FRI/INDUSTRY RESEARCH COOPERATIVES

MANAGEMENT OF EUCALYPTS COOPERATIVE

FOREST RESEARCH INSTITUTE
PRIVATE BAG
ROTORUA

Results of *Eucalyptus regnans* Model Validation

B Murphy
University of Waikato / NZ FRI

Report No. 22 (Revised Version) Sept 1996

Executive Summary

Four multiple regression growth models were previously developed for Eucalyptus regnans, to predict growth at age 11 years using site variables. These models for basal area, volume, mean top height and mean top diameter were then validated against two datasets. The first consisted of ten plots from Kinleith forest, and the second from 55 plots distributed throughout the central North Island region. Testing showed that in the Kinleith region all models under-predicted against the actual yields (-11% for BA, -18% for Vol, -10% for MTD and -9% for MTH), although the differences were not significant. In the larger geographical validation set, three out of the four models over-predicted against the actual field measurements (47% for BA, 51% for Vol, -1% for MTD and 6% for MTH), and only the MTD model was significantly accurate for use. Overall, it appears that the accuracy of the basal area and volume models was affected by the large range of stocking levels present in the validation stands.

INTRODUCTION

Management of Eucalypts Cooperative

With a view to the need to diversify away from New Zealand dependence upon *Pinus radiata* as a solution to New Zealand's wood and wood fibre needs (New Zealand Forest Service, 1981), NZ FRI and the forestry industry responded to the governmental request for greater industry funding by establishing the Management of Eucalypts Cooperative in December 1986. This Cooperative was additional to NZ FRI's existing research programme on special purpose species.

Companies forming the backbone of the Cooperative initially were interested in the potential of two eucalypt species to meet a growing market for pulpwood, in particular for short-fibre pulp. At present it seems that this is gaining importance with renewed interest shown, although new Cooperative members are also contemplating focusing on a range of eucalypt species to fulfil several market niches.

The objectives of the Cooperative, as defined in their sixth annual report (FRI, 1992) were:

1. To define factors controlling growth and yield of a selected number of eucalypt species including response to site, establishment and silvicultural practices.

2. To develop a data base and, where appropriate, growth and yield models.

With this knowledge the onus would then be upon industry to establish sufficient eucalypt resources and a specialised infrastructure (especially for sawlogs that would require modified mills and kilns). In particular, species such as *Eucalyptus regnans, E. fastigata* and *E. nitens* have the potential to produce high quality wood to meet special end-uses such as short-fibre pulp and furniture-quality wood. It is on these species that most research has been directed, with *E. saligna, E. delegatensis, E. botryoides* and *E. fraxinoides* also researched but with less emphasis.

The cooperative has invested considerably into research on the conditions that best support the growth of good quality logs. The desired end result will be an increased database and range of forestry tools to assist forest managers with making investment decisions concerning planting eucalypts, or if the resource is already established, providing the knowledge to manage the plantations successfully.

In the past *E. regnans* and to a lesser extent *E. fastigata* were planted in large plantations for pulpwood (Carter Holt Harvey Forests Ltd) and to a lesser extent for sawlogs (former NZFS) (Fry, 1980). The new wave of interest is focussing on *E. nitens* but these stands have only been recently planted, therefore initial research into eucalypt siting has concentrated on *E. regnans*.

FRI/INDUSTRY RESEARCH COOPERATIVES

MANAGEMENT OF EUCALYPTS COOPERATIVE

RESULTS OF *EUCALYPTUS REGNANS* MODEL VALIDATION

B. MURPHY

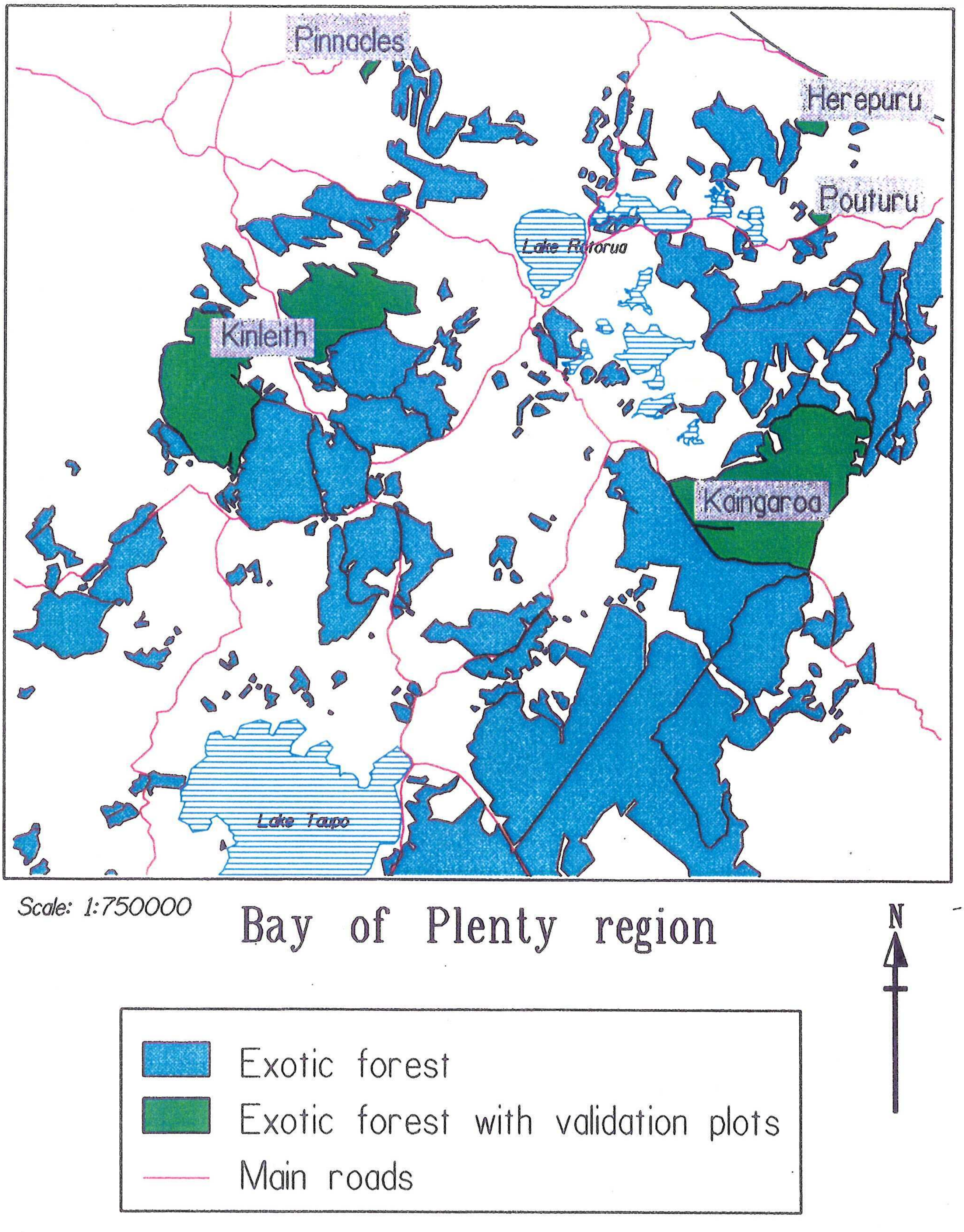
FOREST RESEARCH INSTITUTE

PRIVATE BAG

ROTORUA

FEBRUARY 1995

Forests containing validation plots for Eucalyptus Regnans project



Bay of Plenty region

Eucalyptus regnans

The eucalypt site model project has focused on *E. regnans* which has a potential to meet the demands for short-fibre pulpwood, and has the capacity to assume roles in decorative furniture and veneer production (FRI, 1984). However for this latter use to occur it will require a substantial local resource of *E. regnans* with a guaranteed consistent supply in order for companies to feel confident in investing in the specialised mills and facilities required to process the timber.

