re-estimated to include the new data, resulting in only minor changes to the coefficients in the model. The residuals were relatively unbiased for both the Bay of Plenty and the East Coast data sets; therefore it was concluded that a separate model for the East Coast was not necessary. The fit of the new model is quite good (approximation of an $r^2 = 0.90$), although slightly poorer than the old model (approximation of an $r^2 = 0.92$). As a result of an analysis of the confidence intervals around the estimates of canopy closure for each plot, amendments to the existing sampling methodology were recommended. These guidelines include a greater number of canopy images to be captured for stands of less than 75% canopy closure, and the use of a variable distance between images, depending on the mean height of the stand.

VALIDATION OF A MODEL TO PREDICT CANOPY CLOSURE FOR RADIATA PINE

1. Introduction

Canopy closure, otherwise known as canopy density or crown closure, is defined as the ratio of horizontal area of projected tree canopy, relative to the total ground area covered. In effect it is an expression of the ground area shaded by overhead foliage (Daubenmire, 1959). Canopy closure can be used to describe rainfall interception losses from a forest and is therefore useful as a surrogate for water use (Calder, 1996), and an indicator of the contribution of trees to soil stability (Knowles *et. al.* 1996b). Canopy closure is also directly related to understorey pasture production, and can therefore be used to predict changes in livestock carrying capacity of pastoral farmland planted into forestry (Knowles *et. al.* 1997).

To develop a canopy closure model for radiata pine, canopy images from 79 plots, on six sites from the Bay of Plenty, were digitised and assessed. A function was fitted of the form described by the Chapman-Richard's model (Ratkowsky 1989), which predicts canopy closure (C) from stand basal area (G) and a ratio between height to green crown (H_2) and mean top height (H_1), termed height ratio. The fitted canopy closure function was:

$$C = a*(1-EXP(-b*G*(1-c*((H_2/H_1)-0.4))))^{1/d} \quad (1)$$

where:

C = canopy closure (percent)
G = basal area (m^2/ha)
H_2 = green crown height (m)
H_1 = mean top height (m)
a = 85.8279
b = 0.05967
c = 1.5027
d = 0.6989

Figure 1 illustrates the above relationship with the sampled stands grouped according to their height ratio values. The relationship shows an increase in canopy closure with increasing basal area; early canopy development is rapid, but begins to level out at mid-rotation when basal area is greater than 40 m^2/ha and canopy closure approaches 70%. Increasing height ratios caused by pruning operations or the natural rising of the crown in closed stands are reflected by a decrease in canopy closure. Additional height growth with a constant crown base is reflected by a reduced height ratio and an increase in canopy closure.

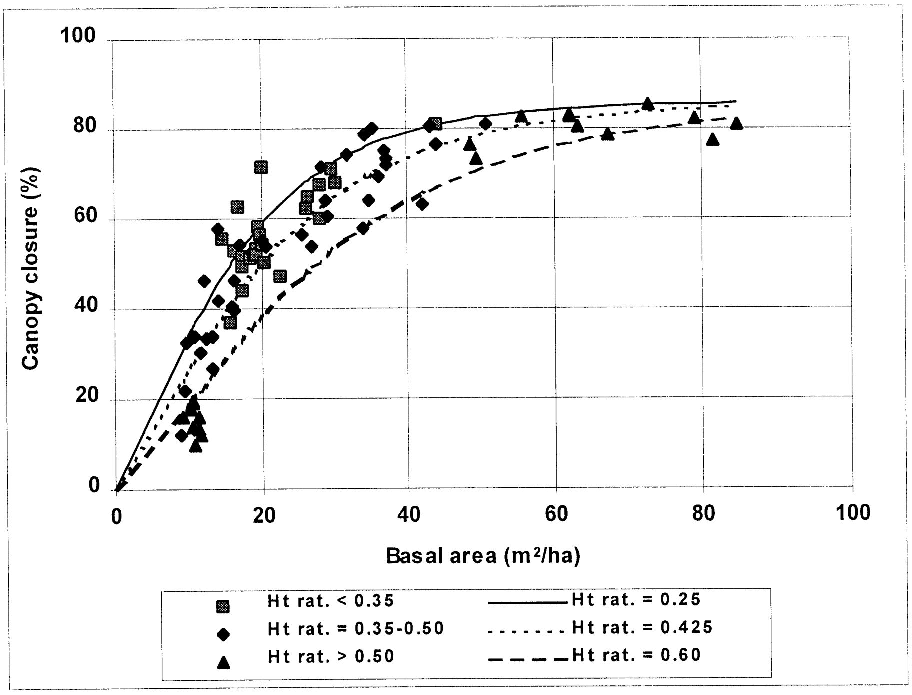

Figure 1. The existing canopy closure model for radiata pine

The canopy closure model has been applied in a project to assess the erosion control potential of radiata pine forests for the Ministry of Forestry's "East Coast Forestry Project" (Knowles *et. al.* 1996b). Higher canopy closure levels were interpreted as having an increased ability to intercept rainfall and transpire water from a catchment and thus aid in the reduction or prevention of hill country soil erosion. A relationship was also developed between canopy closure and understorey pasture production for radiata pine silvopastoral systems (Knowles *et. al.* 1997). A similar model for predicting canopy closure was also developed for *Populus* spp. by McElwee (1998), using the same functional relationship as the radiata pine model.

This report outlines the validation of the canopy closure model using digital canopy images captured from 30 stands on the East Coast of the North Island.

2. Method

A total of 30 permanent sample plots (PSPs) were selected for the validation work on the East Coast. These plots are located within the forest areas of Wharerata, Patunamu, Huanui and Okiwa (Table 1). Stands were selected to cover a wide range of stand characteristics, including basal area, height ratio (green crown height / mean top height), age and stocking. Growth parameters for all plots were retrieved from the PSP database measurements in the same season as the images were captured. Appendix 1 lists stand parameters for the 30 plots used for the model validation, and Appendix 2 summarises the stand parameters for the 79 plots used to estimate the existing model.

Table 1. Location of forest PSPs selected for canopy closure model validation

Forest name	Owner	No. of PSP plots used
Wharerata	Juken Nissho Ltd	10
Patunamu	Juken Nissho Ltd	5
Huanui	Hikurangi Forest Farms	12
Okiwa	Hikurangi Forest Farms	3
		30

The methodology for determining the degree of canopy closure was based on that described in previous ***Forest Research*** project records (Carter 1995; Horvath 1997) and Forest & Farm Plantation Management Research Cooperative presentations (Knowles *et. al.* 1996a; Horvath *et. al.* 1997). The procedure involved capturing a series of colour images using a digital camera mounted on a tripod and set to view vertically into the forest canopy. All images used in this validation exercise were captured using a Kodak DCS 420 digital camera. This camera has a resolution of 1524 X 1012 pixels, compared to 832 X 608 pixels for the Canon PowerShot 600 digital camera which was used for previous assessments.

