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A GROWTH MODEL FOR RADIATA PINE GROWN IN THE NELSON / MARLBOROUGH REGION

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Note : Confidential to Participants of Stand Growth Modelling Programme

: This material is unpublished and must not be cited as a literature reference

FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

The objective of this report is to document the construction and evaluate the performance of NELSON, a stand growth model for radiata pine in the Nelson/Marlborough region. The construction of this new model is a result of the concern expressed over the high mortality in the GDNS model. The NELSON model is one of a number of 'state-space' regional growth models in New Zealand which can be used to derive yield tables and to predict the effect of alternative management options in the region.

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CONTENTS

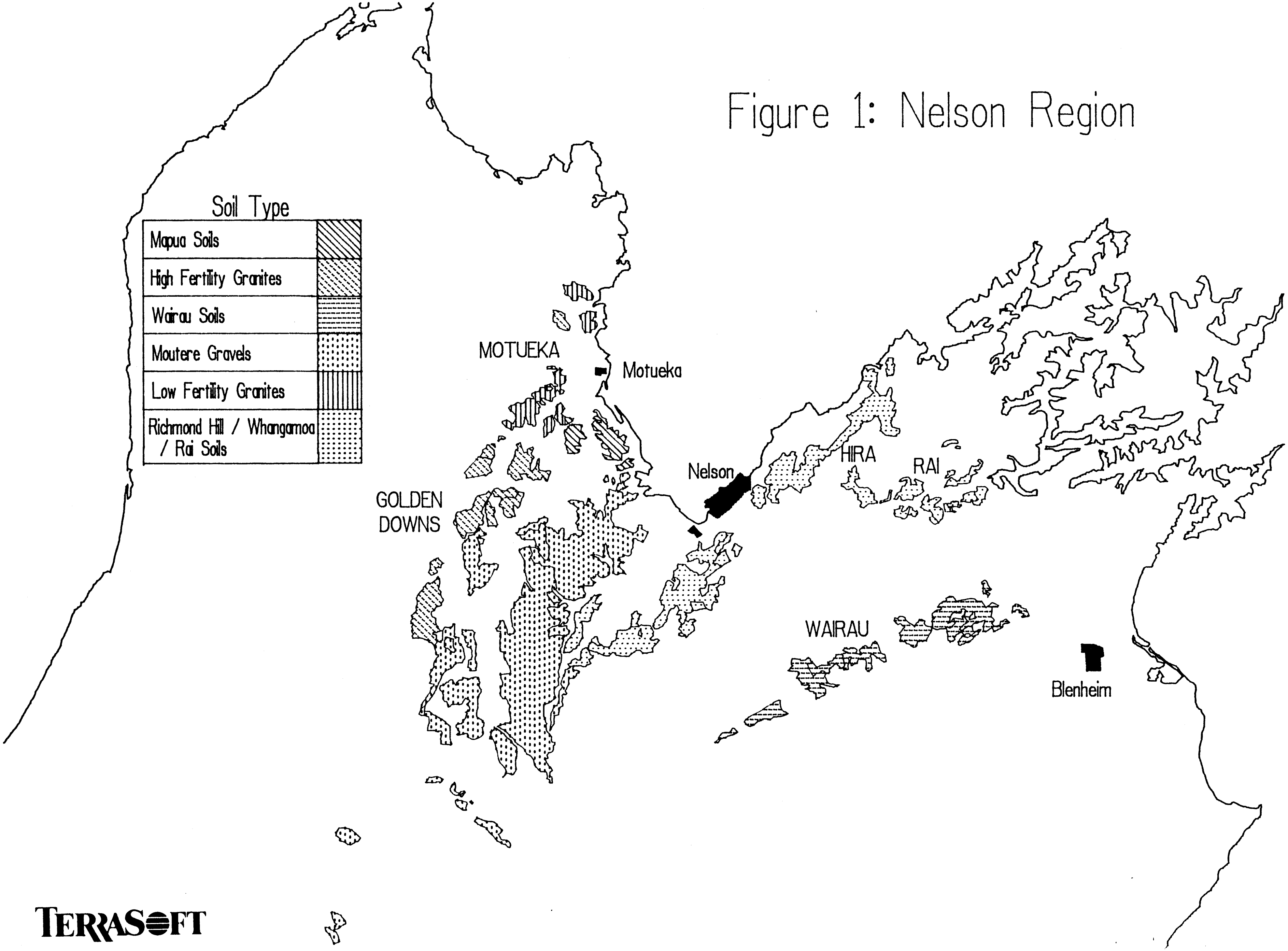
1.0 INTRODUCTION

In 1987 the Growth Modelling Co-operative was presented with *Pinus radiata* data from Baigents forests and Golden Downs forest showing the mortality (in stems/ha) to be significantly less than that predicted by the Golden Downs growth model. At the same time Dr. Garcia produced a report which re-examined the mortality prediction in the Golden Downs Growth Model and concluded that the model fitted the available data well (Garcia, 1987).
It was concluded, therefore, that the original data base does not reflect the current situation and that current mortality at less than 600 stems/ha is primarily due to windthrow and not supression.
Consequently it was decided that a new growth model should be developed and that radiata pine data from the whole Nelson region should be considered.
In July 1988 the staff from Timberlands and Baigents in Nelson provided lists of plots sorted into six soil types:

Mapua
Highfert
Wairau
Richmond
Moutere
Lowfert

These groups of plots were graphed to compare height growth, basal area growth and mortality between soil types. Discussion between FRI and Nelson staff folllowed and it was decided that any trends seen were not significant enough to warrant separate models for different soil types and a new model for the whole of the Nelson region could be developed.
The new model has now been completed under the auspices of the Stand Growth Modelling Co-operative and uses the same methodology as described in the previous Golden Downs Growth Model and later models (Garcia 1984a).
Data used in the construction of the model are from forests spread across the Nelson/Marlborugh area, from Motueka to Blenheim. This is illustrated in Figure 1.

Figure 1: Nelson Region



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2.0 DATA

All the data is taken from the New Zealand Ministry of Forestry permanent sample plot (PSP) System. After the initial screening of data (in particular, windthrow) by the Timberlands and Baigents staff the remaining data was further screened. Those measurements/plots that fell into the following categories were removed :

-fertiliser;
-poison thinning;
-mean DBH of windblown trees > mean DBH of remaining trees;
-basal area, stocking, or height missing;
-less than four height trees;
-only crop trees measured;
-average height substituted for mean top height
(PMH is permitted as a valid estimator of MTH);
-less than two measurements per plot.

Graphical analysis was then used to show up any abnormalities in the data set and 'suspect' measurements, such as those of decreasing height growth, were screened out.

At the conclusion of the screening process the database consisted of 2057 measurements from 410 plots. See Appendix 1. for the list of plots used in the development of the model. The plots are distributed in 26 different forests as shown in Appendix 2. Figures 2a, 2b and 2c show the range of data used in the model.

Ages are calculated according to month and year of measurement minus the month and year of establishment. Months are converted to tenths of a year based on the seasonal growth pattern of radiata pine (McEwan, 1979). Refer to Table 1 for these conversions.

Table 1. Month conversions

Jan	Feb	Mar	Apr	May	Jun
-0.3	-0.2	-0.1	0.0	0.0	0.0
Jul	Aug	Sep	Oct	Nov	Dec
0.0	0.1	0.2	0.3	0.5	0.6

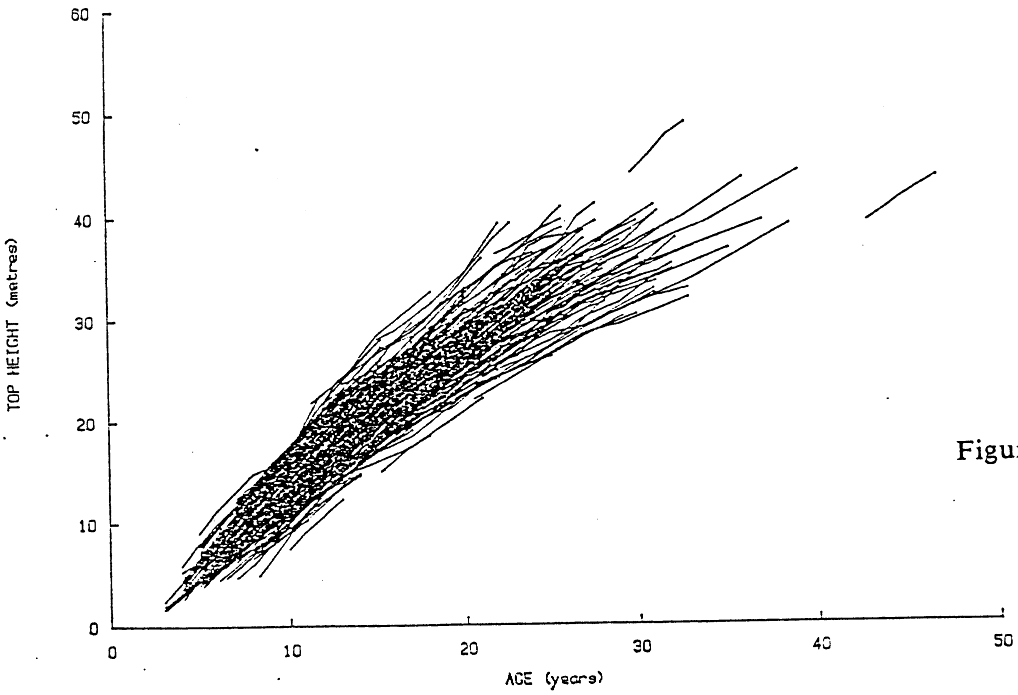


Figure 2a.

