PREDICTING GREEN CROWN LENGTH IN RADIATA PINE

J. Turner

Report No. 51 May 1998

FOREST & FARM PLANTATION MANAGEMENT COOPERATIVE

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EXECUTIVE SUMMARY

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Accurate prediction of green crown length and, hence, green crown height is useful in the prediction of the occurrence of bark encased knots, and therefore aids scheduling of thinning and pruning. Crown length is also an important variable in the prediction of basal area increment in the Early Growth Model. Since the present crown length model was developed *Dothistroma pini* has become widespread. The availability of crown length measurements made over successive years in spacing trials provides useful data for refitting the original crown length model. A linear stepwise regression was developed which models pre and post-canopy closure average crown length as:

C_L = *minimum* ($C_{L(pre}$, $C_{L(post)}$) where $C_{L(pre)}$ is the average crown length before canopy closure and is calculated as:
$C_{L(pre)} = 0.71(MTH-0.1)$ where MTH is plot mean top height.
And $C_{L(post)}$ is the average crown length at canopy closure and is calculated as:
$C_{L(post)} = 13.48+598.63SPH^{-1}$ where SPH is the crop stocking
The effect of pruning and thinning on crown length is calculated as:
$C_{L(thin)} = minimum\ (C_{L(pre)}, H-C_{H(thin)}, H-C_{H(prune)})$ where H is the stand average height, $C_{H(prune)}$
Is the average crown height due to pruning, ie, pruned height, and $C_{H(thin)}$ is the crown height at thinning. If crown height was not measured at thinning, it is calculated as:
$C_{H(thin)} = \text{maximum}\ (H-C_{L(pre)}, H-C_{L(post)})$.

This national level model is a better predictor of crown length than the present model with an R^2 of 0.93 compared with 0.88. The revised model shows a bias in estimates of crown length for Golden Downs and East Coast forests. Future work will attempt to account for this bias in the revised model.

Introduction

Green crown length is used as a driving variable in the prediction of basal area increment in the Early Growth model (West *et al.* 1982). The present refit of the Early Growth model utilises the wealth of growth data collected from trials and PSPs and stored in the ***Forest Research*** PSP System. Not all plot measurements, however, include estimates of crown length, therefore it is necessary to predict crown length for these measurements. Accurate prediction of green crown height is also useful in enabling prediction of the occurrence of bark encased knots in logs (Beekhuis 1965), and thus aids decisions regarding timing of thinning and pruning.

Beekhuis (1965) showed stand maximum green crown length[1] to be dependent on the stocking and height of a stand. Since the development of this model there has been considerable expansion of the crown length data set and collection of crown length data over successive years from spacing trials (Maclaren 1988). This trial data allows the opportunity to explore the relationship between stand height and green crown length as it is influenced by stocking, and also how this relationship differs among site types. Also since the work by Beekhuis (1965) *Dothistroma pini* has become widespread in New Zealand radiata pine forests, and has been identified in a study by Woollons and Hayward (1984) as leading to a reduction in green crown length.

Method

Crown Length Dataset

Green crown height is defined as the position on the stem which is midway between the insertion point of the lowest green branch and the lowest whorl that has a majority of green branches (Ellis & Hayes 1997). Crown height isgenerally measured on sample height trees (Ellis & Hayes 1997). The green crown height on an unpruned tree with green crown to ground level is recorded as 0.1 m (Ellis & Hayes 1997). Crown length, rather than crown height is modelled, as the depth of green crown remains relatively constant once full canopy closure has been reached, while green crown height continues to increase as the stand grows taller (Beekhuis 1965). Crown length is calculated as either mean top height[2]/ predominant mean height[3] minus plot average crown height, which represents the maximum crown length of the plot, or plot average tree height minus plot average crown which represents the average crown length.

The use of mean top height (MTH) to calculate crown length is preferred as the use of the plot average height does not necessarily reflect the stand average height as trees would have to be selected in the right proportion from each height class (Beekhuis 1965). Using plot MTH rather than plot average height to calculate maximum crown length (Beekhuis 1965), however, assumes that individual tree crown height is not related to tree diameter. An analysis of variance (ANOVA) was performed to compare the average crown height of predominant height trees[4] with the average crown height of sample trees. For the three trials analysed, two, Kaingaroa and Woodhill, showed a strongly significant ($p=0.01$) difference in average height to the base of green crown between predominant height trees and sample trees. While this result is counter to that of Beekhuis (1965) it agrees with a study of individual tree crown length made by Zybura (1987) who found crown

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[1] Caculated as predominant mean height minus average crown height (Beekhuis 1965).

[2] This is defined as the height predicted by the Petterson height/ dbh curve for a dbh corresponding to the quadratic mean of the 100 largest trees per hectare (based on dbh) in a stand (Goulding 1995).

[3] The average height of the tallest tree, free of malformation, in each 0.01 ha plot within the stand (Goulding 1995)

[4] A predominant height tree is the tallest in each 0.01 ha quadrant of the permanent sample plot (Ellis & Hayes 1997).

length in pine trees was related to tree age, biosocial position (described using Kraft classes), and site quality. If the number of predominant trees varies among plots then the use of MTH to calculate crown length will underpredict crown length in plots with a high number of predominant trees. Plot average crown length rather than maximum crown length was, therefore, used in the development of the revised crown length model, while Beekhuis' (1965) model predicted maximum green crown length.

Mean top height, where not measured, was calculated from predominant mean heights by (Burkhart & Tennent 1977):

$$MTH = -0.3533+1.0179PMH.$$

This equation was also used to calculate PMH where no measured estimate was available.

The development of the green crown in a stand is confounded by the various thinning and pruning treatments applied to that stand. To accurately model the effect of stand stocking and height on green crown length, regime effects need to be removed. Beekhuis (1965) assumed that crown height would remain at the same level for approximately 5 years following thinning, before beginning to rise. Beekhuis (1965), therefore removed all crown length data within 5 years of thinning. In the dataset used to develop the revised crown length model, crown lengths influenced by pruning and thinning were not removed but incorporated into the model. The revised model was therefore fitted to a larger dataset than that used to check the fit of the Beekhuis (1965) model. Crown length data was obtained from the ***Forest Research*** PSP System. Twenty trials, covering twelve sites, were chosen from a series of spacing trials (Maclaren 1988) which covered a range of mean top heights, stockings and site types (Table 1).

Table 1: Sites used to fit new crown length model. Count refers to the number of plot crown length measurements made in each forest.