Individual images were downloaded onto computer using Photoshop 4.0 image assessment software. All images were cropped to a circular format (1012 pixels diameter), converted from colour to greyscale, and then assessed for canopy closure using computer software developed at ***Forest Research***. Pixels representing tree canopy show up as darker shades of grey, while those representing the sky background show up as lighter shades. Limits are set corresponding to the darkest pixels which represent sky and the lightest pixels which represent canopy. The program then counts the number of canopy and sky pixels, thus giving a measure of percentage canopy closure. Errors may result due to areas of sky and canopy being of a similar shade, but these errors are small in favourable light conditions. Favourable light conditions occur when there is an even cover of cloud, or no cloud cover at all. Less favourable light conditions include patchy cloud or very dark clouds. Very bright conditions can also cause errors if there is significant reflection of light from the tree canopy.

Usually 17 images were taken in each stand in a star shaped pattern (Figure 1), although 25 images were taken in two stands with particularly low basal area. The spacing between images was chosen so as to ensure the images did not overlap at 30m stand height; that is, to ensure that the images were independent. In each case the estimated canopy closure at each site was simply calculated as the mean of the percentage canopy closure as assessed from the individual images.

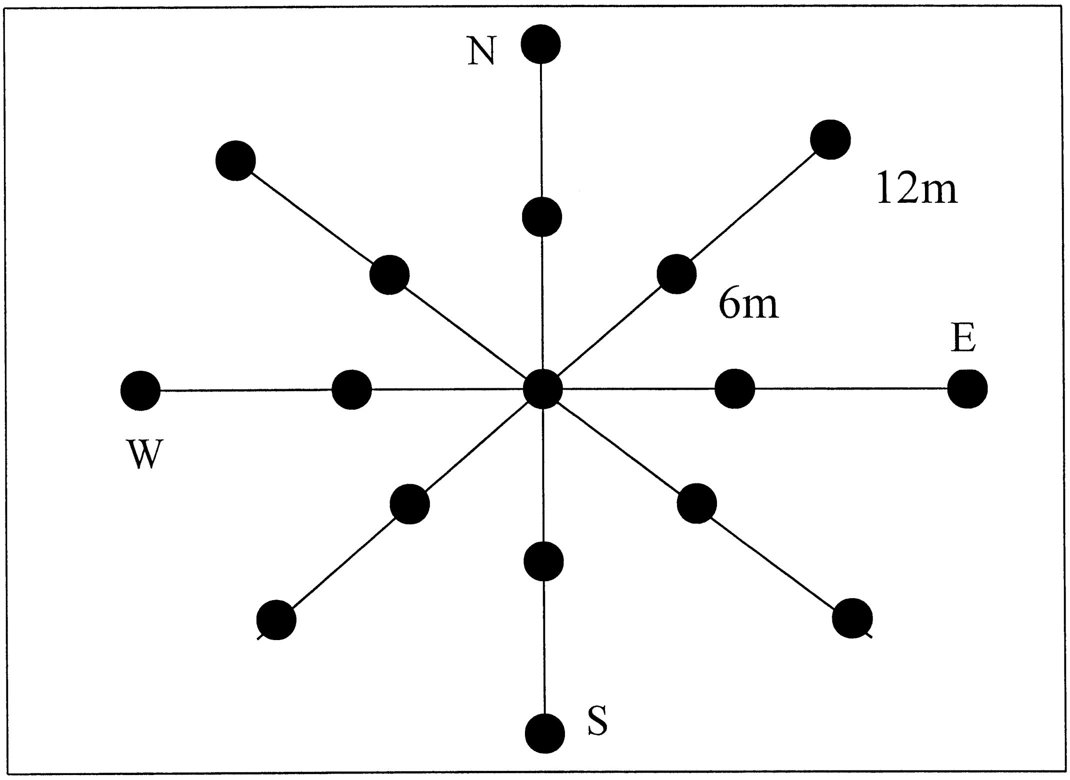

Figure 1. Sampling design for acquiring video images of canopy closure in a sample plot

3. Results

3.1 Re-estimation of the canopy closure function

Residual canopy closure for each of the 30 plots was calculated by subtracting predicted canopy closure using the existing model from the measured values of canopy closure. Figures 2-6 show residual canopy closure plotted against basal area, height ratio, estimated canopy closure, age and stocking. These results indicate that although the variance of the residuals is quite large, the existing model appears to provide relatively unbiased estimates of canopy closure. The mean residual is 3.1% canopy closure with a standard deviation of 9.1% canopy closure.

