F.R.I. PROJECT RECORD

NO. 2488

A GROWTH MODEL FOR DOUGLAS FIR GROWN IN THE SOUTH ISLAND

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REPORT NO. 18 JULY 1990

Note : Confidential to Participants of the Stand Growth Modelling Programme

: This material is unpublished and must not be cited as a literature reference

FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

This report documents the construction and evaluates the performance of **SIDFIR**, a stand growth model for Douglas fir grown in the South Island. The **SIDFIR** model is one of a number of state-space growth models in New Zealand, which can be used to derive yield tables and reliably predict the effects of alternative management options on Douglas fir stands grown throughout the South Island.

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CONTENTS

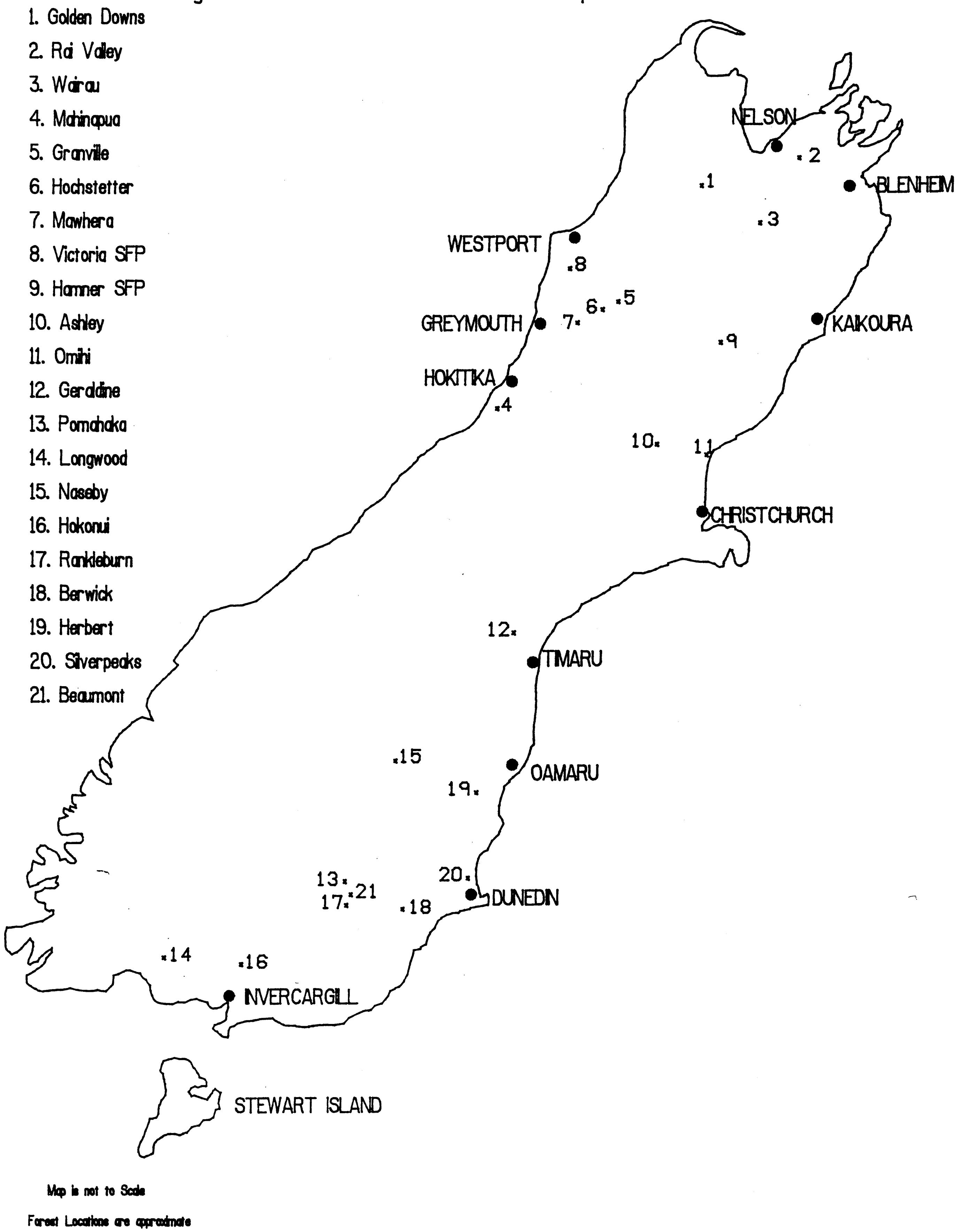
1.0 INTRODUCTION

At the inaugural meeting of the Growth Modelling Co-operative, in 1986, the development of a growth model for Douglas Fir (*Pseudotsuga menziesii*), grown in the South Island of New Zealand, was listed as one of the Co-operative's priorities. At this time the only Douglas Fir models available to the users of *STAGS* (Ministry of Forestry's Stand Treatment and Growth Simulator) were a Golden Downs growth model (**NFIR**) developed in 1979 and **DFIR**, Mountford's Kaingaroa growth model developed in 1975. Modifications of **DFIR**, such as **DFPP, RODF** and **SDFIR**, have also been implemented for use in STAGS. In 1988 NZ Timberlands commissioned the School of Forestry (University of Canterbury) to build a Central North Island Douglas Fir growth model (**DFCNIGM**) and this, along with **DFIR**, is available to the members of the Co-operative on GROPAK.

The Central North Island Douglas fir model, **DFCNIGM**, endeavours to model the effect of *Phaeocryptopus gaeumannii*, a fungus which infects the foliage of Douglas fir. Since the discovery of the fungus in 1959 (Hood, 1973) it has spread to nearly all areas of Douglas fir in the North Island as well as in some areas in the North of the South Island. The fungus has not, however, spread throughout the South Island and for this reason, modelling the effect of *P. gaeumannii* in South Island Douglas fir has not been attempted.

Work on the South Island Douglas fir growth model (**SIDFIR**) began in 1989 and has now been completed under the auspices of the Stand Growth Modelling Cooperative. The model uses the same methodology as described in the Golden Downs Growth Model and later models (Garcia, 1984). Data used in the construction of the model are from forests throughout the South Island, ranging from the Nelson area down to Southland (see Figure 1). There is an estimated net productive stocked area of 28 798 hectares of Douglas fir in the South Island. This is 45% of the total area of Douglas fir established in New Zealand (Turland, 1990).

Figure 1: South Island Forests Represented in the data



2.0 DATA

All the data were taken from the New Zealand Ministry of Forestry permanent sample plot (PSP) system. Preliminary screening consisted of removing those measurements in the database that fell into the following categories:

- measurements taken between the months of October and February;
- poison thinning;
- fertilised;
- regeneration in the stand;
- more than two trees per plot windblown;
- 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.

After the preliminary screening the individual measurements for each plot were graphed and any abnormal growth patterns were identified. Where possible, errors were corrected and the measurement was included, however in some cases 'suspect' measurements, such as those of decreasing height, were deleted from the database.

At the conclusion of the screening process the final database consisted of 1415 measurements from 269 plots. See Appendix 1 for the full list of these plots. They are established in 21 different forests in the South Island which can be seen 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 eastablishment. Months are converted to tenths of a year based on the seasonal growth pattern of Douglas fir. Refer to Table 1. for these conversions.

Table 1. Month conversions

Jan	Feb	Mar	Apr	May	Jun
-0.24	-0.13	-0.06	-0.01	0.00	0.00
Jul	Aug	Sep	Oct	Nov	Dec
0.00	0.00	0.00	0.15	0.40	0.60