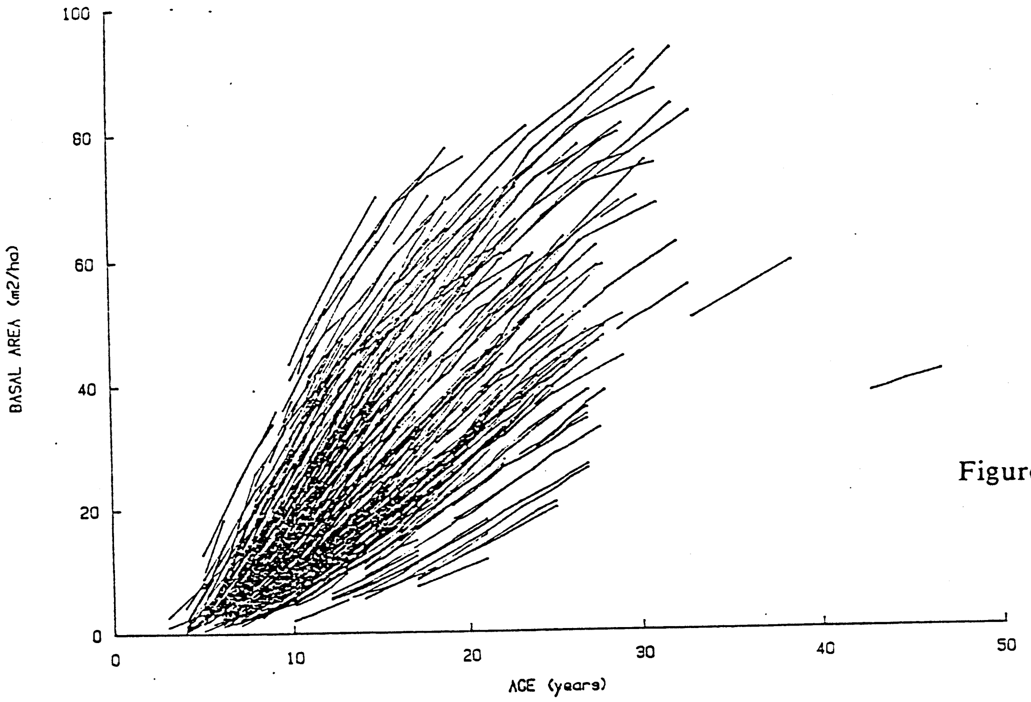


Figure 2b.

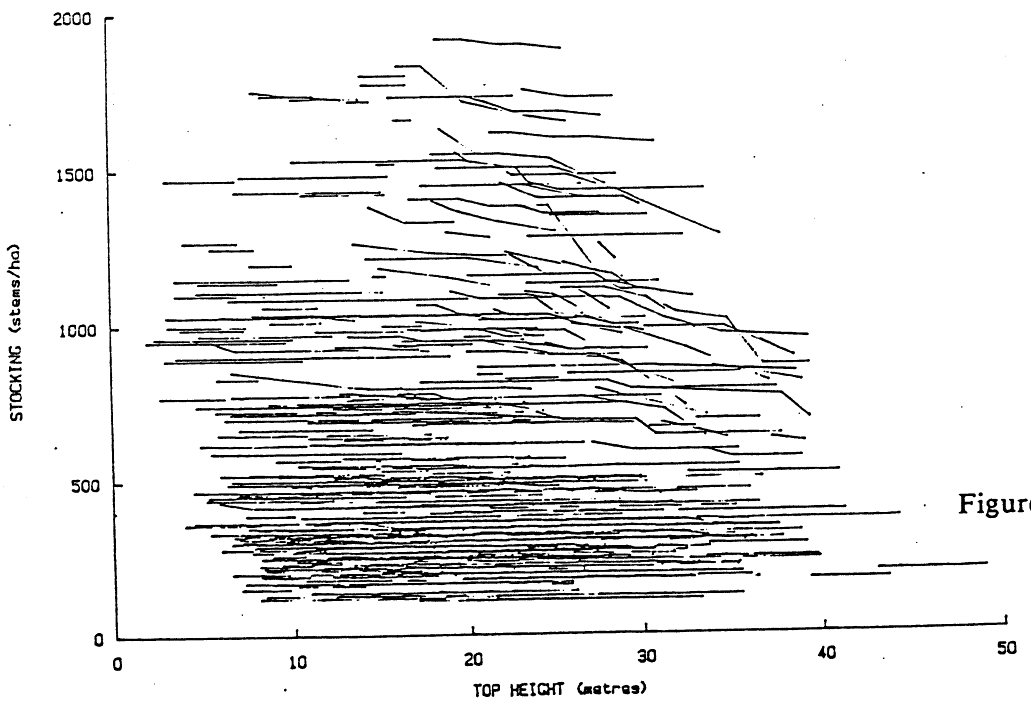


Figure 2c.

2.1 Height Model Data

The data used for the height model comprised 2023 measurements from 385 plots. The statistics of these data are described in Table 2.

Table 2. Height data summary

Initial Values

age			height		
Min	Mean	Max	Min	Mean	Max
3.0	10.2	42.8	2.0	13.6	43.0

Final Values

age			height		
Min	Mean	Max	Min	Mean	Max
6.5	17.4	46.7	7.3	24.2	49.0

Age Difference between initial and final measurements

Min	Mean	Max
1.9	7.2	18.0

Height Difference between initial and final measurements

Min	Mean	Max
1.5	10.5	27.9

Site Index

Min	Mean	Max
18.7	28.5	35.7

2.2 Basal Area and Stocking Model Data

Before the basal area/stocking model can be estimated the data is formed into measurement pairs consisting of basal area, stocking, and top height at the age of each measurement for each plot number. Measurements which were affected by changes in plot area were treated as 'new' plots and any other discontinuity between measurement pairs was due to thinning.
The model used 1655 measurement pairs to model basal area and stocking growth. The data is summarised in Table 3.

Table 3. Basal area and stocking data summary

	Age (yrs)	Ht (m)	St (stems/ha)	BA (m2/ha)
Min	3.0	2.0	110	0.3
Mean	27.4	38.2	597	24.3
Max	46.7	49.0	4075	86.8

2.3 Thinning Function Data

The thinning data is taken from the initial database and includes the basal area and stocking immediately before and after a thinning. This data is used to derive a thinning function to predict either basal area or stocking following a thinning. The thinning database is summarised in Table 4.

Table 4. Thinning function data summary

	St	Resid. St	BA	Resid. BA	Ht	Ratio*
Min	218	95	1.0	0.5	5.0	0.13
Mean	1022	408	23.7	12.9	11.5	0.54
Max	6543	2100	85.8	61.7	37.1	0.99

* Ratio = BA after thinning / BA before thinning

2.4 Volume/Basal Area Function Data

2216 plot measurements were available for developing the volume equation. The data used to estimate the function are summarised in Table 5. The volumes are taken straight from the PSP system which uses the default tree volume tables to calculate volume.

Table 5. Volume/basal area data summary

	Basal Area	Height	Stocking	Volume	Vol/BA
Min	0.3	2.0	110	1	2.1
Mean	23.9	18.8	591	191	6.6
Max	93.3	49.0	4075	1115	15.3

2.5 Initial Growth Function Data

An initial growth function is estimated to enable simulations to start from age 0. The data used consist of the first measurements of only unthinned plots. Table 6 summarises the 78 measurements which were used as a basis to predict early growth.