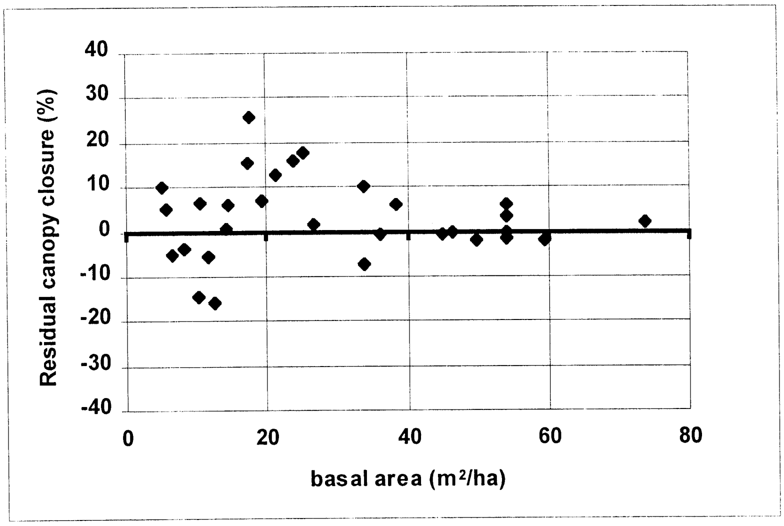

Figure 2. Residual canopy closure versus basal area for 30 East Coast plots

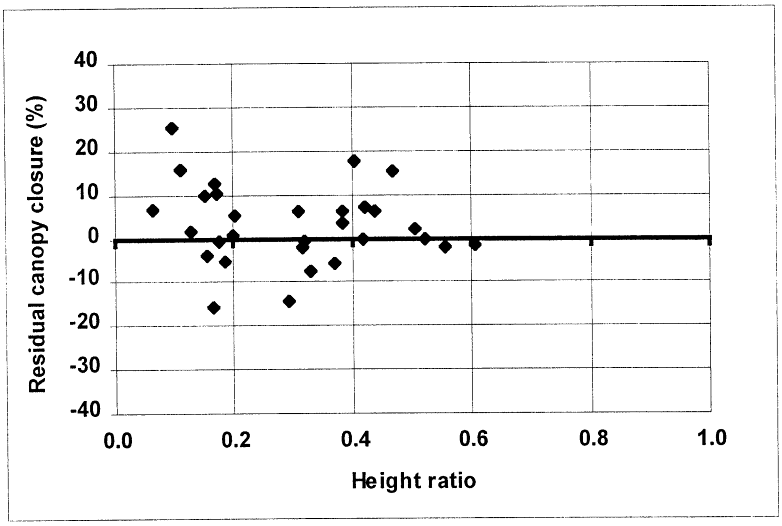

Figure 3. Residual canopy closure versus height ratio for 30 East Coast plots

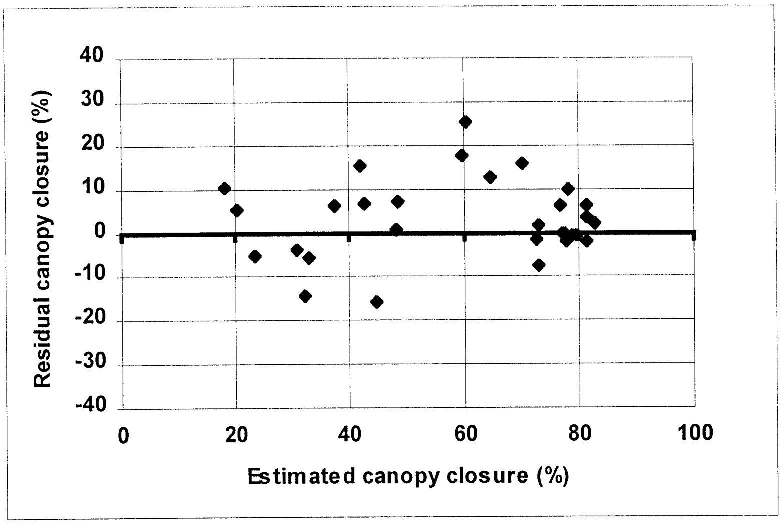

Figure 4. Residual canopy closure versus estimated canopy closure for 30 East Coast plots

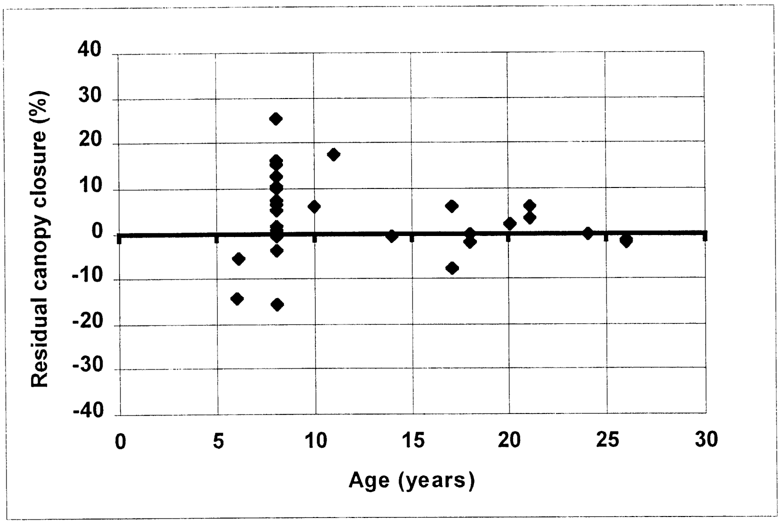

Figure 5. Residual canopy closure versus age for 30 East Coast plots

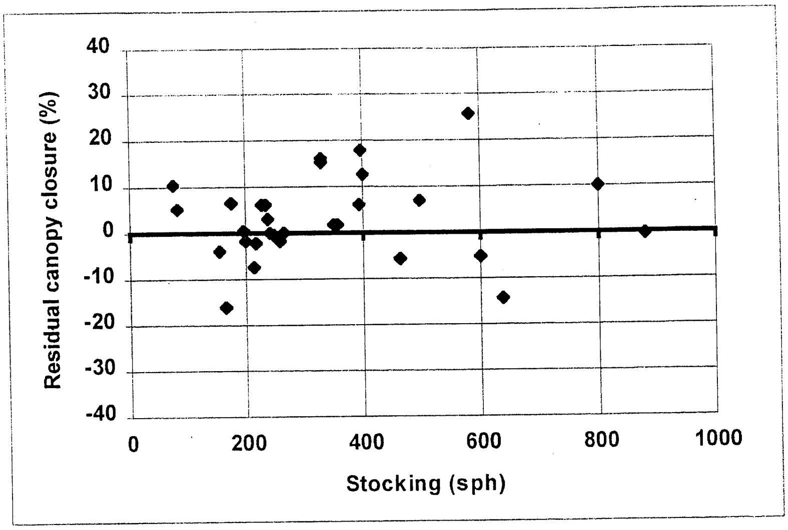

Figure 6. Residual canopy closure versus stocking for 30 East Coast plots

The model was re-estimated using the 30 new data points in addition to the original 79 data points (Table 1). The fit of the new model was slightly poorer than that of the old model, as shown by a higher residual mean square and a lower approximation of an r^2. The overall fit of the model however is still quite good.

Table 1. Coefficients for original canopy closure model and model with expanded data set

	Old model	New model
"a" coefficient	85.8143	86.4729
"b" coefficient	0.0597	0.0618
"c" coefficient	1.5022	1.6179
"d" coefficient	0.6985	0.6776
residual mean square	37.8	51.1
approximation of r^2 [1]	0.921	0.901

The values of the estimated coefficients changed only slightly, with all new coefficients lying within the 95% confidence bounds of the old coefficients. Figure 7 illustrates that predicted canopy closure is very similar for both models.

[1] r^2 for the non linear model is defined as 1-SSE/CSS, where SSE is the variance of the full model and CSS is the variance of the mean model.