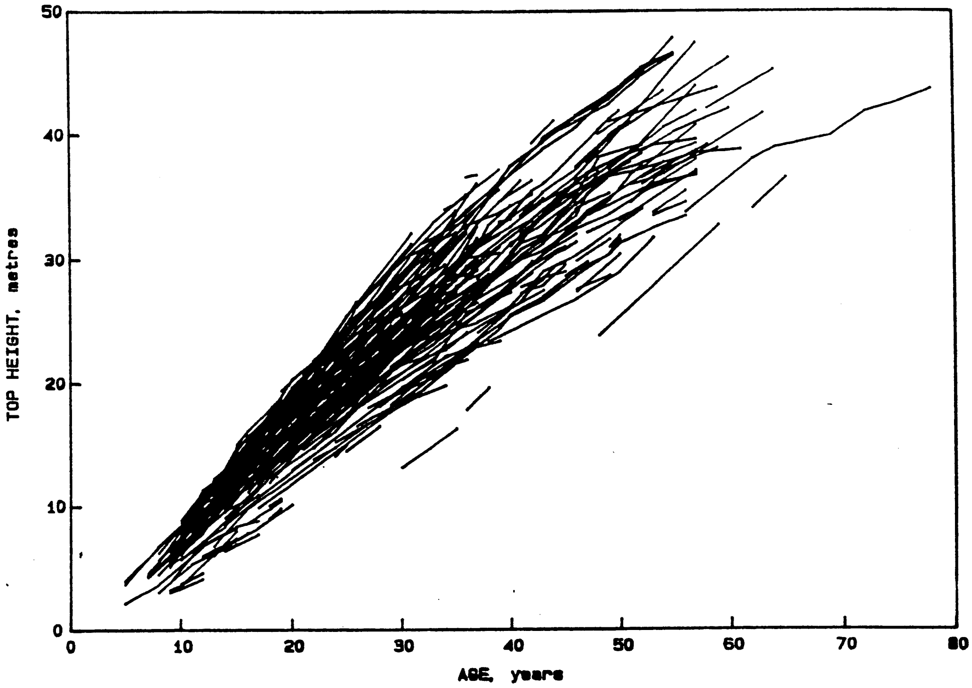


Figure 2a

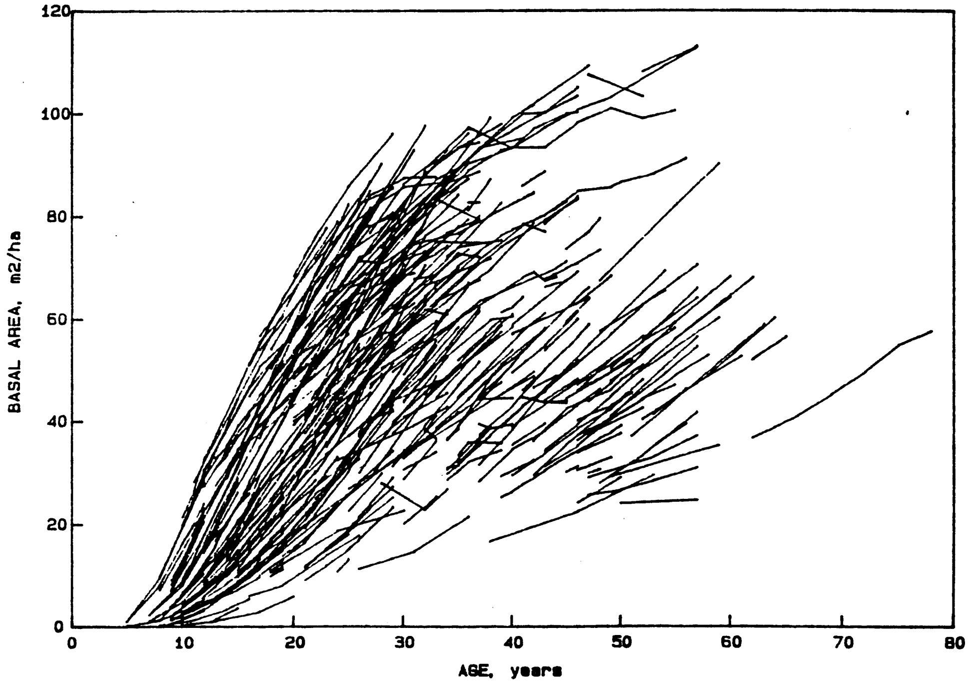


Figure 2b

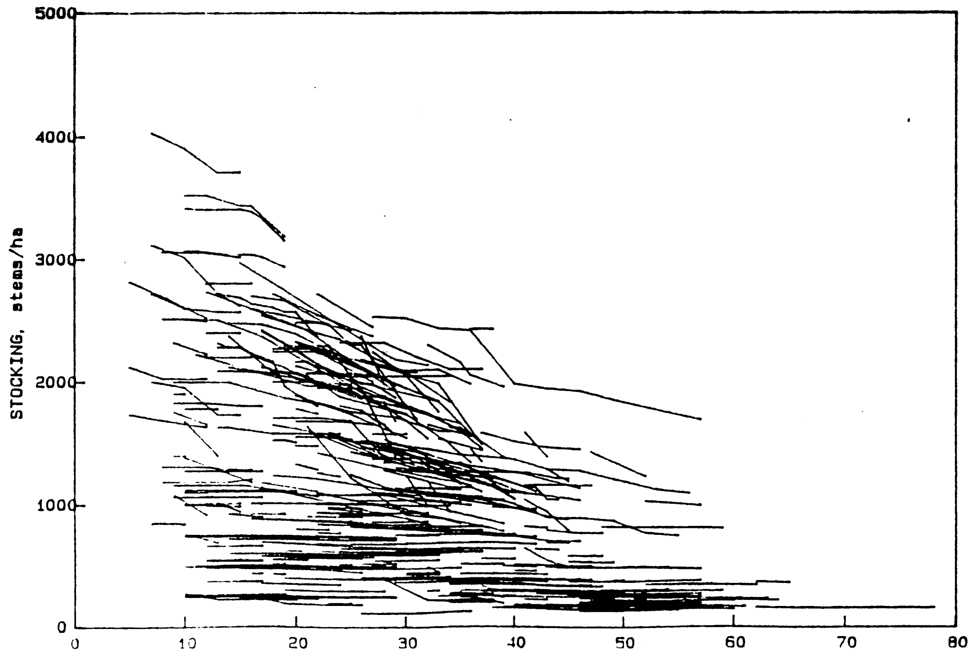


Figure 2c

2.1 Height Model Data

The data used for the height model comprised 1171 measurements from 221 plots. The statistics of these data are described in Table 2.

Table 2. Height data summary

	Age (yrs)	Height (m)	Site Index (m)*
Min	5.0	2.1	18.8
Mean	28.6	22.4	31.7
Max	78.0	47.8	39.0

*site index = height at age 40 years.

2.2 Basal Area and Stocking Model Data

Before the basal area/stocking model can be estimated the data are formed into measurement pairs comprising 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 889 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	5.0	2.1	119	0.07
Mean	28.5	22.4	1023	44.34
Max	78.0	47.8	4025	113.11

2.3 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 4 summarises the 95 measurements which were used as a basis to predict early growth.

Table 4. Initial growth data summary

	Basal area	Stocking	Height
Min	0.5	693	3.0
Mean	43.0	2082	15.0
Max	89.5	4025	36.6

2.4 Thinning Function Data

The thinning data are taken from the initial database and includes the basal area and stocking immediately before and after a thinning. These data are used to derive a thinning function to predict either basal area or stocking following a thinning. The thinning database, which includes the measurements before and after 116 thinnings, is summarised in Table 5.

Table 5. Thinning function data summary

	St.	Resid. St	BA	Resid. BA	Ht	Ratio*
Min	185	119	1.37	1.31	3.3	0.24
Mean	1097	506	53.91	32.47	53.9	0.62
Max	3704	1481	109.36	80.13	109.4	1.00

* Ratio = BA after thinning / BA before thinning

2.5 Volume/Basal Area Function Data

1838 plot measurements were available to develop the volume equation. The data used to estimate the function are summarised in Table 6. The volumes are taken straight from the PSP system which uses the default tree volume tables to calculate volume.

Table 6. Volume/basal area data summary

	Basal area	Height	Stocking	Volume	Vol/BA
Min	0.07	2.1	99	0.2	2.39
Mean	44.00	22.0	1058	403.0	8.17
Max	141.67	51.0	4025	1723.0	17.12

3.0 ANALYSES AND RESULTS

3.1 Height Growth

The height growth equations used in the model are described in detail in Garcia (1983a).
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 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

$$b = -\ln\frac{\left(1-\left(\frac{S}{a}\right)^c\right)}{40-t0} \qquad \ldots(3)$$

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 South Island Douglas fir height model are:

a = 67.332
c = 0.686
t0 = 0.0

b is calculated from equation (3) and the final parameter estimates are substituted in equation (2) to produce the new height curves shown in Figure 3. The comparison of these curves to the old site index curves of NFIR (Figure 4) shows the new model to have a much better fit to the data. This is especially true at the younger ages.

The height residuals of the new model are graphed in Figure 5. They show an unbiassed prediction of height and a good distribution about the axis. The mean residual for top height is 0.04m. The root mean square is 0.695m.