Table 6. Initial growth data summary

	Basal area	Stocking	Height
Min	0.3	692	3.0
Mean	17.0	1465	9.8
Max	51.5	4075	20.1

3.0 ANALYSES AND RESULTS

3.1 Height Growth

The height growth equations used in the model are described in detail in Garcia (1984).
The site index equation has the general form:

$$\frac{dH^c}{dt} = b(a^c - H^c) \qquad \ldots (1)$$

By integrating the equation with H=0 at t=t0, where t=age in years, the general equation for top height is derived:

$$H = a(1 - e^{-b(t-t0)})^{\frac{1}{c}} \qquad \ldots (2)$$

where

$$b = -\ln\frac{\left(1 - \left(\frac{S}{a}\right)^c\right)}{20 - t0} \qquad \ldots (3)$$

S = site index
H = top height in metres
t0 = age (yrs) at H = 0.0m

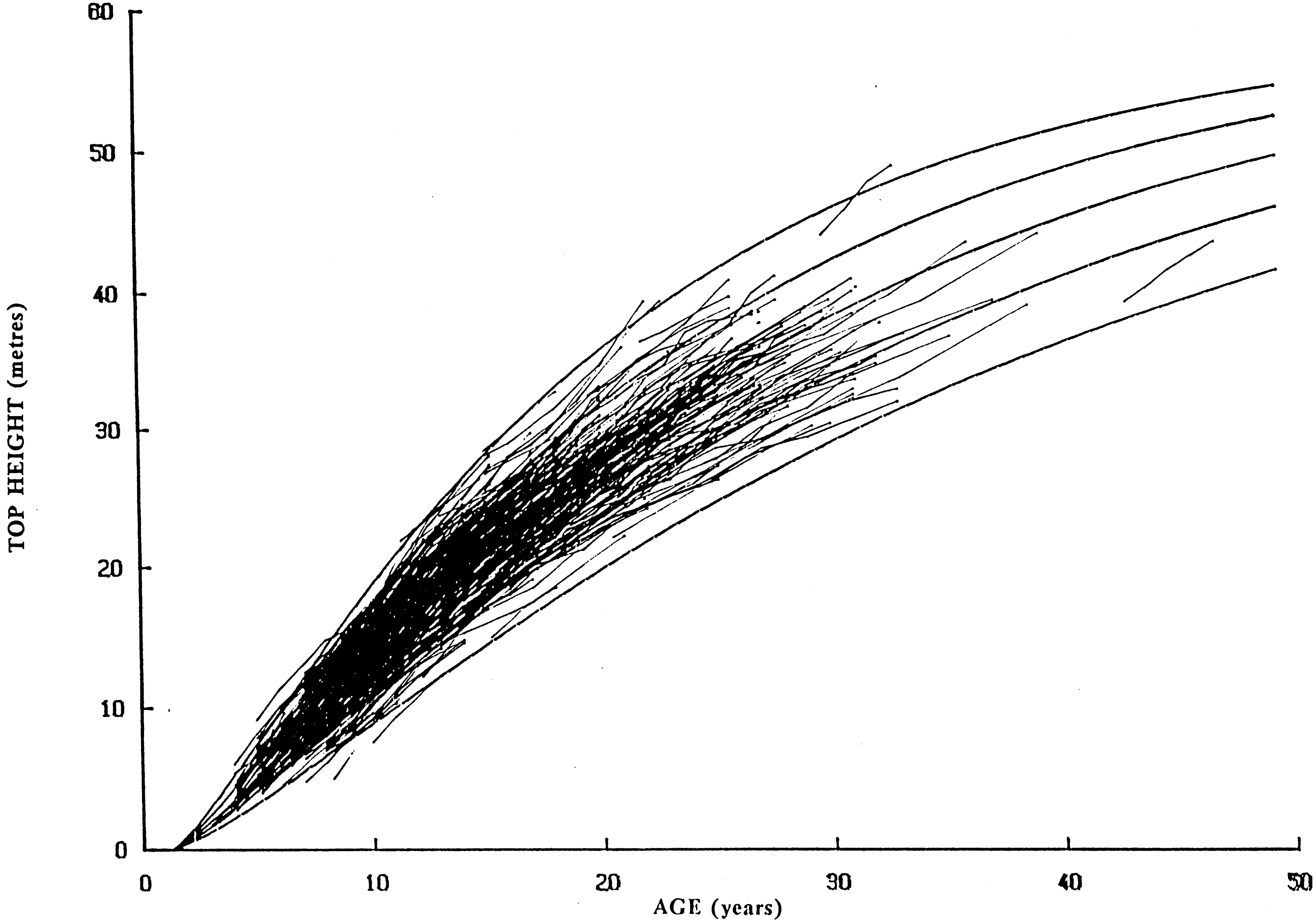
Seven versions of the basic height model were tried by 'constraining' or 'freeing' different parameters. By comparing the log-likelihood values (should be maximised) and the simplicity of the equations the 'best' version is chosen to model height growth. The parameter estimates for the Nelson height model are:

a = 60.386
c = 0.780
t0 = 1.225

b is calculated from equation (2) and the final parameter estimates are substituted in equation (3) to produce the new height curves shown in Figure 3. These site index curves can also be compared to the old ones of GDNS. Further visual analysis with the data shows that the new curves are a better fit, particularly at the very young ages.
The height residuals from this model are graphed in Figure 4. This residual analysis shows an unbiassed prediction of height and a reasonable distribution about the axis.

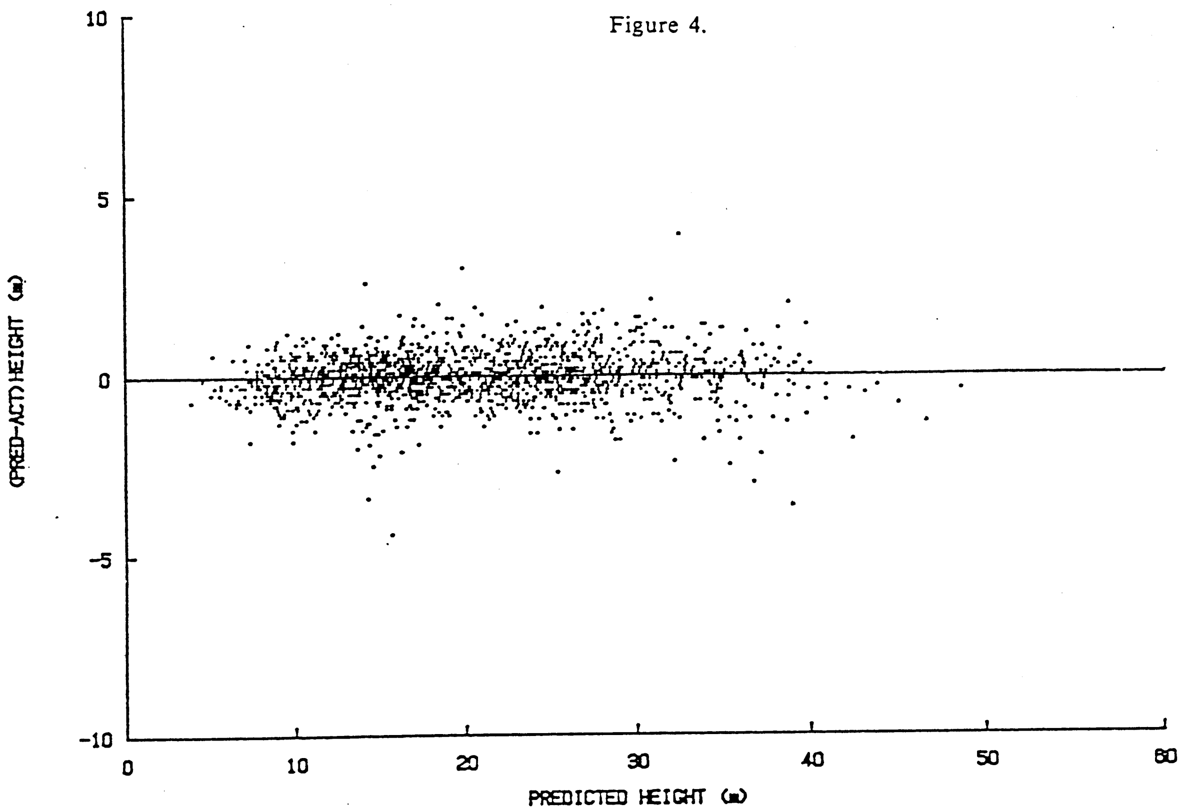
NELSON HEIGHT MODEL

Figure 3.