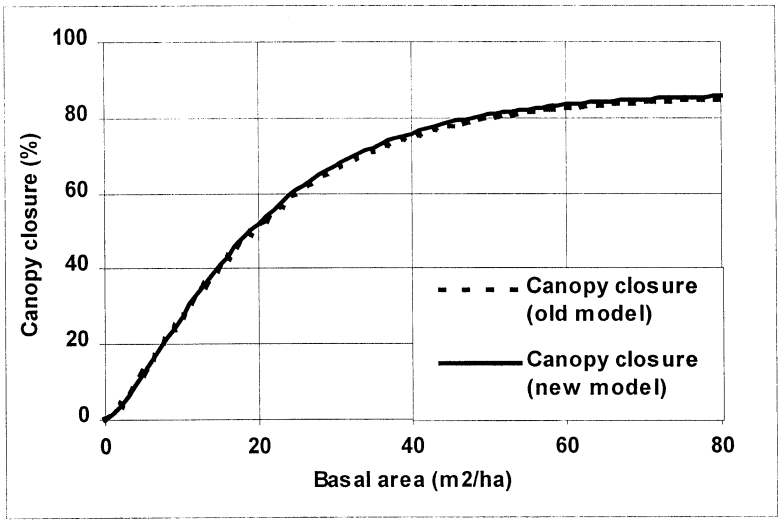

Figure 7. Predicted canopy closure for original canopy closure model and model with expanded data set (for height ratio = 0.4)

The residuals for all 109 data point in the new model are plotted against estimated canopy closure in Figure 8. Both sets of residuals appear unbiased, although it is again apparent that the variance of the residuals is greater for the 30 East Coast plots than for the original 79 data points from the Bay of Plenty. The mean residual for the East Coast data is 2.0% canopy closure with a standard deviation of 9.0% canopy closure, while the mean residual for the original data set is -0.7% canopy closure with a standard deviation of 6.1% canopy closure. Because the residuals were relatively unbiased for both the Bay of Plenty and the East Coast data sets, it was concluded that a separate model for the East Coast was not necessary

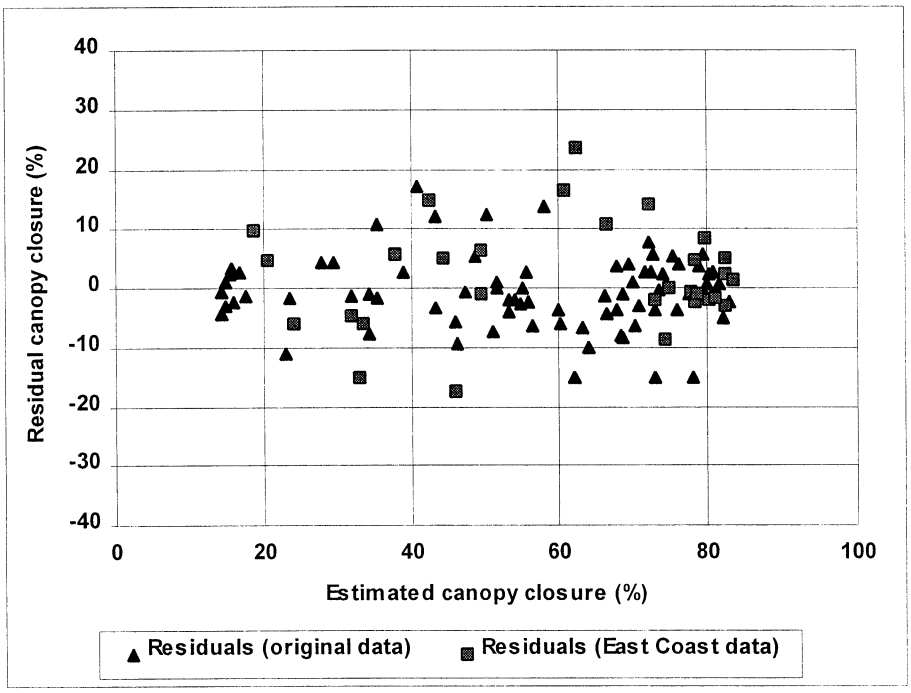

Figure 8. Residuals from re-estimated canopy closure model

3.2 Sample size analysis and revised methodology for canopy closure assessment

The average of 17 images was used to estimate stand canopy closure for 28 of the 30 plots used for the model validation, while 25 images were used for the remaining two plots. However, Figure 9 shows that the 90% confidence intervals for the estimates of canopy closure from the East Coast are quite wide in many instances, indicating that it would be desirable to increase the number of images assessed for a number of the plots. In particular, the plots of relatively low basal area and canopy closure have wide confidence intervals.

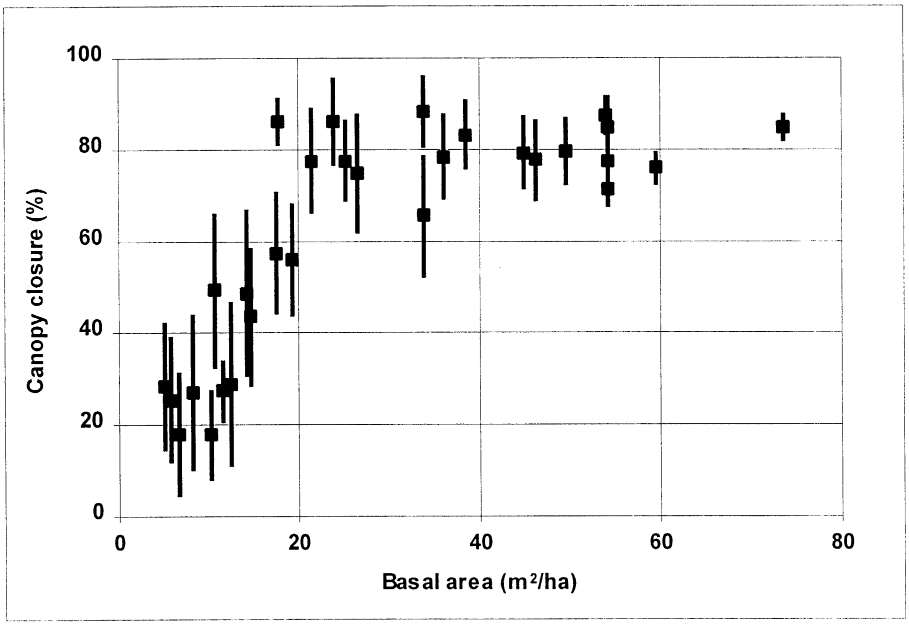

Figure 9. Measured canopy closure versus basal area for 30 East Coast plots, including 90% confidence intervals

The sample sizes required to reduce the 90% confidence intervals to ± 10% canopy closure and ± 5% canopy closure are displayed in Figures 10 and 11. These graphs reveal that stands of very high or very low canopy closure require relatively small samples while stands of intermediate canopy closure require larger sample sizes. That is, the variance of measured canopy closure was greatest in stands with an intermediate level of canopy closure, peaking at about 40-50% canopy closure. Figure 11 reveals that the required sample sizes necessary to reduce the 90% confidence interval to ± 5% canopy closure are impractical in most cases, due to the amount of memory space required for storing images (approximately 1.5 MB per image) and the time required for downloading and processing of images.