Figure 3 **SIDFIR Height Curves, site indices 22,26,30,34,38 metres**

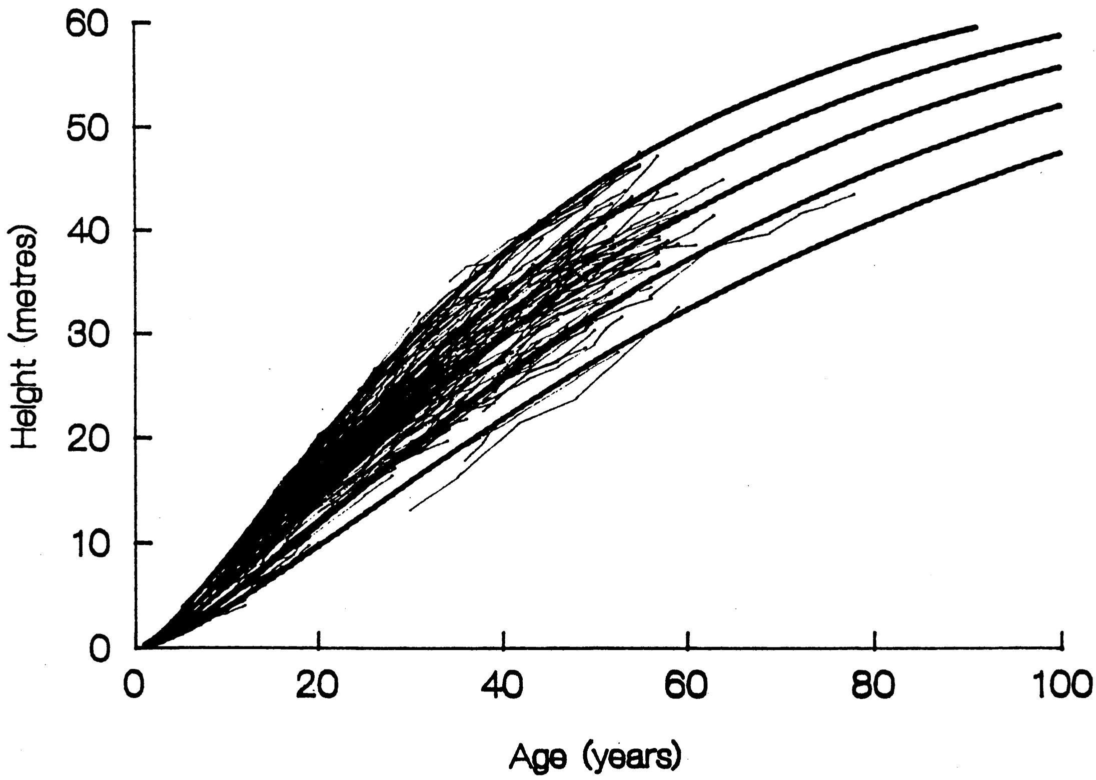


Figure 4 **SIDFIR and NFIR Height Curves, site indices 22,26,30,34,38 metres**

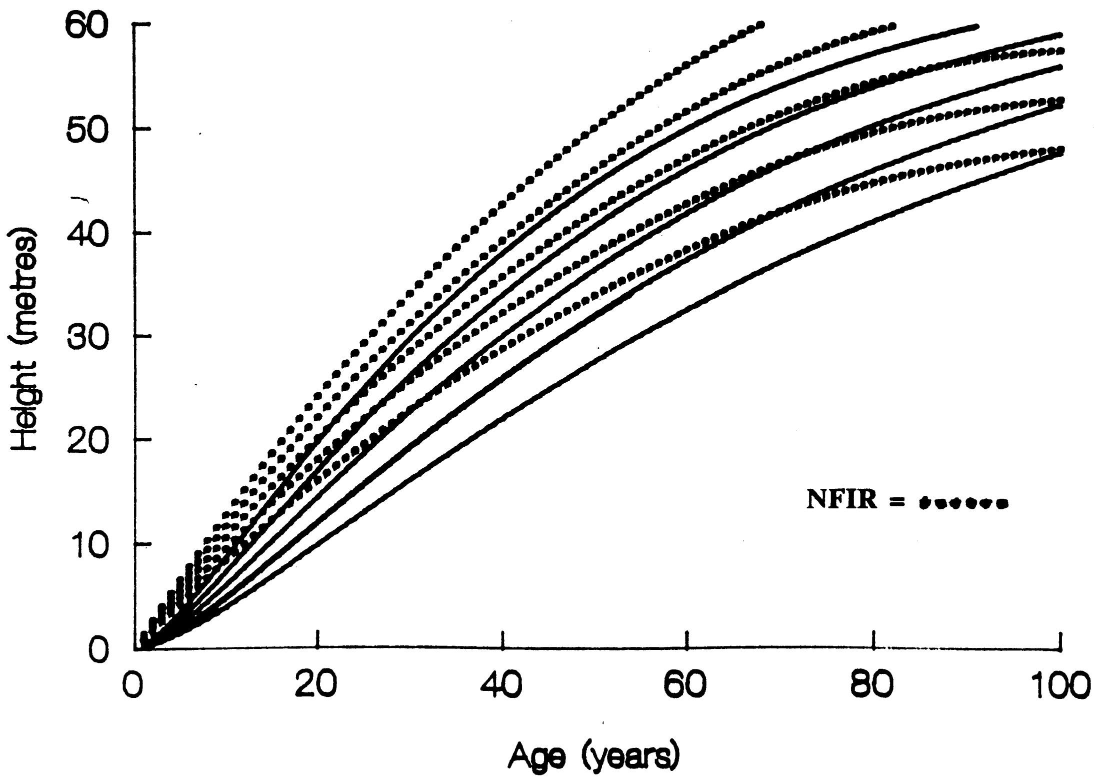
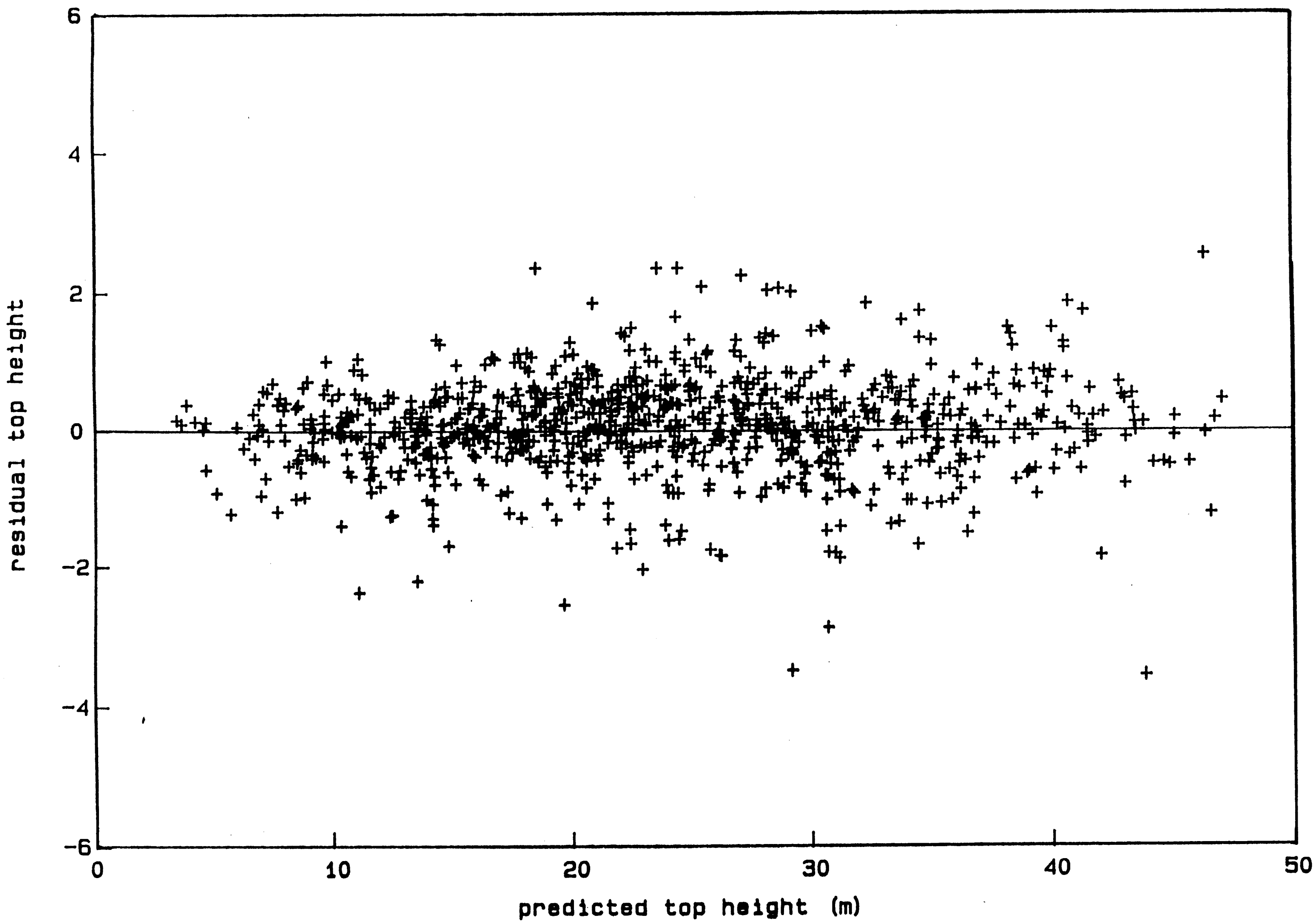


Figure 5 **<u>Height residuals</u>**



3.2 Basal Area and Stocking Model

The parameters of 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 negative log-likelihood value, relative to the number of parameters. This is estimated by an optimisation 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 'Grofit907' which is a standard 3x3 model (Garcia, 1984, eqn4) with two parameters constrained (set to zero).

The specific form of the model which was used is then:

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

$$\frac{dN^{c22}}{dT} = a_{21}B^{c11}N^{c12}H^{c13} + a_{22}N^{c22} + a_{23}H^{c33} \qquad \ldots(4)$$

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

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	Log-like value	No. params.	Model description
Grofit901	-0.4016	14	parameters all free
Grofit902	-0.4022	13	c23=0
Grofit904	-0.4634	9	a23,a22,c21,c23,b2=0
Grofit907	-0.3876	12	c21,c23=0

'Grofit907' is chosen as the best model for its function value and its good residual pattern.

The parameter estimates for the model are:

$$C = \begin{pmatrix} 0.09309 & -0.01349 & 0.68178 \\ 0 & -0.10990 & 0 \\ 0 & 0 & 0.68649 \end{pmatrix}$$

$$A = \begin{pmatrix} -0.40764 & 0.22018 & -0.55851 \\ 0.13895 & -0.24122 & -0.12634 \\ 0 & 0 & -1 \end{pmatrix}$$

$$P = \begin{pmatrix} 1 & -11.42039 & -1.31518 \\ 0.03494 & 1 & -0.04506 \\ 0 & 0 & 1 \end{pmatrix}$$

$$b = \begin{pmatrix} 3.54488 \\ 0.28531 \\ 3.70319 \end{pmatrix} \qquad a = \begin{pmatrix} 4.66497 \\ 1.93027 \\ 3.70319 \end{pmatrix}$$

$$\lambda_1 = -0.51813$$
$$\lambda_2 = -0.13074 \qquad where \quad a = -A^{-1}b$$
$$\lambda_3 = -1$$

Units: basal area m2/ha); stocking (stems/ha); height (m)

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.

The residuals, from this model, for basal area and stocking are shown in Figures 6 and 7 respectively. The basal area residuals show a good distribution, no bias and a mean residual of only -0.09 m2/ha. The root mean square is 2.63 m2/ha. The stocking residuals are also well distributed and although there are a few measurements that over and under predict by more than 15% the overall mean residual is -1.14 stems/ha. These mean residuals are comparable to those of other recent growth models in different regions.