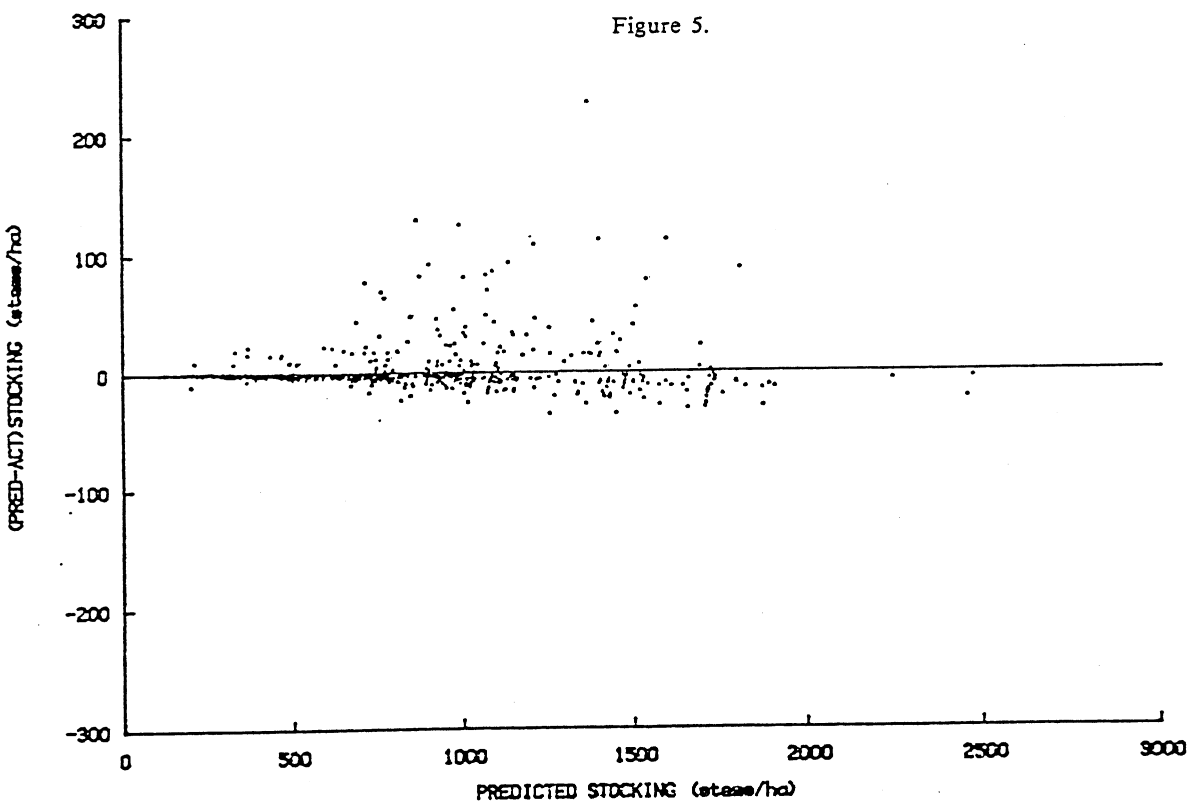
HEIGHT RESIDUALS

Figure 4.



STOCKING RESIDUALS

Figure 5.



3.2 Basal Area and Stocking Model

The parameters from the height model are incorporated in the model to predict basal area growth and changes in stocking. Different versions of the basal area and stocking model are tested on the data and the model of best fit is that with the minimum function value, dependant on the number of parameters. This is estimated by a likelihood maximisation subroutine (Biggs 1971,1973; N.O.C. 1976). Residual analysis is also used to compare the behaviour of the various versions.
The model assumes that the effect of site index is a change in the time scale with no effect on the relationships between the state variables. In equation (3) the effect of site in the model is represented by using a scaled time, $T = bt$, in the place of t.
The version of the model found to have the best fit is 'Grofit3' which is a standard 3*3 model (Garcia, 1984, eqn 4) with two parameters constrained (set to zero).
The specific form of the model which was used is then:

$$\frac{dB^{c11}N^{c12}H^{c13}}{dT} = a_{11}B^{c11}N^{c12}H^{c13} + a_{12}N^{c22} + a_{13}H^{c33} + b_1$$

$$\frac{dN^{c22}}{dT} = a_{21}B^{c11}N^{c12}H^{c13} + a_{22}B^{c21}N^{c22}H^{c23} \qquad \ldots (4)$$

$$\frac{dH^{c33}}{dT} = -H^{c33} + b_3$$

Table 7 gives a short description of each of the versions tested to predict stocking and basal area growth.

Table 7. Basal area/stocking model versions

Version	Fn. value	No. variables	Model description
Grofit1	0.0478	14	parameters all free
Grofit2	0.0479	13	as above but b2 set to 0
Grofit3	0.0479	12	b2 & a23 set to 0
Grofit4	0.0504	11	b2, a23 & a12 set to 0
Grofit5	0.0547	12	a23 & c21 set to 0

'Grofit1' appears to have the best function value but has 14 variables which involves a higher degree of over fitting. As 'Grofit3' has a function value that is not significantly different and uses fewer variables, this version is chosen as the 'best'.

The parameter estimates for the model are:

$$C = \begin{pmatrix} 0.10625 & -0.04490 & 0.72620 \\ 0.00715 & -0.93997 & -0.02238 \\ 0 & 0 & 0.78080 \end{pmatrix}$$

$$A = \begin{pmatrix} -0.37270 & 0.01396 & -0.51657 \\ 0.06975 & -0.04209 & 0 \\ 0 & 0 & -1.0 \end{pmatrix}$$

$$P = \begin{pmatrix} 1 & -179.37287 & -0.87272 \\ 0.0000488039 & 1 & -0.000027678 \\ 0 & 0 & 1 \end{pmatrix}$$

$$b = \begin{pmatrix} 3.71855 \\ 0 \\ 4.07158 \end{pmatrix} \qquad a = \begin{pmatrix} 4.62083 \\ 7.65710 \\ 4.07158 \end{pmatrix}$$

$$\lambda_1 = -0.37562$$
$$\lambda_2 = -0.03917 \qquad \textit{where} \quad a = -A^{-1}b$$
$$\lambda_3 = -1$$

Lambdas 1, 2 and 3 are the eigenvalues of A and the rows of P are the left eigenvectors such that

$$A = P^{-1}\Lambda P$$

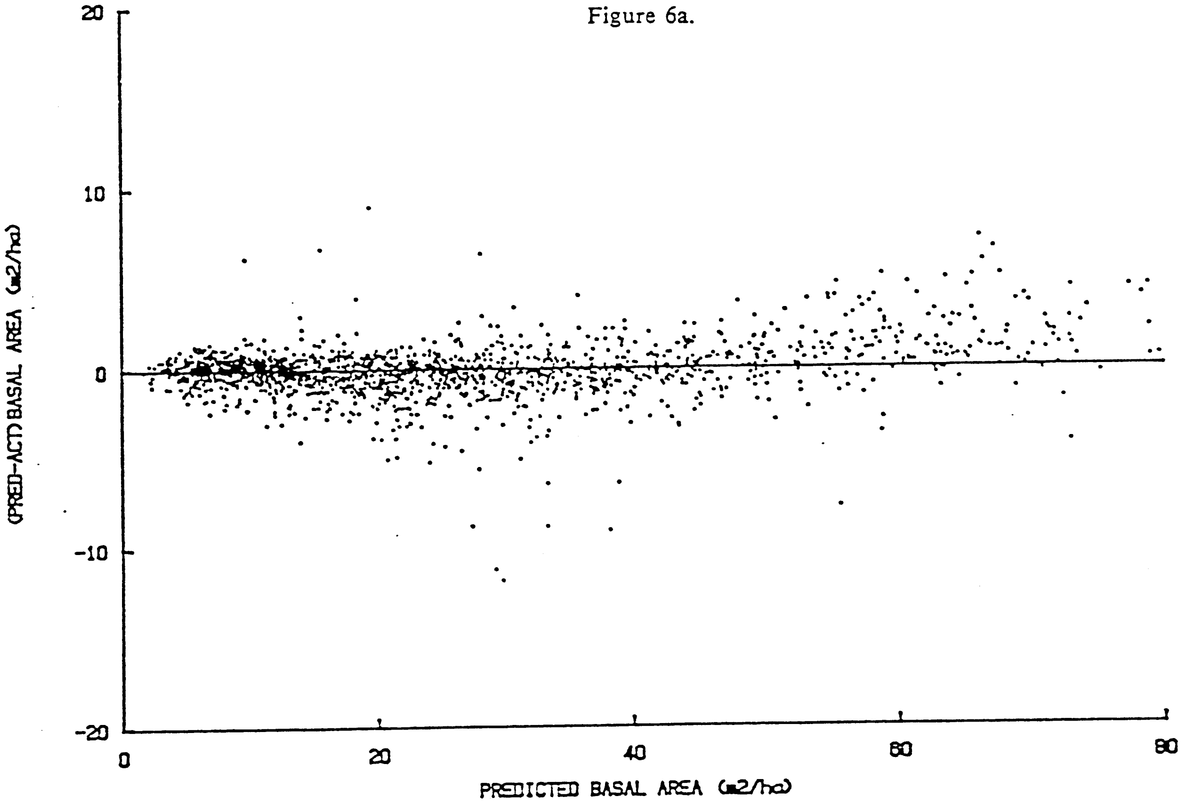
and lambdas 1,2 and 3 are the elements on the diagonal of Λ.

Refer to Garcia (1984) for a detailed explanation of the working of these parameters.

Residual analysis of this model (Grofit3) for both stocking and basal area is shown in Figures 5, 6a and 6b. The stocking residuals are fairly well distributed with a mean residual of only -1.08 stems/hectare. At higher stockings there are several measurements that are overpredicted by the model but with the exception of four, these measurement predictions are over by less than 10%. In Figure 6a the basal area residuals are well distributed until a predicted basal area of approximately 57 m2/ha. After this basal area the residuals are biassed towards overprediction of up to 10%. The mean basal area residual is -0.03 m2/ha which is comparable to other regional growth models. Figure 6b is included to show that there is no basal area prediction bias across the range of site indices.