Based on Figure 10, it appears that stands of less than 50% canopy closure require about 50 images to be reasonably certain that the 90% confidence interval is smaller than ± 10% canopy closure. Stands of 50-75% canopy closure require up to about 30 images, while stands of greater than 75% canopy closure require a maximum of about 15 images. It is recommended that these guidelines be used for future measurements of canopy closure. Actual canopy closure can be estimated from PSP data or pre-measurement of stand parameters (basal area, MTH and mean crown height), and this can be used to estimate the required sample size. A 170 MB memory card can store two plots of less than 50% canopy closure, three plots of 50-75% canopy closure, or six plots of greater than 75% canopy closure. Although downloading and processing time will be greater for plots of low canopy closure, a proportion of these images are likely to contain no canopy at all, and therefore will not require processing.

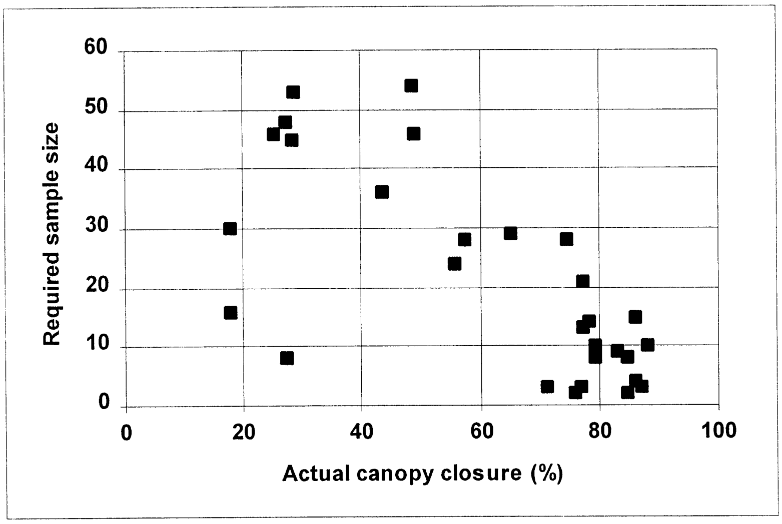

Figure 10. Sample size required to reduce 90% confidence interval to ±10% canopy closure

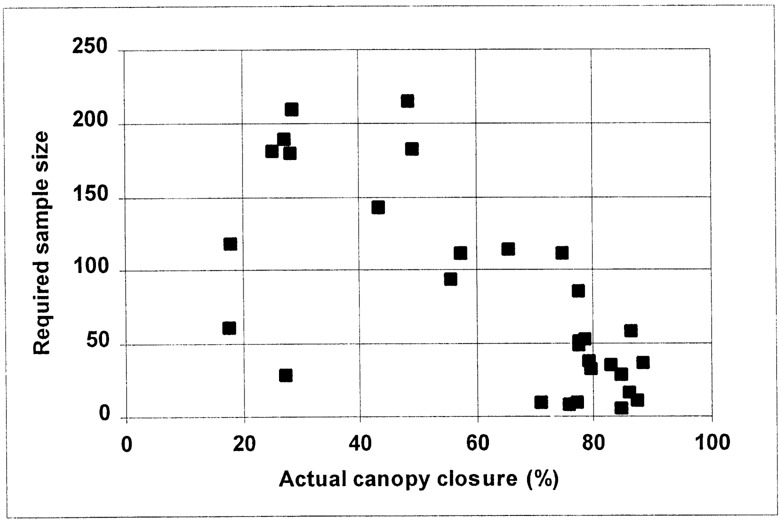

Figure 11. Sample size required to reduce 90% confidence interval to ±5% canopy closure

If a greater number of images are recorded for plots of lower canopy closure, the size of the plot needs to be larger to accommodate the additional images, or the images need to be taken closer together. Using the Kodak DCS 420 digital camera, the ratio between the image dimensions along the shortest axis (i.e. the width of canopy in the image) and the distance from the canopy was estimated (Figure 12).

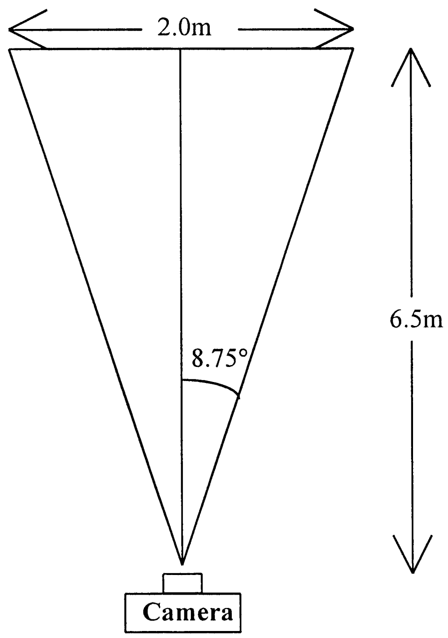

Figure 12. Calculation of canopy image dimensions along the shortest axis

Using this ratio, the minimum spacing required between images to avoid overlap between photos can be calculated (Table 2). It is assumed here that only canopy in the lower three quarters of a tree's height will be visible in the canopy closure images, and that overlap between the top quarter of the crown of adjacent trees can be ignored. Based on these calculations, recommended image spacings are outlined in Table 3.

Table 2. Minimum distance required between images required to avoid overlap between photos

Tree height (m)	Minimum distance between images (m)
6	1.38
8	1.85
10	2.31
12	2.77
14	3.23
16	3.69
18	4.15
20	4.62
22	5.08
24	5.54
26	6.00
28	6.46
30	6.92
32	7.38
34	7.85
36	8.31
38	8.77
40	9.23

Table 3. Recommended distances between canopy closure images

Mean stand height (m)	Recommended distance between images (m)
<8 m	2 m
8-12 m	3 m
12-18 m	4 m
18-22 m	5 m
22-26 m	6 m
26-30 m	7 m
>30 m	8 m

It is also recommended that that the star shaped pattern used to mark out the position for each image be reduced to six radii, rather than the original eight (Figure 13). This will ensure no overlap between the inner ring of images, as the distance between these images will be the same as the distance between images along a single radius.