Within the Australian continent *E. regnans* occurs naturally in Victoria and Tasmania, from 37-43°S. The altitudinal range stretches from 150 to 1100 m in Victoria and from sea level to 600 m in Tasmania. Under these conditions heights regularly reach 55-75 m and diameters of 2.5 m are attained in mature stands (Boland *et al*, 1984). Within New Zealand attempts have been made to plant *E. regnans* in suitable sites, and this has resulted in plantations being established at sites in most of the North Island south of Auckland, and in the Nelson, Westland, Canterbury and Otago regions of the South Island (Payn & Oliver, 1994).

It has already been suggested that the most suitable climatic conditions for *E. regnans* are cool, temperate areas, with an annual rainfall of 750-2000 mm, a maximum frost of -10° C, and with a mean annual temperature of 7.5-10° C (FRI, 1984). Payn and Oliver (1994) suggest that the most important site characteristics are sloping ground with adequate moisture during the whole year, good soil drainage and protection from salt winds.

About 15,000 ha or 1.4% of the total exotic forest area is currently planted with eucalypt species (FRI, 1987). However, being native to Australia, many of these species are intolerant to some conditions found in New Zealand, in particular frosts, high winds and poor drainage of soils, which all lead to stressed plants with poor growth and form (FRI, 1984). When grown under optimum conditions, Fry (1980) suggests that "A production of 300 m^3 ha^{-1} (volume) by age 10 appears feasible".

The Eucalyptus regnans Model Project

Forest managers soon identified excessive variability of growth within stands as a problem in managing those stands and achieving full growth potential. With this in mind the Cooperative suggested a study designed to investigate the factors that were causing this irregularity, and in particular sought to examine the role of environmental and soil factors. Multiple regression models were developed from sites in Kinleith that used site and soil measurements as parameters for the model analysis (Payn & Oliver, 1994). Models predicted outputs of basal area, volume, mean top height or mean top diameter for a given site. These models could be useful for land owners who were potentially interested in investing in eucalypt plantations, but who had no knowledge as to the suitability of their land.

As part of the project to test and possibly expand the regression models for the *E. regnans* site study, the models were tested against two sets of validation data; one from the Kinleith region (10 plots) where the models were originally developed, and the second (53 plots) encompassing a variety of locations from around the central North Island (Appendix 1). This second dataset was used in order to increase the scale of the model to a manageable area, while retaining similar soil types and climatic conditions. Locations of the sites are shown in Table 1.

Table 1. Validation Data Sets - Forest and Plot Ownership.

Forest	No. Of Plots	Owner	Validation Set*
Kinleith	10	Carter Holt Harvey Forests Ltd.	1
Kinleith	14	Carter Holt Harvey Forests Ltd.	2
Kaingaroa	31	Forestry Corp. of NZ Ltd	2
Herepuru	3	Tasman Forestry Ltd.	2
Pinnacles	3	Tasman Forestry Ltd.	2
Pouturu	2	Caxton Forests Ltd.	2

* 1 = Original survey area validation plots.

2 = Central North Island validation plots.

The rationale for the two datasets was to first establish the accuracy of the model against plots from the same geographic locality that the model building data was taken from, and secondly to test its usefulness against plots from a wider geographical area. The predicted values from the models and the actual values for each plot were then compared, statistically analysed and graphed to present the results.

METHOD

Site Description

Kinleith Validation Plots

In the Kinleith region ten 0.04 ha plots specially put in for the study were used for the collection of the first subset of data that was used for the first validation test of the initial survey model.

North Island Plots

Suitable sites were chosen in the Kinleith, Kaingaroa, Herepuru, Pouturu and Pinnacles forests in the central North Island. An independent set of 14 Kinleith plots was used as part of this second group of validation data. In the Kaingaroa forest 31 plots were established, and both Herepuru and the Pinnacles contributed 3 plots each, with the remaining two plots coming from Pouturu Forest. This gave a total of 53 plots for the second dataset.

Field Data

Permanent Sample Plots (PSP)

Each plot is a 0.04 ha subplot of an existing PSP. A PSP is a circular grid, which generally covers 0.1 hectares. A permanent central peg determines the centre of the PSP plot which has a radius of 11 - 12 metres (based on slope corrections). It was within these subplots that Coop members collected the site data, which was then utilised to assemble the site and tree data for each subplot.

Data Collection

For the majority of validation plots data was collected in the months of November and December of 1994 to determine which trees existed within each plot. Where possible, data was collected from the stands at age 11 years.

Some plots contained stands that were below 11 years of age at the end of 1984 (ie. Pouturu sites that contained stands from 1985-1987 plantings) and these were 'grown' using the NZFP *E. regnans* growth model (Hayward, 1991) to an age of 11 years. Occasionally growth data was only available for ages 10 and 12 years, and in these cases the mean of the values for both years were taken and used as the assumed values for age 11 years.

Trees within each PSP plot were measured for diameter at 1.4m above ground (DBH), and a sample of trees were measured for height to derive a growth function. This allowed for the calculation of basal area (BA), volume (VOL), mean top height (MTH) and mean top diameter (MTD) for each plot using the database and Petterson function derived from the previous data.

Kinleith Validation Plots

Site and tree data gathering for these 10 plots in the Kinleith Forest was done by NZ FRI staff in 1993. The collection method was the same as that for the North Island dataset plots. This data was analysed and a summary sheet containing relevant information for this project was produced prior to its commencement.

North Island Dataset

Data were collected by the forest owners and recorded on the designated EUCALYPT SITE SURVEY sheet (Appendix Two). On this sheet a record of the forest, compartment, plot number, species, age and date of the measurements were kept. Other parameters recorded included the longitude, latitude, altitude, average slope of the plot, and aspect which was then converted to a compass direction. The land form was taken as one of 6 possible forms that are described on the back of the site survey sheet. Topex was taken using a hypsometer at 8 compass points to give an indication of the terrain. At 25 randomly selected points spade cuts were made into the soil so that "A" soil horizon thicknesses could be measured and these were then averaged over the plot to give a mean A horizon depth in cm.

Where possible the identification numbers of trees that occurred within each subplot were recorded as this made it simple to calculate the data for each plot from the PSP records. Where the tree numbers were not recorded it was necessary to take the plot slope, then use slope corrections for plot radii to establish the distance that the PSP reached from the central point and then establish which trees were inside this boundary from the records, as all the PSPs have trees mapped by bearing and distance to the centre, and are then numbered for identification.

pH Analysis

Within each plot 25 soil samples were taken for analysis of soil pH. The soil samples were air dried, bulked together to form a composite sample for each plot, and then analysed in the NZ FRI laboratories to determine the soil pH which was evaluated as pH in H_2O as per Nicholson (1984).

Data Preparation

Calculation of Growth Variables

The regression models give predicted values of growth for each site; in order to test the models against actual field results it was necessary to determine these actual values for each site. The first task was to determine the basal area for each plot, and this was achieved by using the formula;

$$BA = \text{TOTAL } D^2 * \text{AREA SCALE} * \frac{\pi}{4} * \text{UNIT-CONVERSION}$$

The validation plots were 0.04 ha in size, so the end results were multiplied by 25 and then divided by 10000 (to convert from cm to m) to give a BA of m^2 ha^{-1}.

The mean top diameter was found by taking the 4 "fattest" trees from each plot (proportional to the 100 "fattest" stems per ha usually used in New Zealand) and this was processed with the formula;

$$MTD = \sqrt{\frac{\Sigma D^2}{4}}$$

This had to be modified for those plots that only contained 2 or 3 trees within the plot by changing the divisor to 2 or 3 respectively. The MTH is the mean height of the trees corresponding to the MTD. As only a sample of tree heights is taken because the process is time consuming, a dbh/height regression is calculated. The regression accepted as the standard by New Zealand forestry is the Petterson equation. Using the Petterson equation regression coefficients b_1 and b_2 for each plot, the formula;

$$MTH = 1.4 + \left\{ b_1 + \frac{b_2}{MTD} \right\}^{-2.5}$$

was used to calculate the MTH for each plot.