Forest	Count	Average Crown Length (m)			Mean Top Height (m)			Stocking (stems/ ha)		
		Average	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.
Auckland Sands										
Aupouri	54	12.0	6.9	19.0	18.9	11.7	30.5	268	50	601
Woodhill	210	13.8	9.1	20.3	21.0	14.7	30.0	346	90	700
Low BA Inc. Sites										
Eyrewell	216	12.1	7.4	20.3	16.5	10.2	25.3	358	80	600
Golden Downs	240	14.2	5.9	25.0	21.6	12.5	33.1	345	90	675
Hawke's Bay										
Gwavas	34	18.3	14.3	22.1	17.6	4.5	36.9	727	198	2488
Mohaka	242	14.7	2.7	23.2	20.3	3.1	38.6	411	87	1621
Central North Island										
Kaingaroa	408	15.0	9.0	20.9	27.0	6.7	45	327	75	1483
Tarawera	485	13.1	8.8	20.3	31.3	11.6	50.8	700	181	5239
Otago										
Otago Coast	42	13.6	7.9	19.6	13.8	3.8	27.6	241	80	800
Fertile Farm Sites										
Tikiteri	542	15.9	3.4	23.4	17.5	2.4	44.6	199	40	800
Waratah	65	16.0	13.1	20.1	27.9	10.7	46.2	193	165	214
Whatawhata	62	18.3	14.8	22.9	18.6	4.3	37.1	254	83	800
Total Plot Measurements	2600									

Analysis

Plots of average crown length against mean top height were made by measurement plot for several of the trials analysed to identify trends in crown length with stocking and mean top height. From the exploration of plots a linear stepwise regression model was fitted using PROC NLIN in the SAS System (SAS Institute Inc. 1986). The revised model was compared with the original Beekhuis (1965) crown length model, and the Beekhuis (1965) model refitted to the same dataset, by comparing mean square errors (MSE), coefficients of determination (R^2) and residual (actual - predicted) plots.

To identify influences on the fit of the revised model to individual sites, residuals were plotted against site index, basal area, and precentage canopy closure. Percentage canopy closure was calculated from the following equation(Horvath 1998):

$$CC = a(1 - e^{bBA(1+c((C_H / H)-0.4))})^{1/d} \qquad \text{[Equation 1]}$$

where a, b, c and d are model parameters;
CC = canopy closure (%);
BA = stand basal area (m^2);
C_H = stand average crown height (m);
H = stand average height (m).

Results and Discussion

Plots of maximum green crown length against mean top height (Figure 1 and Figure 2) show a clear trend in green crown length for each stocking. Crown length for each stocking follows a curvilinear relationship with mean top height. The maximum achievable crown length for each stocking differs, with lower stockings having a higher maximum achievable crown length (Figure 1 and Figure 2). The relationship between stocking and maximum achievable crown length appears to agree with the relationship identified in previous studies (van Laar 1963; Beekhuis 1965; Incoll & Baker 1980; van Laar 1982; Woollons & Hayward 1984; Madgwick & Oliver 1985). Green crown length is related to stocking curvilinearily by the equation:

$$C_L = a + bSPH^{-0.5}$$

where a and b vary with locality (Beekhuis 1965).

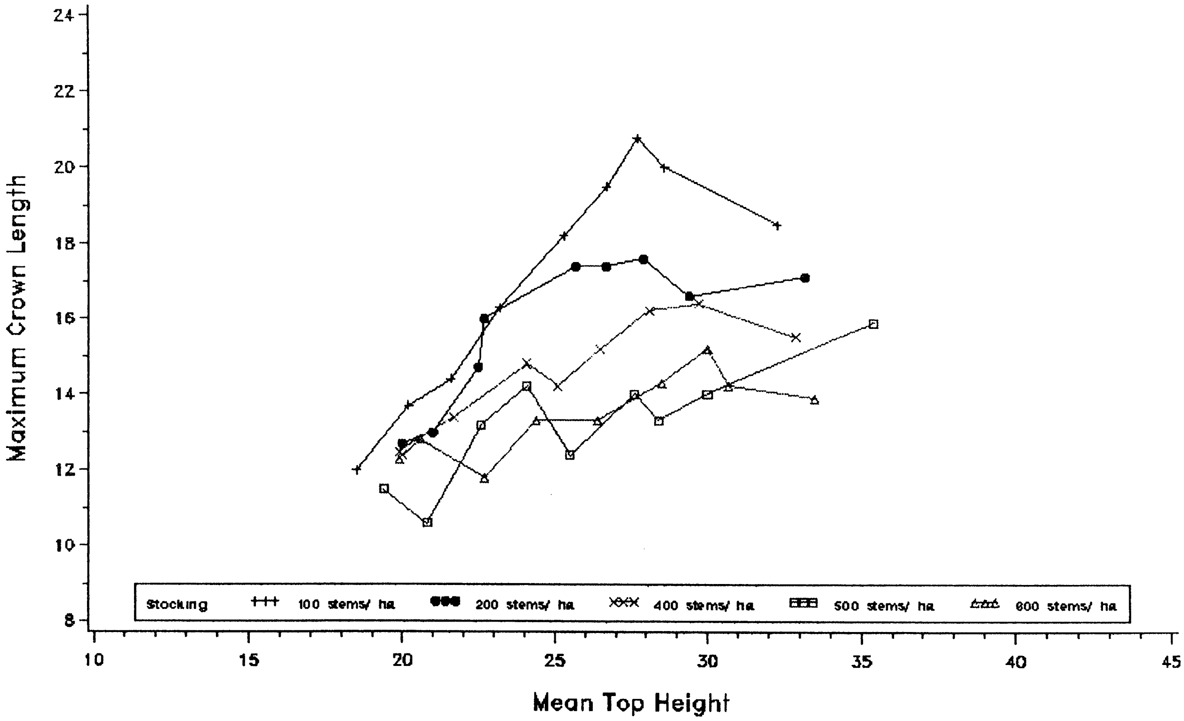

Figure 1: Maximum crown length (m) against mean top height (m) for five plots at different crop stockings in the Kaingaroa Spacing Trial (RO2098_0.)

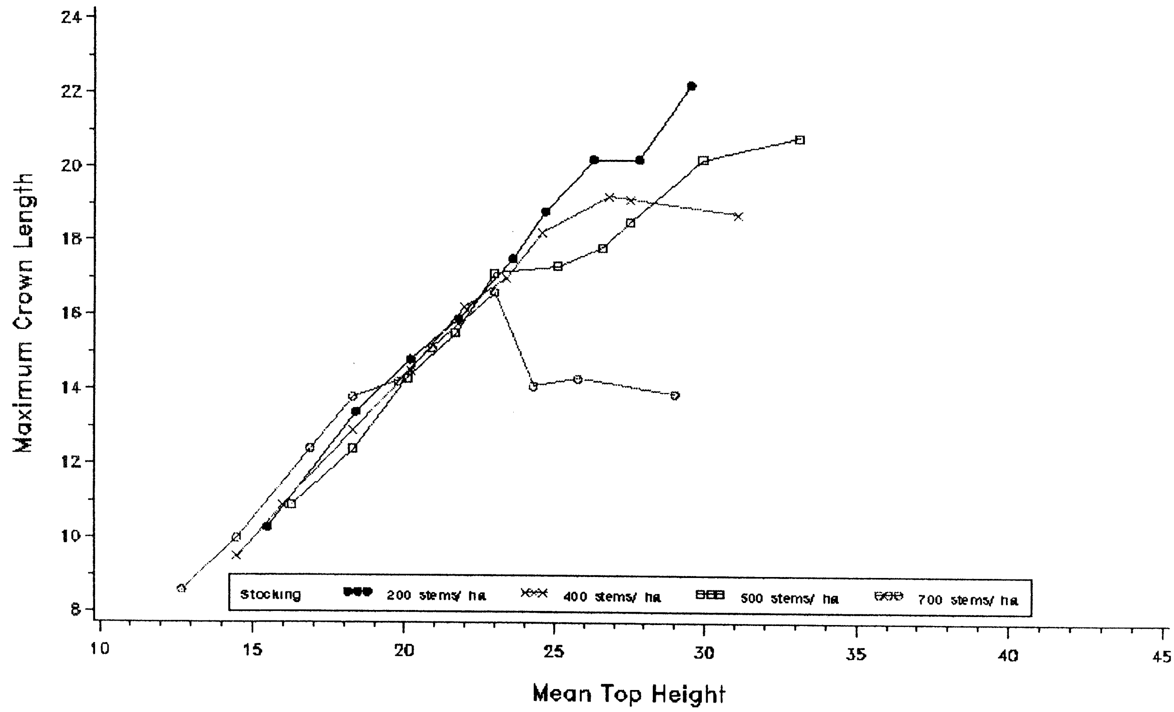

Figure 2: Maximum crown length (m) against mean top height (m) for four plots at different crop stockings in the Golden Downs Spacing Trial (NN529_1.)