The design illustrated in Figure 13 would be suitable for stands less than 22-26 m tall, with predicted canopy closure greater than 75% (i.e. 13 images is approximately equal to the guideline of 15 images for stands with greater than 75% canopy closure). If predicted canopy closure were less than 75%, more images would be added by adding more rings at 6 m intervals. If mean stand height were lower, the rings could be more closely spaced. That is, the number of rings of images will be determined by the required sample size, and the spacing between rings will be determined by the mean height of the stand.

It should be noted however that the distance between images may be *greater* than the recommended minimum in many cases, in order to ensure that images are taken from different locations across the PSP, not just all from one small part. The purpose of setting a minimum distance between images is to fit as many independent images as possible into the PSP area when a large sample size is required.

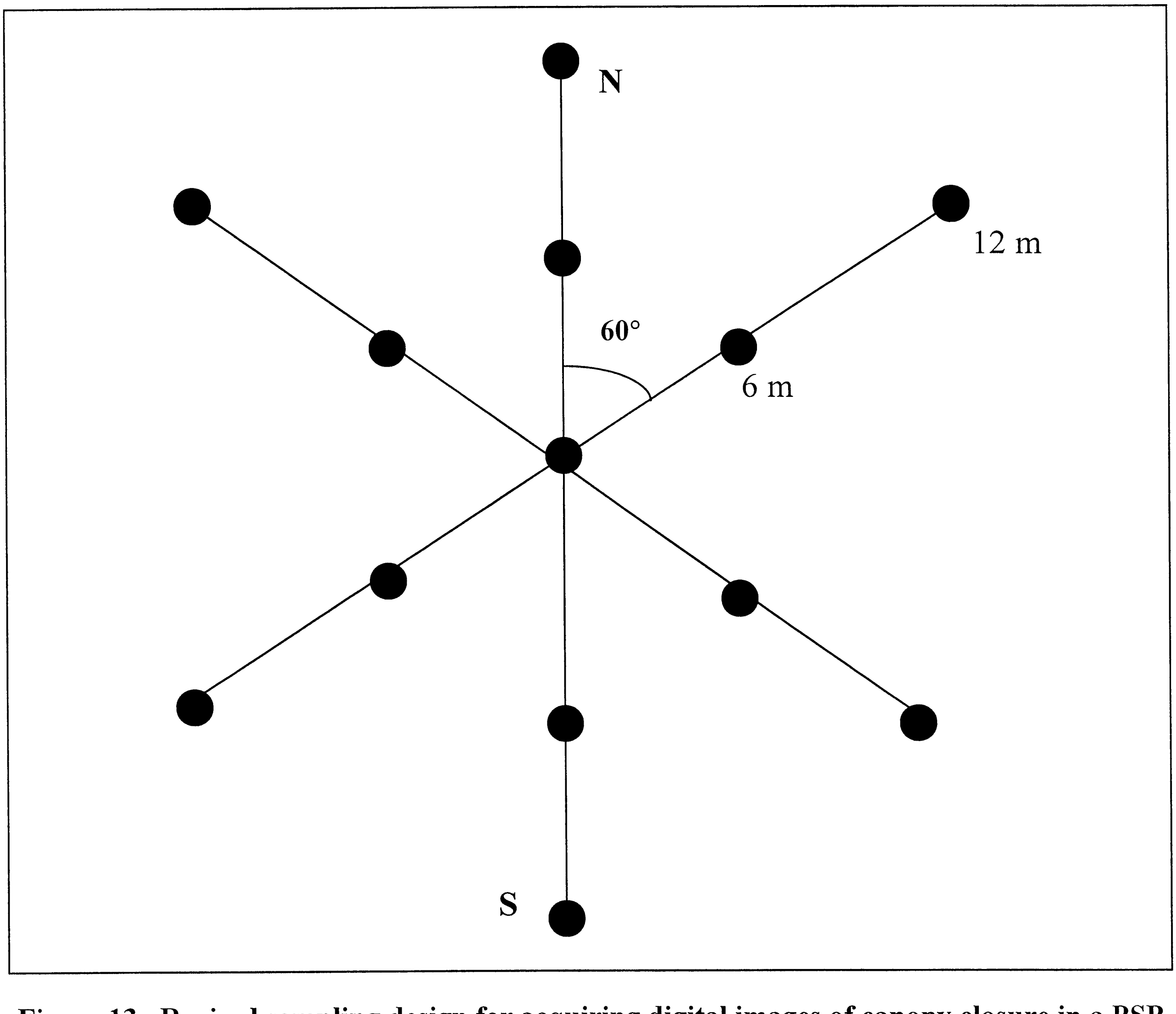

Figure 13. Revised sampling design for acquiring digital images of canopy closure in a PSP plot

4. Discussion

Overall, the fit of the radiata pine canopy closure model is quite good and the East Coast data appears to be consistent with data collected previously in the Bay of Plenty. There are however some minor factors which may help explain the residual variation. Firstly, it appears that in many cases the sample sizes used previously were insufficient to reduce the 90% confidence intervals to less than ± 10% canopy closure. Because of the magnitude of this random sampling error, a revised sampling methodology was recommended in the results section.

Also, genetics may have an impact on canopy closure, although there is insufficient data to quantitatively estimate this effect. For example, the data from Huanui Forest was from 12 plots in a genetic gains trial. Six plots were GF7 climbing select, while other six were comprised of GF14 '850' open pollinated (1 plot), GF16 '268' open pollinated (1 plot), and GF25 '268' control pollinated (4 plots). Measured canopy closure was between 5% and 25% greater than predicted canopy closure for all six GF7 plots (mean residual was +12.6%), while measured canopy closure was more than 2% greater than predicted canopy closure in only one of the other six plots (mean residual was -1.3%) (Table 4). While this is too small a sample to draw any firm conclusions from, it appears reasonable that superior genetic stock which are selected for good form and small branches may have lower canopy closure for a given basal area and height ratio than poor genetic stock.