For each plot the volume was also calculated, and this was achieved by using the volume formula for *E. regnans* developed by Hayward (1987), in which the volume of the tree was functioned by $V = 0.00002984D^2H$. The volume was found for each individual tree by first finding the height of each tree using the Petterson coefficients again in the formula,

$$H = 1.4 + \left\{ b_1 + \frac{b_2}{D} \right\}^{-2.5}$$

then the height and diameter of the trees were treated with the Hayward formula to give an individual tree volume. The volumes within a plot were then summed and multiplied by 25 to give a total volume of m^3ha^{-1}, *Comparison of the Model and the Plot Data*

The main purpose of the gathering of the data from the *E. regnans* plots was to calculate four measures of tree growth, basal area, volume, mean top height and mean top diameter for the plots, and then compare these with the values that were predicted for each plot by the models (using site related factors) developed for the species in 1993.

The models function by assigning a coefficient for each of the four parameters measured; these parameters consist of the aspect of the plot (compass heading), the landform (as defined on the field record sheet), the pH and the depth of the A soil horizon. For the first two parameters the coefficient is a standard value for each measure, but for the pH and A horizon thickness the coefficient is multiplied by the measurement value. These four values are then summed for each plot, along with an *Intercept* value that is constant for each model. The sum of the values for each plot provides the models predicted value for that plot, and is an estimation of how the model predicts that *E. regnans* should be growing on that plot, based on the environmental factors.

Thus in the case of the BALIVE model, the final value is an estimated basal area measure for one hectare of that plot at a crop age of 11 years. This is then compared to the actual basal area for the plot to give an indication of the accuracy of the model.

The four models developed in 1993 gave predicted values of basal area, volume, mean top height and mean top diameter for each plot. In the initial models the stocking was meant to be consistent across the plots - this consistency meant that BA and VOL models would be produced that should be expected to be reasonably accurate. However in reality the stocking levels in the second dataset varied considerably, therefore hampering the precision of the model predictions. The MTD and MTH models were therefore particularly necessary because they have been found to be relatively independent of stocking, and therefore independent of the variation in stocking levels that occurred throughout the validation plots. But at the same time it is realised that these two measures do not yield as much useful information as basal area or volume would for a potential user of the system.

Statistical Analysis

Residual Analysis

To clarify whether each model was unbiased ie. doesn't over or under-predict, a residual analysis was performed on the results from the model testing. The residuals (the difference between the predicted and actual values for each model) for each dataset were collected and summed; this number was then divided by the total number of residuals. The closer to zero the final number is then the less bias the model exhibits. A number above zero suggests that the model is over-predicting, while a value below zero indicates a tendency to under-predict by the model. This data was then graphed.

t-test (Paired Two Samples For Means)

The results from the model validation were tested via a t-test. This operates by comparing each set of paired data (in this case each pair of predicted and actual values) and tests whether the two sets of data are significantly different (Freese, 1967).

RESULTS

Site Descriptions

Growth data for the Kinleith plots is summarised in Table 2.

Table 2. Summary of growth data for the Kinleith validation plots (Set One).

Statistic	Stocking stems ha^{-1}	BA (m^2 ha^{-1})	VOL (m^3 ha^{-1})	MTD (cm)	MTH (m)
Mean	652.5	27.5	246.2	29.2	25.9
Min	475	16.7	124.9	24.6	22.2
Max	950	42.2	404.2	33.4	28.9
S. Dev	151.1	8.0	87.8	3.1	1.9
C.V. (%)	23.2	29.2	35.7	10.6	7.6

From this data it can be seen that the Coefficient of Variation (CV %) for stocking is relatively high, and this has influenced the coefficients of variation in the basal area and volume measurements. The MTD and MTH CV levels are less influenced by the stocking, and remain at or under 10%.

Growth data for the 53 North Island dataset plots are summarised in Table 3. From this it can be seen that the variation in stocking levels is excessive, ranging from 87 to 2144 spha. This shows in a CV of nearly 100%, and once again this also is reflected in high CVs for basal area and volume. The MTD shows a rise in variation, but MTH remains relatively independent.

Table 3. Summary of growth data for the North Island dataset plots (Set Two).

Statistic	Stocking stems ha^{-1}	BA (m^2 ha^{-1})	VOL (m^3 ha^{-1})	MTD (cm)	MTH (m)
Mean	535.9	17.1	147.9	31.5	23.9
Min	87	4.3	32.7	23.6	19.0
Max	2144	39.7	364.8	46.3	29.3
S. Dev	529.3	8.4	79.3	5.4	2.2
C.V. (%)	98.8	49.4	53.6	17.2	9.0

Graphical Analysis

Kinleith Validation Plots (Set One)

The Kinleith plots were graphed to show the results of the model predicted values. In this case the four models on average under-predicted. The models for basal area (Fig. 1), volume (Fig. 2) and MTH (Fig. 4) all had under-predicted the actual field measures 70% of the time. The model for MTD under-predicted 80% of the plots (Fig. 3). In the examples where the model over-predicted the same plots were concerned, Plots 53, 56 and 60 (which appear as plots 3, 6 and 10 on the graphs).

North Island Dataset (Set Two)

Graphical portrayal of the residuals of each model for the North Island Dataset shows the models generally over-predict for these sites. In Figure 5 (BA) it is shown that for 82% of the plots the model has over-predicted. This level rises to 83% for the volume model (Figure 6). The model for MTD (Figure 7) is slightly more balanced but still over-predicts 66% of the time, while the MTH model (Figure 8) over-predicts 75% of the time.

Residuals

Kinleith Residuals (Set One)

Determination of the residuals for the Kinleith plots was used to give an indication as to the bias of the models towards the plots, where an unbiased model would return a residual of zero. In the case of all four models the residuals show that they are consistently under-predicting (Table 4). The least biased model appears to be for MTH where the mean residual = -2.41. The residuals for MTD and BA give similar results with -3.36 and -3.06 respectively, but the volume model is far more biased with a figure of -44.58.

Table 4. Residuals of Kinleith Validation Plots (Set One).

Plot No.	Stocking	Residual BA	Residual VOL	Residual MTD	Residual MTH
1	550	-4.23	-65.89	-4.21	-3.41
2	600	-6.07	-69.60	-8.18	-3.57
3	475	6.23	48.62	-2.08	1.11
4	675	-3.48	-48.79	-0.26	-1.86
5	725	-18.51	-225.70	-7.94	-7.23
6	525	12.75	150.25	0.69	2.69
7	800	-12.14	-139.04	-6.76	-4.43
8	950	-9.41	-137.89	-4.77	-6.20
9	500	-7.98	-98.42	-5.07	-4.01
10	725	12.19	140.64	5.01	2.76
Total		-30.65	-445.82	-33.57	-24.15
Residual		-3.07	-44.58	-3.36	-2.42

North Island Dataset Residuals (Set Two)

Residual calculations for the North Island dataset reveal that three of the four models are over-predicting (Table 5). The least biased model is that for MTD which has a very low value of -0.23. The next best is that of the MTH model which is only 1.38, and is followed by the residual for BA which is at 7.99. The volume residual is very high (75.75) which suggests that possibly a combination of factors are hindering the accuracy of that model.

It may be possible that the difference in stocking levels between the trials used to develop the model (650 to 712 stems/ha) and the plots that the model has been tested on (87 to 2144 stems/ha for the North Island dataset and 475 to 950 stems/ha for the Kinleith dataset) is leading to large anomalies in the results. This wide range of stocking levels will have an important effect upon models based on volume and basal area because they are influenced by stocking. Evidence for this can be shown by taking the volume residuals for those plots with <=300 spha. Within this range only 1 out of 25 plots is under-predicted from the volume model, showing that the volume model is consistently over-predicting at these low stocking levels, and indeed this is shown in the residual value that rises

Table 5: Residuals of North Island Dataset.