Beekhuis Model

The original green crown length model developed by Beekhuis (1965) is (O.P. Garcia pers. comm.):

$$C_L = 14.8116PMH^{0.2837} \times SPH^{-0.1467} \qquad \text{[Equation 2]}$$

where C_L = maximum crown length (m), ie., predominant mean height minus plot average crown height;

PMH = predominant mean height (m);

SPH = stocking (stems/ ha).

This model shows an excellent fit against the data, with an R^2 of 0.88 and a mean square error (MSE) of 4.195. Refitting the form of the Beekhuis (1965) model to the dataset gives a green crown length model of:

$$C_L = 15.6346PMH^{0.1888} \times SPH^{-0.1059} \qquad \text{[Equation 3]}$$

with an R^2 of 0.91 and a mean square error (MSE) of 3.252.

The differences between actual and predicted values (residuals) from the original Beekhuis (1965) model [Equation 2], plotted against predicted crown length, mean top height, and stocking show conditions under which error increases or bias is introduced. Figure 3 shows the errors in prediction of maximum green crown length. Based on this plot, the error in predicting average crown length using Equation 2 can be expected to fall within ±5 m. There are no obvious biases or trends in residuals for any of the sites when plotted against mean top height (Figure 4), stocking (Figure 5), canopy closure (Figure 6), basal area (Figure 7) and site index (Figure 8).

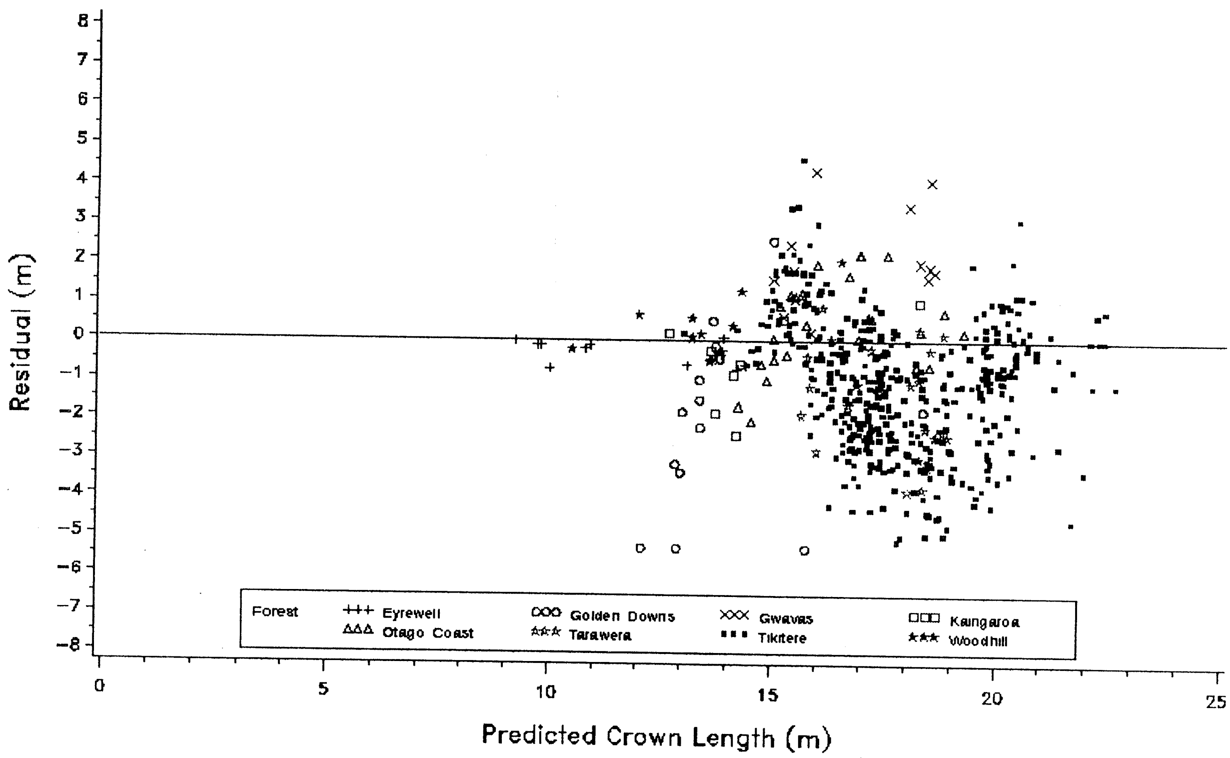

Figure 3: Residuals against predicted average crown length (m), by forest.

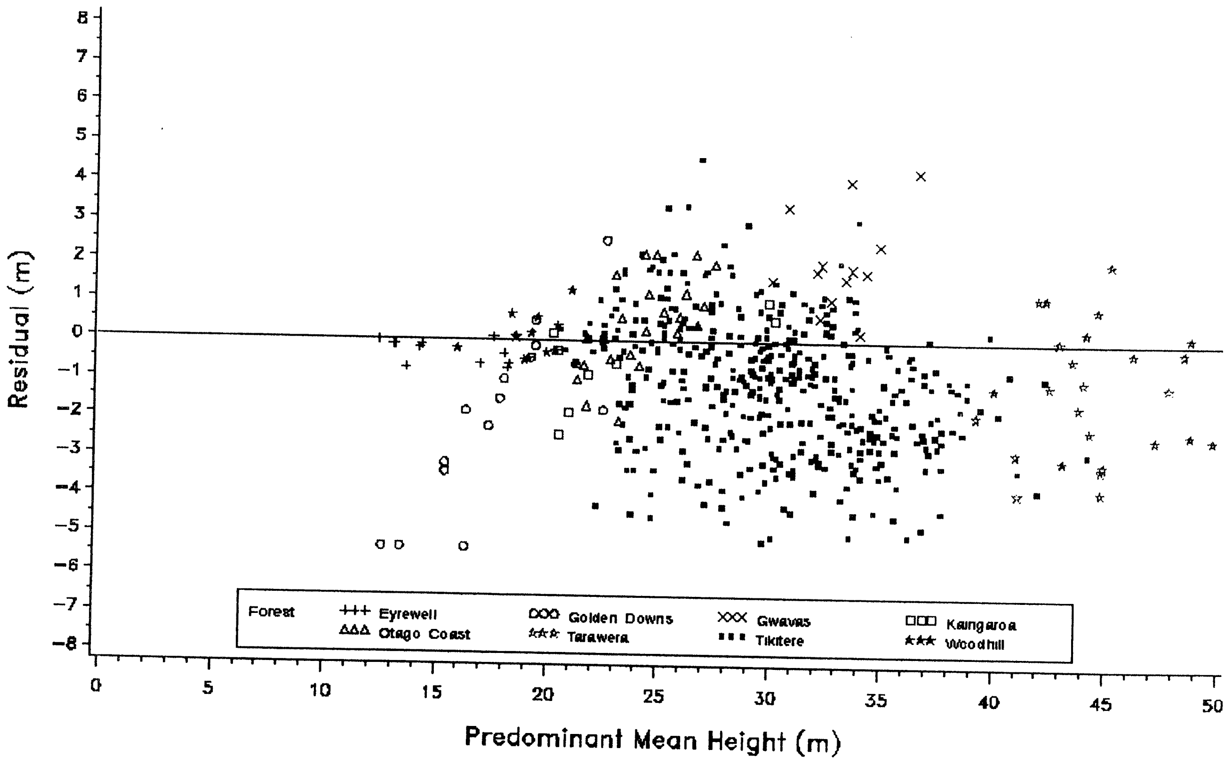

Figure 4: Residuals against predominant mean height (m), by forest.