Table 4. Residual canopy closure for Huanui Forest plots (calculated as actual canopy closure minus predicted canopy closure using the original model)

Plot	GF	Residual canopy closure (%)
1/11	25	10.26
6/12	25	0.48
11/15	25	1.66
16/17	25	-0.61
5/12	16	-3.74
3/12	14	-15.88
2/11	7	5.11
10/14	7	6.53
12/15	7	15.94
7/13	7	12.67
13/16	7	25.55
15/17	7	9.95

5. Conclusions

The original radiata pine canopy closure model provided relatively unbiased estimates of canopy closure in 30 plots from four forests on the East Coast of the North Island. However, the variance of the residuals was larger than the variance of the residuals from the original data set of 79 plots. The model was re-estimated to include the new data, resulting in only minor changes to the coefficients in the model. The fit of the new model is quite good (approximation of an $r^2 = 0.90$), although slightly poorer than the old model (approximation of an $r^2 = 0.92$).

As a result of an analysis of the confidence intervals around the estimates of canopy closure for each plot, amendments to the existing sampling methodology were recommended. These guidelines include a greater number of canopy images to be captured for stands of less than 75% canopy closure, and the use of a variable distance between images, depending on the mean height of the stand.

6. Acknowledgments

The author wishes to acknowledge the support of the Ministry of Agriculture and Forestry, and the Forest & Farm Plantation Management Cooperative.

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Appendix 1. Stand parameters for the 30 East Coast plots used to validate the canopy closure model for radiata pine

Forest	Experiment	Plot	GF rating	Age (yrs)	Stocking (sph)	Mean top height (m)	Mean Crown Height (m)	Height ratio	Basal area (m^2/ha)	Canopy closure (%)
Huanui	FR 121/7	1/11	25	8	77	12.2	2.1	0.1721	5.15	28.44
Huanui	FR 121/7	2/11	7	8	82	11.9	2.4	0.2017	5.82	25.23
Huanui	FR 121/7	5/12	16	8	153	10.9	1.7	0.1560	8.26	27.20
Huanui	FR 121/7	3/12	14	8	163	12.7	2.1	0.1654	12.41	28.71
Huanui	FR 121/7	10/14	7	8	173	12.4	0.8	0.0645	10.58	49.15
Huanui	FR 121/7	6/12	25	8	194	11.5	2.3	0.2000	14.18	48.59
Huanui	FR 121/7	12/15	7	8	329	13.3	1.5	0.1128	23.83	86.19
Huanui	FR 121/7	11/15	25	8	357	14.1	1.8	0.1277	26.67	74.75
Huanui	FR 121/7	7/13	7	8	400	11.9	2.0	0.1681	21.42	77.46
Huanui	FR 121/7	13/16	7	8	583	13.2	1.3	0.0985	17.63	86.05
Huanui	FR 121/7	15/17	7	8	800	13.3	2.0	0.1504	33.82	88.23
Huanui	FR 121/7	16/17	25	8	880	13.6	2.4	0.1765	36.06	78.37
Okiwa	HF 1206/0	2/0	17	6	463	10.1	3.8	0.3713	11.55	27.33
Okiwa	HF 1206/0	1/0	25	6	600	6.5	1.2	0.1862	6.54	18.04
Okiwa	HF 1206/0	4/0	17	6	638	8.2	2.4	0.2915	10.11	17.76
Patunamu	RO 1850/63	22/0	5	26	198	44.8	27.2	0.6071	54.19	71.13
Patunamu	RO 1850/68	36/0	7	24	240	41.7	21.8	0.5228	54.23	77.10
Patunamu	RO 1850/63	31/0	7	26	258	46.3	25.8	0.5572	59.61	75.90
Patunamu	RO 1850/68	35/0	14	10	395	15.5	6.8	0.4387	14.63	43.45
Patunamu	RO 1850/68	34/0	14	11	398	21.2	8.6	0.4057	25.33	77.38
Wharerata	RO 1850/62	28/0	14	17	212	24.8	8.2	0.3306	33.81	65.36
Wharerata	RO 1850/62	33/0	14	18	216	27.8	8.8	0.3165	49.68	79.52
Wharerata	RO 1850/62	31/0	14	17	225	22.7	7.0	0.3084	38.50	83.00
Wharerata	RO 1850/62	29/0	7	21	234	31.4	12.1	0.3854	54.03	87.29
Wharerata	RO 1850/62	32/0	7	21	235	30.0	11.5	0.3833	54.23	84.64
Wharerata	RO 1850/62	30/0	14	14	245	24.0	7.7	0.3208	45.00	79.23
Wharerata	RO 1850/62	34/0	14	18	262	30.2	12.6	0.4172	46.38	77.53
Wharerata	RO 1850/62	36/0	*	8	328	17.4	8.2	0.4684	17.48	57.33
Wharerata	RO 1850/62	35/0	7	20	348	35.5	17.9	0.5042	73.61	84.76
Wharerata	RO 1850/62	37/0	*	8	498	17.5	7.4	0.4200	19.30	55.76

* Value not recorded

Appendix 2. Stand parameters of 79 plots used for the estimation of the original canopy closure model for radiata pine