Forest	Stocking	Residual BA	Residual VOL	Residual MTD	Residual MTH
Kinleith	180	12.21	113.76	-4.36	0.96
Kinleith	240	0.87	35.72	-5.38	4.53
Kinleith	100	5.27	54.80	-8.26	1.81
Kinleith	1060	-10.08	-75.56	2.30	0.14
Kinleith	320	4.97	38.26	-3.69	0.17
Kinleith	160	19.42	198.44	5.39	1.60
Kinleith	500	-7.73	-96.17	-5.95	-1.76
Kinleith	470	5.04	50.71	-1.13	1.66
Kinleith	150	17.16	163.39	1.98	4.20
Kinleith	280	8.84	82.25	-2.54	0.43
Kinleith	950	-9.11	-17.38	4.60	6.38
Kinleith	590	-2.07	-21.01	1.14	0.91
Kinleith	380	7.57	97.03	5.42	4.07
Kinleith	190	19.47	214.10	1.85	5.54
Kaingaroa	2144	-9.10	-45.35	3.97	0.74
Kaingaroa	1500	11.80	121.04	5.60	3.10
Kaingaroa	1178	15.28	130.55	2.56	-0.63
Kaingaroa	922	1.08	22.53	1.59	-0.48
Kaingaroa	422	16.77	181.78	7.15	3.52
Kaingaroa	311	13.78	141.39	2.41	2.67
Kaingaroa	256	1.21	121.04	0.53	2.94
Kaingaroa	100	22.53	215.84	4.25	4.55
Kaingaroa	200	8.64	34.37	-6.46	-2.85
Kaingaroa	111	22.16	195.19	-0.53	1.15
Kaingaroa	100	8.69	25.62	-10.12	-3.03
Kaingaroa	1689	-2.44	13..24	2.16	0.23
Kaingaroa	1389	3.91	17.78	2.84	-0.96
Kaingaroa	1133	16.15	149.38	4.49	0.67
Kaingaroa	933	-7.64	-99.95	-6.35	-3.96
Kaingaroa	411	5.46	35.39	1.32	0.26
Kaingaroa	311	6.81	27.57	-2.49	-2.78
Kaingaroa	256	17.89	196.57	6.23	4.21
Kaingaroa	100	26.67	270.10	6.00	4.32
Kaingaroa	200	9.58	62.52	0.38	0.87
Kaingaroa	111	19.75	183.01	3.47	5.15
Kaingaroa	100	14.62	95.65	-15.20	-2.42
Kaingaroa	2078	-0.38	39.88	4.05	1.58
Kaingaroa	1456	5.35	30.64	1.11	-0.11
Kaingaroa	1156	14.24	147.76	3.05	2.66
Kaingaroa	911	8.07	78.09	4.57	0.65
Kaingaroa	400	5.53	66.66	1.01	1.26
Kaingaroa	322	10.92	90.36	-0.93	0.88
Kaingaroa	256	12.77	127.55	0.52	2.15
Kaingaroa	100	23.15	214.60	4.18	3.19
Kaingaroa	211	13.62	105.83	2.14	3.23
Herepuru	207	3.90	62.75	-3.92	5.09
Herepuru	160	-4.83	-77.17	-13.29	-1.88
Herepuru	87	3.52	13.49	-16.49	0.78
Pinnacles	250	0.15	7.41	-5.54	2.55
Pinnacles	290	10.25	108.54	0.93	2.31
Pinnacles	320	13.81	175.39	1.83	5.31
Pouturu	430	3.76	-6.43	5.74	-0.63
Pouturu	310	-5.58	-104.49	-6.27	-4.04
RESIDUAL		7.99	75.75	-0.23	1.38

from 75.75 to 113.02. The basal area residuals rise slightly from 7.99 to 12.3 , the MTH residuals rise from 1.38 to 2.05, but the MTD residuals drop from -0.23 to -0.10. These seem to confirm that the residuals for MTH and MTD are affected less by stocking levels than basal area and volume.

When the residuals are taken from those plots that have stockings closer to those used in the model building project (using residuals from stockings of 400 - 1000 stems/ha) the bias of the models tends to decrease. At this level the residuals for MTH are 0.71, for MTD are 1.25, for BA 1.74 and for volume 17.66.

This suggests that the model is far more accurate when working with stocking levels which approximate those in which the models were developed; plots with extremes in stocking levels will be less useful for testing the model. It is for this reason that models for MTH and MTD were developed because these measurements are theoretically not affected by stocking levels, but at the same time these measures do not yield as much useful information as basal area or volume would for a potential user of the system.

t - test Results

Kinleith and North Island dataset Results

The results from the t-test (Paired two samples for means) are shown in Table 6.

Table 6. Results of t-test analysis on *E. regnans* models, at $p<0.05$ level of significance.

Dataset	Measure	($p<0.05$)
Kinleith	BA	Not Significant
	VOL	Not Significant
	MTD	Not Significant
	MTH	Not Significant
North Island	BA	Significant
	VOL	Significant
	MTD	Not Significant
	MTH	Significant

At the 0.05 level of significance it is shown that for the Kinleith dataset all four models show no significant difference between the predicted and actual values. For the North Island dataset only the model for MTD shows no significant difference when tested against the actual measurements.

DISCUSSION

Having available a range of data from both the same site as where the model was developed and also a more widespread geographical range gives good insight as to the strengths and weaknesses of the models developed for this project.

Easily measured site factors means that any plot can be sampled and the results can be determined within 2 weeks (the longest process is that of determining the soil pH). This ease of use means that the potential for wide use of the model to determine suitable sites and help create a productivity map for the Bay of Plenty region exists.

The accuracy of the basal area and volume models, when tested against the 'control' Kinleith sites is of concern, and it will need to be debated as to whether the models now require 'tweaking' in order to adjust their consistent under-predicting for these plots or to whether they are suitable for use now. A balance must be established between how much time and resources can be used and to how much this will improve the accuracy of the models.

Any adjustments to the model will be determined by the available resources of *E. regnans* plots of suitable age. Problems associated with development of the models were the scarcity of suitable plots in the Kinleith region (a problem that is mirrored in all regions of the North Island), where only 47 plots could be used as a database for the regression models. In perfect circumstances it would be hoped to have between 100 and 200 suitable plots for this purpose.

The next step to improve the model, according to Goulding (1979) is to adopt the best of existing models for operational use. This does not mean the end of the validation process, because "with changing goals, increasing computer power, and more data available, the objectives can be redefined and more components included." This suggests that we now need to assess which of the models is at a stage where it is useful. From the results it could be suggested that the four models are suitable for use in the Kinleith region, but to use them outside this region could lead to misleading results.

The next process might then be to start adding more plots from a gradually increasing radius away from the Kinleith region, modifying the models as it needs adjusting. The models would need constant evaluation to see at which point the added plots start leading to redundancies in the model's accuracy.

If this is not feasible due to restrictions on time and resources, it may be more resourceful to improve the model by looking at what could be other important variables for the growth of *E. regnans* - eg. altitude. This factor has already been recorded for each plot used in this validation, and appears to have effected yields in the Kinleith model development plots, so it's incorporation as a coefficient in the yield models may result in more accurate predictions.

Another consideration with the accuracy of the models is the actual range of measurements - if the mean basal area was 30 m^2 ha^{-1} then a degree of error of 3 m^2 each side may be acceptable. At the same time a volume mean of 300 m^3 ha^{-1} may have an acceptable limit of 30 m^3 ha^{-1}each side - the sheer size of the volume measures may mean that a larger absolute bias on the part of the models may be acceptable.

Validation of all four models that were tested against the Kinleith validation plots showed no significant difference when comparing their predicted values with the actual values. For the North Island dataset only the model for MTD was shown to produce predicted values that were not significantly different from the actual values.