Figure 6 <u>Basal area residuals</u>

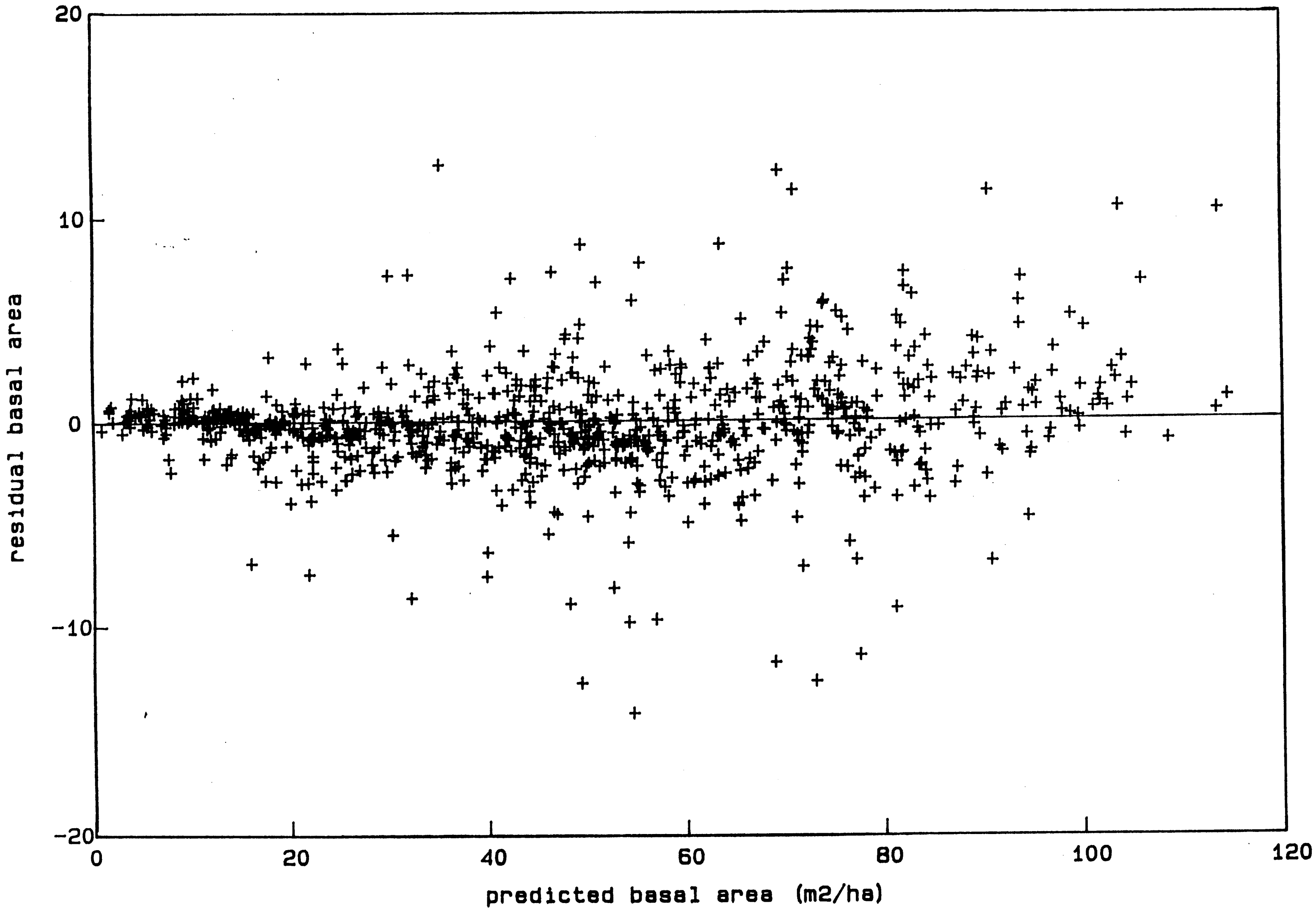
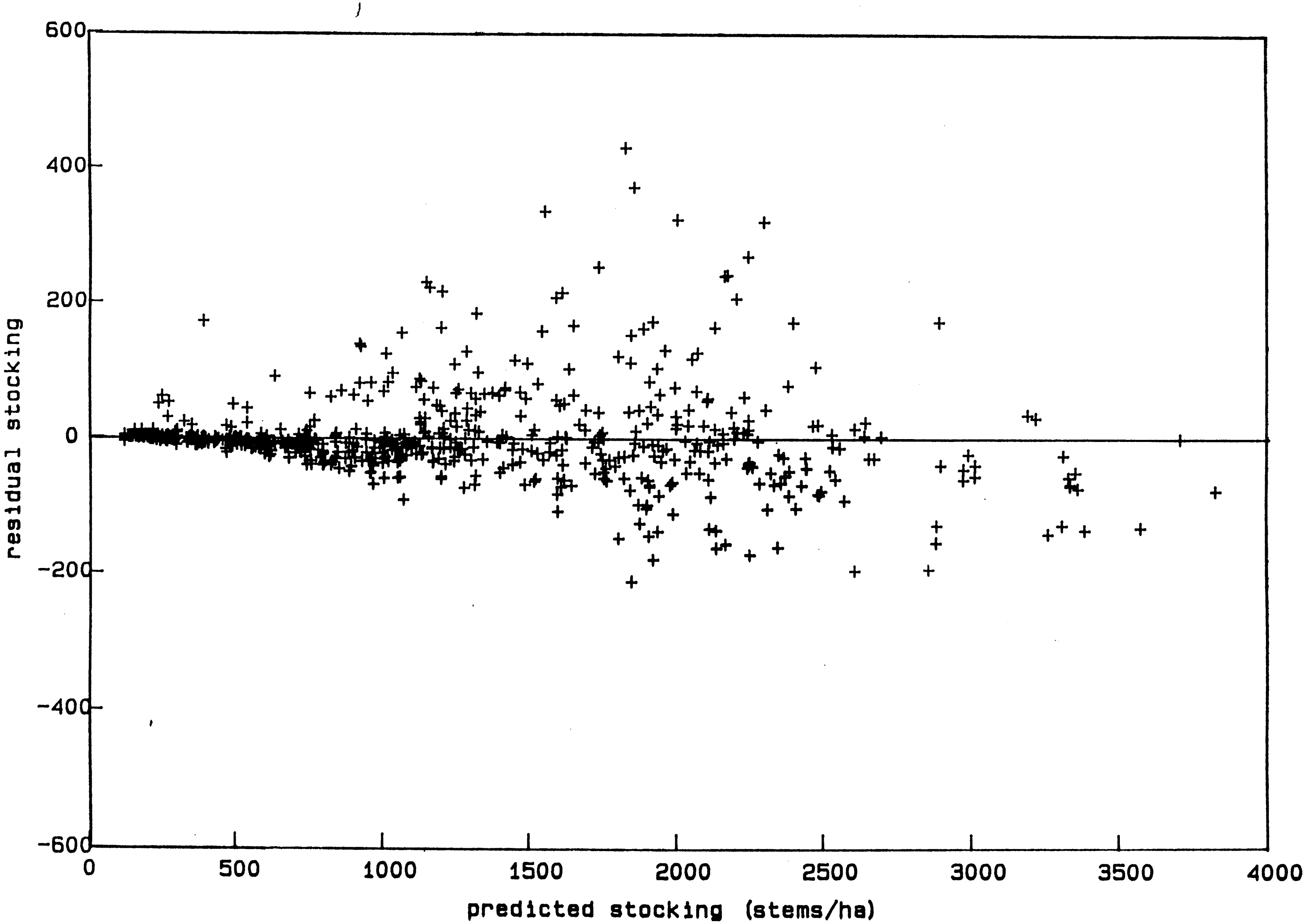


Figure 7 Stocking residuals



3.3 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:

$$B = \begin{cases} (a/c - b)N & \text{for} \quad N \le c \\ a \ln N - bN + a(1 - lnC) & \text{for} \quad N > c \end{cases} \qquad \ldots(5)$$

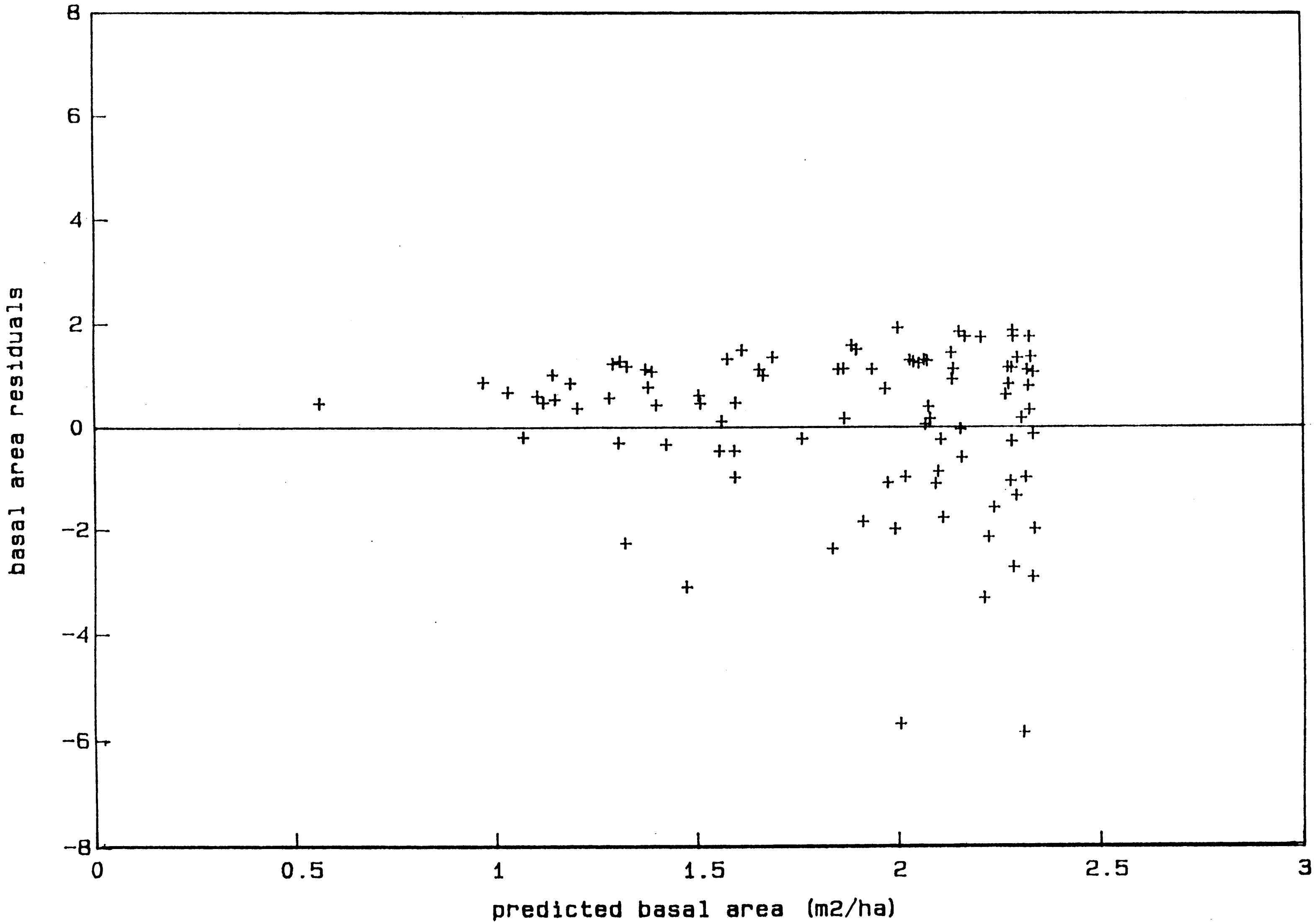
where B = basal area (m2/ha)
N = stocking (stems/ha)

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

$$B = \begin{cases} 0.00079N & \text{for} \quad N \le 2414 \\ 5.6324 \ln N - 0.00015N - 38.241 & \text{for} \quad N > c \end{cases} \qquad \ldots(6)$$

Figure 8 shows the residuals for initial growth. The graph indicates a high percentage error but there is no bias shown by the the mean residual of 0.119 m2/ha.