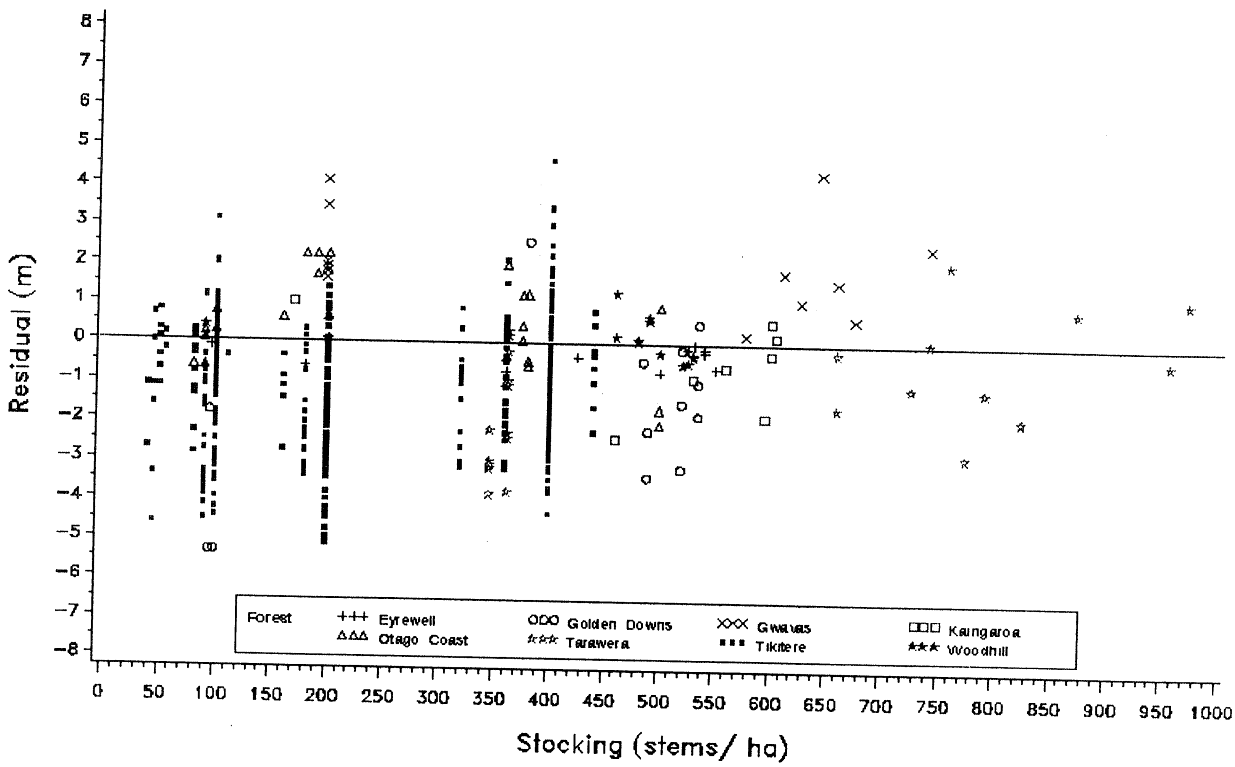

Figure 5: Residuals against stocking (stems/ ha), by forest.

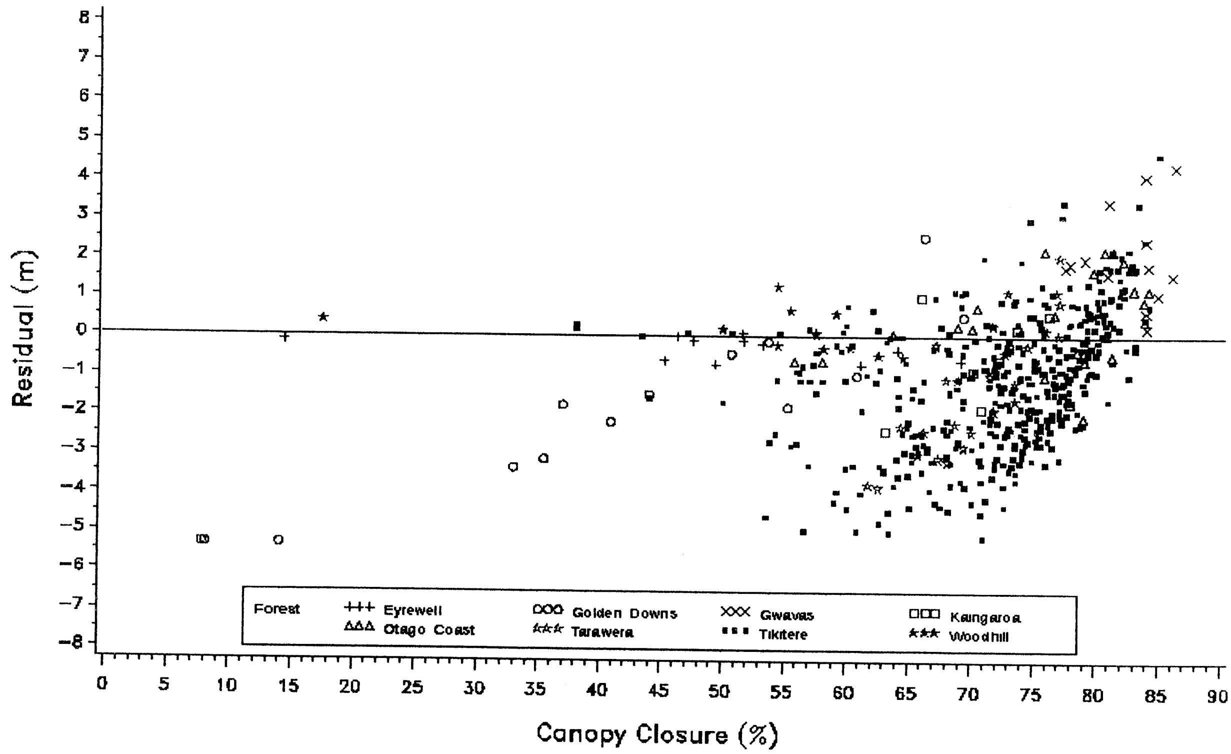

Figure 6: Residuals against canopy closure (%), by forest.

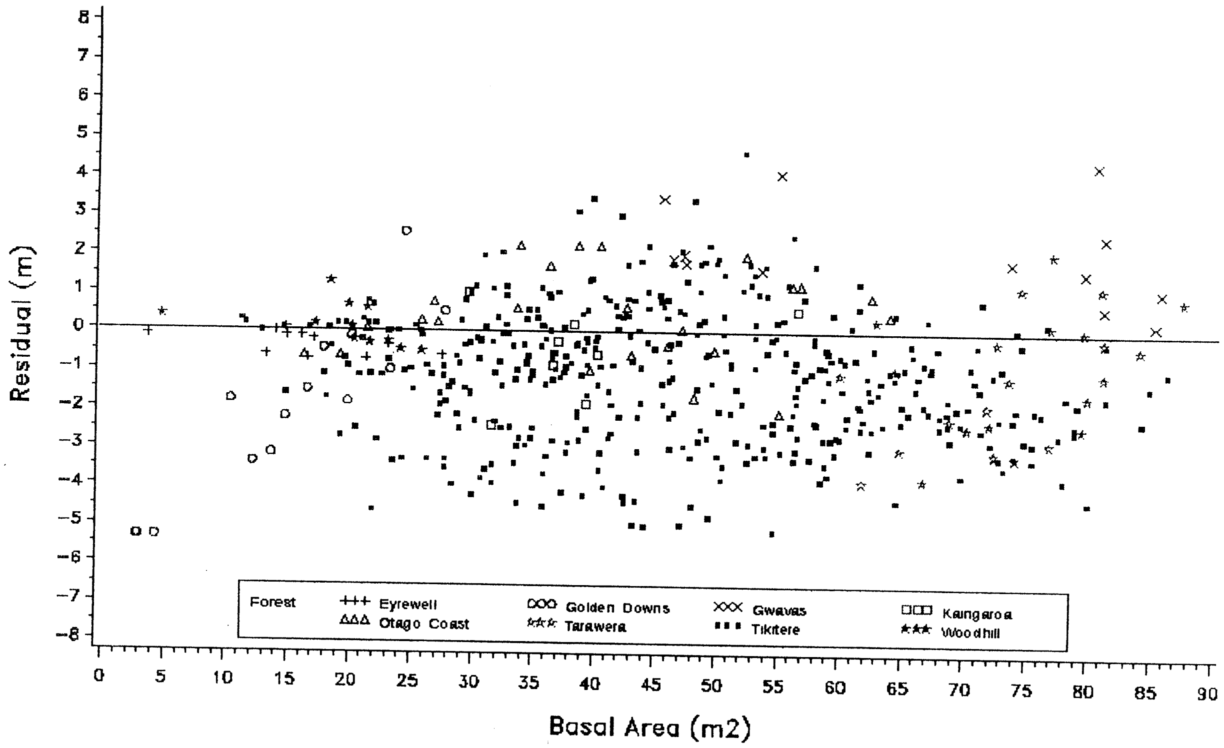

Figure 7: Residuals against basal area (m^2), by forest.

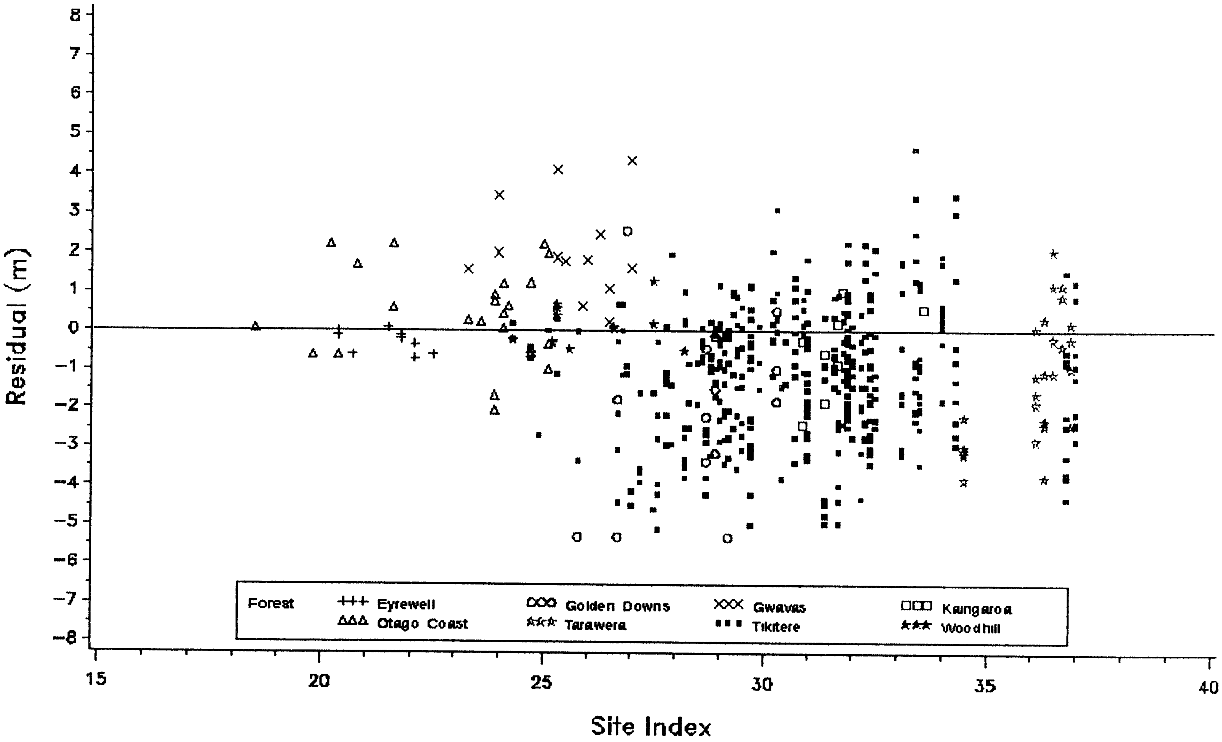

Figure 8: Residuals against site index, by forest.

Revised Crown Length Model

Average green crown length is calculated as (Figure 9):

$C_L = minimum(C_{L(pre)}, C_{L(post)})$ [Equation 4], where $C_{L(pre)}$ is the average crown length before canopy closure and is calculated as:

$C_{L(pre)} = k(MTH-0.1)$ where k is a model parameter (Table 2) and MTH is plot mean top height;

and $C_{L(post)}$ is the average crown length at canopy closure and is calculated as:

$C_{L(post)} = a+bSPH^{-1}$ where a and b are model parameters (Table 2).

The effect of pruning and thinning on crown length is calculated as:

$C_{L(thin)} = minimum(C_{L(pre)}, H-C_{H(thin)}, H-C_{H(prune)})$ where H is the stand average height, $C_{H(prune)}$ is the average crown height due to pruning, ie., pruned height,

and $C_{H(thin)}$ is the crown height at thinning. If crown height was not measured at thinning, it is calculated as:

$C_{H(thin)} = maximum(H- C_{L(pre)}, H- C_{L(post)})$.

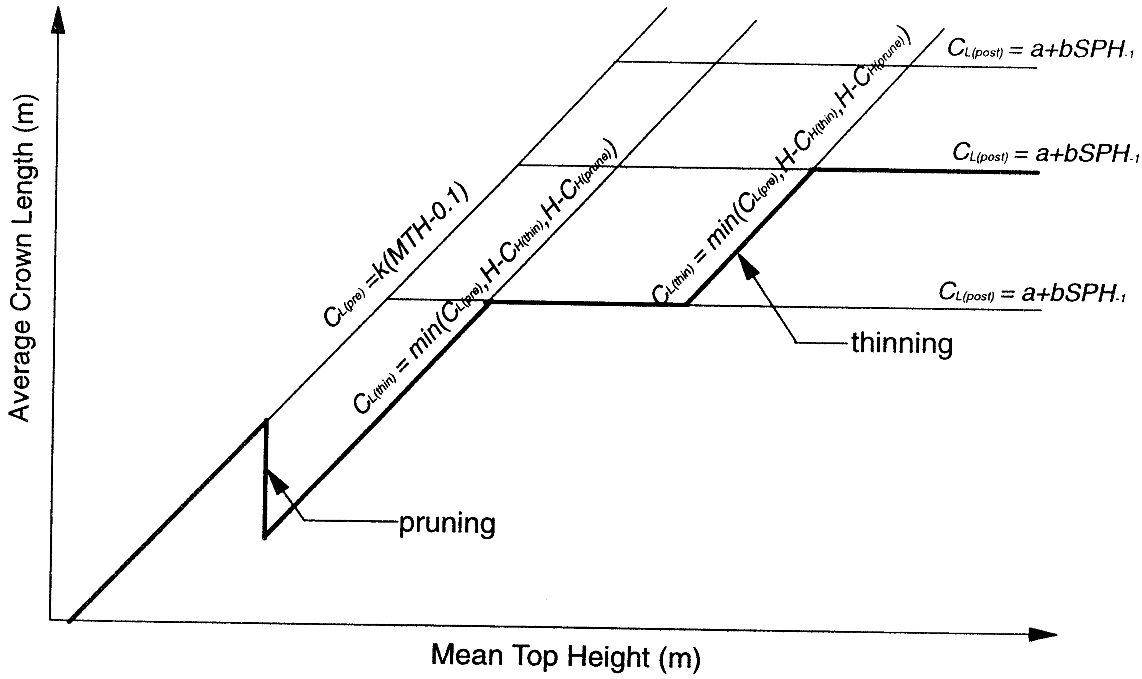

Figure 9: Steps in the progression of stand crown length from pre-canopy closure to post-canopy closure with pruning and thinning treatments. Each step is represented by a separate equation in the revised crown length model.

Table 2: Revised crown length model parameter estimates, and asymptotic standard errors for parameter estimates.

Parameter	Estimate	Standard Error
a	13.48	0.0893
b	598.63	19.9690
k	0.71	0.0036

When the revised crown length model is fitted to the same data as that used to test the fit of the original Beekhuis (1965) model, there is an improved fit with an R^2 of 0.93 and a MSE of 2.902. Fitting the model to the complete dataset (Table 2) from 12 forests shows a good fit with an R^2 of 0.76 and a MSE of 3.034.

When the new model is fitted to individual forest data there is a large difference in the mean square errors among the sites (Table 3). The model is a good predictor of average green crown length for most sites except for Golden Downs, Gwavas and Mohaka which have high mean square errors. Comparison of the fit of the Beekhuis model and the revised model to individual site data (as shown in the final two columns of (Table 3) shows both models are poor predictors of crown length for certain sites. The Beekhuis (1965) model is a particularly poor predictor of crown length for the farm sites in the dataset.

Table 3: Revised crown length model parameter estimates and model mean square errors for individual sites. The mean square errors have been calculated for crown length models fitted to the individual sites, the overall model, the Beekhuis model, and the new model fitted to the Beekhuis data set.

Forest	Count	Parameter Estimates			Mean Square Errors			
		a	b	k	Individual	Overall	Beekhuis	New
Auckland Sands								
Aupouri	54	9.22	1758.03	0.67	0.8649	2.0726	2.5860	3.8081
Woodhill	210	11.18	1318.62	0.74	0.4868	0.7188	0.4264	0.2537
Low BA Inc. Sites								
Eyrewell	216	10.18	1567.16	0.79	0.2240	0.5543	0.2361	0.4235
Golden Downs	240	9.25	3580.06	0.69	2.2954	5.0932	11.5644	5.7056
Hawke's Bay								
Gwavas	34	15.35	960.58	0.73	1.3528	8.2507	7.5738	12.1527
Mohaka	242	8.85	3039.40	0.73	1.8580	6.1047	5.5993	8.4893
Central North Island								
Kaingaroa	408	10.60	1240.15	0.66	2.0067	2.7675	3.1738	3.8000
Tarawera	485	13.07	769.72	0.73	2.2008	2.2278	5.0774	3.6563
Otago								
Otago Coast	42	10.23	1631.35	0.81	0.5075	1.4942	1.7625	3.0964
Fertile Farm Sites								
Tikiteri	542	12.61	583.75	0.68	1.7720	2.4971	4.1334	3.1430
Waratah	65	12.97	558.88	0.62	1.6144	2.0009	29.8982	2.5622
Whatawhata	62	14.77	608.42	0.69	1.1854	2.2448	3.2121	2.3626

The differences between actual and predicted values (residuals) were then plotted against predicted crown length, mean top height, and stocking to look for conditions under which error increased or bias was introduced. Figure 10 shows the errors in prediction of average green crown length. Based on this plot, the error in predicting average crown length using Equation 4 can be expected to fall within ± 5 m. The model appears to under-predict crown length at higher crown lengths for both Golden Downs and Gwavas (Figure 10). The under-prediction of crown length for these two sites is also apparent at higher mean top heights and stockings (Figure 11 and Figure 12) suggesting that trees on these sites may be able to hold their crowns, for a given stocking and mean top height, for longer than trees at the other sites studied. There is no apparent relationship between the residuals and level of canopy closure (Figure 13), basal area (Figure 14), or site index (Figure 15) suggesting that differences in the crown length model among sites is not due to these factors. There is, however, a slight trend in the residuals for Golden Downs and Gwavas when plotted against canopy closure (Figure 13) where crown length appears to be under-predicted at high canopy closure. This suggests that these sites are able to retain crowns for longer at canopy closure.

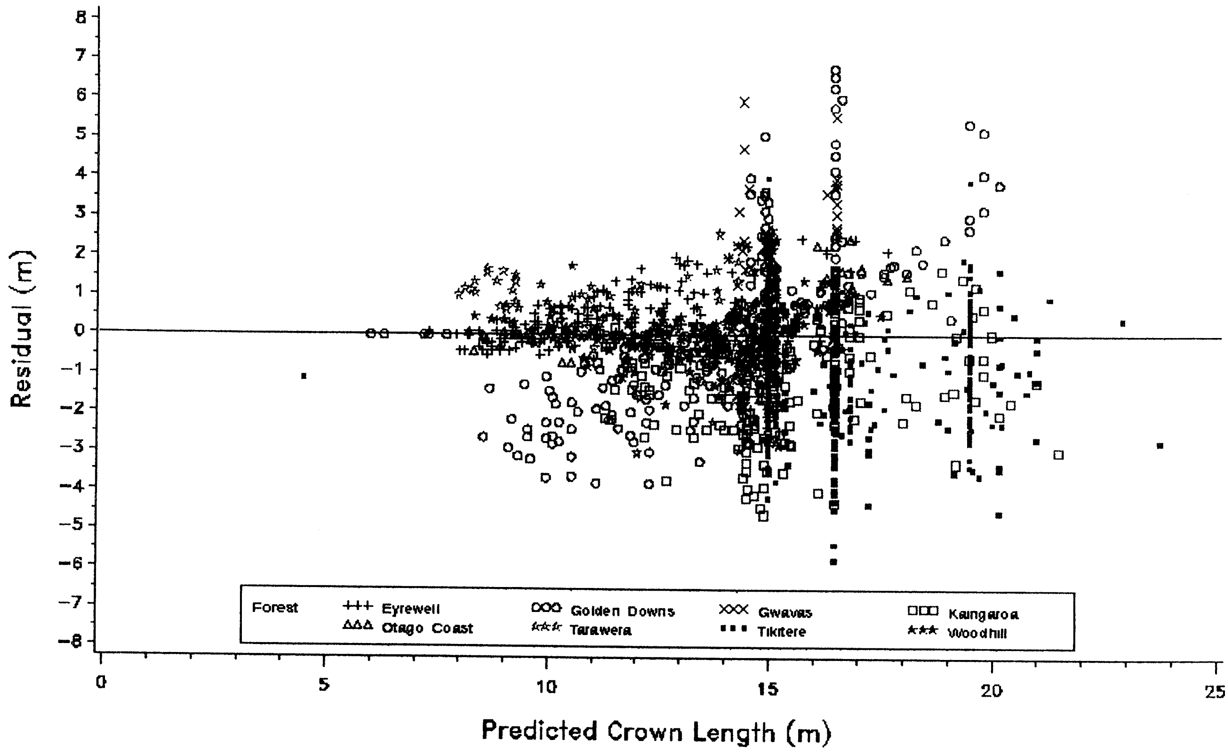

Figure 10: Residuals against predicted average crown length (m), by forest.

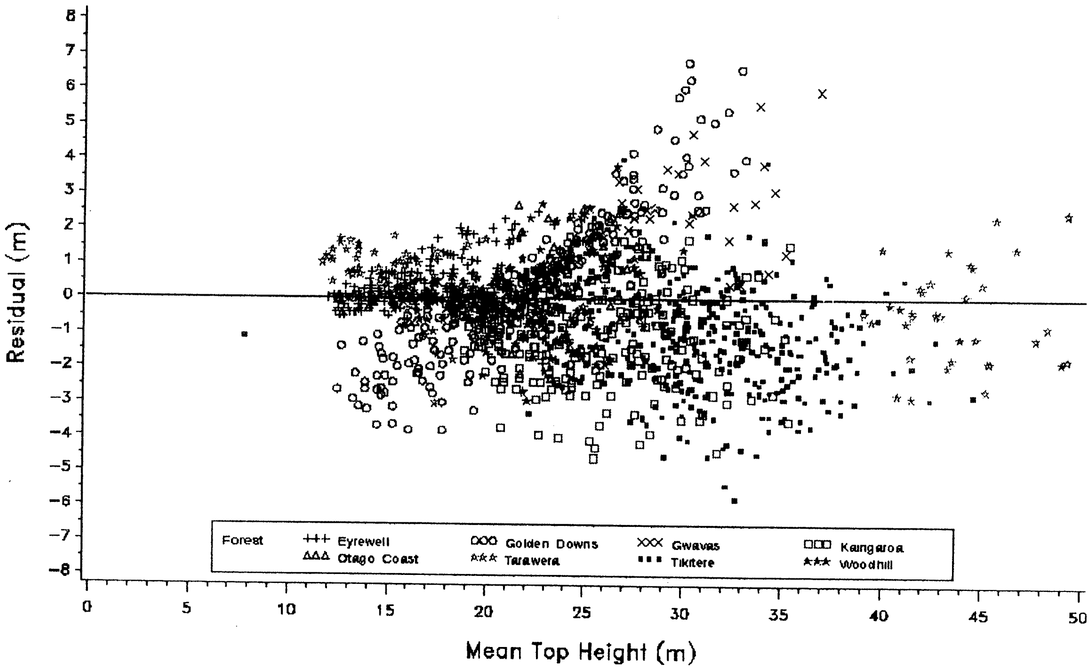

Figure 11: Residuals against mean top height (m), by forest.

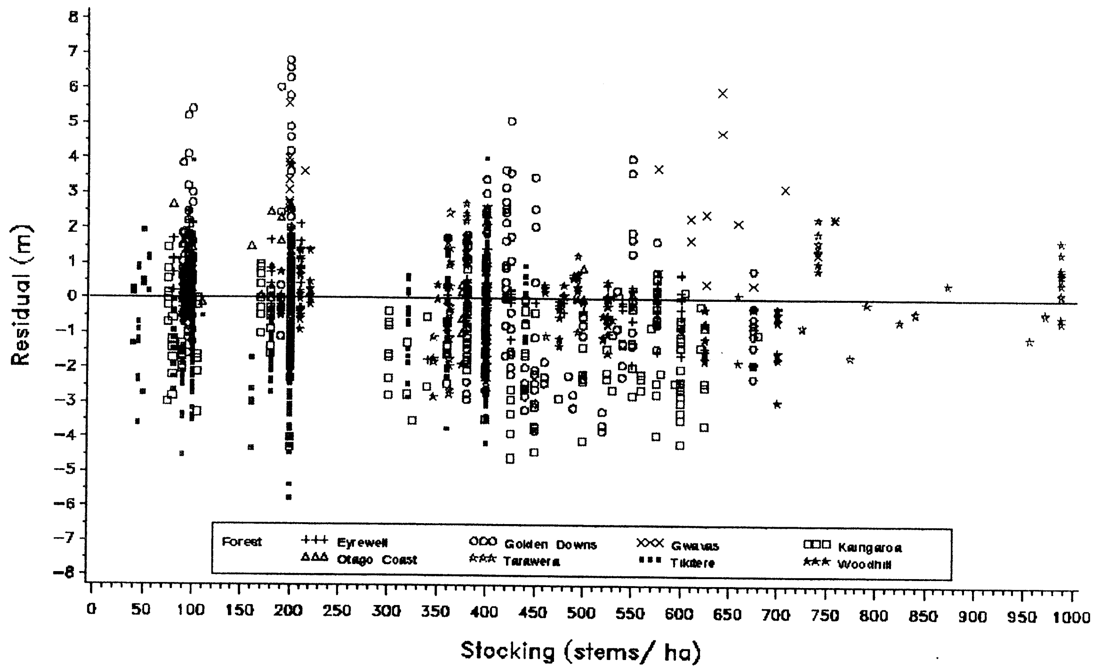

Figure 12: Residuals against stocking (stems/ ha), by forest.

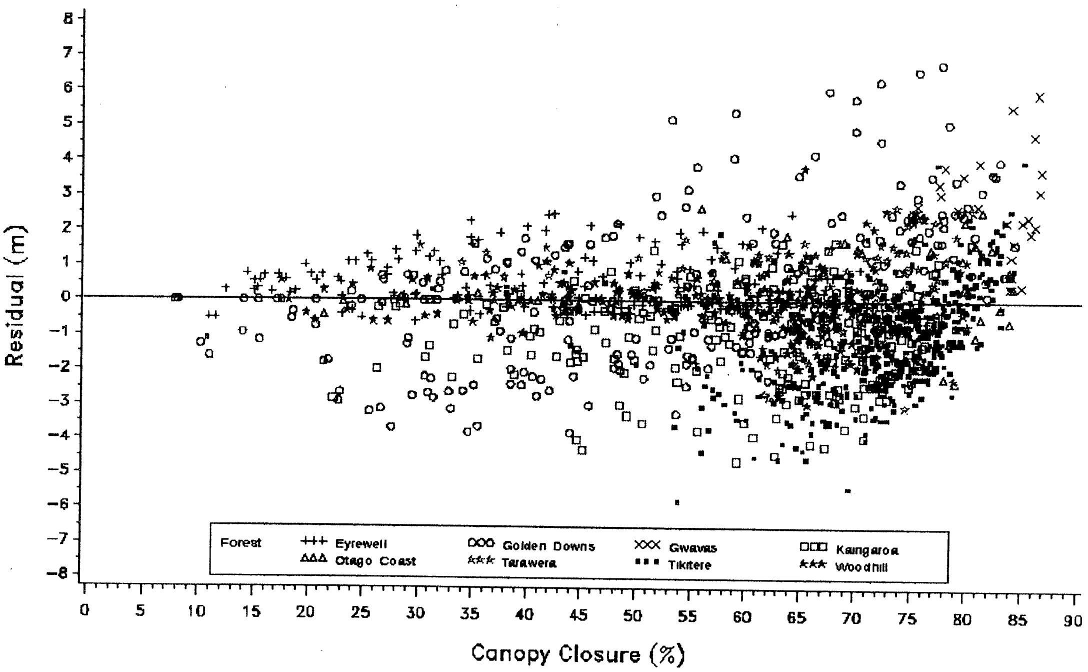

Figure 13: Residuals against canopy closure (%), by forest.

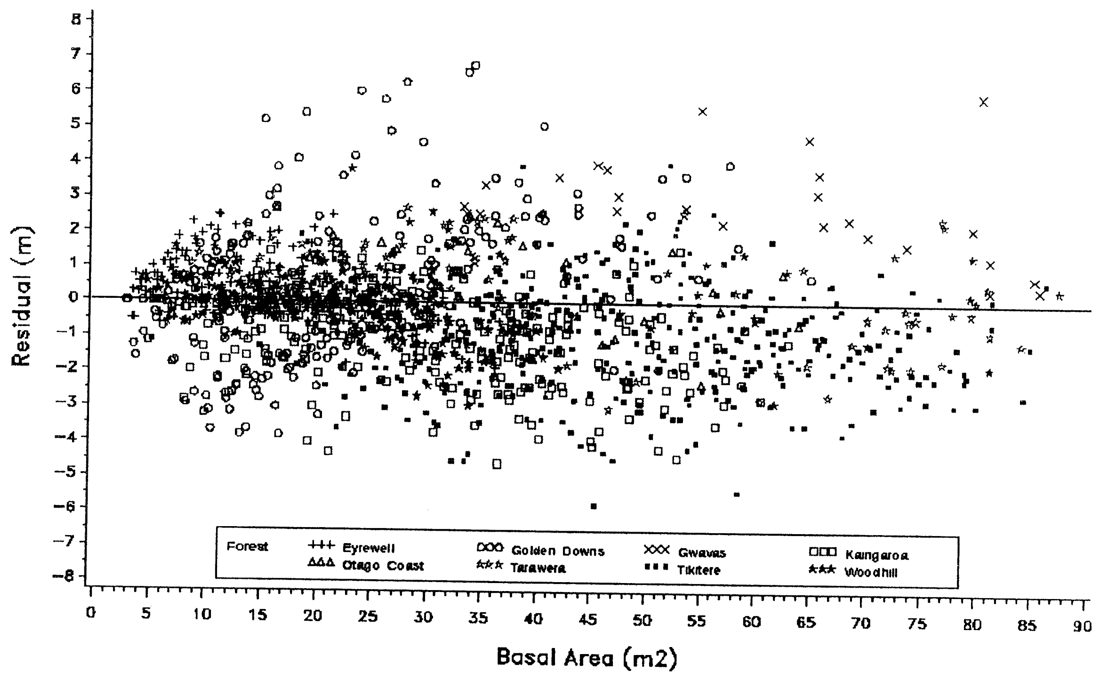

Figure 14: Residuals against basal area (m^2), by forest.

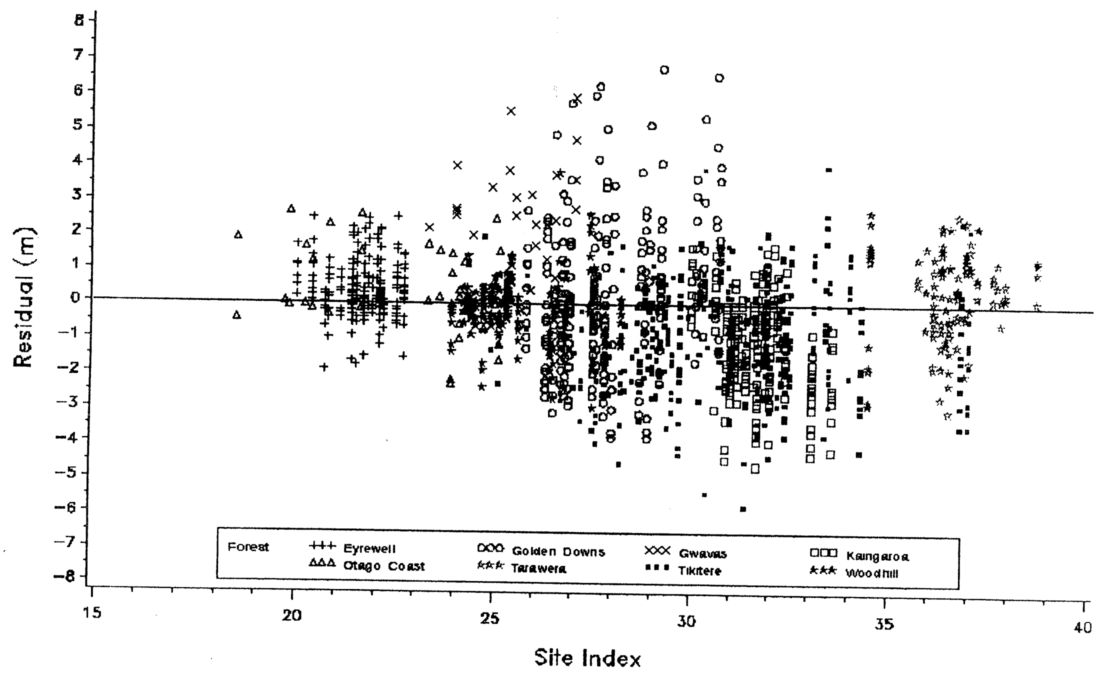

Figure 15: Residuals against site index, by forest.

Conclusion

The new model developed to predict average green crown length gives more precise estimates of crown length than those provided by the model developed by Beekhuis (1965). The new model also incorporates thinning and pruning effects on crown length. There appears to be a slight under-prediction of green crown length for two sites studied, Gwavas and Golden Downs by the new model. Trees at these sites seem to be able to retain their green crown, for a given stocking and mean top height, for longer than trees at the other sites studied. Further work is therefore necessary to develop separate crown length models for Golden Downs and East Coast forests.

Acknowledgments
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