The purpose of the residual analysis was to determine the bias of the models. That there was a difference in the form of bias between the two datasets was not surprising. The Kinleith dataset was quite small so that a bias on the part of the model was likely and for the most part these biases were quite small, whereas the North Island dataset contained 53 plots that were dispersed throughout the central N.I. geographic region. This would have the effect of containing sites that could vary dramatically with regards to their site quality, soils, microclimate, macroclimate and site index (with respect to *E. regnans*). Therefore it is possible that many of these sites offer a lower potential for the growth of *E. regnans* than do the Kinleith sites, which would account for the models predicting larger growth values than actually exist.

One obvious weakness of the models seems to be how they are affected by stocking levels, but as it would be impossible to develop models for different stocking levels this factor must be dismissed. It is of course important to note that there is a difference between taking data from an established 11 year old plot and testing the model, and running the model against a bare piece of farm land in order to predict the growth of *E. regnans* on it - in the latter case the problem of stocking levels would not come into consideration.

It may be of future interest to ascertain the value of testing further trials on plots that contain an east facing aspect. An anomaly arises on the two east facing slopes in the Kinleith dataset, where although they are assumed to be poor sites for the growth of *E. regnans* (Payn & Oliver, 1984), these sites actually have a far superior performance than the model predicts. For plot 5 the site has a volume measure of 225 m^3ha^{-1} more than is predicted by the model, and plot 9 has a volume measure of 98 m^3ha^{-1} more than predicted by the model. This possible error is difficult to confirm because the North Island dataset contains no east facing sites at all, so at the moment it is impossible to determine whether this is a dysfunction of the model or is influenced by other site factors outside those used by the model.

Considering the volume of additional (to those actually utilised by the model) measurements taken for each plot, there is ample room for a study and analysis of these other environmental factors which could possibly affect growth patterns of *E. regnans.* Payn and Oliver (1994) have established that soil nutrition was important but that "site factors are affecting tree growth more strongly than soil chemical factors", and therefore it may be rewarding to examine the role of factors such as altitude or topex upon the sites.

The three Kinleith sites that contained values under those predicted by the model seem to have little to separate them from the rest of that group of data, except that their topex values seem to be well above average. This parameter may need to be studied in relation to the aspect of each plot, to determine whether plots with high topex values and certain aspects may receive far less solar radiation that would be expected.

Whether or not the A soil horizon depth is a completely reliable constant for the use of the model may also need to be considered. The horizon depth may be rendered disturbed by cultivation, previous crops at the site, the root systems of existing crops or even changed by erosional events (ie. deposited in hollows during heavy rain). As well as this it must be recognised that soil pH may have changed since the trees were originally established, due to over 11 years of litter fall, decomposition of vegetation, and the recycling of nutrients over that time (some nutrients are removed by the crop species, and others are replaced by decomposition and nitrogen fixers such as Tutu (*Coriaria* sp.) which is common as part of the regenerating vegetation).

CONCLUSIONS

Analysis of the results from the model validation process show that in the Kinleith forest, all four models show a tendency to under-predict against the actual field values. This however is not significantly different, and the models are therefore accurate enough for use in that region and plantation management tools. In the wider central North Island area, only the MTD model produces results not significantly different from the field measures, with the other models over-predicting by significant levels. These models have been influenced by a large variation in stocking levels across the plots. Future work incorporating an extended database and other environmental parameters may help increase the accuracy of the models.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of Heather McKenzie and Tim Payn for their advice and guidance on this project. Mention must also go to Errol Hay, Ham Gifford, Justin Ford-Robertson, Ian Nicholas and Lisa Te Morenga for their assistance and establishment of a friendly working environment, plus thanks to Mark Kimberly for his help with the statistics and Christian Pilaar for his time and skills developing the maps. Thanks must also go to Cooperative members for their time and effort involved in the collection of data from the sample sites, and for their funding which made my work placement possible.

REFERENCES

BOLAND, D.J., BROOKER, M.I.H., CHIPPENDALE, G.M., HALL, N., HYLAND, B.P.M., JOHNSTON, R.D., KLEINIG, D.A., TURNER, J.D. (1984): Forest Trees of Australia. Nelson - CSIRO, Melbourne, Australia.

FOREST RESEARCH INSTITUTE (1984): Eucalypts: Species Choice and Site Requirements. *What's New in Forest Research*, No. 124.

FOREST RESEARCH INSTITUTE (1987): Eucalypts - Selecting High Quality Crop Trees. *What's New in Forest Research*, No. 155.

FOREST RESEARCH INSTITUTE (1992): Management of Eucalypts Cooperative Programme: Sixth Annual Report. *FRI/Industry Research Cooperatives.*

FREESE, F. (1967): Elementary Statistical Methods for Foresters. U.S. Dept. of Agriculture, Forest Service.

FRY, G. (1980): Eucalypts in New Zealand: A Position Report. *New Zealand Journal of Forestry* 3: 394-411

GOULDING, C.J. (1979): Validation of Growth Models Used in Forest Management. *New Zealand Journal of Forestry*, 24 (1): 108-124

HAYWARD, W.J. (1987): Volume and Taper of *Eucalyptus regnans* grown in the Central North Island of New Zealand. *New Zealand Journal of Forestry*, 17 (1): 109-120

HAYWARD, W.J. (1991): *Eucalyptus regnans* Growth Model. NZFP/FRI/Ministry of Forestry.

NEW ZEALAND FOREST SERVICE (1981): Policy on Exotic Special Purpose Species. Government Printer, Wellington.

NEW ZEALAND INSTITUTE OF FORESTERS (1986): Forestry Handbook. Wellington.

NICHOLSON, G. (1984): Methods of Soil, Water and Plant Analysis. N.Z. Forest Service, Forest Research Institute, Rotorua. F.R.I. *Bulletin* 70.

PAYN, T.W. & OLIVER, G.R. (1984): The Effect of Site Factors on the Growth of *Eucalyptus regnans* in Kinleith Forest. Management of Eucalypts Cooperative, Report No. 21 (unpublished).

GLOSSARY

ANOVA

Analysis of variance. This is a statistical procedure used to determine whether means from two or more samples are taken from populations with the same means.

Basal Area

The sum of the cross-sectional areas of all living stems at breast height, expressed in m^2/ha. Basal area is very dependant on stand age, stocking and site.

DBH

Diameter at breast height. This is measured by a special tape that converts the trees' circumference into a diameter measurement (cm). The measurement is usually taken over the bark and at a height of 1.4m above ground on the uphill side of the tree.

MTD

Mean Top Diameter. The average diameter in cm of the 100 fattest stems per hectare

MTH

Mean Top Height. The height corresponding to the mean top diameter, and calculated using the Petterson equation.