Location	Experiment	Plot	Mean top height (m)	Mean Crown Height (m)	Height ratio	Basal area (m2/ha)	Canopy closure (%)
Paengaroa	RO 2021/6	4/0	27.2	9.2	0.3433	29.74	70.91
Paengaroa	RO 2021/6	1/0	22.4	5.6	0.2500	19.80	56.40
Paengaroa	RO 2021/6	2/0	25.8	9.3	0.3605	28.80	64.10
Paengaroa	RO 2021/6	3/0	26.6	9.4	0.3715	37.10	72.20
Paengaroa	RO 2021/6	*4/0	29.5	10.4	0.3574	31.90	74.19
Paengaroa	RO 2021/6	*5/0	29.5	12.3	0.4184	44.15	76.63
Paengaroa	RO 2021/6	*6/0	29.4	12.8	0.4444	50.95	80.71
Paengaroa	RO 2021/6	*7/0	32.2	14.7	0.4594	43.08	80.66
Paengaroa	RO 2021/6	*8/0	34.3	17.5	0.5147	55.78	82.71
Paengaroa	RO 2021/6	*4/0	30.7	11.4	0.3826	34.20	78.70
Kaharoa	FR 186/0	*1/4	16.5	6.1	0.3697	14.20	57.78
Kaharoa	FR 186/0	*2/3	15.3	9.5	0.6209	9.16	16.00
Kaharoa	FR 186/0	*1/1	17.7	6.2	0.3543	16.35	46.44
Kaharoa	FR 186/0	*1/2	18.3	6.2	0.3407	15.63	36.85
Kaharoa	FR 186/0	*1/3	18.5	6.0	0.3279	17.42	43.89
Kaharoa	FR 186/0	*1/4	19.3	6.1	0.3177	16.81	62.56
Kaharoa	FR 186/0	*2/1	16.7	11.0	0.6587	10.43	17.70
Kaharoa	FR 186/0	*2/2	17.6	12.1	0.6914	10.66	13.79
Kaharoa	FR 186/0	*2/3	18.0	11.6	0.6444	10.70	19.59
Kaharoa	FR 186/0	*2/4	18.4	12.2	0.6630	10.71	19.03
Kaharoa	FR 186/0	*1/1	18.8	6.3	0.3443	19.40	52.00
Kaharoa	FR 186/0	*1/2	19.0	6.2	0.3425	18.40	51.00
Kaharoa	FR 186/0	*1/3	20.0	6.0	0.3125	20.10	71.70
Kaharoa	FR 186/0	*1/4	19.5	6.1	0.3128	19.40	53.50
Kaharoa	FR 186/0	*2/1	17.7	12.4	0.7086	11.00	9.70
Kaharoa	FR 186/0	*2/2	18.8	12.9	0.6973	11.50	13.50
Kaharoa	FR 186/0	*2/3	18.4	13.0	0.3476	11.60	11.80
Kaharoa	FR 186/0	*2/4	19.1	12.5	0.6545	11.50	16.20
Kaingaroa	RO 1891/2	*2/1	22.4	8.7	0.3973	27.01	54.00
Kaingaroa	RO 1891/4	*1/1	24.1	10.4	0.4643	34.65	63.89
Kaingaroa	RO 1891/1	*3/1	21.9	5.8	0.2648	16.25	52.82
Kaingaroa	RO 1891/1	*1/1	23.6	6.0	0.2542	20.07	54.36
Kaingaroa	RO 1891/1	*1/2	22.9	6.6	0.2882	17.51	49.16
Kaingaroa	RO 1891/2	*1/1	23.8	7.9	0.3391	30.23	67.80
Kaingaroa	RO 1891/2	*1/2	26.3	9.6	0.3735	25.45	56.60
Kaingaroa	RO 1891/2	*2/1	25.2	9.0	0.3644	29.09	60.31
Kaingaroa	RO 1891/2	*2/2	25.3	7.7	0.3092	22.58	47.15
Kaingaroa	RO 1891/4	*1/1	26.6	10.8	0.4372	36.24	69.13
Kaingaroa	RO 1891/4	*1/2	26.4	10.8	0.4286	37.25	73.12
Kaharoa	RO 2036/0	*1/3	18.4	6.9	0.3876	42.01	62.90
Kaharoa	RO 2036/0	*2/1	19.9	6.8	0.3560	43.97	80.82
Paengaroa	FR 133/3	*3/1	18.1	5.9	0.3450	27.92	67.43
Paengaroa	FR 133/2	*2/2	18.4	6.5	0.3591	17.03	54.16
Paengaroa	FR 133/4	*2/3	17.8	6.2	0.3626	14.71	55.58
Paengaroa	FR 133/3	*3/4	18.0	5.9	0.3333	28.09	60.18
Paengaroa	FR 133/0	*0/5	17.4	6.1	0.3547	20.53	53.82
Paengaroa	FR 133/3	*3/6	18.4	6.6	0.3750	16.07	40.33
Paengaroa	FR 133/3	*5/7	20.5	8.8	0.4467	36.96	75.09
Paengaroa	FR 133/5	*3/8	19.6	7.9	0.4136	14.19	41.66

Location	Experiment	Plot	Mean top height (m)	Mean Crown Height (m)	Height ratio	Basal area (m2/ha)	Canopy closure (%)
Paengaroa	FR 133/0	*0/9	18.1	6.1	0.3466	20.29	50.03
Paengaroa	FR 133/2	*4/10	18.5	6.5	0.3552	28.28	71.58
Paengaroa	FR 133/0	*0/11	16.9	5.6	0.3478	19.01	52.00
Paengaroa	FR 133/1	*3/12	19.1	6.3	0.3316	26.24	64.87
Paengaroa	FR 133/3	*3/13	18.4	6.7	0.3964	33.93	57.89
Paengaroa	FR 133/3	*3/14	19.0	7.7	0.4208	35.40	80.07
Paengaroa	FR 133/4	*4/15	18.9	6.1	0.3389	26.14	62.30
Paengaroa	FR 133/3	*1/16	18.2	6.4	0.3556	20.11	55.22
Paengaroa	FR 133/5	*3/8	22.4	7.2	0.3318	17.50	51.40
Paengaroa	FR 133/3	*3/14	20.7	6.8	0.3350	19.70	58.40
Tikitere	RO 382	*8/1	39.8	24.0	0.6250	81.40	77.15
Tikitere	RO 382	*8/3	37.3	23.1	0.6381	72.80	85.36
Tikitere	RO 382	*9/3	38.4	20.4	0.5795	62.20	82.74
Tikitere	RO 382	*22/2	39.1	23.1	0.6260	84.90	80.76
Tikitere	RO 382	*22/4	40.6	24.6	0.6525	79.10	82.16
Tikitere	RO 382	*23/4	39.1	22.7	0.6070	67.30	78.72
Tikitere	RO 382	*6/2	36.4	19.0	0.5539	62.30	83.25
Tikitere	RO 382	*6/4	35.4	19.2	0.5697	48.70	76.50
Tikitere	RO 382	*8/4	38.0	23.7	0.6270	63.40	80.35
Tikitere	RO 382	*2/3	37.1	22.9	0.6274	49.40	73.27
Kaingaroa	FR 274/3	*3/1	11.3	5.0	0.4854	13.30	26.50
Kaingaroa	FR 274/0	*0/2	10.5	4.5	0.4500	8.90	12.00
Kaingaroa	FR 274/2	*2/4	10.4	4.3	0.4343	10.90	33.90
Kaingaroa	FR 274/3	*3/5	11.4	4.8	0.4706	13.30	33.80
Kaingaroa	FR 274/3	*3/6	11.1	4.5	0.4500	11.60	30.40
Kaingaroa	FR 274/4	*2/7	11.4	4.7	0.4393	16.20	39.70
Kaingaroa	FR 274/3	*3/8	10.7	4.3	0.4257	12.40	33.20
Kaingaroa	FR 274/5	*3/9	10.4	3.8	0.4043	12.10	46.10
Kaingaroa	FR 274/1	*3/12	11.2	5.0	0.4808	9.40	21.80
Kaingaroa	FR 274/3	*5/13	10.4	4.0	0.4167	9.90	32.30