Figure 8 <u>Initial growth residuals</u>



3.4 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:

$$\frac{d\ln B}{d\ln N} = aB^{b}N^{c}H^{d} \qquad ...(7)$$

where *a*, *b*, *c* and *d* are parameters to be estimated. Several forms of non-linear regression were fitted to the integrated form of equation (7) and the thinning data. The best form of the equation was found to be:

$$B = \left(B_0^{-b} - \frac{ab}{c} H^{d} (N^{c} - N_0^{c}) \right)^{-\frac{1}{b}} \qquad ...(8)$$

or

$$N = \left(N_0^{c} + \frac{c}{ab} H^{-d} (B^{-b} - B_0^{-b}) \right)^{\frac{1}{c}} \qquad ...(9)$$

where

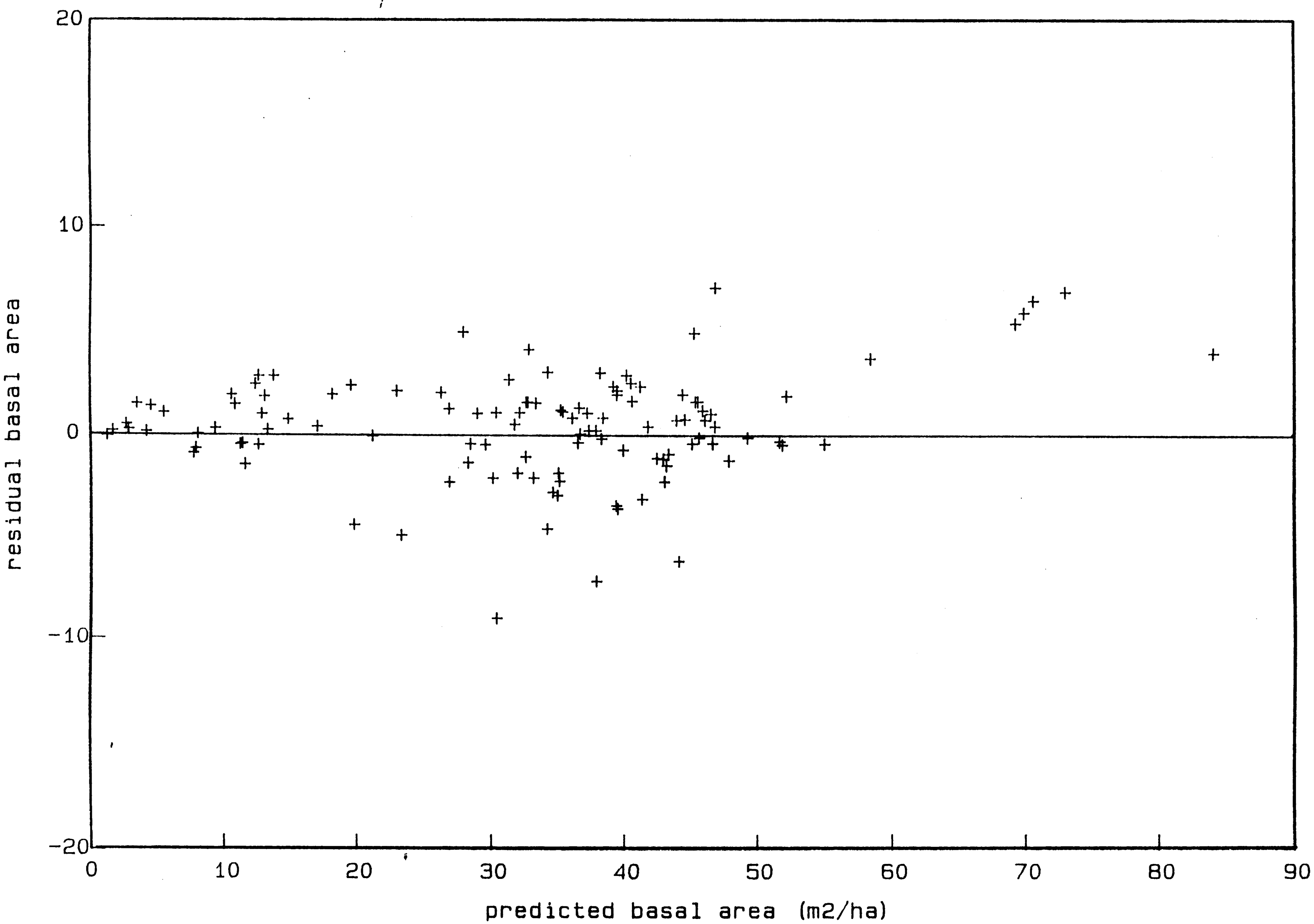
B_0 = basal area before thinning (m2/ha)
B = basal area after thinning (m2/ha)
N_0 = stocking before thinning (stems/ha)
N = stocking after thinning (stems/ha)
H = top height (m)

and

a = 1.1281
b = 0.27041
c = -0.15058
d = -0.15703

The residuals for the chosen thinning function are shown in Figure 9. The mean residual is -0.363 m2/ha.

Figure 9 **Thinning function residuals**



3.5 Volume/Basal Area Function

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

$$\frac{V}{B} = a + bH \qquad \text{. . .(10)}$$

where

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

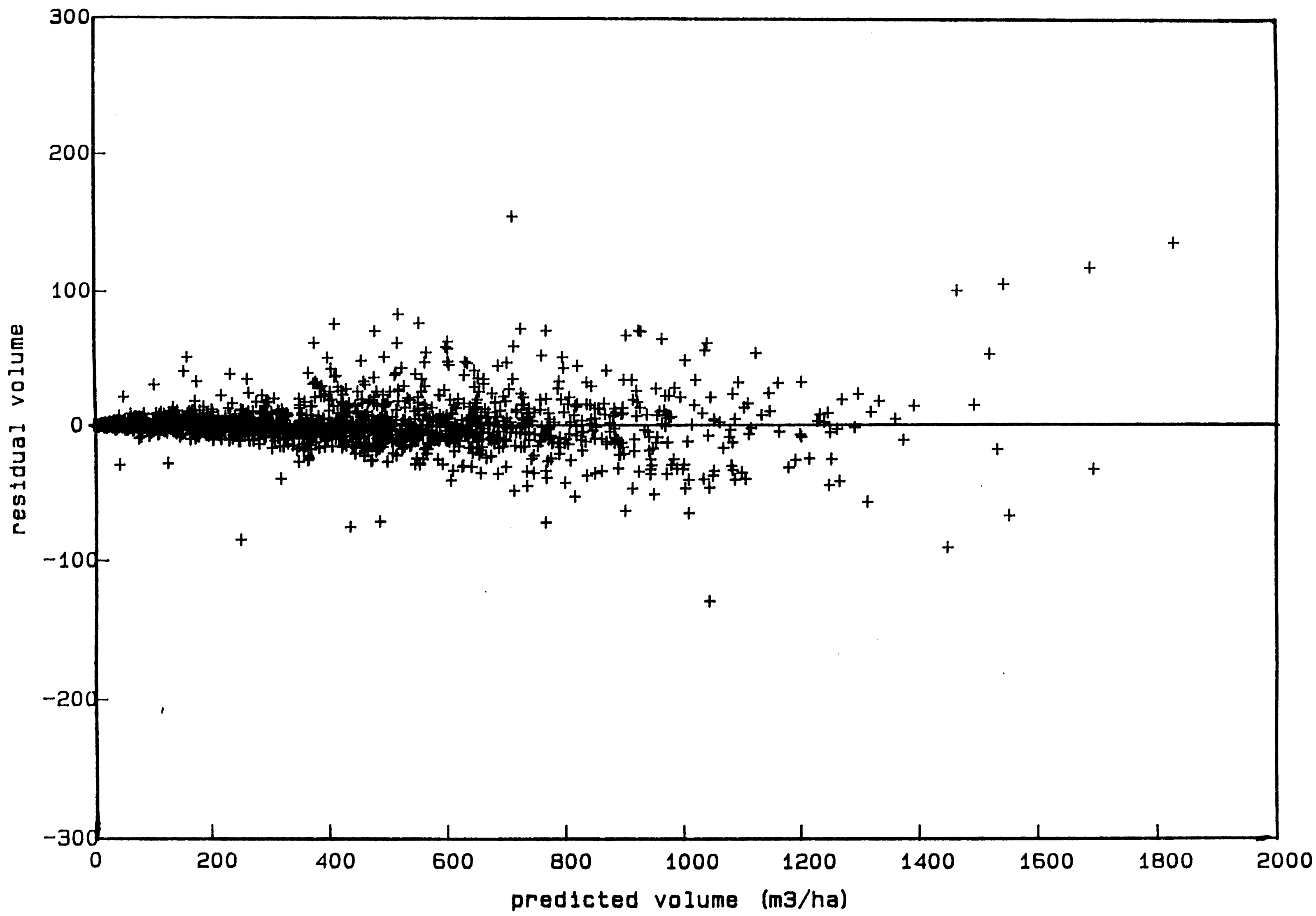
This equation (10) cannot be true both before and after a thinning because the thinned trees tend to be smaller than the average so that the V/B ratio after the thinning must be greater than that before the thinning (Beekhuis, 1966). A stepwise linear regression is used to estimate V/B as a function of independent variables N and/or B in addition to H.

The best regression was found to be equation (11) as follows:

$$\frac{V}{B} = 0.85020 + 0.33337H + 0.00005 \times \frac{N \times H}{B} \qquad \text{. . .(11)}$$

The volume residuals are shown in Figure 10. They are evenly spread giving a mean residual of 0.955 m3/ha.

Figure 10 Volume residuals



4.O 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 root mean squares (RMS) for the major variables are calculated in Table 8. Compared to the recent radiata pine growth models the RMS values for this model (**SIDFIR**) are fairly similar.

Table 8. Measurement Pair Residuals

	mean	RMS
Basal area (m2/ha)	-0.09	2.63
Stocking (stems/ha)	-1.14	57.4
Top height (m)	0.04	0.695
Basal area x height (m3/ha)	-4.17	85.90
Mean DBH (cm)	-0.03	0.68
Average spacing (m)	-0.0009	0.09

Graphs of these residuals are in Figures 5-10.

The residual pattern for height shows that the height model chosen is a good and unbiassed predictor of height for Douglas fir in the South Island.
The basal area residuals, graphed in Figure 6, show no obvious trends and, although there are a few measurements where the model has either under-predicted or over-predicted by more than 15%, the root mean square of 2.63 m2/ha is similar to that of other recent models.

The stocking residuals in Figure 7 show a very similar pattern to those of the most recently developed growth models. There is no significant bias in predicted mortality and the RMS value of 57.4 stems/ha is acceptable. Overall, the basal area and stocking model chosen shows a good fit to the data.

The initial growth residuals do not show any obvious bias but, as is common also in other regional growth models, the error in prediction is often quite significant. It is recommended therefore, that whenever possible, young ages should be initiated with actual basal area input rather than starting the model from age zero.

The residuals for the prediction of basal area after thinning and for volumes (Figures 9 and 10) do not show any obvious trends and have a reasonable distribution about the zero line, indicating a good fit to the data.

4.2 Growth and Yield Analysis

Three different management regimes were modelled by **SIDFIR**. The regimes used have been taken from those recommended in the 1986 Forestry Handbook (Williams, 1986) for Douglas fir. While the three management regimes may not be directly represented in the data it is thought that the simulated curves for basal area and volume may approximate the trends in the data. The regimes are:

1. Initial stocking 1600 stems/ha, unthinned.
2. Initial stocking 1600 stems/ha, thinned at 10m to 400 stems/ha.
3. Initial stocking 1600 stems/ha, thinned at 10m to 600 stems/ha, thinned at 20m to 250 stems/ha.

Each regime was simulated with a site index of 30.0m and grown from age 0 to 45 years.

The yield curves resulting from these simulations have been superimposed on the basal area/age data and the volume/age data, in Figures 11 and 12 respectively. Both these graphs illustrate how the long term projections follow the general trend of the data. Overall the **SIDFIR** model estimates the basal area and volume growth data well.

Figure 11 Management regime simulations, basal area curves

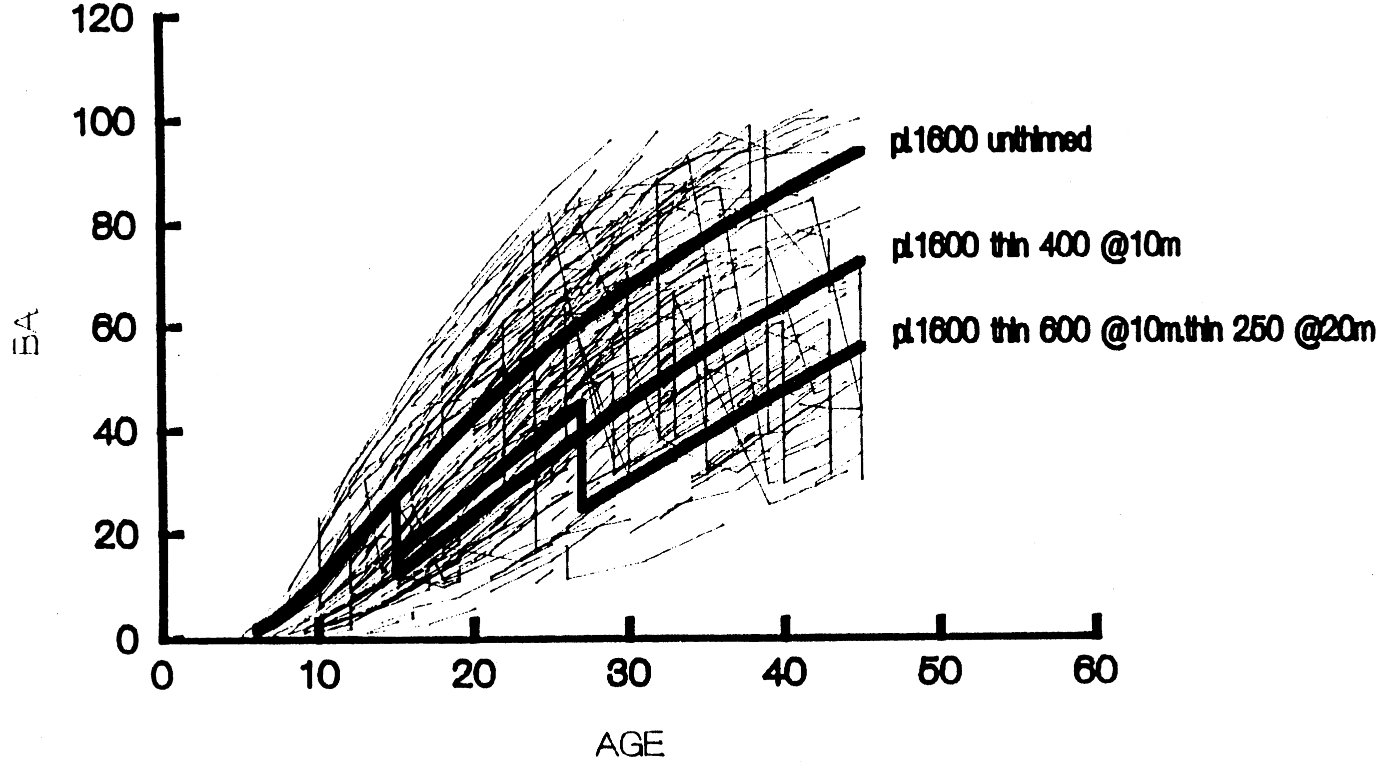
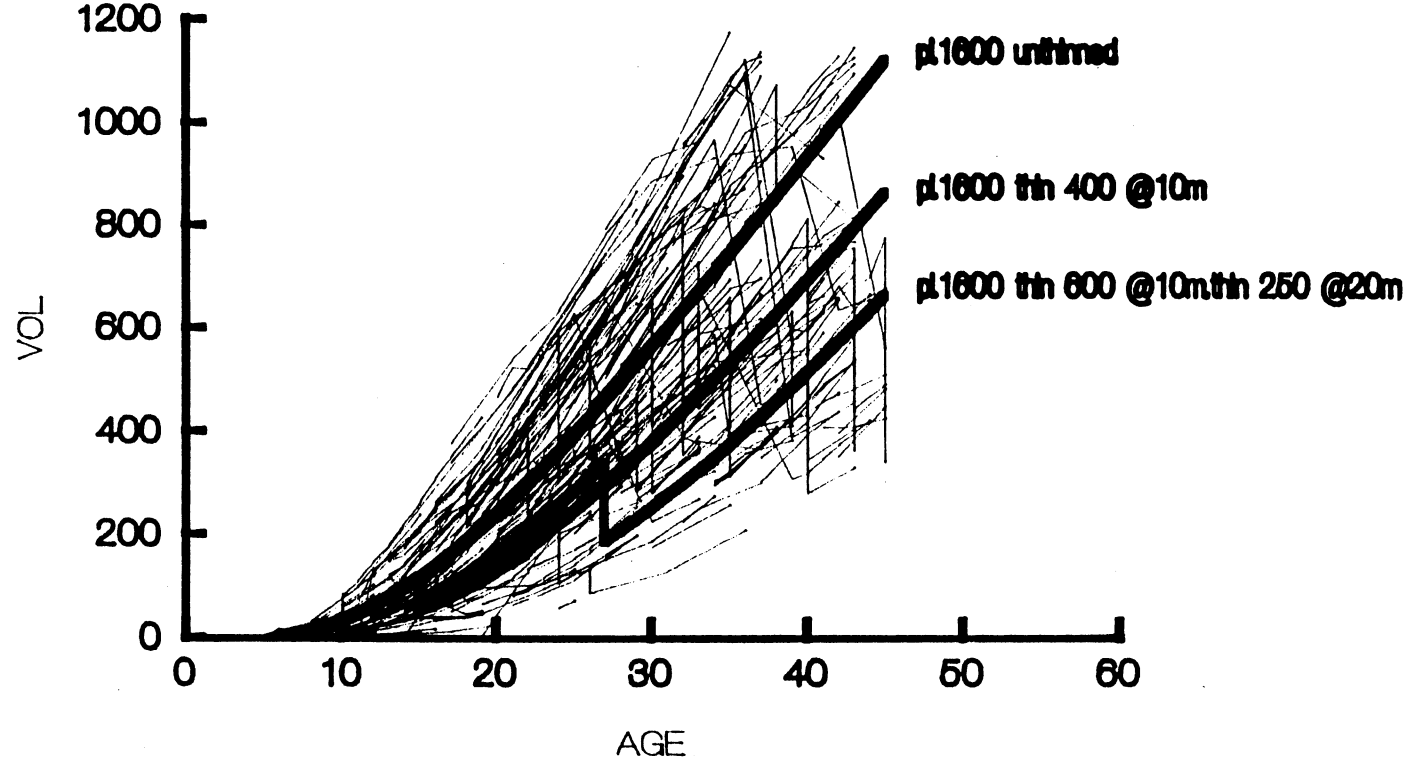


Figure 12 Management regime simulations, volume curves



4.3 Comparison of SIDFIR and NFIR

The same simulations as listed above (listed in Section 4.2) were also run through the **NFIR** model. NFIR was developed in 1979 and is one of the two models found in *STAGS* that predicts the growth of Douglas fir in the South Island. It is based on data from the Nelson region. Each simulation was started from age zero. The values given in Table 9 and Table 10 are the predicted values and percentage differences, respectively, at age 45 years.

Table 9. Comparison between **SIDFIR** and **NFIR**
all values at SI = 30m and age = 45yrs

regime	height		stocking		basal area		mean DBH		volume	
	NFIR	SIDFIR	NFIR	SIDFIR	NFIR	SIDFIR	NFIR	SIDFIR	NFIR	SIDFIR
1	35.7	33.3	1031	1023	89.7	93.5	33.3	34.1	1153	1117
2	35.7	33.3	396	354	73.8	72.0	48.7	50.9	949	859
3	35.7	33.3	249	243	61.5	55.2	56.0	53.9	791	659

Table 10. Percentage Differences between **SIDFIR** and **NFIR**

regime	*height*	*stocking*	*basal area*	*mean DBH*	*volume*
1	-7.2%	-0.8%	4.1%	2.3%	-3.2%
2	-7.2%	-11.9%	-2.6%	4.3%	-10.5%
3	-7.2%	-2.5%	-11.4%	-3.9%	-20.0%

*% Diff = (SIDFIR)-(NFIR)/(SIDFIR) * 100%*

These differences show that, in general, **SIDFIR** is predicting less volume growth than **NFIR**. This is particularly so for the more intensively thinned stand, primarily as a result of less basal area growth.

4.4 Comparison of SIDFIR and DFCNIGM

DFCNIGM is a model developed at the University of Canterbury to simulate growth and yield of Douglas fir growing in the Central North Island (Liu Xu, 1990). The model predicts the growth of both diseased stands (with *Phaeocryptopus*) and undiseased stands. The following table shows the results given by this model compared with that of **SIDFIR**. The regimes 1, 2 and 3 are the same as those listed in Section 4.2 and the values given here are for a site index of 30.0m and an age of 45 years. The (-) sign, after **DFCNIGM**, indicates no disease and the (+) sign implies the modelling of a diseased stand.

Table 11. Comparison of **SIDFIR** and **DFCNIGM**

regime/model		*height*	*stocking*	*basal area*	*mean DBH*	*volume*
1	**SIDFIR**	33.3	1023	93.5	34.1	1117
	DFCNIGM (-)	32.5	978	103.4	36.7	1208
	DFCNIGM (+)	32.5	1176	75.1	28.5	868
2	**SIDFIR**	33.3	354	72.0	50.9	859
	DFCNIGM (-)	32.5	371	91.7	56.1	1073
	DFCNIGM (+)	32.5	379	70.2	48.6	816
3	**SIDFIR**	33.3	243	55.2	53.9	659
	DFCNIGM (-)	32.5	237	78.7	65.0	921
	DFCNIGM (+)	32.5	242	56.4	54.5	656

The table above shows that **SIDFIR** predicts taller trees at age 45 years than does **DFCNIGM** for diseased or undiseased stands. Predicted mortality is very similar for all the models in the two thinned regimes but for the unthinned regime the stocking prediction of **SIDFIR** is greater than **DFCNIGM (-)** but less than **DFCNIGM (+)**. The predicton of basal area by **SIDFIR** and **DFCNIGM (+)** are almost the same in both the thinned regimes but in the unthinned regime the prediction of **DFCNIGM (+)** is nearly 20% less than that of **SIDFIR** which is also less than that predicted by **DFCNIGM (-)**. Volume and mean DBH predictions follow a similar pattern.

4.5 Plot History Simulations

Several plots were selected from each region in the data set to evaluate how well the **SIDFIR** model simulates stand growth given management history as input. Plots were selected acording to the following criteria:

- reasonable period of time between first at last measurement (>10 years where possible)
- include a range of site indices, ages and basal areas
- include both thinned and unthinned stocking levels.

Those plots that were selected for the simulations are listed in the table below.

Table 12. Description of plot simulations

Region	Plot	Site(m)	Description
Nelson	3990101100	37.6	unthinned plot; initial stocking 3400 stems/ha at age 10.
(Fig. 13)	1050000100	32.6	Two thinnings; first at age 22 from 2026 to 1087 stems/ha; next at age 30 to 618 stems/ha.
	790000700	32.2	unthinned plot; initial stocking 1500 stems/ha at age 22.
Canterbury	880000300	25.1	unthinned plot; initial stocking 1500 stems/ha at age 26.
(Fig 14)	1120000100	29.7	thinned several times from 623 stems down to 168 stems/ha.
Westland	1300000200	30.8	thinned once at age 24 from 1333 to 864 stems/ha.
(Fig 15)	3750000100	35.7	unthinned plot; started at age 24 with 1808 stems/ha.
Southland	390000300	33.2	thinned at age 37 from 287 stems to 188 stems/ha.
(Fig 15)	1320000100	25.0	thinned late at age 56 from 346 stems to 161 stems/ha.
	132000400	34.9	unthinned plot; initial stocking 1550 stems/ha at age 20.

Simulations with **SIDFIR** were started with the initial age, height, basal area and stocking values of the actual plot data. Thinnings were scheduled according to age with residual stocking being given but not residual basal area, thereby utilising the thinning function. Plots included in the simulations are listed in the table above. The simulations are graphed alongside the actual plot data in Figures 13-15.

Looking at the graphs of these simulations show the majority of these plots to be modelled well. Plots that are poorly modelled are the unthinned plot in Canterbury where **SIDFIR** under-predicted the heavy mortality before the last measurement, and the thinned plot in Nelson where the thinning function has badly estimated the basal area after thinning. With the exception of these couple of plots the model does appear to perform well across the range of sites, ages, basal areas and stockings, described in Table 12.

Figure 13 **Plot history simulations, Nelson region**

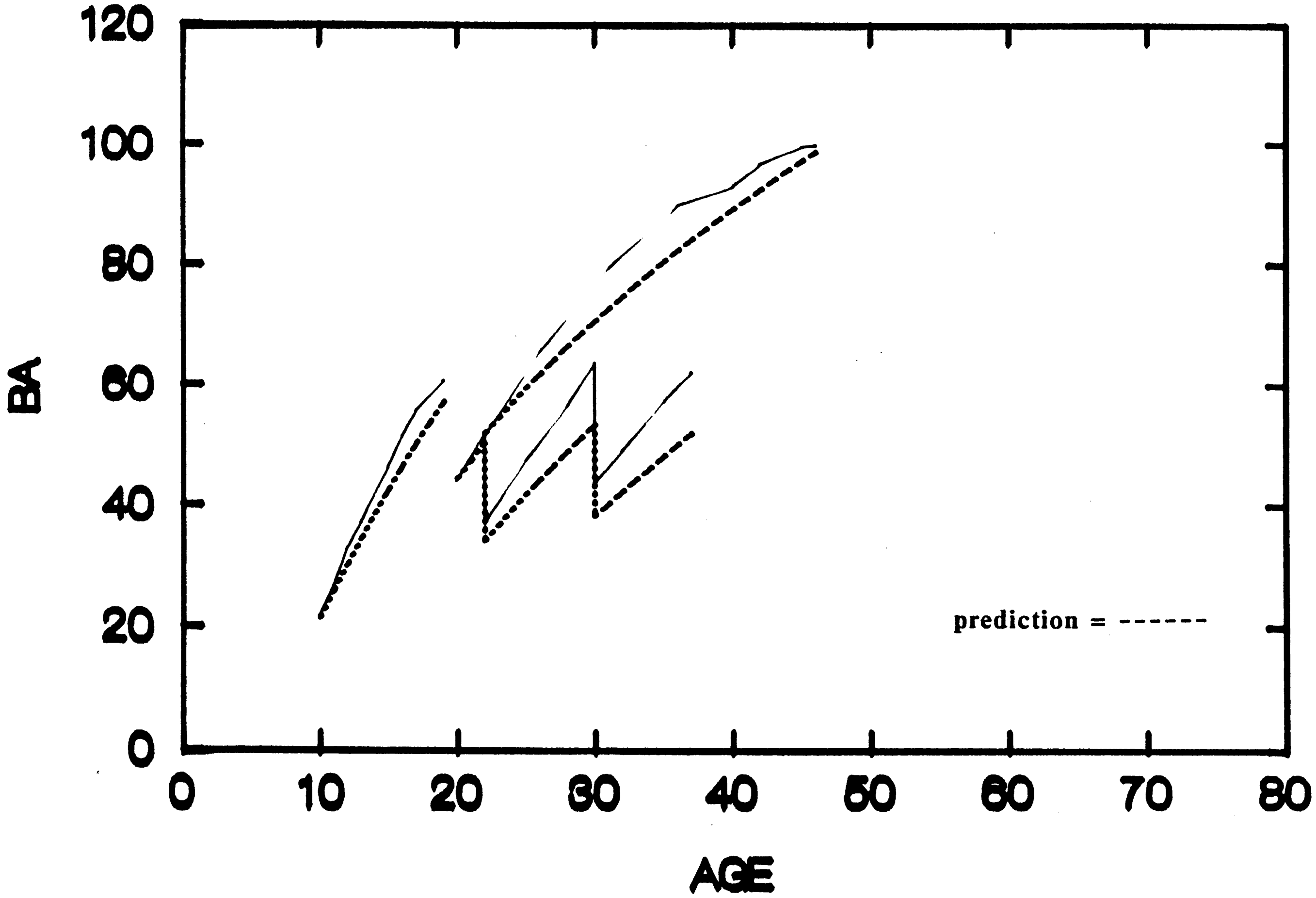


Figure 14 Plot history simulations, Canterbury region

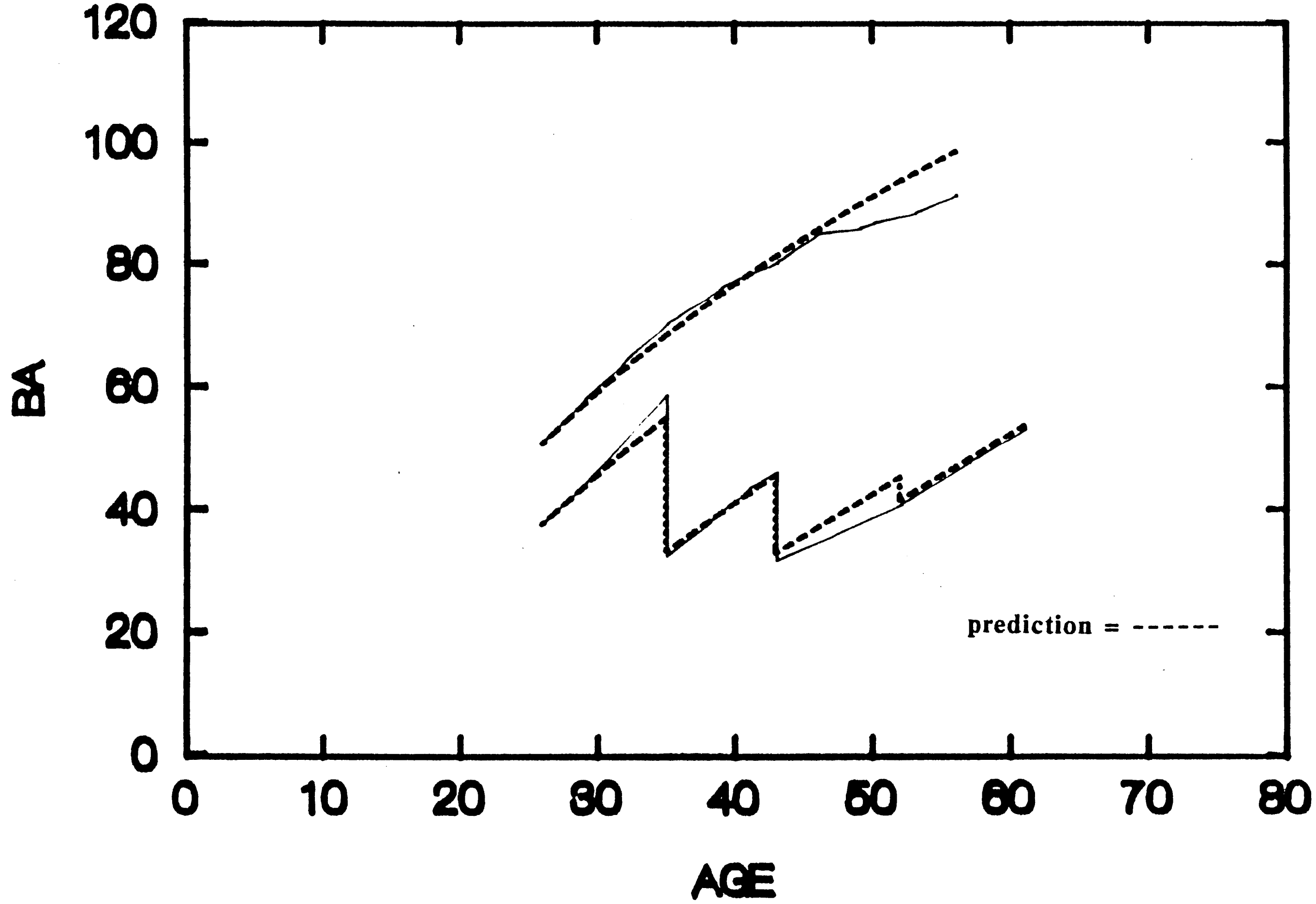
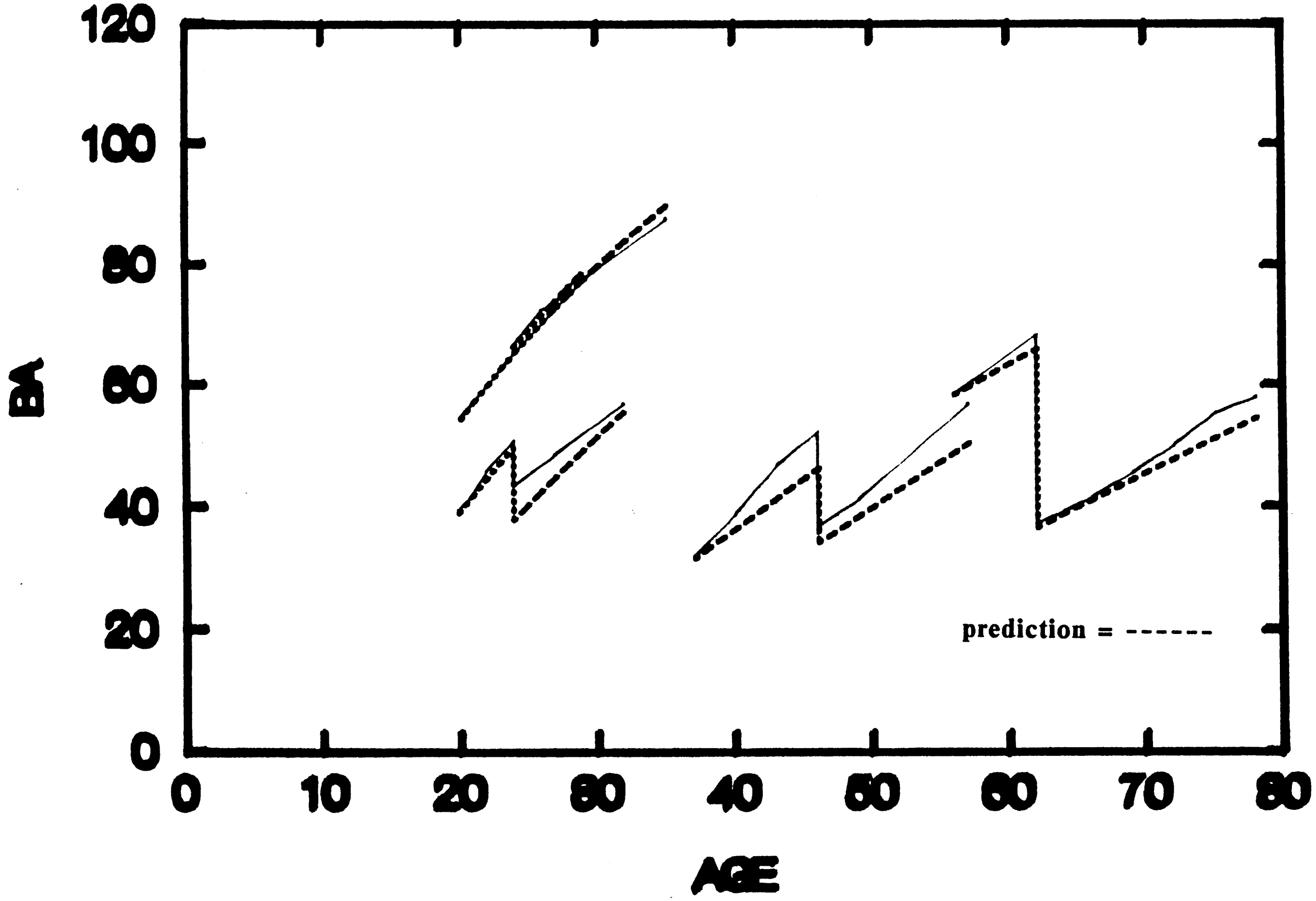


Figure 15 Plot history simulations, Westland/Southland region



5.0 SUMMARY

The objectives of this report were to document the construction of a growth model for Douglas fir in the South Island and to evaluate its performance. These objectives have been met although further evaluation of the model is likely once the users of **SIDFIR** put it to practical use. Following the limited evaluation that has been carried out and documented in this report the author is satisfied that the model behaves logically and well for the described range of data.

6.0 ACKNOWLEDGEMENTS

The author would like to thank all those people who have helped in the development of this growth model:

The NZ Timberlands staff in the South Island who helped provide the necessary stand history data;

Mrs Judy Dunlop who was often called upon to extract various forms of data from the PSP system;

Mr Murray Lawrence, Mr Paul Lane and Mr Andrew Dunningham for their technical and programming support.

Dr Oscar Garcia and Dr Chris Goulding for their knowledge, advice and support throughout.

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APPENDICES

(1) List of all plots used in the development of the **SIDFIR** model.

(2) Number of plots used from each forest.

Appendix 1. List of all plots used in the development of the SIDFIR model

Nelson

790003401.
790010000.
790010100.
790010200.
790010300.
790010400.
790010500.
790010600.
790010700.
790011300.
790011400.
790011500.
790011600.
790011700.
790011800.
790012100.
790012201.
790012300.
790012400.
790030201.
1000000100.
1000000200.
1000000300.
1000000400.
1050000100.
1050000200.
1050000300.
1200000000.
1450000100.
1460000100.
1710000100.
1720000100.
3990100100.
3990100200.
3990100300.
3990100400.
3990100500.
3990100600.
3990100700.
3990100800.
3990100900.
3990101000.
3990101100.
3990101200.
3990201300.
3990201400.
3990201500.
3990201600.
3990201700.
3990201800.
3990201900.
3990202000.
3990202100.
3990202200.
3990202300.
3990202400.
3990302500.
3990302600.
3990302700.
3990302800.
3990302900.
3990303000.
3990303100.
3990303200.
3990303300.
3990303400.
3990303500.
3990303600.
3990403800.
3990403900.
4120000100.
4470006801.
4470006803.
4470006804.
4470006805.
4470006806.
4470006807.
4470006808.
4470006809.
4470006810.
4470006812.
4470006813.
4470006814.
4470006815.
4470006816.
4470006817.
4470006818.
4470007301.
4470007601.
4470007602.
4470007603.
4470007605.
4470007606.
4470007607.
4470007608.
4470007610.
4470007611.
4470007612.
4470007613.
4470007614.
4470007615.
4470007616.
4630006901.
4630006902.
4630006903.
4680000100.
4680000700.
4680001000.
4700008001.
5510000100.
5510000200.

Westland

810000000.
1300000100.
1300000200.
1300000300.
1300000400.
1300000500.
1300000600.
1300000700.
1300000800.
1300000900.
1300001000.
1300001100.
1300001200.
1300001300.
1300001400.
1300001500.
1300001600.
1300001700.
1300001800.
1300002000.
1300002100.
1300002200.
1300002400.
1300002500.
1300002600.
1300002700.
3140000000.
3750000100.

Canterbury

880000100.
880000200.
880000300.
1120000100.
1120000200.
1120000300.
1120000400.
1880000100.
1880000200.
1880000300.
2880000100.
2880000200.
2880000300.
2880000400.
2880000500.
2880000700.
2880000900.
2880001100.
2930000100.
2930000200.
2930000300.
2930000400.
2930000500.
2930000700.
2930000800.
2930000900.
2930001000.
3200000300.
3720000200.
3720000300.
3720000400.
3760900214.
3760900445.
3761000439.
4260000100.
4260000200.
4260000300.
4350000100.
4350000200.
4350000300.
4350000400.
4350000500.
4350000700.
4700000100.
4700000200.
4700000300.
4700000600.

Southland

370000100.
370000200.
370000300.
390000100.
390000200.
390000300.
390000400.
440000100.
440000200.
440000300.
900003800.
900004000.
900004100.
900004200.
900004300.
900004400.
1240001500.
1240001700.
1240001900.
1240002100.
1240002600.
1320000100.
1320000300.
1320000400.
1420000400.
1420001100.
1420001300.
1420001700.
1420002100.
1420002300.
1420002500.
1420002600.
1520000100.
1720000100.
1720000200.
1720000300.
1720000500.
1720000600.
1720000700.
1720000800.
1720000900.
1720001000.
1820000300.
1820000400.
1820000500.
1820000600.
1820000700.
1820000900.
1920000400.
1920000600.
1920001100.
1920001200.
3160000101.
3160000105.
3160000106.
3160000107.
3160000109.
3160000210.
3160000301.
3160000302.
3160000307.
3160000308.
3160000309.
5160000100.
5160000200.
5160000300.
5160000400.
7020000100.
7020000200.
7080000100.
7080000200.
7160000500.
7170000100.
7170000200.
7170000300.
7170000400.
7190000100.
7190000200.
7190000300.
7190000400.
7190000500.
7190000600.
7190000700.

Appendix 2. Number of plots used from each forest

Forest	*No.*	*Forest*	*No.*	*Forest*	*No.*
Golden Downs	103	Rai	7	Wairau	1
Mahinapua	1	Granville	2	Hochstetter	11
Mawhera	12	Victoria SFP	2		
Hanmer	11	Ashley	27	Omihi	3
Geraldine	6				
Pomahaka	26	Longwood	24	Naseby	2
Hokonui	5	Rankleburn	9	Berwick	6
Herbert	4	Silver Peaks	6	Beaumont	1