Petterson Equation

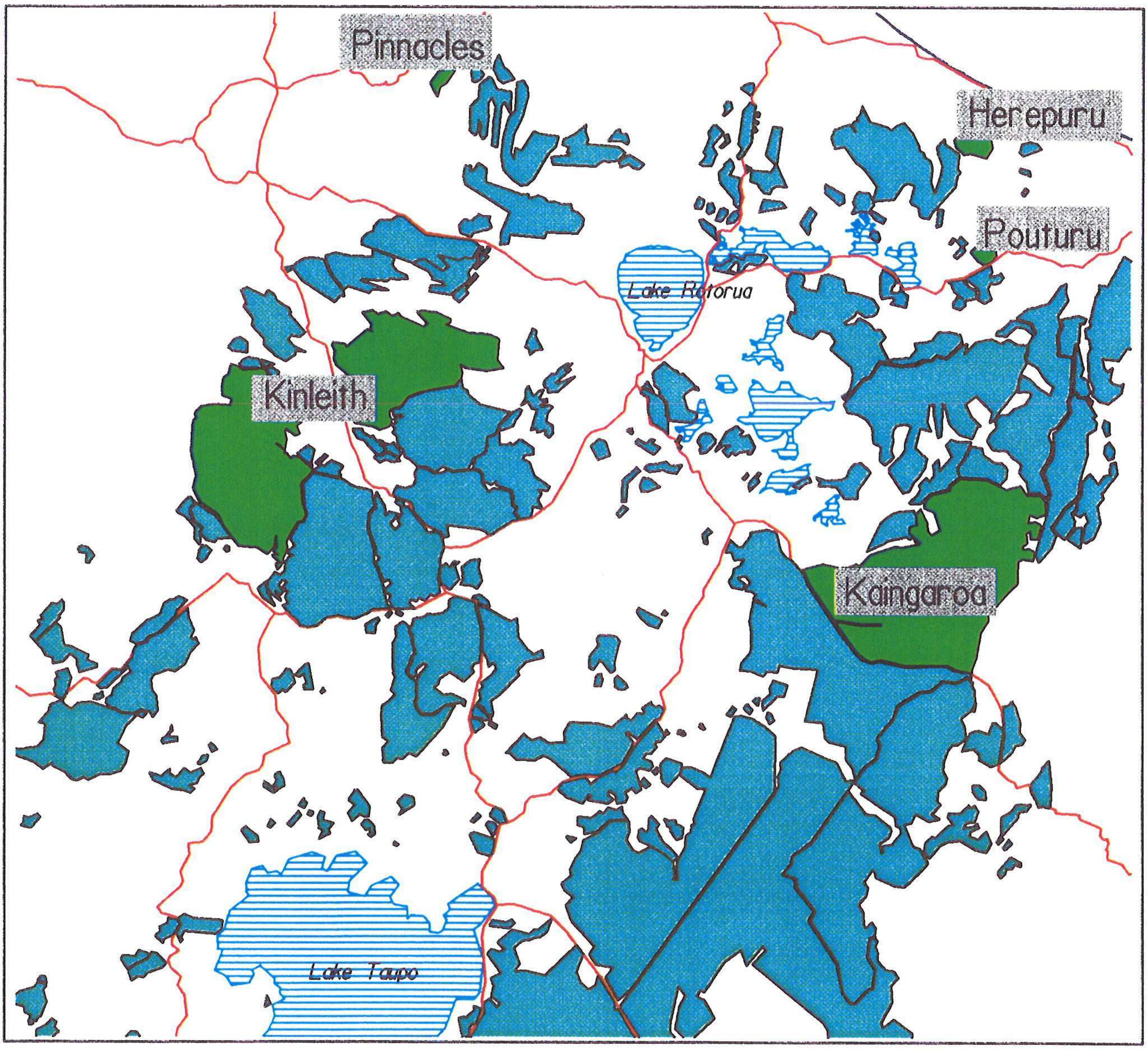
Because tree heights are often difficult to measure, it is often useful to estimate them indirectly. In New Zealand this is achieved using the Petterson function, which is created by measuring a sample of trees for dbh and height. A regression equation is fitted to the data and then used to predict the heights for trees in which only dbh has been measured (NZIF, 1986).

Volume

Volume of the main stem under bark from ground level to the tip of trees. Volume is expressed as m^3 per hectare, but is not the measure of the actual merchantable wood. The measure is derived from the sum of squares of diameters and the regression coefficients derived from the Petterson equation.

APPENDIX 1. Map of Bay of Plenty Region with forests containing validation plots for the *E. regnans* project.

Forests containing validation plots for Eucalyptus Regnans project



Scale: 1:750000

Bay of Plenty region

N

- Exotic forest
- Exotic forest with validation plots
- Main roads

APPENDIX 2. Plot sheet for gathering information from PSP plots for model testing.

Management of Eucalypts Cooperative

EUCALYPT SITE SURVEY

Forest:

Compartment:

Plot Number:

(Use PSP Number if appropriate)

Species:

Age:

Date:

Person collecting data:

Longitude _____° _____'

Latitude _____° _____'

Altitude: _________m

Aspect downhill_____° Compass pt_________

Slope: Uphill ° Opposite____°

Average_____°

Landform

Topex:	
Cardinal Points (°)	Elevation angle (°)
0°	
45°	
90°	
135°	
180°	
225°	
270°	
315°	
Sum	

A Horizon Depths: (mm)	
1:	14:
2:	15:
3:	16:
4:	17:
5:	18:
6:	19:
7:	20:
8:	21:
9:	22:
10:	23:
11:	24:
12:	25:
13:	
Mean	

Map attached to show plot locations? ☐

Date soil samples sent to NZFRI for pH: ..../......../.......

Notes:

Aspect: Assessed within boundaries of plot. Use compass then convert to compass point (N, NE, E, SE, S, SW, W, NW)

Slope: Average of the angle taken from plot centre to highest point on plot perimeter and the angle to the plot perimeter directly opposite. Ignore negatives in calculating average slope.

Topex: Using hypsometer take angle to horizon or lowest point of sky if land obscured by trees etc.

A Horizon: Randomly locate 25 sample points. Remove litter layer to mineral soil. Make spade cut. Measure depth of black or dark brown soil in millimetres.

pH: Take a small subsample of soil (½cup approx) from each A horizon point and add to a plastic bag in which all 25 samples are bulked. Label bag clearly with plot number (as on this sheet), date, forest, company.

Landform:

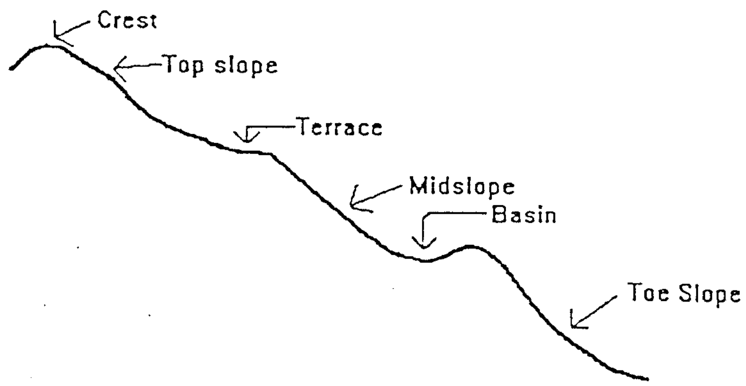


Figure 1. Residuals of Basal Area for Kinleith Plots.

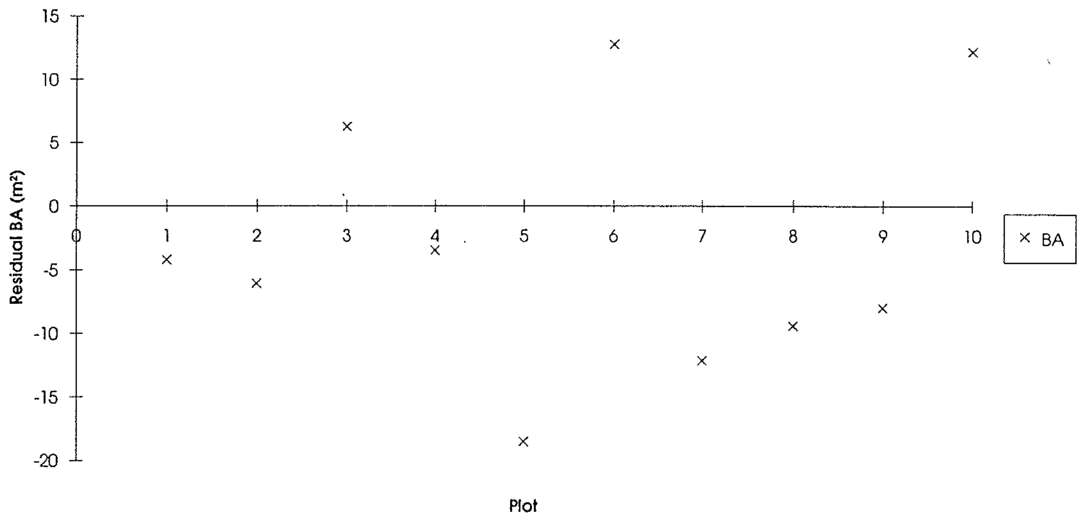
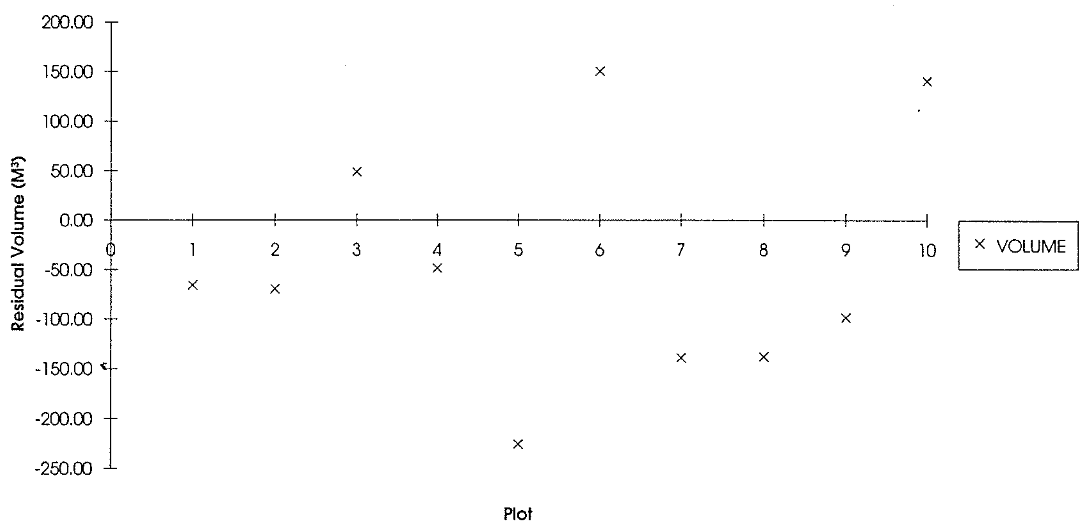