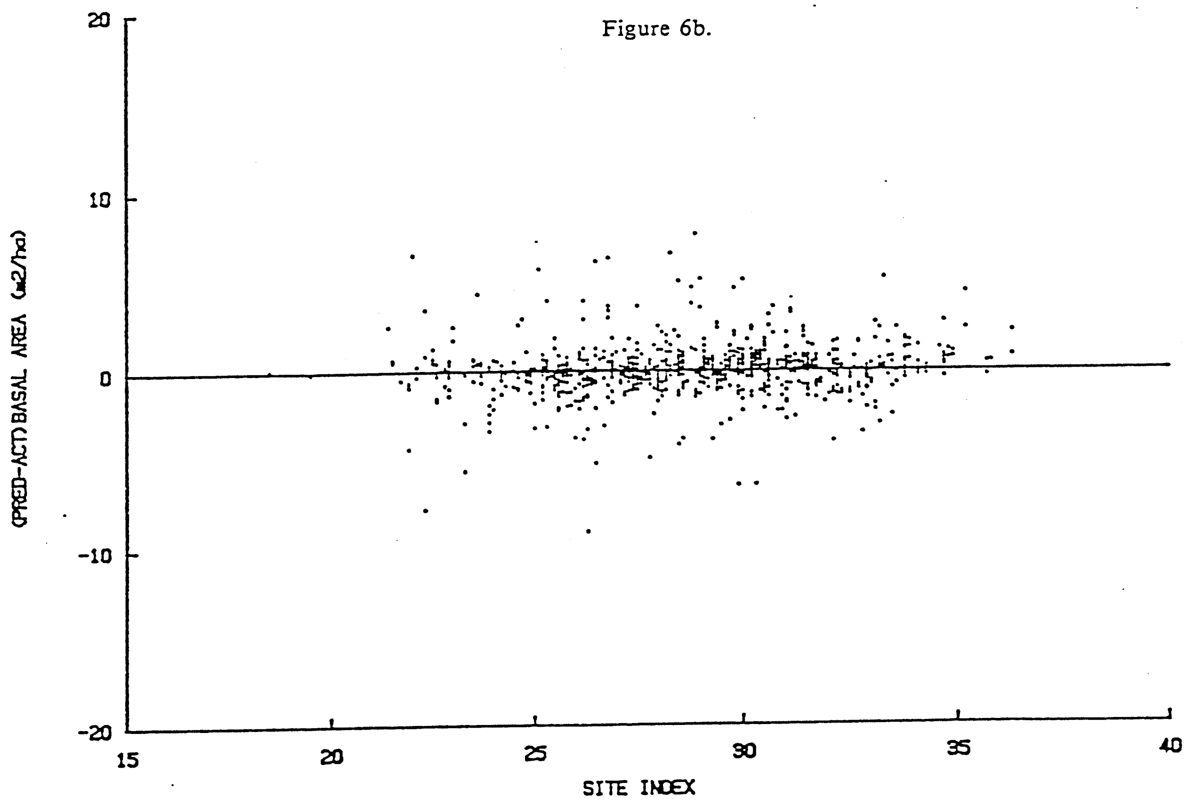
BA RESIDUALS

Figure 6a.



BA RESIDUALS

Figure 6b.



3.3 Thinning Function

The thinning model is used to predict basal area after thinning given the number of trees removed (or the stocking given basal area removed). The general form of the equation is:

$$\frac{d\ln B}{d\ln N} = aB^{b}N^{c}H^{d} \qquad \ldots (5)$$

where a,b,c and d are parameters to be estimated. Several forms of non-linear regression are fitted to the integrated form of equation (5) and the thinning data. The best form of the equation was found by making b=0 so the final function becomes:

$$B = B_0 \times \exp(a/c \times H^{d} \times (N^{c} - N_0^{c})) \qquad \ldots (6)$$

or

$$N = \left(N_0^{c} - \frac{1}{a/c} \times H^{d} \times \mathrm{LOG}(B/B_0)\right)^{\frac{1}{c}} \qquad \ldots (7)$$

where

B_o= basal area before thinning (m2/ha)
B = basal area after thinning (m2/ha)
N_o= stocking before thinning (stems/ha)
N = stocking after thinning (stems/ha)
H = top height (m)

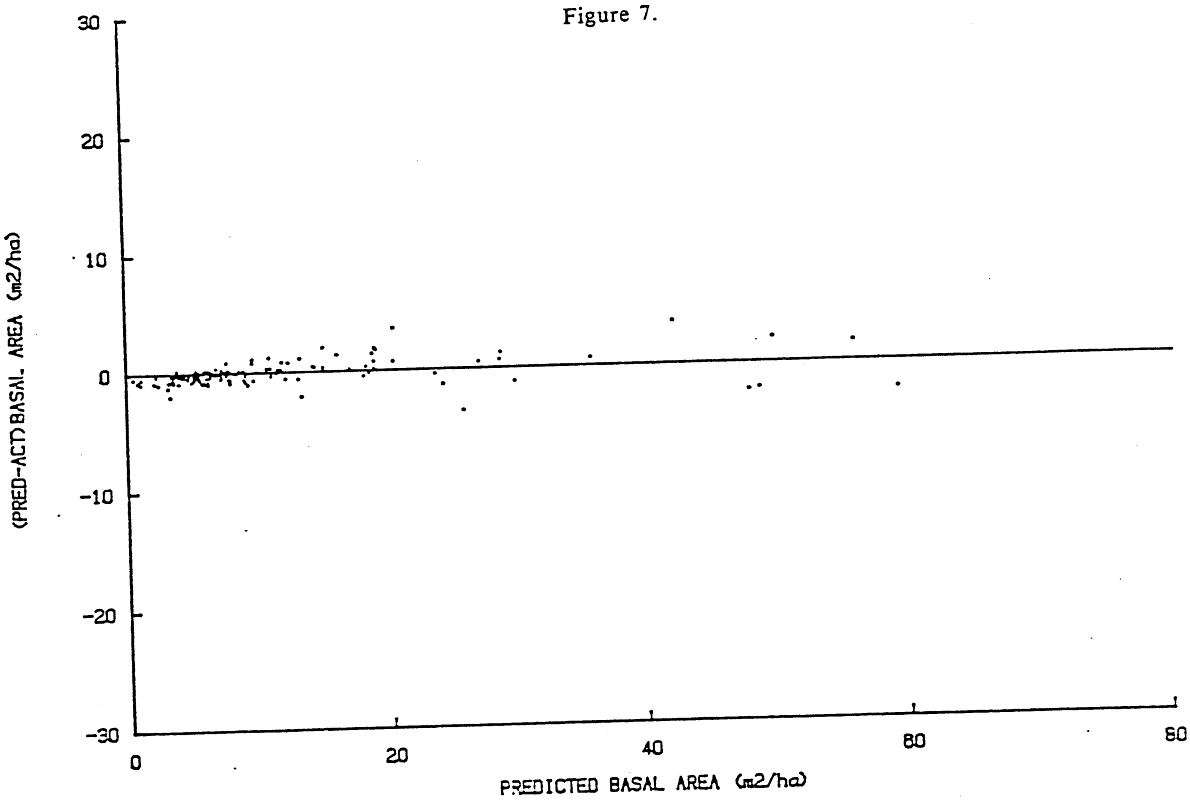
and

a = 3.80379
c = -0.08991
d = -0.36013

The residuals for the chosen thinning function are shown in Figure 7. There is a good distribution about the axis with a mean residual of only 0.003 m2/ha and a residual mean square of 0.957 m2/ha.

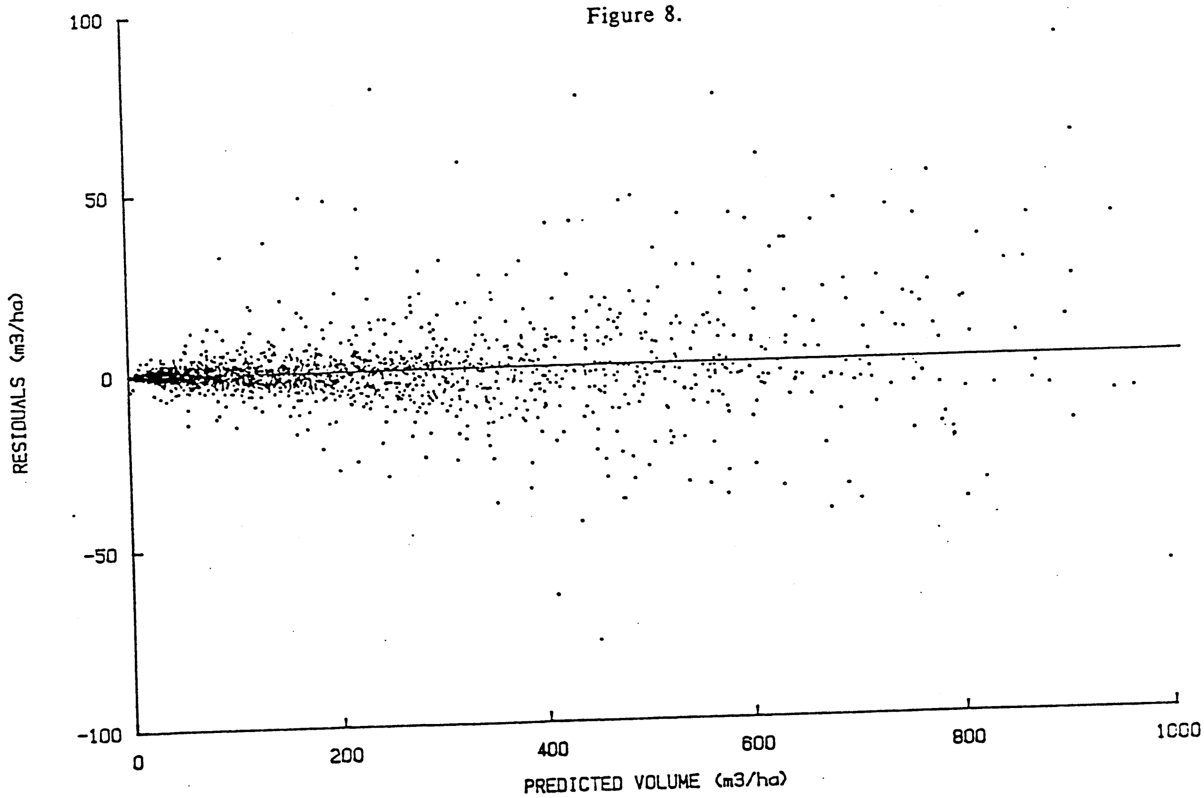
THINNING RESIDUALS

Figure 7.



VOLUME RESIDUALS

Figure 8.



3.4 Volume/Basal Area Function

The stand volume equations used in NZ are mostly of the form:

$$V/B = a + bH \qquad \ldots (8)$$

where

V = volume per hectare (m3/ha)
B = basal area per hectare (m2/ha)
H = top height (m)

This equation (8) cannot be true both before and after a thinning because the thinned trees tend to be smaller than the average so that the V/B ratio after the thinning must be greater than that before the thinning (Beekhuis, 1966). A stepwise linear regression is used to estimate V/B as a function of independent variables N and/or B in addition to H.

The best regresion was found to be equation (9) as follows:

$$V/B = 1.0539 + 0.292048H + (0.0000609(N \times H/B)) \qquad \ldots (9)$$

The volume residuals are shown in Figure 8. They are reasonably well distributed around zero with a mean residual of -1.39 m3/ha.

3.5 Initial Growth Function

A separate model is needed to predict growth from age zero. As there is minimal data available at the very young ages, data is obtained by using the growth equations to grow measurements forward or backward in time, to a specific top height. A function to estimate basal area, given stocking and a fixed top height, is fitted to this data.

The function has the general form:

$$B = \begin{cases} (a/c - b)N & \text{for} \quad N \leq c \\ a \ln N - bN + a(1 - \ln c) & \text{for} \quad N > c \end{cases} \qquad \ldots (10)$$

where B = basal area (m2/ha)
N = stocking (stems/ha)

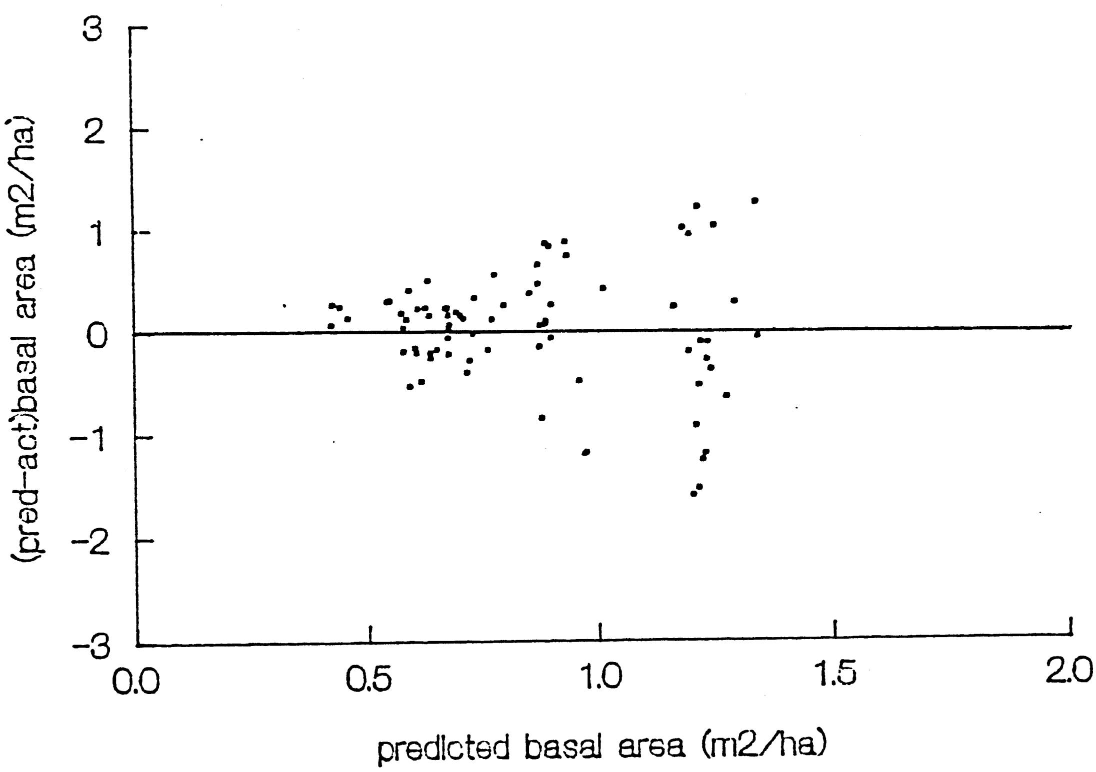
The parameters *a*, *b* and *c* are estimated by non-linear least squares, resulting in the final equation, for top height at 3m:

$$B = \begin{cases} 0.0006860N & \text{for} \quad N \leq 1623 \\ 3.75880 \ln N - 0.00163N - 24.02624 & \text{for} \quad N > 1623 \end{cases} \qquad \ldots (11)$$

Figure 9 shows the residuals for initial growth. Although the mean residual is only 0.006m2/ha there is a fairly wide dispersal (both over and underestimation) indicating a high percentage error particularly at the higher basal area stages of initial growth.

INITIAL GROWTH RESIDUALS - MTH 3.0m

Figure 9.



4.0 EVALUATION AND DISCUSSION

4.1 Residual Analysis

Residual analysis is the primary method in which the functions and models have been compared and selected.
The residual mean squares (RMS) for the major variables are calculated in Table 8. These RMS values are all similar and in some cases better than those for other regional models in New Zealand.

Table 8. Residual Mean Squares

	RMS
Basal area (m2/ha)	1.51
Stocking (stems/ha)	14.30
Top height (m)	0.65
Basal area * height (m3/ha)	44.72
Mean DBH (cm)	0.163
Average spacing (m)	0.024

Residual analysis is seen graphically in Figures 4 to 9. The residuals for height show that the height model chosen is a good and unbiassed predictor of height in the Nelson area.
The stocking residuals in Figure 5 indicate no significant bias in predicted mortality and appear to show a similar pattern to other recently developed growth models.
The basal area residuals are graphed on page 14, against both predicted basal area and site index. When plotted on site index there appears to be no bias and the dispersal looks good compared to that of models in other regions. The residuals in Figure 6a, however, show that there is a bias in the model at high basal areas (>57m2/ha). All the basal area/stocking models tried showed this same pattern in the residual analysis which caused some concern. It was suggested that across the Nelson area there may be different rates of height growth, due to soil, climate, etc and that there may be two distinct groups. On going through the data again no groups could be isolated as growing differently due to a particular factor. Regeneration was also considered but graphing regenerated plots and planted plots separately showed no obvious pattern. There was therefore no basis on which data could be dropped out of the data set or two separate models be estimated.

At this stage it was decided to release the model in its present form and let the forest owners use and test it. Although the model is biassed towards over-predicting the basal area after 57m2/ha the over-predictions are still no greater than that predicted by growth models in other regions.
Figures 7 and 8 do not show any bias in the prediction of volume or basal area after thinning with a reasonable distribution around the zero line.
The initial growth residuals, shown in Figure 9 do not show bias but are fairly widely dispersed. It is recommended that, whenever possible, young ages should be initiated with actual basal area input rather than starting the model from age 0.

4.2 Growth and Yield Analysis

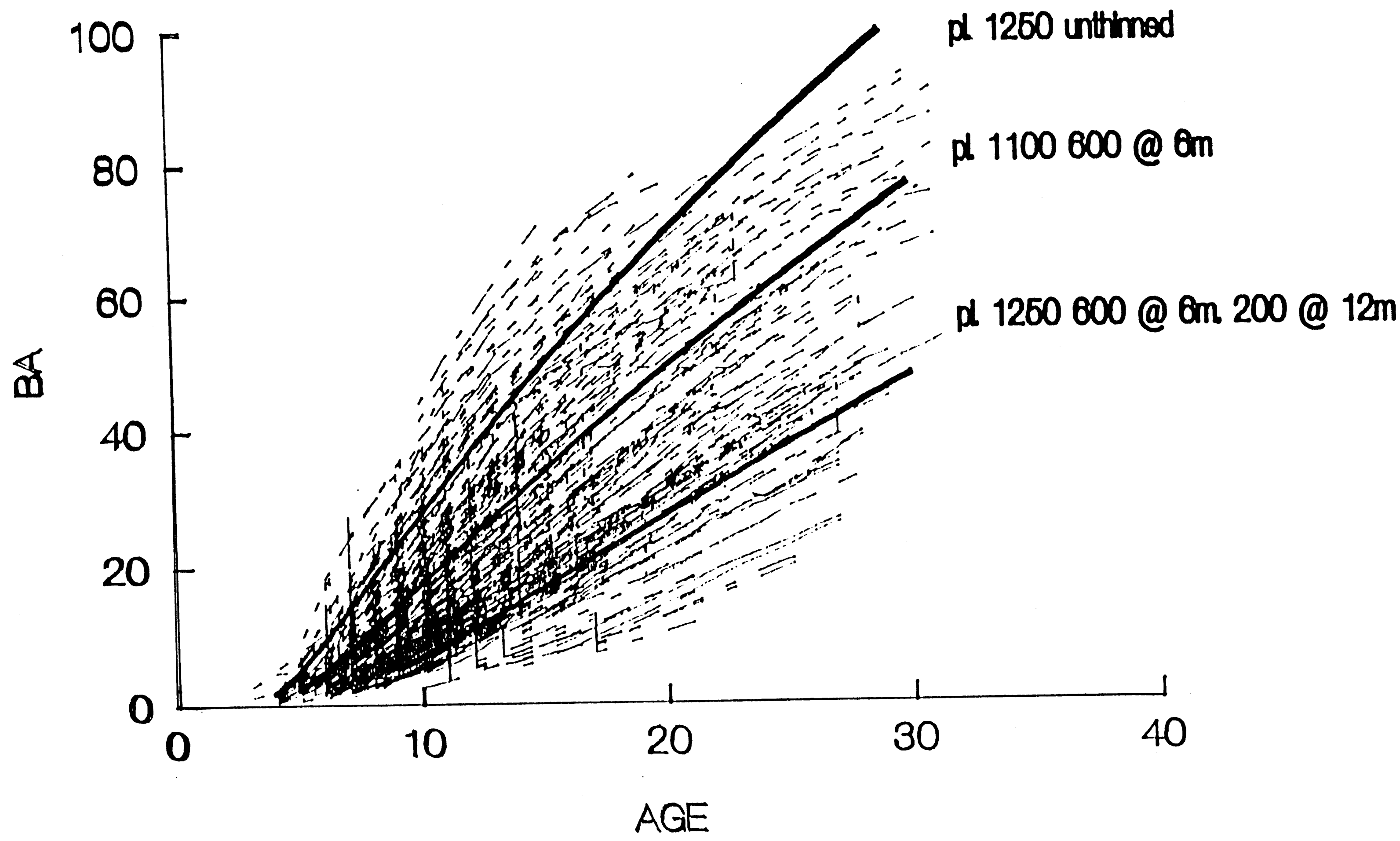
Three different regimes were run through NELSON. The simulations are all run at the average site index of 28.5m. The regimes shown in Figure 10 and 11 are:

1. Initial stocking 1250 stems/ha. Unthinned.
2. Initial stocking 1100 stems/ha. Thinned to 600 stems/ha at MTH 6m.
3. Initial stocking 1250 stems/ha. Thinned to 600 stems/ha at MTH 6m, thinned to 200m at MTH 12m.

The curves have been superimposed on the basal area/age data in Figure 10 and on the volume/age data in Figure 11. The basal area growth curves fit the data well except for the unthinned regime where the predicted growth does not appear to flatten out at the older ages as the data shows. The 'two thin' regime compares the best with the data. In Figure 11 the volume prediction of regime 1 (unthinned)also goes slightly higher than the trend of the data. Both graphs show that basal area and volume is overestimated at the later (25+) ages which is probably a direct result of the aforementioned problems with basal area (page 20). Overall, however, the NELSON model does well to approximate the volume growth in the data.

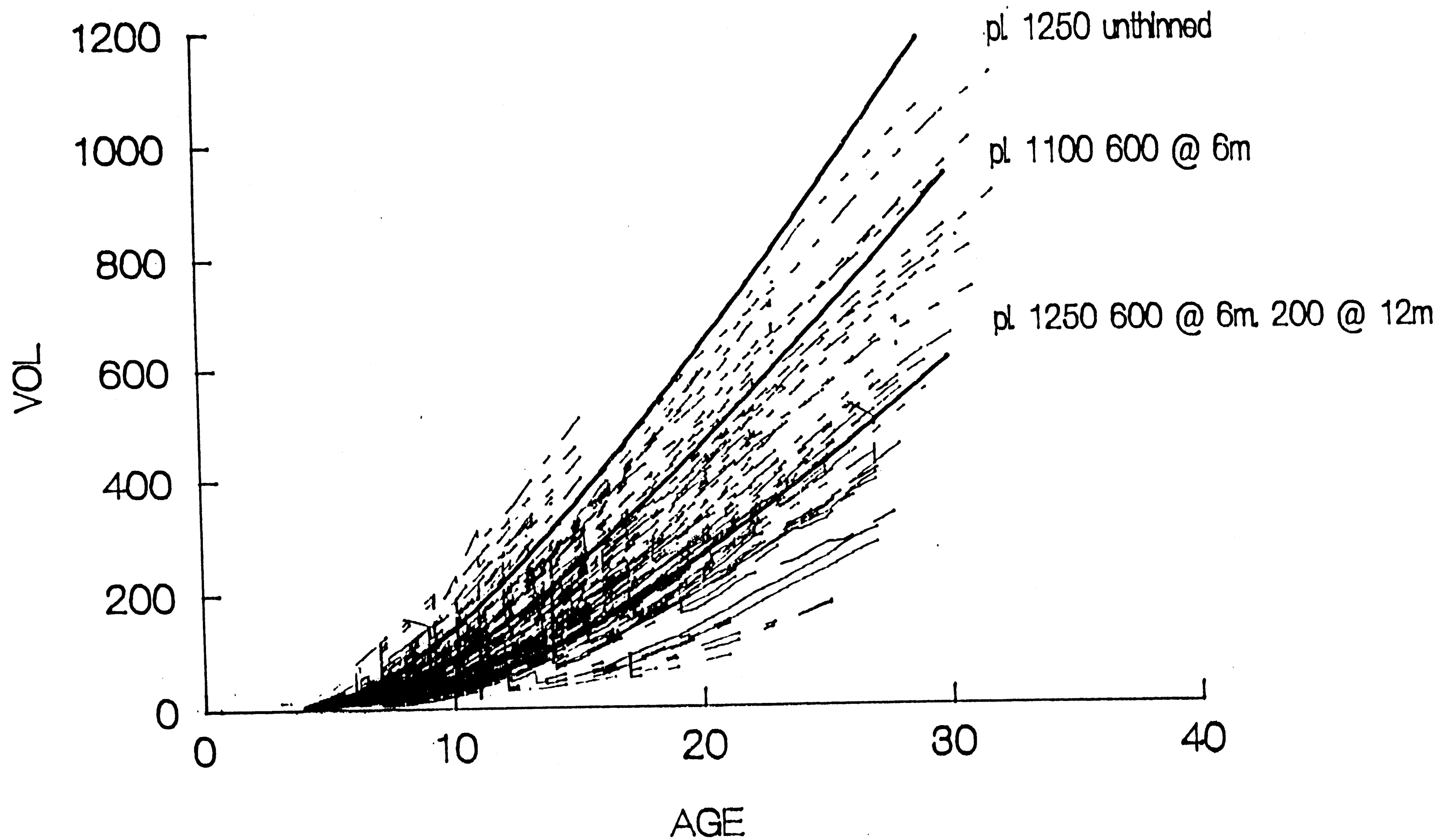
MANAGEMENT REGIME SIMULATIONS - BA BY AGE

Figure 10.



MANAGEMENT REGIME SIMULATIONS - VOL BY AGE

Figure 11.



4.3 Comparison with Golden Downs Model (GDNS)

Several simulations were run through both the NELSON and GDNS models. The regimes used are the same as those used in section 4.2, also with a site index of 28.5. Each simulation was started from age 0 and the values given in Table 9 are at age 30.

Table 9. Comparison between GDNS and NELSON
all values at SI = 28.5 and age = 30

regime	*height*		*stocking*		*basal area*		*mean DBH*		*volume*	
	NELS	GDNS	NELS	GDNS	NELS	GDNS	NELS	GDNS	NELS	GDNS
1	39.1	38.9	1055	797	102.6	84.3	35.2	36.7	1244	1032
2	39.1	38.9	553	443	76.8	66.3	42.0	43.7	944	816
3	39.1	38.9	197	171	48.1	43.9	55.8	57.1	612	548

The biggest difference between the results from the two models is in the residual stocking. There is significantly less mortality produced by the NELSON model as compared to the GDNS model. As a result the basal areas and volumes are greater in the NELSON model than the GDNS model at age 30. Table 10 shows the percentage differences between the models.

Table 10. Percentage Differences between GDNS and NELSON

regime	*height*	*stocking*	*basal area*	*mean DBH*	*volume*
1	0.5%	24.5%	17.8%	4.3%	17.0%
2	0.5%	19.9%	13.7%	4.0%	13.5%
3	0.5%	13.2%	8.7%	2.3%	10.5%

% Diff = Diff(NELSON)-Diff(GDNS)/Diff(NELSON) * 100%

These differences show that there is very little difference in the mean diameter between the two models so that the increase in basal area and volume produced from NELSON is a reflection of the reduction in mortality. When stocking is increased mean DBH is not affected, resulting in more trees of equal size and a greater volume per hectare. As tending becomes more intensive the difference between the two models is less.

5.0 SUMMARY

The objectives of this report were to document the construction of the NELSON growth model and to evaluate its performance. These objectives have been achieved although further validation is required by the users. The major area of concern is the over-prediction of basal area in older stands, yet there has been no reason found for this unusual behaviour. Apart from this the model appears to perform well and mortality, the main concern in the GDNS model, is considerably less and would expect to model stand behaviour in the Nelson area accurately.

6.0 ACKNOWLEDGEMENTS

I would like to thank Mr Steve McIntosh, of NZ Timberlands Ltd, and Mr Neil Eder, of Baigent Forest Industries Ltd, for the time that they spent in screening the data in the early stages.

I am also grateful to the people at FRI who have contributed towards this work. In particular:

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Mr Murray Lawrence and Mr Andrew Dunningham both of whom provided assistance throughout the entire project.

Dr Oscar Garcia who provided the knowledge and help when it was needed.

Dr Chris Goulding for his support and advice.

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APPENDICES

(1) List of all plots used for the NELSON model.

(2) No. of plots used from each forest.

Appendix 1. List of all plots used for the NELSON model.

Mapua

1500000100.	4960007108.	4980000100.
4960007111.	4960007242.	4980000200.
4960007113.	4960007447.	4980000300.
4960007114.	4960008058.	4980000400.
4960007124.	4960008059.	4980000500.
4960007226.	4960008069.	4980000600.
4960007228.	4960008083.	4980000700.
4960007229.	4960008085.	4980000800.
4960007231.	4960008181.	4980000900.
4960007232.	4960008291.	4980001000.
4960007233.	4960008402.	4980001100.
4960007241.	4960008403.	4980001200.

Wairau

4440000400.	4690007704.	4690007905.
4440001100.	4690007707.	4690007906.
4500008402.	4690007708.	4690008301.
4500008403.	4690007709.	4840000100.
4520215001.	4690007710.	4840000200.
4520235001.	4690007711.	4840000300.
4520325002.	4690007713.	4840000400.
4520325003.	4690007714.	4840000500.
4520325004.	4690007716.	4840000600.
4520339001.	4690007717.	4840000700.
4520415002.	4690007718.	4840000800.
4520435002.	4690007719.	4840000900.
4520525007.	4690007720.	4840001000.
4690007702.	4690007721.	4840001100.
4690007702.	4690007901.	4840001200.
4690007703.	4690007902.	

Lowfert

870000400.	1950000300.	1950001900.
870000800.	1950000500.	1950002100.
1410400700.	1950000700.	1950002300.
1930000100.	1950000900.	4210000400.
1930000500.	1950001000.	4210001000.
1930000700.	1950001200.	4210001400.
1930000900.	1950001400.	4210002600.
1930001000.	1950001500.	5140200300.
1930001500.	1950001700.	5140200400.

Moutere

790000200.	3100000600.	4930001200.
790001300.	3100000700.	4930001300.
790001700.	3100000800.	4930001400.
790001800.	3100000900.	4960007116.
790002000.	3100001000.	4960007117.
790005500.	3100001100.	4960007118.
790005600.	3100001200.	4960007119.
790005900.	3100001300.	4960007120.
790006000.	3100001400.	4960007122.
790006100.	3100001500.	4960007123.
790006200.	3240000100.	4960007203.
790006300.	3240000200.	4960007204.
790006400.	3240000300.	4960007205.
1510000100.	3240000400.	4960007207.
1510000200.	3240000600.	4960007209.
1510000300.	3240000800.	4960007215.
1510000400.	3240000900.	4960007225.
1620000100.	3240001100.	4960007230.
1620000200.	3240001200.	4960007235.
1620000300.	3710000100.	4960007236.
1620000400.	3710000200.	4960007237.
1620000500.	3710000300.	4960007239.
1620000600.	3710000400.	4960007243.
1620000700.	3710000500.	4960007345.
1620000800.	3710000600.	4960007346.
2390000300.	3710000700.	4960008061.
2390000500.	3710000800.	4960008062.
2390000600.	3790000200.	4960008063.
2620000100.	3790000500.	4960008064.

2620000300.	3790001200.	4960008065.
2620000500.	3920000100.	4960008067.
2670000100.	3920000800.	4960008068.
2670000200.	3920001100.	4960008070.
2670000300.	4140001400.	4960008071.
2670000400.	4460006802.	4960008072.
2670000500.	4460006803.	4960008074.
2670000600.	4460006804.	4960008075.
2670000700.	4460006806.	4960008076.
2670000800.	4460006807.	4960008078.
2670000900.	4460006816.	4960008079.
2780000100.	4460006828.	4960008080.
2780000200.	4460007502.	4960008082.
2780000300.	4460007503.	4960008293.
2780000400.	4460007504.	4960008294.
2780000500.	4460007505.	4960008396.
2780000600.	4460007506.	4960008397.
2780000700.	4460007507.	4960008404.
2780000800.	4460007609.	5140100100.
2780000900.	4460007610.	5140100200.
2780001000.	4460007611.	5140100500.
2780001100.	4460007612.	5140100600.
2780001200.	4460007613.	5140100700.
2780001300.	4460007614.	5140100800.
2990005001.	4460007615.	5140100900.
2990005002.	4460007701.	5140101000.
2990010001.	4460007702.	5140101100.
2990010002.	4460007708.	5140101300.
2990020001.	4460007710.	5140101500.
2990020002.	4460007711.	5140101600.
2990030001.	4460007814.	5140101700.
2990030002.	4460007844.	5140101900.
3000000100.	4460007866.	5140102000.
3000000200.	4460007878.	5140102100.
3000000300.	4930000100.	5460000400.
3000000400.	4930000200.	5460001000.
3000000500.	4930000300.	5460001500.
3000000600.	4930000400.	5460001600.
3000000800.	4930000600.	5460001700.
3000000900.	4930000700.	5460001900.
3100000100.	4930000800.	5740000100.
3100000200.	4930000900.	5740000200.

3100000300.	4930001000.
3100000400.	4930001100.
3100000500.	

Richmond

1830000100.	4620007201.	4960008184.
1840000100.	4620007202.	4960008186.
2400000300.	4620007801.	4960008289.
3760000100.	4620007804.	4960008290.
3760000200.	4620007805.	4960008295.
3760000300.	4620007806.	4960008398.
3760000400.	4620007807.	4960008401.
3760000500.	4620007810.	4960008406.
3760000600.	4620008303.	4960008407.
3760000700.	4860008101.	4960008499.
3760000800.	4860008102.	4960008509.
3760000900.	4860008103.	4960008610.
3760001000.	4860008104.	4960008611.
4620006901.	4860008105.	5730000200.
4620006903.	4860008106.	5750000300.
4620006904.	4860008107.	5750000500.
4620006905.	4860008108.	5750001200.
4620006908.	4860008309.	5750001300.

Highfert

3110000100.	4910000600.	4960008054.
3110000200.	4910000700.	4960008055.
3110000300.	4910000800.	4960008056.
3110000400.	4960007101.	4960008057.
3110000500.	4960007102.	4960008187.
4910000100.	4960007234.	4960008188.
4910000200.	4960008051.	4960008292.
4910000300.	4960008052.	5140101200.
4910000400.	4960008053.	5140101400.
		5140101700.

Appendix 2. Number of plots used from each forest.

NZ Timberlands, Nelson

Forest	*No.*	*Forest*	*No.*	*Forest*	*No.*
Golden Dns	161	Motueka	27	Rai Valley	17
Hira	24	Wairau	46	Tutaki	2

Baigent Forests

Harakeke	6	Sth Pigeon	11	Waiwhero	8
Greenhill	15	Dovedale	20	Orinoco	2
Trass	12	Mahana	17	Hoults	8
Waimea West	2	Nth Pigeon	3	Sunrise	4
Tasman	1	Sunset	3	Redwoods	1
Riwa	1	Pece	3	Mariri	3
Lee	10	Richmond	3		

Total number of forests: 26

Total number of plots : 410