Figure 2. Residuals of Volume for Kinleith Plots.



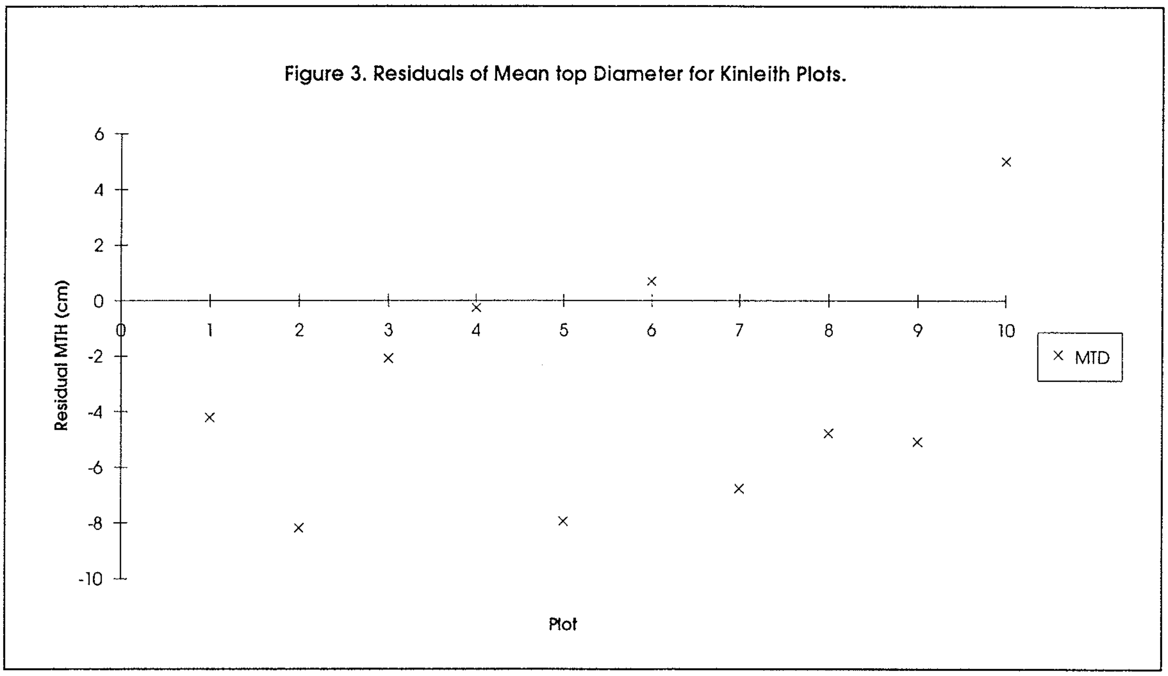


Figure 3. Residuals of Mean top Diameter for Kinleith Plots.
Residual MTH (cm)
6
4
2
0
-2
-4
-6
-8
-10
0
1
2
3
4
5
6
7
8
9
10
Plot
MTD

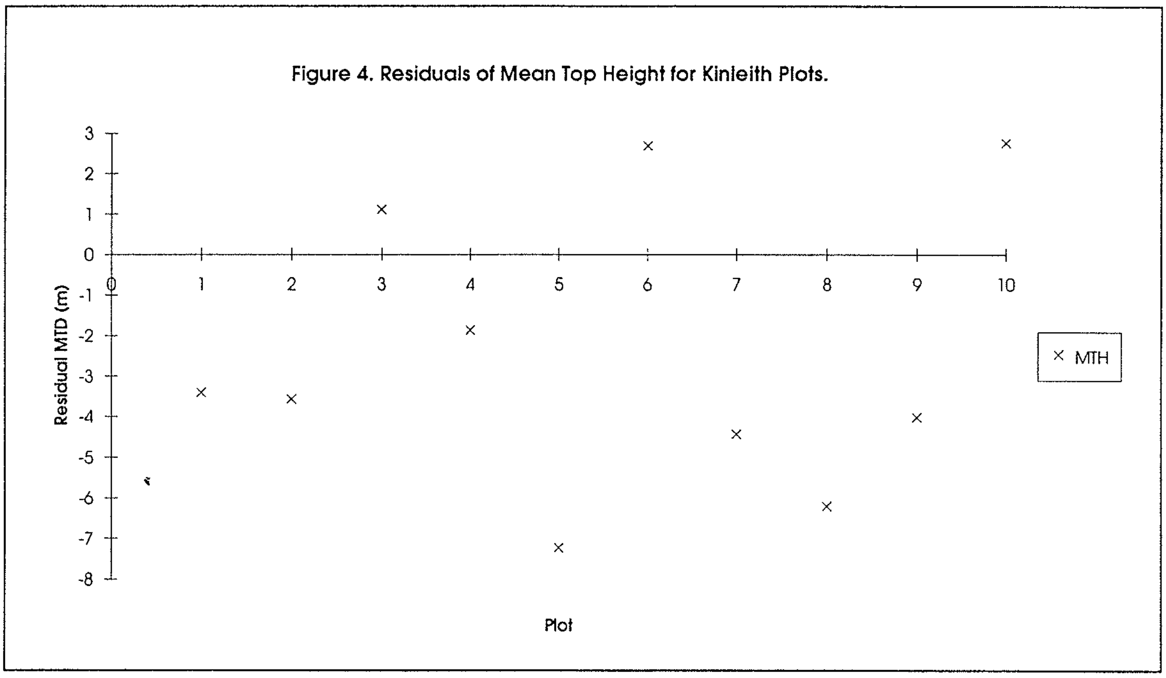


Figure 4. Residuals of Mean Top Height for Kinleith Plots.
Residual MTD (m)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0
1
2
3
4
5
6
7
8
9
10
Plot
MTH

Figure 5. Residuals of Basal Area for B.O.P. Plots.

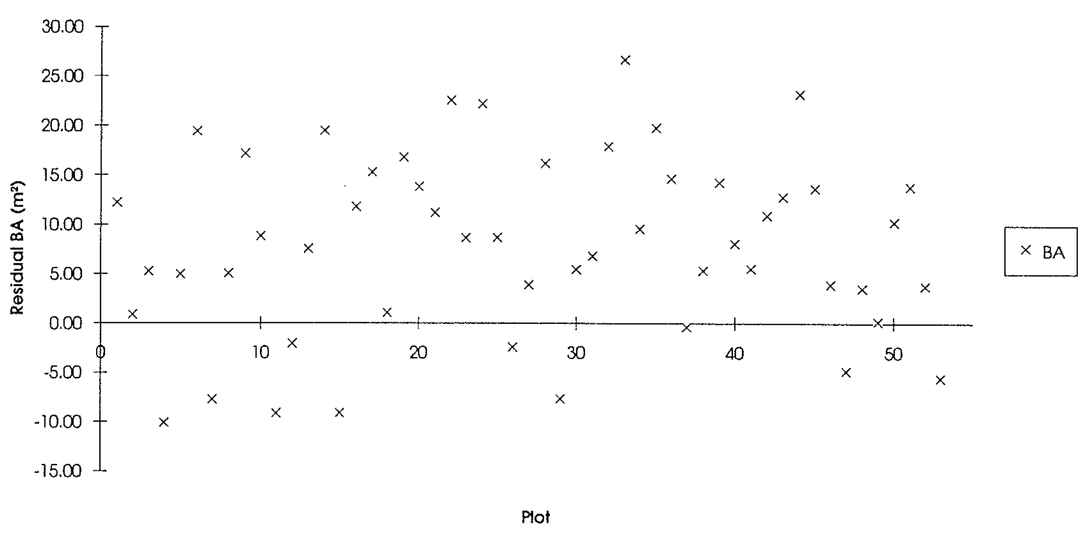


Figure 6. Residuals of Volume for B.O.P. Plots.

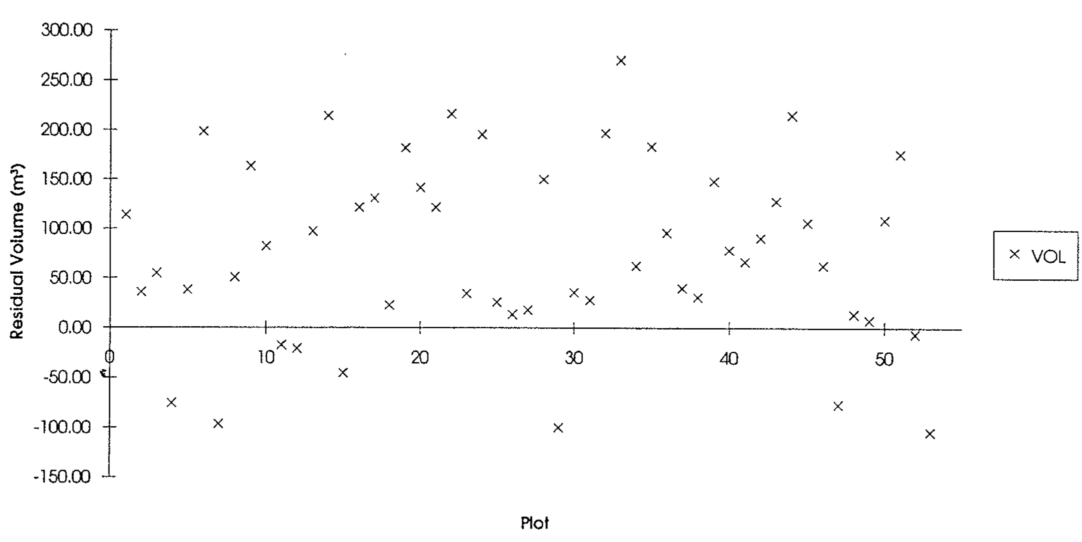


Figure 7. Residuals of Mean Top Diameter for B.O.P. Plots.

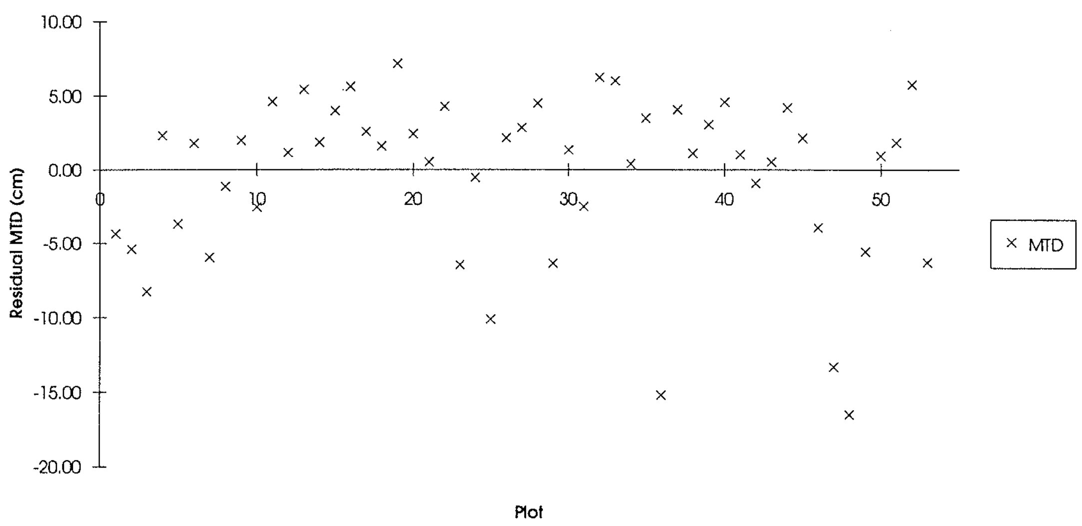
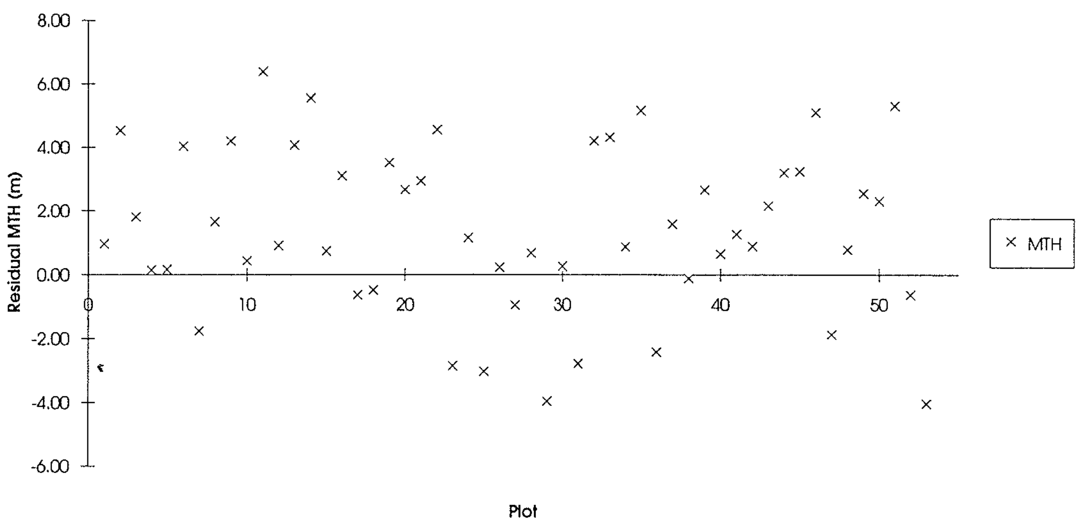


Figure 8. Residuals of Mean Top Height for B.O.P. Plots.



Notes:

Aspect: Assessed within boundaries of plot. Use compass then convert to compass point (N, NE, E, SE, S, SW, W, NW)

Slope: Average of the angle taken from plot centre to highest point on plot perimeter and the angle to the plot perimeter directly opposite. Ignore negatives in calculating average slope.

Topex: Using hypsometer take angle to horizon or lowest point of sky if land obscured by trees etc.

A Horizon: Randomly locate 25 sample points. Remove litter layer to mineral soil. Make spade cut. Measure depth of black or dark brown soil in millimetres.

pH: Take a small subsample of soil (½cup approx) from each A horizon point and add to a plastic bag in which all 25 samples are bulked. Label bag clearly with plot number (as on this sheet), date, forest, company.

Landform: