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AUCKLAND CLAYS RADIATA PINE GROWTH AND YIELD MODEL:

DEVELOPMENT HISTORY AND PERFORMANCE

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1.0 INTRODUCTION

The objective of this report is to document the construction and evaluate the peformance of a stand-based growth model for radiata pine applicable to forests occurring on 'classic clay' soils in the Auckland Conservancy locale. An underlying assumption further defining the model's applicability is that the forest soil has an 'adequate' phosphorus ('P') nutrient level (0.11% foliar 'P') to enable "normal" tree growth. For the 'clays' model described herein, growth and yield of a forest stand <u>without</u> adequate phosphorus amelioration can <u>not</u> be successfully predicted. Developmental work is on-going to produce a 'phosphorus fertiliser effects' model which will be able to predict stand growth and yield at various levels of phosphorus fertility.

2.0 MODELLING METHODOLOGY

The modelling methodology employed uses the 'state-space approach', whereby a set of stochastic differential equations predict changes (increments) in forest stand variables (states of the stand) e.g. top height, basal area, stocking and site occupancy after thinning. The methodology was devised and described by Dr O Garcia (Garcia 1979) and has been successfully applied in the development of several radiata pine growth and yield models: Golden Downs (Garcia 1984), Hawkes Bay (Lawrence), Northland sands (Dunningham 1985) and Southland (Garcia 1979).

In addition to the 'state-space approach' for constructing the predictive growth equations, regression analysis was employed to derive various mathematical functions which are necessary for a holistic model; namely, functions to predict 'after-thinning basal area or stocking'; volume/basal area ratio; and, basal area of very young forest stands (top height, less than 5 metres).

3.0 DATA BASE
3.1 General Description
3.11 Plot Data

The data is entirely from the N.Z. Forest Service Permanent Sample Plot system. An initial cursory examination of PSP's "suitable" for consideration was made by Mrs P. Lonn, at the request of Dr C Goulding, project leader Forest Mensuration and Managment Systems Research Field. In the final selection, eight (8) Auckland Conservancy forests are represented (Figure 1) , providing data from both F.R.I. research and Conservancy management growth plots. Specific details on the amount and proportion of data from each forest and controlling agent is described in sections 3.21 - 3.25 in relation to particular analyses, e.g. top height, basal area, thinning function. Specific details are necessary because each particular analysis uses a different "mix" of data from the overall data base. For the principle analyses, top height and basal area, the bulk of data in broad terms is represented by ca 100 - 200 plots, 500-800 individual observations, and 400-500 paired observations.

AUCKLAND CLAY GROWTH MODEL

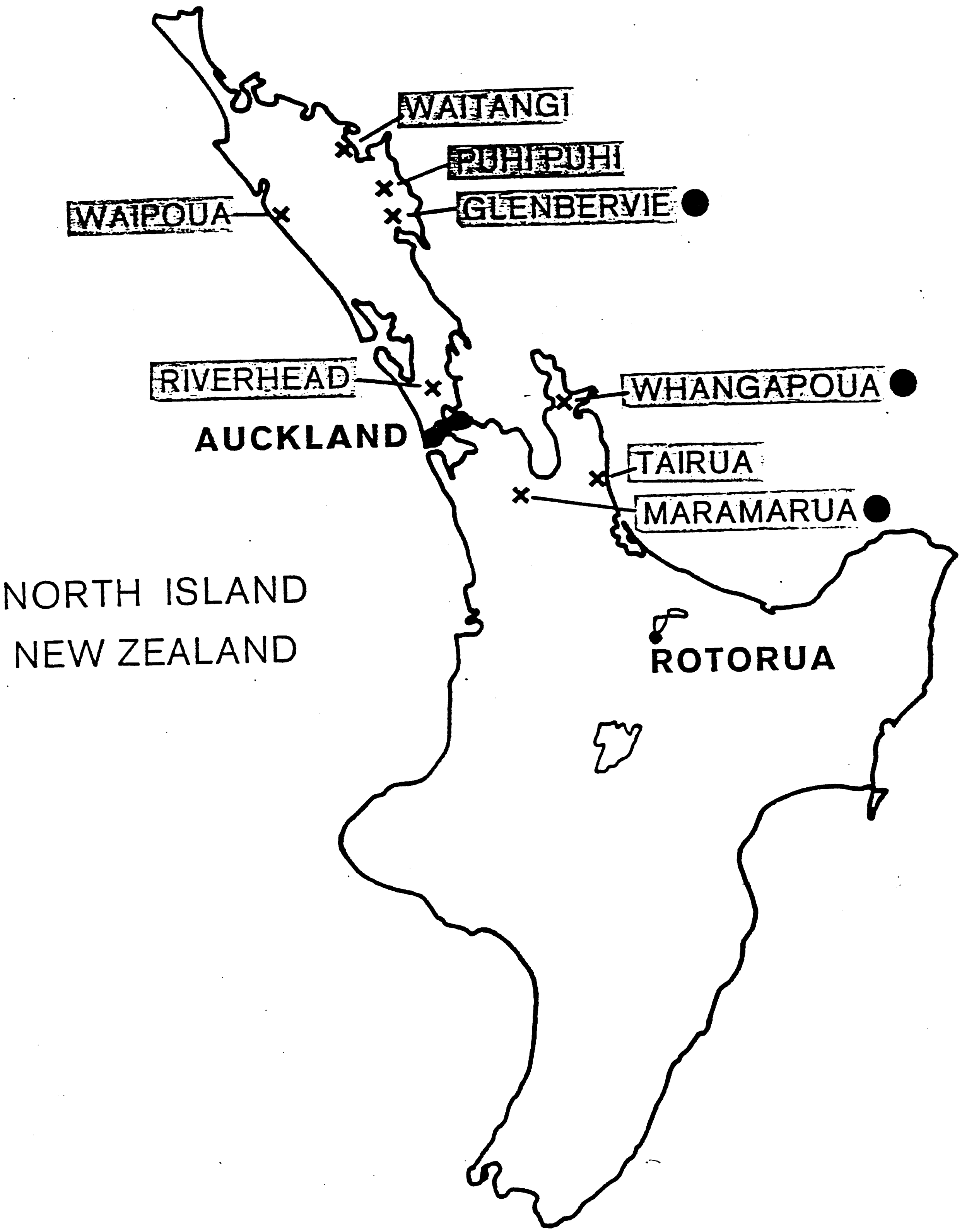

Figure 1. Auckland Conservancy Forests represented in the data.

3.12 Soil Type

Checks on soil type for the plots were performed by examining plot history sheet records. Plots were accepted for further consideration if the soil type could be broadly classified as a 'classical' clay. A 'classical' clay is described as having (a) medium 'P' retention, (b) low available 'P', and (c) medium available nitrogen (Hunter 1986). A list of represented soil types is provided in Appendix 1.

For purposes of further clarification, soil types broadly classified as 'volcanic' or 'podzol' clays were expressly excluded from consideration (at the direction of I. Hunter, project leader Soil and Site Amendment Research Field). These clays are described as having contrasting extremes of high and low 'P' retention, respectively. The judgement was made that inclusion of plot data from these 'clays' would be deleterious to the modelling effort. This is because the response to 'P' fertilisation on these 'clays' is variable, complex, and much less well understood than the response expressed on the 'classical' clays. About 100 plots in Tairua and Athenree forests were excluded on the foregoing basis. On a purely mensurational basis, the suitability of the data from these plots for growth modelling is unknown.

3.13 Fertiliser history

A wide range in phosphorus fertiliser histories are exhibited in the data base. Documentation of these histories for Conservancy and F.R.I. plots were obtained from plot history sheet records and experimental trial records, respectively. The rates of fertilisation are considered to be more accurate and uniform on F.R.I. plots because the the applications were hand, ground-based; rather than by aerial top-dressing as on Conservancy plots.

The data has been carefully screened to exclude paired measurements (growth increments) which are dated prior to fertilisation, or which involve fertilisation with nitrogen. 'Time since fertiliser applied' relative to remeasurement date ranges from 1 to 15 years, number of applications ranges from 1 to 4; while rate of application ranges from 625 kg/ha to 2500 kg/ha. The rate of application for individual trees ranges from 100 to 170 grams. The most common form of phosphorus used was 'super', although 'rock' phosphate was applied in some cases.

3.2 Data Descriptions - specific analyses

3.21 Height model data

The following is a list of criteria upon which plot measurements were preliminary screened (prior to further consideration on mensurational merit):

- a minimum of 3 consecutive top height measurements (provides 2 growth increments, or 2 'paired measurements');
- a minimum of 3 height sample trees;
- measurements excluding November, December, January;
- measurements excluding windthrow greater than 2 trees per plot, or if the mean DBH of windthrown trees is greater than the mean DBH for the plot; and
- measurements excluding poison thinnings.

Following the preliminary screening, data continued to be screened on the basis of mensurational merit. Graphical analysis was used to identify 'unique shifts' in mean top height relative to consecutive measurements for a plot, or relative to the overall 'spread' of the data. For example, decreasing height over consecutive measurements for a plot were identified and disallowed by deleting 'suspect' measurements. In general, the occurrence of 'decreasing heights' was not common, or problematic.

A unique shift in height data relative to the overall spread of the data was identified in the Riverhead 286/6 (all) and 439/0 (some) plot series. Mean top height for ages 7 to 17 years was significantly lower, although growth rate was similar to the bulk of the data. Because this data occupied a unique region in the range of height-ages, the decision was made to delete these plots from consideration. The 286/6 plot series comprised 16 plots and 94 measurements; the 439/0 series, 6 plots and 23 measurements.

A unique shift in height data was also identified in the Riverhead 189 plots series. Six (6) plots in this series totalled 30 measurements and represented the only ages from 34 to 49 years. The data was unique both in age and declining growth increments. The decision was made to delete these plots from consideration, in order to not condition the model with limited data from over-mature stands.

The final height model data set represents 6 forests and 114 plots totalling 421 measurement pairs from 535 individual measurements. A descriptive breakdown on the basis of 'bulk of data' by forest and controlling agent (FRI or Conservancy) is provided in Table 1. A list of plots by forest is provided in Appendix 2.

On the basis of 'measurement pairs', 56% of the data is from Whangapoua Forest with Glenbervie and Maramarua Forests providing a combined total of 32%. Riverhead and Tairua make minor contributions totalling 12%, while Waitangi contributes less than 0.5%. Nearly 70% of the data is from FRI research plots.

A descriptive breakdown of the data by forest on the basis of age, top height and site index is provided in Table 2. Age ranges from 5 to 32 years; height, 4 to 44 metres; and site index (from the height model), 24 to 37 metres. Mean age is 14.5 years, while mean site index is 30.0 metres. Mean age increment (time period) from paired measurements is 2.3 years from a range of 0.7 to 9.3 years.

3.22 Basal area/stocking model data

The following is a list of criteria upon which plot measurements were preliminarily screened (prior to further consideration on mensurational merit):

- a minimum of 2 consecutive, complete (BA, HT, SPH) measurements with no thinnings between dates (provides one growth increment, or one 'paired measurement');
- measurements excluding November, December, January;
- measurements excluding windthrow greater than 2 trees per plot, or if the mean DBH of windthrown trees is greater than the mean DBH for the plot;
- measurements excluding poison thinnings; and
- measurement dates at least 8 months apart.

Table 1. Height model data - bulk of data by forest and controlling agent

Forest	No. Plots FRI	No. Plots CON	No. Plots TOT	No. Measurements FRI	No. Measurements CON	No. Measurements TOT	No. Pairs FRI	No. Pairs CON	No. Pairs TOT	% of NO. PAIRS
Whangapoua	30	15	45	234	45	279	204	30	234	56
Glenbervie	7	24	31	37	75	112	30	51	81	19
Maramarua	7	14	21	34	42	76	27	28	55	13
Riverhead	6	4	10	24	16	40	18	12	30	7
Tairua	6	0	6	25	0	25	19	0	19	5
Waitangi	0	1	1	0	3	3	0	2	2	0
TOTAL	56	58		354	181		298	123		100
GRAND TOTAL	114			535			421			
% of GRAND TOTAL	49	51		66	34		71	29		

Table 2. Height model data - stand parameters

Forest (n)	AGE Min	AGE Mean (σ)	AGE Max	TOP HEIGHT Min	TOP HEIGHT Mean (σ)	TOP HEIGHT Max	SITE INDEX* Min	SITE INDEX* Mean (σ)	SITE INDEX* Max
Whangapoua (279)	6.1	14.2 (4.8)	23.1	7.4	22.2 (6.9)	37.1	24.2	30.7 (2.1)	36.5
Glenbervie (112)	5.2	16.0 (7.9)	31.9	6.6	23.1 (9.4)	42.2	24.4	29.9 (2.5)	34.9
Maramarua (76)	8.9	18.8 (5.3)	28.8	10.0	27.6 (8.3)	43.9	23.7	29.5 (3.1)	37.0
Riverhead (40)	4.9	9.4 (3.2)	16.9	4.1	13.0 (5.1)	23.3	23.8	27.9 (2.1)	31.9
Tairua (25)	4.9	6.9 (1.8)	9.9	4.6	9.1 (3.2)	15.3	24.8	27.9 (1.6)	30.1
Waitangi (3)	10.1	11.1 (1.0)	12.0	13.7	15.9 (2.1)	17.8	27.0	27.8 (0.8)	28.6
ALL FORESTS (535)	4.9	14.5 (6.1)	31.9	4.1	21.8 (8.6)	43.9	23.7	30.0 (2.5)	37.0

* Based on the height model, and for each height/age measurement.

Following the preliminary screening, data continued to be screened on the basis of mensurational merit using graphical analysis. Measurements excluded in the height model data-set were also excluded in the basal area/stocking analysis because site index as determined by the height model is an independent variable. Measurements which were affected by changes in plot area (often due to thinnings) were treated as 'new' plots, provided the preliminary screening criteria were satisfied. Twenty-five (25) plots were affected by plot area changes. In general 'suspect' measurements were not common or problematic.

The final basal area/stocking data set represents 8 forests and 228 plots totalling 510 measurement pairs from 785 individual measurements. A descriptive breakdown on the basis of 'bulk of data' by forest and controlling agent is provided in Table 3. A list of plots by forest is provided in Appendix 3.

On the basis of 'measurement pairs', 46% of the data is from Whangapoua Forest with Glenbervie and Maramarua Forests providing nearly equal shares totalling 40%. Riverhead and Tairua Forests make a minor combined contribution of 10%; while Waipoua, Puhi Puhi, and Waitangi combined, total 3%. Over one-half of the data is from FRI research plots.

A descriptive breakdown of the data by forest on the basis of age, top height, site index, basal area, stocking, and years since thinning and thinning ratio (BA after/BA before) is provided in Tables 4 and 5, respectively. Age ranges from 5 to 32 years; site index, 24 to 39 metres; basal area, 2 to 76 m^2/ha; and stocking; 100 to 2247 stems per hectare. Mean age is 14.8 years while mean site index is 30.2 metres. Mean age increment (time period) from paired measurements is 2.9 years from a range of 0.8 to 9.7 years. Mean 'years since thinning' is 10.0 years, while mean 'thinning ratio' is 0.562 from a range of 0.299 to 0.991.

3.23 Thinning function data

A sub-set of data from the bulk of the data base was selected, upon which to base the derivation of a 'thinning function', i.e. a function to predict either 'residual basal area' or 'residual stocking' following a thinning. Measurements involving thinning were selected from the data-sets for the height and basal area/stocking models. An exception for inclusion of data was made with regards to the previously excluded 439/0 and 286/6 plot series. These plot series were included because the analysis seeks a relation between before-and after-thinning basal area or stocking, not a relation involving site quality and growth.

The final thinning function data-set represents 6 forests and 78 plots totalling 85 observations. A descriptive breakdown on the basis of 'bulk of data' by forest and controlling agent is provided in Table 6. A list of plots by forest is provided in Appendix 4.

On the basis of number of observations, Riverhead; Glenbervie; and Whangapoua Forests contribute on nearly an equal basis, over 80% of the data. Maramarua Forest makes a minor contribution (9%), while Waitangi and Waipoua combined, total 7%. Over 60% of the data is from FRI research plots.

Table 3. Basal area/stocking model data - bulk of data by forest and controlling agent.

Forest	No. Plots FRI	No. Plots CON	No. Plots TOT	No. Measurements FRI	No. Measurements CON	No. Measurements TOT	No. Pairs FRI	No. Pairs CON	No. Pairs TOT	% of NO. PAIRS
Whangapoua	35	21	56	259	57	316	198	36	234	46
Glenbervie	13	65	78	43	158	201	24	87	111	22
Maramarua	7	49	56	40	114	154	27	65	92	18
Riverhead	6	4	10	24	19	43	18	12	30	6
Tairua	6	0	6	27	0	27	21	0	21	4
Waipoua	0	10	10	0	20	20	0	10	10	2
Puhi Puhi	0	8	8	0	16	16	0	8	8	1
Waitangi	0	4	4	0	8	8	0	4	4	1
TOTAL	67	161		393	392		288	222		100
GRAND TOTAL	228			785			510			
% of GRAND TOTAL	29	71		50	50		56	44		

*Includes 'double-counting' of plots affected by area changes. A total of 25 plots are 'double-counted', leaving an individual total of 203 plots.

Table 4. Basal area/stocking model data – stand parameters

Forest (n)	AGE Min	AGE Mean (σ)	AGE Max	TOP HEIGHT Min	TOP HEIGHT Mean (σ)	TOP HEIGHT Max	SITE INDEX* Min	SITE INDEX* Mean (σ)	SITE INDEX* Max	BASAL AREA Min	BASAL AREA Mean (σ)	BASAL AREA Max	STOCKING Min	STOCKING Mean (σ)	STOCKING Max
Whangapoua (316)	6.1	13.9 (4.7)	23.1	7.4	21.9 (6.9)	37.1	24.2	30.8 (2.1)	37.2	6.3	30.0 (14.4)	74.2	198	708 (568)	2148
Glenerbvie (201)	5.2	16.7 (6.8)	31.9	6.6	25.0 (8.5)	42.2	24.2	30.4 (2.6)	37.6	5.9	36.5 (14.6)	76.4	119	748 (550)	2099
Maramarua (154)	8.9	17.8 (5.1)	28.8	10.0	26.7 (7.7)	43.9	23.7	30.0 (3.0)	38.7	5.5	28.3 (14.5)	60.8	100	449 (238)	1235
Riverhead (43)	4.9	9.6 (3.2)	16.9	4.1	13.4 (5.1)	23.3	23.8	27.9 (2.1)	31.9	1.9	19.8 (11.7)	48.0	420	1227 (444)	2123
Tairua (27)	4.9	7.0 (1.8)	9.9	4.6	9.1 (3.1)	15.3	24.8	27.9 (1.6)	30.1	3.0	16.7 (10.4)	39.8	950	1174 (179)	1450
Waipoua (20)	7.8	10.3 (2.2)	14.8	10.4	15.9 (4.2)	26.3	26.8	29.7 (2.1)	33.5	5.4	13.6 (7.5)	30.0	385	461 (46)	543
Puhi Puhi (16)	8.9	15.1 (4.0)	21.8	14.8	23.8 (6.0)	34.2	23.5	30.8 (3.1)	34.8	13.6	35.0 (18.0)	72.3	275	674 (569)	2125
Waitangi (8)	5.9	11.7 (2.9)	14.8	6.0	15.6 (4.7)	20.5	23.8	26.4 (1.7)	29.3	6.2	22.5 (15.1)	46.3	396	1264 (696)	2247
ALL FORESTS (785)	4.9	14.8 (5.9)	31.9	4.1	22.5 (8.3)	43.9	23.5	30.2 (2.6)	38.7	1.9	29.9 (15.2)	76.4	100	711 (530)	2247

* Based on the height model, and for each height/age measurement.

Table 5. Basal area/stocking model data - 'years since thinning' and thinning ratio

Forest	No. Paired Mea	Year Since* Thinning Min	Mean (σ)	Max	No. Paired Mea	Thinning** Ratio Min	Mean (σ)	Max
Whangapoua	214	0.3	8.5 (5.0)	22.2	20	.346	.567 (.262)	.991
Glenbervie	88	0.2	11.6 (9.1)	30.8	23	.299	.602 (.175)	.878
Maramarua	82	3.0	14.2 (6.4)	24.9	10	.424	.541 (.088)	.691
Riverhead	27	2.0	7.6 (2.4)	11.9	3	.345	.397 (.058)	.459
Tairua	21	4.9	6.3 (1.2)	8.0	0	-	-	-
Waipoua	10	7.8	8.9 (1.1)	10.8	0	-	-	-
Puhi Puhi	6	3.4	6.7 (3.0)	10.9	2	.340	.389 (.069)	.438
Waitangi	4	5.9	10.2 (3.3)	13.8	0	-	-	-
ALL FORESTS	452	0.2	10.0 (6.5)	30.8	58	.299	.562 (1.98)	.991

* when YST = is greater than zero.
** when YST = 0, (i.e. current thinning)

Table 6. Thinning Function data - bulk of data by forest and controlling agent.

Forest	No. Plots FRI	No. Plots CON	No. Plots TOTAL	No. Measurements FRI	No. Measurements CON	No. Measurements TOTAL	% of No. Measurements
Riverhead	16	10	26	17	10	27	32
Glenbervie	7	15	22	7	15	22	26
Whangapoua	16	0	16	22	0	22	26
Maramarua	7	1	8	7	1	8	9
Waitangi	0	4	4	0	4	4	5
Waipoua	0	2	2	0	2	2	2
TOTAL	46	32		53	32		100
GRAND TOTAL	78			85			
% OF GRAND TOTAL	59	41		62	38		

A descriptive breakdown of the data by forest on the basis of before-and after-thinning stand parameters is provided in Tables 7 and 8, respectively. Age ranges from 9 to 17 years with initial stocking ranging from 370 to 2173 stems per hectare. Mean age and initial stocking is 12 years and 1190 stems per hectare, respectively. Thinning ratio (BA after:BA before) ranges from 0.299 to 0.991 with final stocking ranging from 138 to 1139 stems per hectare. Mean thinning ratio and final stocking is 0.543 and 425 stems per hectare, respectively.

3.24 Volume/basal area function data

Nearly the bulk of the entire data base was used as a data-set for the derivation of a volume/basal area function. All plots and measurements were accepted provided basal area, stocking, top height, and volume were available from PSP summaries. 'Volume' was taken directly from the PSP summaries, accepting the 'default' volume table and number. Volume table 'TØØ9' was most common, although tables 'T074' and 'TØ75' had also been used.

The final volume/basal area function data set represents 8 forests and 336 plots totalling 1090 observations. A descriptive breakdown on the basis of 'bulk of data' by forest and controlling agent is provided in Table 9. A list of plots by forset is provided in Appendix 5.

On the basis of number of observations, Whangapua and Glenbervie Forests provide most (57%) of the data, while Riverhead and Maramarua contribute essentially equal secondary amounts totalling 33%. Puhi Puhi, Tairua, Waipoua and Waitangi each make similar minor contributions totalling 10%. Over 55% of the data is from FRI research plots.

A description breakdown of the data by forest on the basis of basal area, volume, V/B ratio, stocking, and top height is provided in Table 10. Basal area ranges from 1 to 76 m^2/ha; volume, 2 to 862 m^3/ha; and V/B ratio, 2.5 to 15.0. Mean basal area is 27 m^2/ha, mean volume 223 m^3/ha, and mean V/B ratio is 7.2. Tairua and Riverhead Forests have much lower mean V/B ratios relative to the overall mean, i.e. 49% and 32% less, repsectively.

3.25 'Young Stand' function data

The prediction of growth and yield of very young stands (top height less than 5 metres) is disadvantaged by a lack of data. A separate 'young stand' function is required to enable simulations to start at age zero and link with the main modelling procedures at top height 5 metres. Data for the derivation of the 'young stand' function was selected from the bulk of the entire data base. The selection criteria was initial measurements of unthinned plots with stocking greater than 1200 stems per hectare.

The final 'young stand' function data-set represents 7 forests and 73 plots and measurements. A descriptive breakdown on the basis of 'bulk of data' by forest and controlling agent is provided in Table 11. A list of plots by forest is provided in Appendix 6. Nearly one-half of the data is from Glenbervie Forest, while Whangapoua Forest contributes 25% of the data. Riverhead and Puhi Puhi Forests each make similar contributions totalling 22%; while Maramarua, Tairua, and Waitangi make minor similar contributions totalling 12%. Nearly one-half of the data is from Conservancy management plots.

Table 7. Thinning function data - Before-thinning stand parameters.

Forest (n)	AGE Min	AGE Mean (σ)	AGE Max	STOCKING Min	STOCKING Mean (σ)	STOCKING Max	BASAL AREA Min	BASAL AREA Mean (σ)	BASAL AREA Max	TOP HEIGHT Min	TOP HEIGHT Mean (σ)	TOP HEIGHT Max
Riverhead (27)	11.9	12.7 (0.8)	16.0	370	1171 (380)	2074	11.73	22.79 (8.49)	47.98	11.2	14.9 (2.5)	21.0
Glenbervie (22)	9.2	13.2 (1.7)	16.8	494	1183 (559)	2030	27.20	42.04 (9.70)	67.27	15.2	21.4 (2.0)	27.7
Whangapoua (22)	9.0	9.9 (0.6)	11.2	420	1283 (630)	2099	14.21	26.74 (7.92)	40.75	14.7	16.9 (1.4)	20.2
Maramarua (8)	13.0	13.0 (0)	13.0	938	1090 (120)	1265	17.34	24.76 (6.51)	37.87	16.2	18.6 (2.1)	23.2
Waitangi (4)	11.3	12.5 (1.6)	14.8	1089	1496 (473)	2173	19.06	30.79 (11.38)	46.33	16.1	18.8 (2.1)	20.5
Waipoua (2)	13.9	13.9 (0)	13.9	385	730 (63)	474	22.24	26.05 (5.39)	29.86	20.4	21.9 (2.1)	23.4
ALL FORESTS (85)	9.0	12.1 (1.7)	16.8	370	1193 (503)	2173	11.73	29.43 (11.41)	67.27	11.2	17.8 (3.5)	27.7

Table 8. Thinning function data - after-thinning stand parameters

Forest (n)	THINNING* RATIO Min	Mean (σ)	Max	STOCKING Min	Mean (σ)	Max	BASAL AREA Min	Mean (σ)	Max
Riverhead (27)	.341	.464 (.115)	.942	247	384 (58)	568	5.47	10.41 (4.05)	23.10
Glenbervie (22)	.299	.638 (.183)	.878	300	497 (194)	1139	10.19	25.90 (5.99)	35.29
Whangapoua (22)	.346	.582 (.253)	.991	370	433 (37)	519	9.39	13.96 (2.85)	20.91
Maramarua (8)	.424	.509 (.062)	.615	326	399 (34)	444	9.86	12.29 (1.82)	16.04
Waitangi (4)	.334	.444 (.097)	.571	396	458 (123)	642	9.98	13.32 (4.75)	20.32
Waipoua (2)	.407	.457 (.071)	.508	138	158 (28)	178	11.29	11.72 (0.60)	12.14
ALL FORESTS (85)	.299	.543 (.186)	.991	138	425 (123)	1139	5.47	15.68 (7.48)	35.29

* Ratio of BA after/BA before thinning.

Table 9. Volume/basal area function data - bulk of data by forest and controlling agent.

Forest	No. Plots* FRI	CON	TOTAL	No. Measurements FRI	CON	TOTAL	% of No. Measruements
Whangapoua	34	30	64	267	66	333	31
Glenbervie	7	111	118	245	44	289	26
Riverhead	6	26	32	24	162	186	17
Maramarua	7	68	75	41	138	179	16
Puhi Puhi	0	16	16	0	29	29	3
Tairua	6	0	6	28	0	28	3
Waipoua	0	12	12	0	24	24	2
Waitangi	0	13	13	0	22	22	2
TOTAL	60	276		605	485		100
GRAND TOTAL	336			1090			
% OF GRAND TOTAL	18	82		56	44		

* Includes 'double-counting' of plots affected by area changes. A total of 53 plots are 'double-counted', leaving an individual total of 283 plots.

Table 10. Volume/basal area function data - stand parameters.

Forest (n)	BASAL AREA Min	BASAL AREA Mean (σ)	BASAL AREA Max	VOLUME Min	VOLUME Mean (σ)	VOLUME Max	V/B RATIO Min	V/B RATIO Mean (σ)	V/B RATIO Max	STOCKING Min	STOCKING Mean (σ)	STOCKING Max	TOP HEIGHT Min	TOP HEIGHT Mean (σ)	TOP HEIGHT Max
Whangapoua (333)	2.57	29.37 (14.67)	74.24	8.4	247.8 (182.9)	861.8	2.91	7.54 (2.14)	14.90	198	718 (569)	2148	5.3	21.51 (7.14)	37.5
Glenbervie (289)	1.53	33.37 (15.47)	76.42	4.9	286.7 (180.5)	815.0	3.10	7.88 (2.10)	13.16	119	730 (507)	2099	4.2	23.2 (8.5)	42.2
Riverhead (186)	0.73	14.16 (8.71)	47.98	2.0	77.7 (60.0)	300.9	2.49	4.89 (1.39)	8.19	247	863 (455)	2123	3.0	13.0 (4.7)	23.3
Maramarua (179)	4.73	27.10 (14.29)	60.78	20.6	265.3 (193.2)	744.8	3.77	8.78 (2.21)	14.01	100	468 (254)	1275	10.0	25.8 (7.5)	43.9
Puhi Puhi (29)	13.55	37.18 (14.12)	72.29	73.3	293.5 (147.8)	631.0	4.88	7.69 (1.72)	10.80	275	937 (737)	2625	14.8	23.0 (5.9)	34.2
Tairua (28)	2.98	17.42 (10.85)	39.78	7.3	73.2 (61.2)	201.6	2.45	3.66 (0.93)	5.42	950	1169 (178)	1450	4.6	9.3 (3.2)	15.3
Waipoua (24)	5.39	13.38 (6.88)	29.95	24.0	88.5 (63.9)	266.3	4.02	6.08 (1.34)	8.89	138	430 (96)	543	10.4	16.4 (4.3)	26.3
ALL FORESTS (1090)	0.73	26.82 (15.39)	76.42	2.0	223.0 (181.1)	861.8	2.45	7.24 (2.39)	14.90	100	719 (508)	2626	3.0	20.8 (8.3)	43.9

Table 11. 'Young Stand' function data - bulk of data by forest and controlling agent

Forest	No. Plots (Measurements) FRI	CON	Total	% of No. Measurements
Glenbervie	6	24	30	41
Whangapoua	12	6	18	25
Riverhead	3	6	9	12
Puhi Puhi	0	7	7	10
Maramarua	1	2	3	4
Tairua	3	0	3	4
Waitangi	0	3	3	4
TOTAL	25	48		100
GRAND TOTAL	73			
% OF GRAND TOTAL	34	66		

A descriptive breakdown of the data by forest on the basis of age, basal area, stocking, and height is provided in Table 12. Age ranges from 5 to 15 years; basal area, 2 to 61 m^2/ha; stocking, 1200 to 2625 stems per hectare; and top height, 4 to 27 metres. Mean age is 8.5 years, while mean basal area and top height is 23 m^2/ha and 12.5 metres, respectively.

4.0 RESULTS

4.1 Model Descriptions

4.11 Height model description

Height growth is modelled by a differential equation which includes a maximum of 8 parameters. Six (6) versions of the basic model (Garcia 1984) were attempted as a result of 'constraining' or 'freeing' different parameters. Selection of the 'best' model was determined by comparing log-likelihood values (probability function with respect to optimising parameter estimates) computed by the various models. Log-likelihood values and parameter estimates for the various models are provided in Appendix 7.

Based on the selected version of the height model (Appendix 7), the calculation of height is as follows:

HEIGHT = A* (1-1.06382*b**AGE)**1.09265

where, b = height growth-rate coefficient
= ((1-(SITE/A)**0.91521)/1.06382)**0.05,
A = asymptote of height (m)
= 60.49445,

and, HEIGHT = mean top height (m),
AGE = age (years),
SITE = site index (m)

Site index at a given height and age is calculated as follows:

SITE = A * (1-1.06382*b**20)**1.09265

where, b = ((1-(HEIGHT/A)**0.91521)/1.06382)**(1/AGE).

Age at a given height and site is calculated as follows:

AGE = 20*LOG((1-(HEIGHT/A)**0.91521)/1.06382)/LOG((1-(SITE/A)**0.91521)/1.06382).

Height-age curves from the selected model have a common Y-intercept at -2.7 metres. Curves from the other versions of the basic model were constrained to have a Y-intercept of zero, however these curves did not fit the bulk of the data well (Figure 8 identifies the lack of height data for very young stands).

The 'young stand' function enables simulations to start at top height 5 metres on micro computer applications, e.g. 'GROPAK' (reporting begins at 5m). In order to permit reporting at heights <u>less than</u> 5 metres on mainframe computer applications, e.g. 'STAGS', an adjustment was made which linearly extrapolates height or age back to a Y-intercept of zero for a particular site index-age or height pair (as given to initiate the simulation).

Table 12. 'Young Stand' function data - stand parameters.

Forest	AGE			BASAL AREA			STOCKING			TOP HEIGHT		
(n)	Min	Mean (σ)	Max	Min	Mean (σ)	Max	Min	Mean (σ)	Max	Min	Mean (σ)	Max
Glenbervie	4.8	9.2	15.3	2.48	29.03	60.57	1210	1592	2099	4.7	14.5	26.6
(30)	(3.4)				(17.55)			(232)			(6.7)	
Whangapoua	5.9	6.6	9.0	3.76	16.01	31.43	1436	1718	2148	5.3	10.0	16.4
(18)	(1.1)			(7.64)				(197)			(3.0)	
Riverhead	4.9	7.2	9.9	2.25	8.33	32.41	1200	1615	2123	4.1	8.2	13.8
(9)		(1.9)			(9.44)			(327)			(3.1)	
Puhi Puhi	8.9	11.3	13.8	30.93	40.62	47.45	1350	2014	2625	14.8	16.8	22.0
(7))		(1.5)			(6.04)			(509)			(2.5	
Maramarua	8.9	11.5	13.3	8.29	25.76	36.07	1235	1258	1275	11.9	17.8	22.2
(3)		(2.3)			(15.21)			(21)			(5.3)	
Tairua	4.9	4.9	4.9	2.98	4.39	5.67	1250	1350	1450	4.6	5.0	5.7
(3)		(0)			(1.35)			(100)			(0.6)	
Waitangi	5.9	9.9	13.8	7.8	23.0	41.38	1436	1970	2247	6.0	12.4	18.7
(3)		(4.0)			(17.0)			(463)			(6.4)	
ALL FORESTS	4.8	8.5	15.3	2.25	22.98	60.57	1200	1658	2625	4.1	12.5	26.6
(73)		(3.1)			(16.27)			(317)			(5.9)	

The asymptote of the height model is 60.5 metres. Height model residuals using the data-set from the basal area/stocking analysis (n=510) are presented in Figure 2. Over 80% of the residuals are within 1.5 metres of the observed, while nearly 95% are within 10% of the observed. Residuals are evenly distributed around zero (51% positive).

4.12 Basal area/stocking model description.

The specific form of the growth equations for basal area and stocking have been described in Garcia (1984). The basic growth model, (Garcia 1984) equation (4) was fit to the data both with and without parameters a22, a23, b2, c21, c23 as 'free'. An extension of the basic equation, (Garcia 1984) equation (7) was fit to the data to model 'thinning effects'. 'Thinning effect' is in reference to a reduction in growth as a result of a lack of site occupancy. The 'effect' is present for 4 years after thinning. Three variations of equation (7) were attempted setting various parameters 'free'. Selection of the 'best' model was based on the rationalisation of log-likelihood values, residual analysis, and the ability of models to 'converge' in optimising parameter estimates. Log-likelihood values and a description of parameter 'settings' for the models attempted are provided in Table 13.

The selected basal area/stocking model is the 'thinning effect' model, 'T58'. Parameter estimates are provided in Appendix 8. Basal area and stocking residuals are plotted in Figures 3 and 4, respectively.

For basal area, over 70% of the residuals (n=510) are within $2m^2$ of the observed, while 90% are within 10% of the observed. The distribution of residuals is towards under-estimation as evidenced by 55% of the residuals being negative.

For stocking, over 80% of the residuals (n=510) are within 15 trees of the observed, while 93% are within 5% of the actual. The distribution of residuals is strongly towards under-estimation as evidenced by 76% of the residuals being negative. Three (3) percent of the residuals are gross over-estimates of stocking as a result of heavy mortality on the respective plots.

The 'ALL FREE' model has the 'best' log-likelihood value, but has 14 variables involving a higher degree of 'over-fitting'. Residual analysis of 'T58' and 'ALL FREE' resulted in very similar distributions of residuals with only a slight favouring of the 'ALL FREE' model. Given the higher degree of 'over-fitting', and the 'ALL FREE' model's tendency to predict stockings increasing with time (Garcia 1984), 'T58' was favoured over 'ALL FREE'. Model 'T56' did not 'converge' and was not considered further. Model 'T44' was disregarded because basal area residuals were well beyond acceptability when the 'thinning ratio' was below 0.394. Model 'M2' had the 'worst' log-likelihood value which was mirrored by poor residuals relative to the other models.

4.13 Thinning Function description

The thinning function is derived from a differential equation for the change in basal area with respect to the change in stocking. The

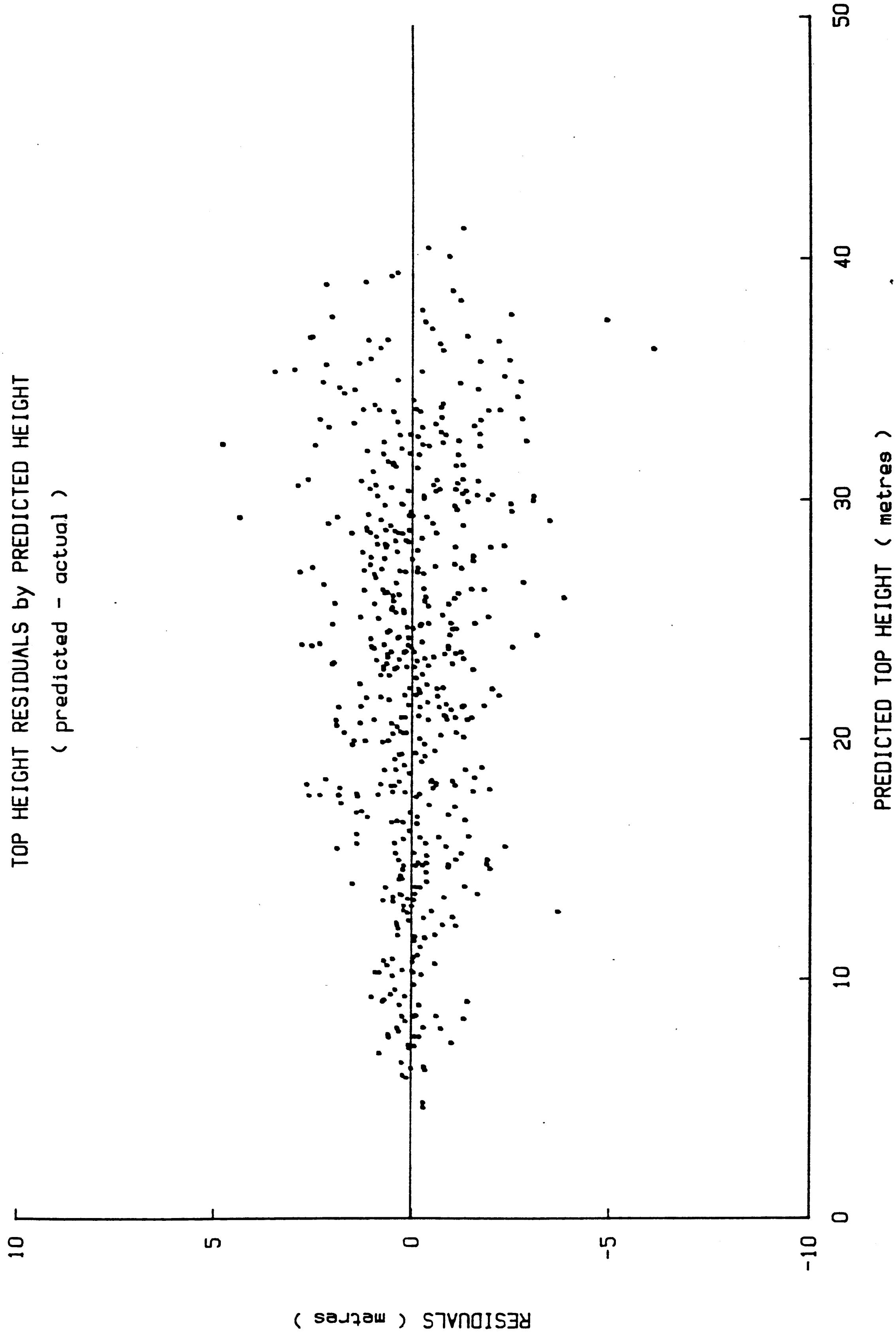

Figure 2. Height model residuals.

Table 13: Basal area/stocking model - comparison of log-likelihood values.

Model	Log-Likelihood	No. Variables	Description
M2	220.5	9	Eq(4) w/a22,a23,b2,c21,c23=0
ALL FREE	203.1	14	Eq(4) w/all parameters FREE
T44	207.0	12	Eq(7) w/a14,a22,a23,a24,b2,c21,c23,c24=0
T58	211.3	12	Eq(7) w/a22,a23,a24,b2,c21,c23,c24=0
T56	206.9	14	Eq(7) w/a22,a23,a24,b2,c21,c23=0

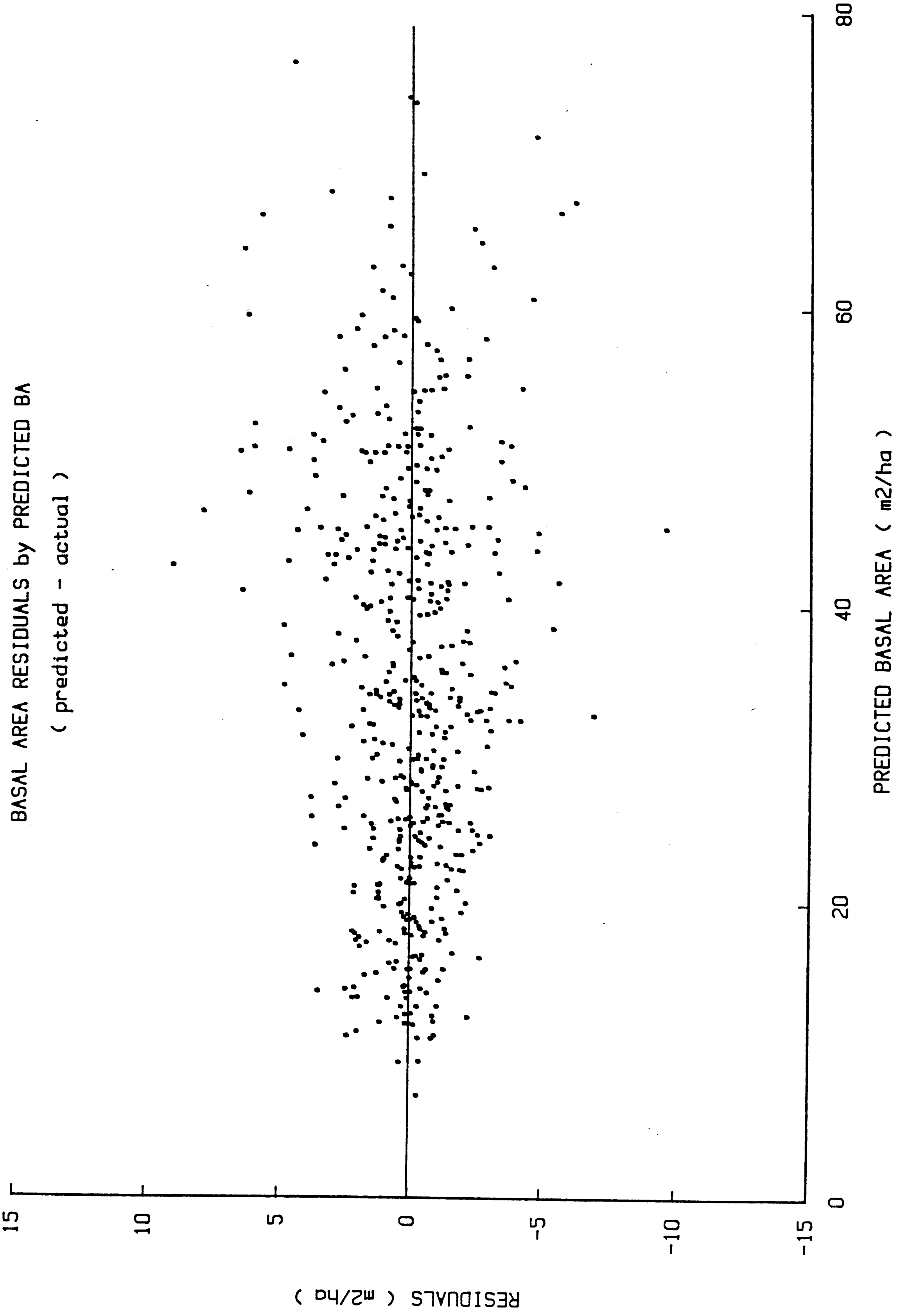

Figure 3. Basal area model residuals.

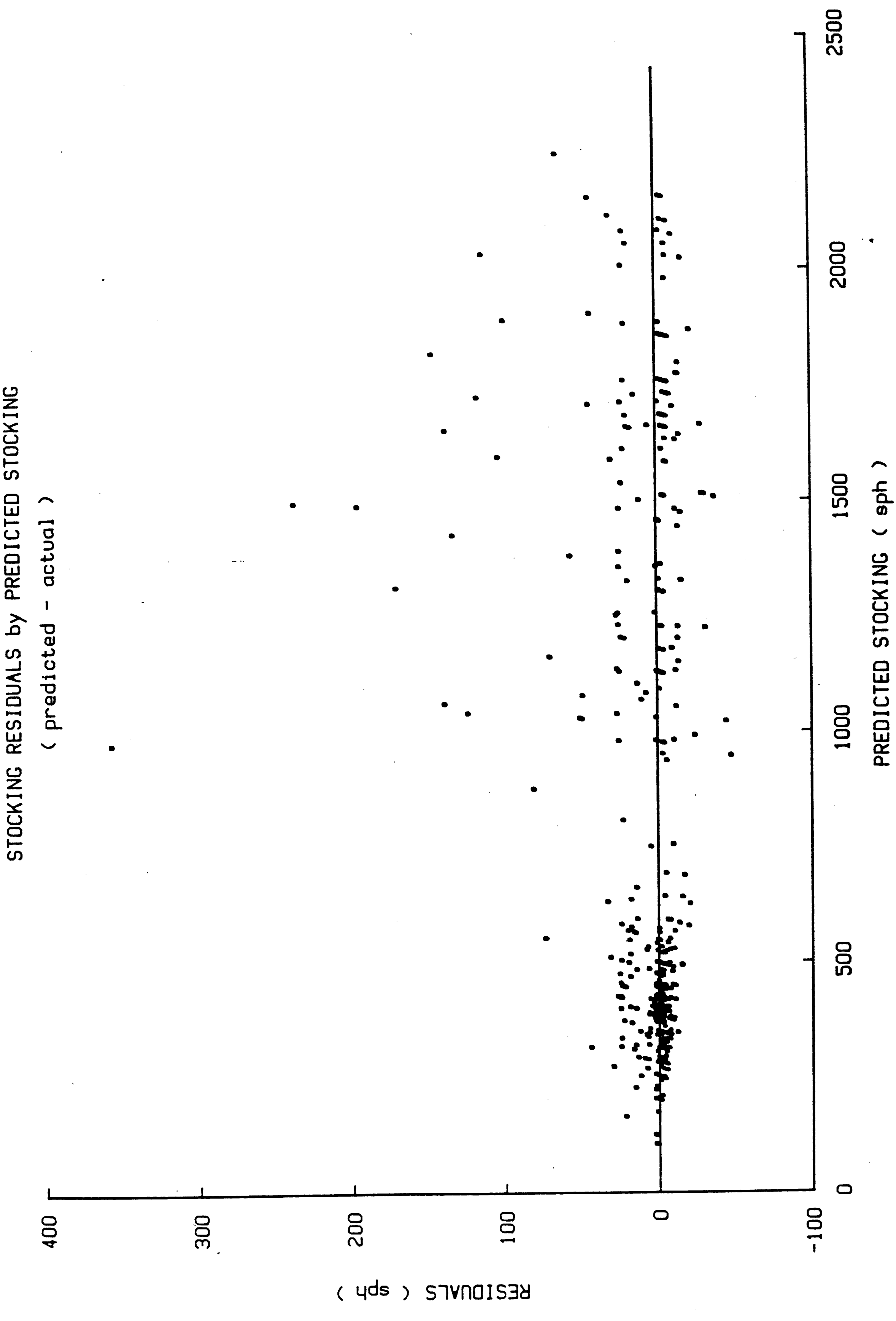

Figure 4. Stocking model residuals.

general form of the equation has been described in Garcia (1984), (equation 10). The integrated form, equation (11) was fitted with least squares to the thinning function data using 8 combinations of parameters set to zero. Selection of the 'best' function was based on comparison of residual mean square values (RMS). RMS values and parameter estimates for the various functions are provided in Appendix 9. An "F" test was performed which confirmed that FRI and Conservancy data could be combined for the fitting of the thinning function.

The selected thinning function accounts for 96% of the variance, and has the form:

BAA = BAB * (SPHA/SPHB)**(2.50955*HT**-0.45495)

where, BAA = basal area after thinning (m^2/ha),
BAB = basal area before thinning (m^2/ha),
SPHA = stems per hectare after thinning,
SPHB = stem per hectare before thinning, and
HT = top height at thinning (m).

Basal area residuals of the function are plotted in Figure 5. Over 70% of the residuals are within 1.5 m^2 of the observed, while 71% are within 10% of the observed. The distribution of residuals is towards under-estimation as evidenced by 54% of the residuals being negative.

Stocking after thinning can be predicted if basal area after-thinning is known instead by rearrangement as follows:

SPHA = SPHB * (BAA/BAB)**(1/(2.50955*HT**-0.45495)).

At the time of thinning, Ro (relative site occupany or thinning ratio) is calculated from the basal area after thinning/basal area before thinning ratio. In the years following a thinning, this ratio (R) increases and is used as a measure of 'thinning effect', or the lack of full site occupancy. R appears in the fourth equation of the basal area/stocking model and approaches an asymptotic value of 1.0 (full site occupancy) in 4 years after thinning. R is calculated as follows:

R = (1-(1-Ro**c44)*EXP(a44*YST*b))**(1/c44)

where, b = -(LOG((1-(SITE/A)**0.91521)/1.06382)/20)

and, A = asymptote of the height model (m),
a44 and c44 = coefficients from the basal area/stocking model,
Ro = BAA/BAB at time of thinning,
SITE = site index (m), and
YST = years since thinning.

For simulations starting within 4 years since thinning, thinning ratio at the time of thinning must be known, or can be estimated using an abbreviated form of the thinning function, i.e.

Ro = (SPHA/SPHB)**(2.50955*HT**-0.45495).

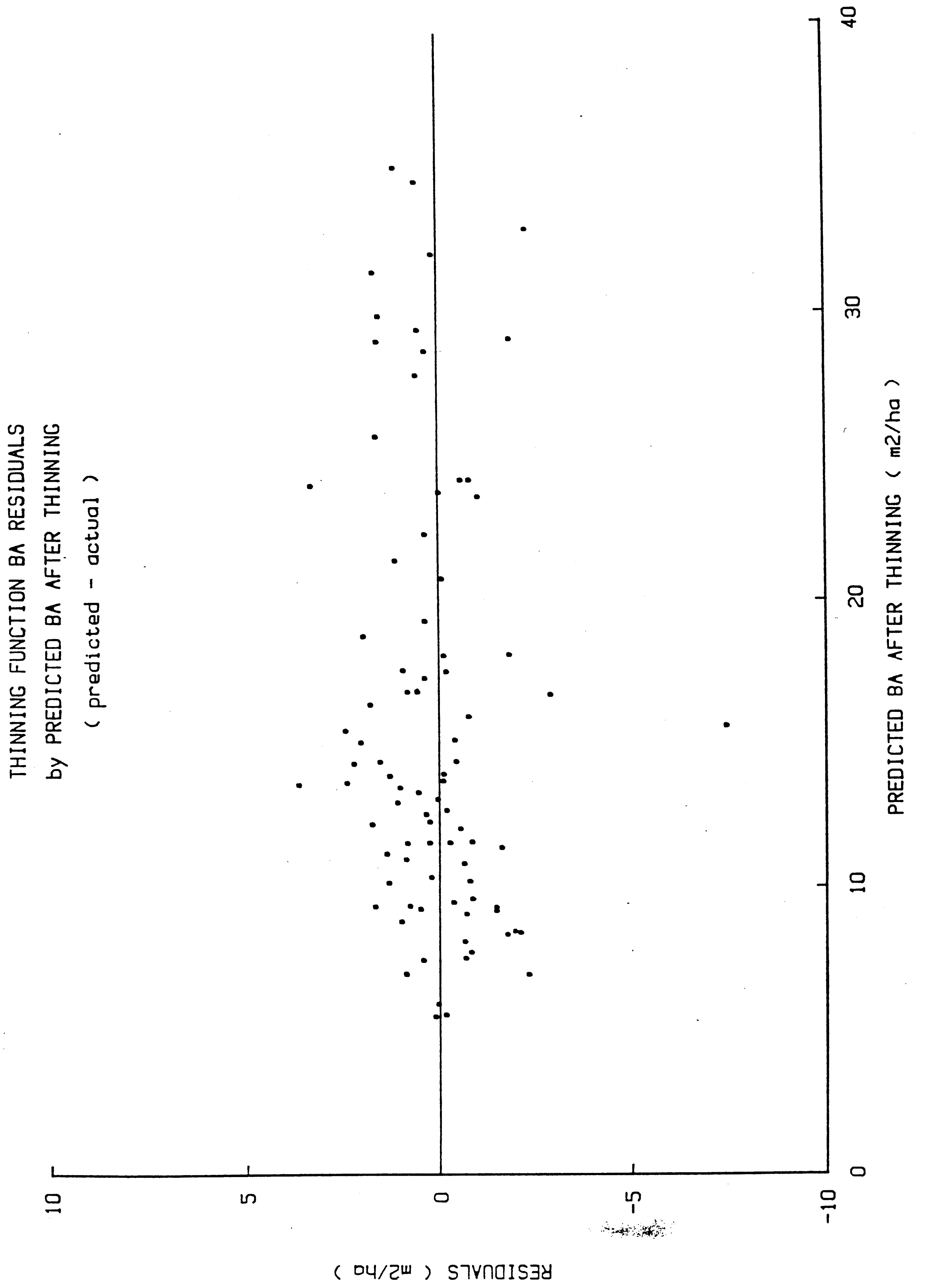

Figure 5. Thinning function residuals.

4.14 Volume/basal area function description

Stepwise multiple regression was used to derive a volume/basal area function from the independent variables top height (H), stocking (SPH), basal area (B), and the transformed variables H/SPH, H/SQR(SPH), and SPH*H/B. The best fit accounting for 96% of the variance is the function:

$$V/B = 1.58809 + 0.27588*H + (-0.00013*(SPH*H/B))$$

where, V/B = volume/basal area ratio,
B = basal area (m^2/ha),
H = top height (m), and
SPH = stems per hectare.

Volume residuals are plotted in Figure 6. Over 70% of the residuals (n=1090) are within 10 m^3 of the observed, while nearly 90% are within 10% of the observed. The residuals are evenly distributed around zero as evidenced by 51% of the residuals being negative. Nine (9) residuals are in excess of 100 m^3 representing observations with peculiar combinations of the independent variables resulting from mortality, and perhaps measurement error.

4.15 'Young Stand' function description

The 'young stand' function is based on the assumption that for young stands, basal area achieved at a particular mean top height (e.g. 5 metres) is dependent solely on stocking. The basal area/stocking model was used to project the first measurement of unthinned plots (SPH greater than 1200) forwards or backwards to a range of top heights (4 to 7 metres) with corresponding basal areas and stockings. Non-linear least squares regression was used to estimate basal area at a particular top height as a function of the corresponding stocking using equation (15) from Garcia (1984). The best fit was achieved at top height 5 metres where there were 32 'reasonable' observations of basal area and stocking from a total of 66 back projections. The final form of the 'young stand' function is as follows:

$$B5 = 0.00194*SPH, \text{ if SPH is less than } 8329$$

where, B5 and SPH are basal area and stocking at mean top height 5 metres.

Basal area residuals are plotted in Figure 7. The function lacks reliability as evidenced by only 25% of the residuals being with 15% of the 'observed' (back-projected), although percentage figures are somewhat misleading at low base quantities. Never-the-less, the function is at best a 'guestimate'. Whenever possible, simulations at young ages should be initiated with actual basal area as input.

5.0 PERFORMANCE EVALUATIONS

5.1 Site Index Curves

Site index curves derived from the height model are provided in Figure 8 in conjunction with the height data. Mean site index of the data is 30.0 metres. Burkhart and Tennent (1977) site index 30 metres is included for comparison. Table 2 provides information on the mean and range of site indices for the forests represented in the data.

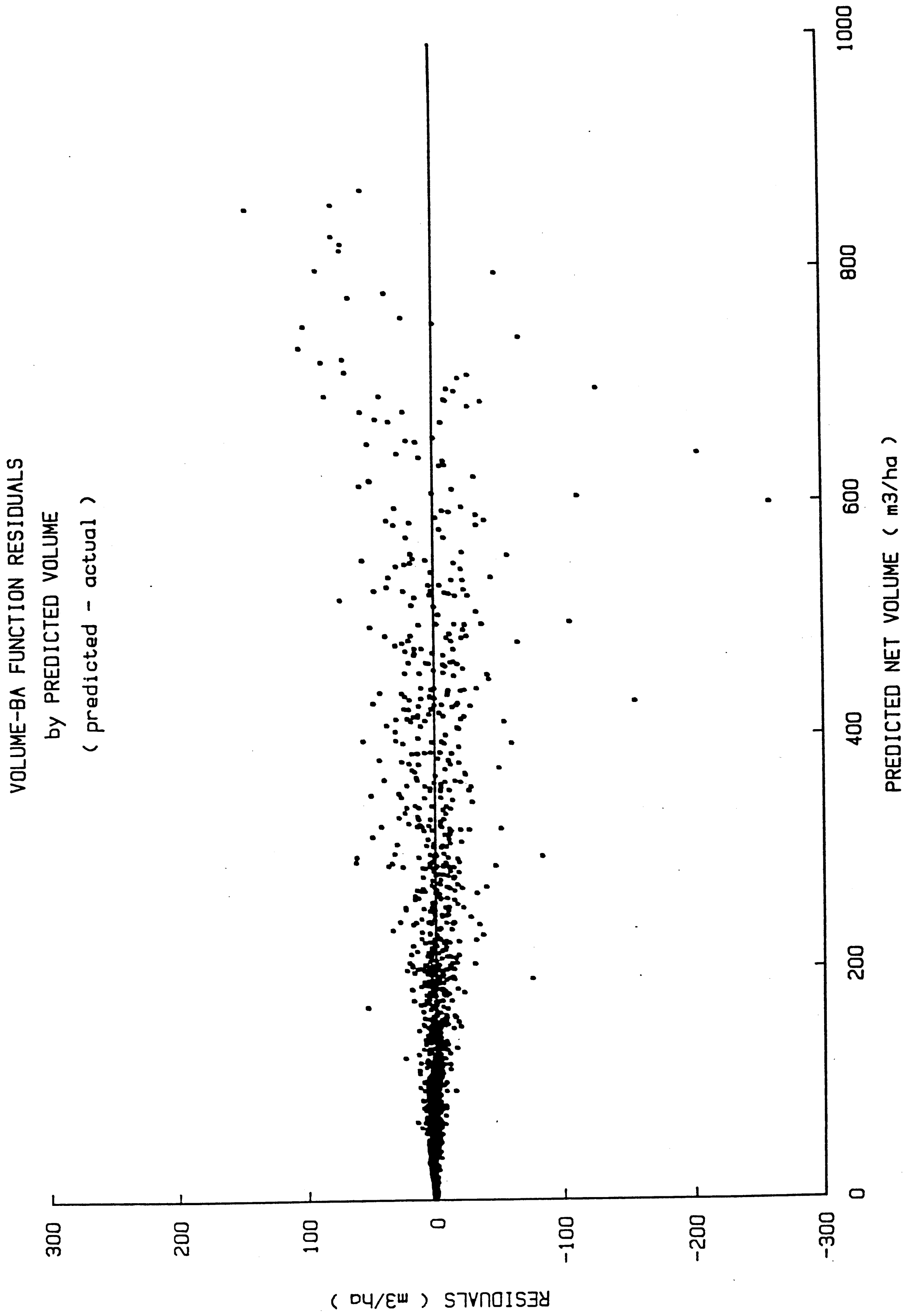

Figure 6. Volume/basal area function residuals.

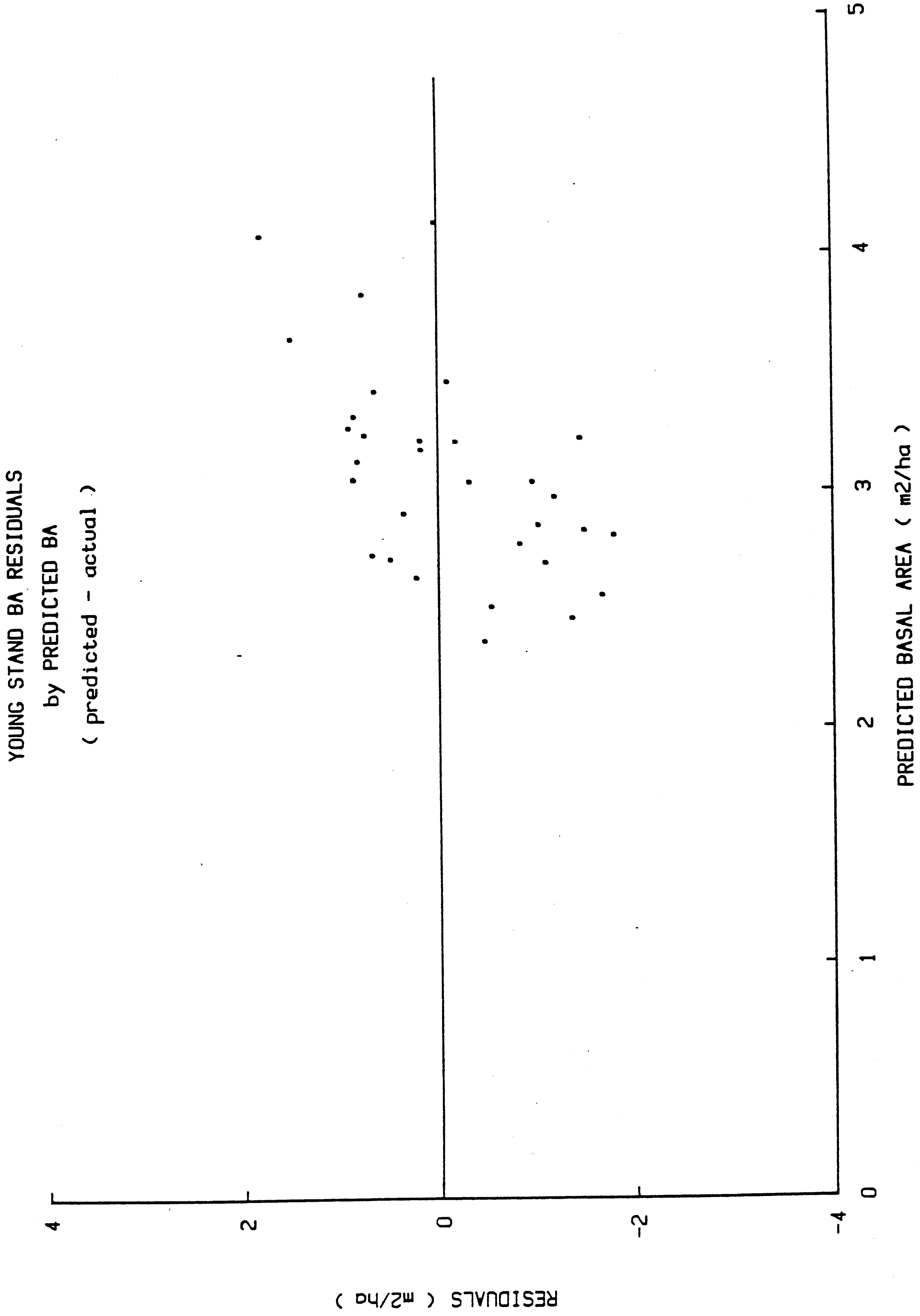

Figure 7. 'Young stand' function residuals.

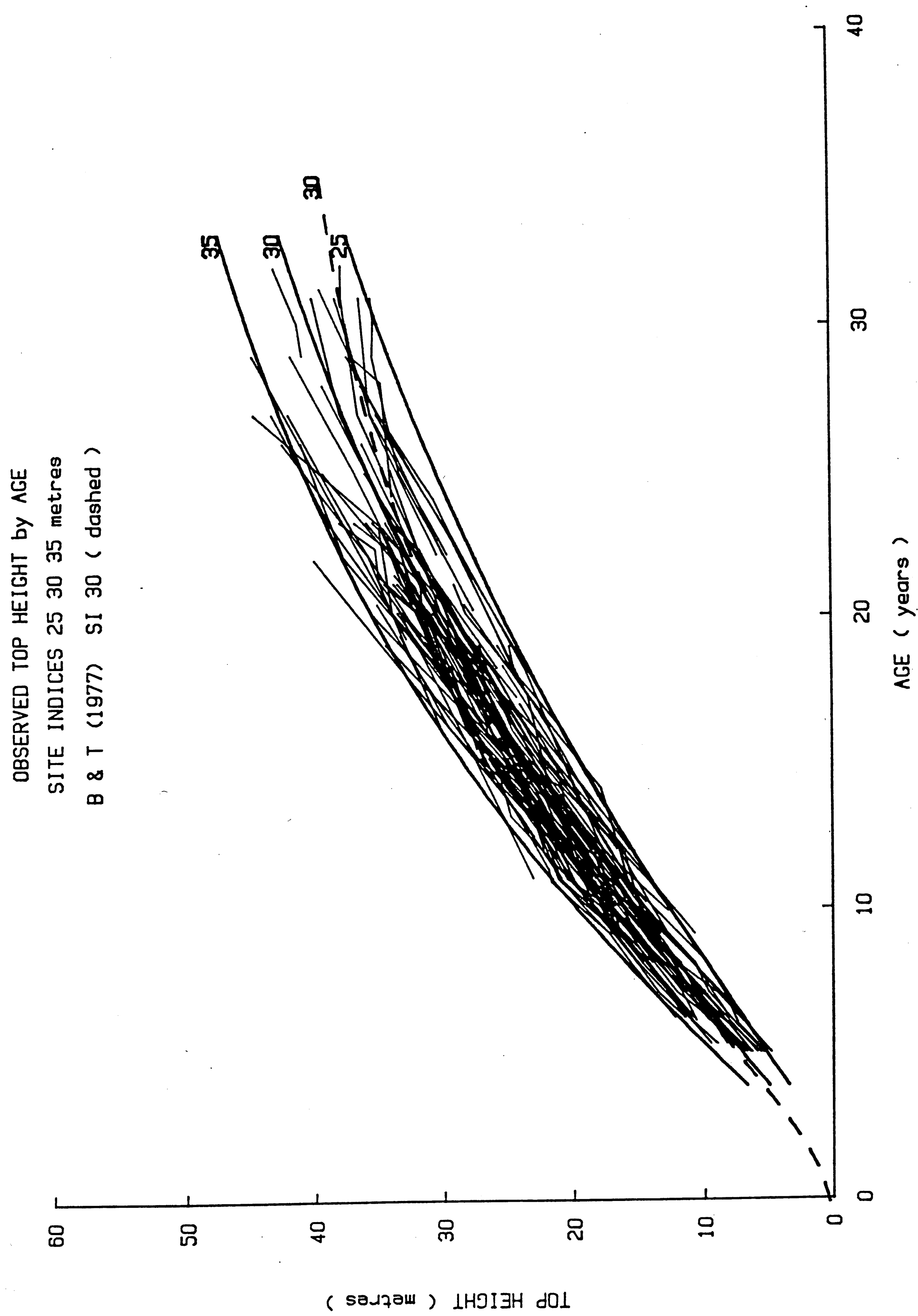

Figure 8. Site index curves with B & T (1977) for comparison.

For site index 30 metres up until age 20, the Burkhart and Tennent (B & T) curve fits closely the 'clays' curve; however beyond age 20, the B & T curve drops below the 'clays' site curve approching 'clays' site curve 25 metres at about age 33. For site indices either side of 30 metres, the B & T curves are similar, but have varying degrees of slope relative to the 'clay' curves up until age 20. Beyond age 20, the B & T curves follow the trend as described for site index 30, approaching the lower respective 'clay' curves.

5.11 Basal area error analysis

An analysis of error in predicting basal area increment was performed similar to Manley (1986). Paired measurements from the basal area/stocking model data (n=510) formed the basis of the analysis. As described in section 3.22, mean age increment (time period) was 2.9 years from a range of 0.8 to 9.7 years. Error in basal area increment prediction was calculated on an annual basis and is plotted against stocking in Figure 9. Due to a range in age increments (even though the error is expressed annually), Figure 10 is provided which presents the actual error in basal area increment plotted against age increment.

Figure 9 shows that for a range in stocking from 100 to 2247 stems per hectare, the distribution of errors is towards under-estimation as evidenced by 55% of the errors being negative. There is no apparent bias with regard to low stocking, however there are only 10 observations at stocking less than or equal to 200 stems per hectare, upon which to judge.

Figure 10 shows that for a range in age increment from 0.8 to 9.7 years, the bias in actual basal area increment prediction is similar to the bias exhibited in Figure 9. Regardless of stocking or time period, basal area increment is predicted with only a minor bias towards under-estimation.

5.12 Plot history simulations

Twenty-eight (28) plots were selected from the basal area/stocking model data set to evaluate the performance of the 'clays' model to simulate stand growth given management history as input. Plots were selected according to the following criteria:

- extended time periods whenever possible (greater than 5 years preferably);
- representing the range in site, age, basal area; and
- unthinned and thinned stocking levels.

Plots were <u>not</u> selected according to forests, or the ability/inability to produce 'good' simulations.

Simulations were started with the initial stand conditions as obtained from PSP summaries i.e. age, mean top height, stocking, basal area; and whether or not the stand had been thinned in the previous four years (if so, the thinning ratio was included). Thinnings were scheduled according to age (from the PSP summaries) with residual stocking as the 'after-thinning' initialising parameter (thereby, utilising the thinning function). Duration of the simulation was determined by age taken from the PSP summaries.

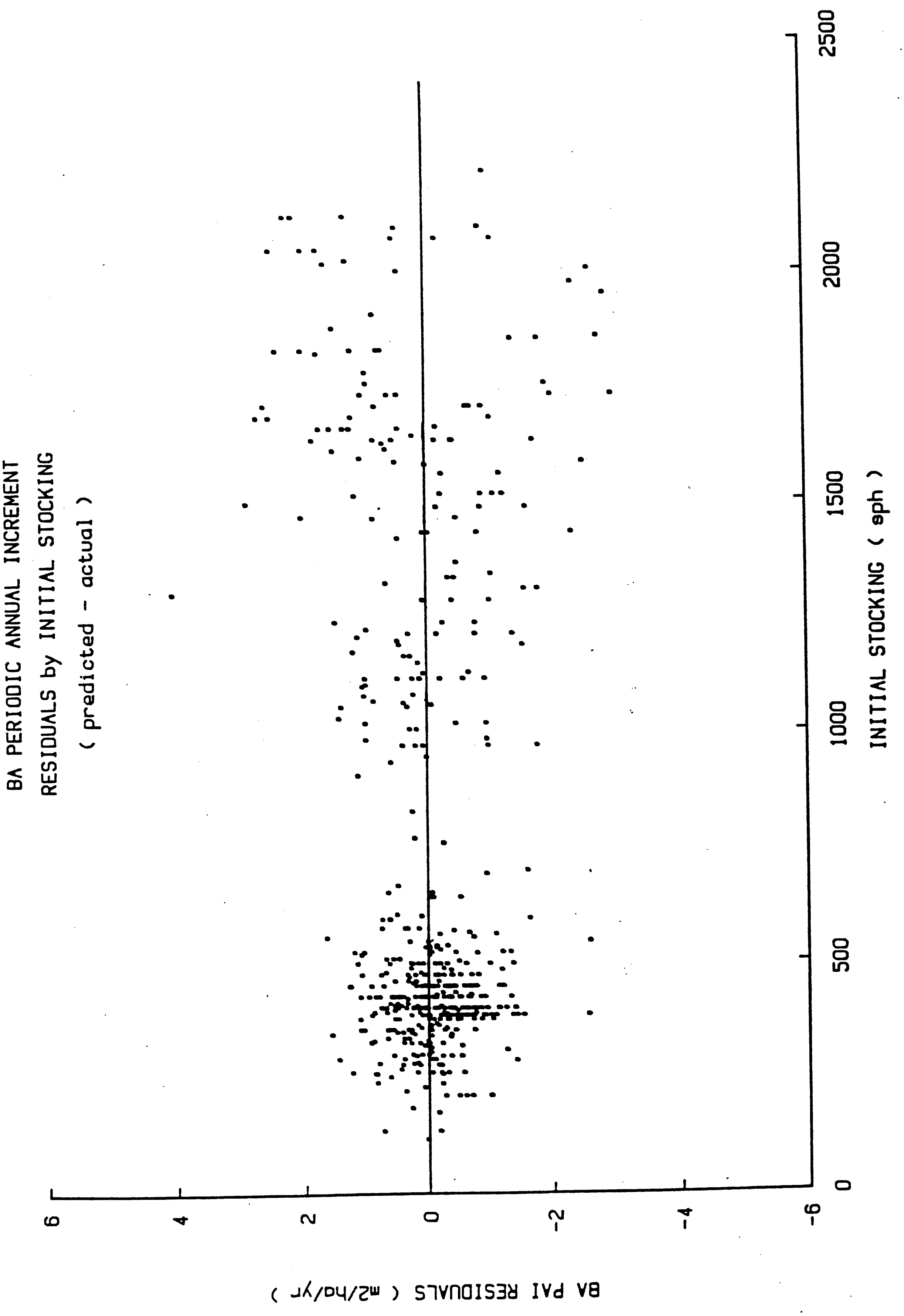

Figure 9. Basal area periodic annual increment residuals.

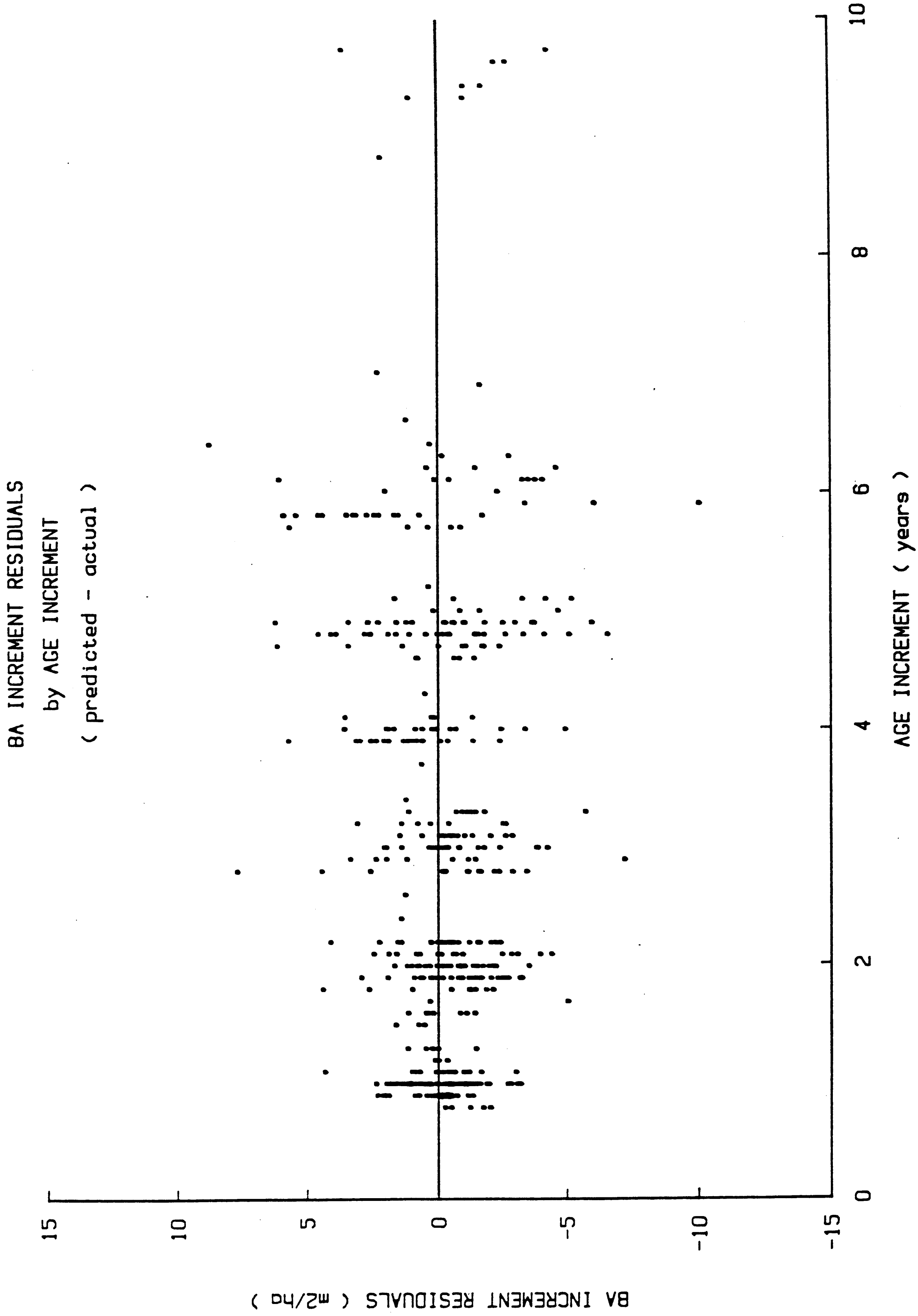

Figure 10. Basal area increment residuals.

Plots included in the simulations are listed in Appendix 10. A descriptive breakdown of stand parameters for the plots with regard to the criteria for their inclusion is provided in Appendix 11. Simulations are plotted in Figures 11 - 14 with the following allocation for ease of viewing:

Simulation Nos.	Figure No.
1-3, 5-7, 17-19	11,
4, 8-16, 20-24	12,
25, 28	13,
26-27	14.

Upon inspection, most large discrepancies between actual and predicted final basal areas were in conjunction with under-predictions of heavy-moderate mortality (e.g. simulations 4-5, 10, 14), or over-predictions (e.g. simultations 6-8). Simulation 20 is an anomaly as mortality was seriously under-predicted, however, basal area was not, in turn, over-predicted. Simulation 12 is an example of an inability of the thinning function to perform properly, however, the growth rate after-thinning is predicted well. In most all cases, the thinning function performs well (note simulation 24 where thinning ratio is 0.299). Simulation 17 is an example of the 'clays' model performing well at a low stocking of 100 stems per hectare, age 17-22. Withstanding plots with heavy mortality, the 'clays' model performs well across the range of sites, ages, basal areas, and stockings.

5.13 Management regime simulations

Five (5) management regimes were simulated for site index 30 metres as a performance check against the data used to derive the volume/basal area function (refer section 3.24). While the 5 management regimes may not be directly represented in the data, the regimes are thought to be indirectly representative to the degree that simulated curves for basal area, volume, and stocking should approximate the trends in the data. The 5 regimes are as follows:

1. Plant 1540 stems/ha without management, clearfell at age 30.
2. As in 1, but thin at mean top height (MTH) 6 metres to 600 stems/ha.
3. As in 2, but perform a second thinning at MTH 11 metres to 370 stems/hectare.
4. As in 3, but thin at MTH 11 metres to 200 stems/hectare.
5. As in 3, but thin at MTH 11 metres to 100 stems/hectare.

The results of the simulations are presented in Figures 15 and 16 for basal area and volume by top height, respectively. Results are also presented in Figures 17, 18 and 19 for basal area, volume, and stocking by age, respectively. In Figures 17 - 19, plot data representing site indices 29 - 31 metres were selected for comparison with the regimes at site index 30 metres. A simulation curve for regime 3 using KGM2 (B & T site index 30) is included for comparison.

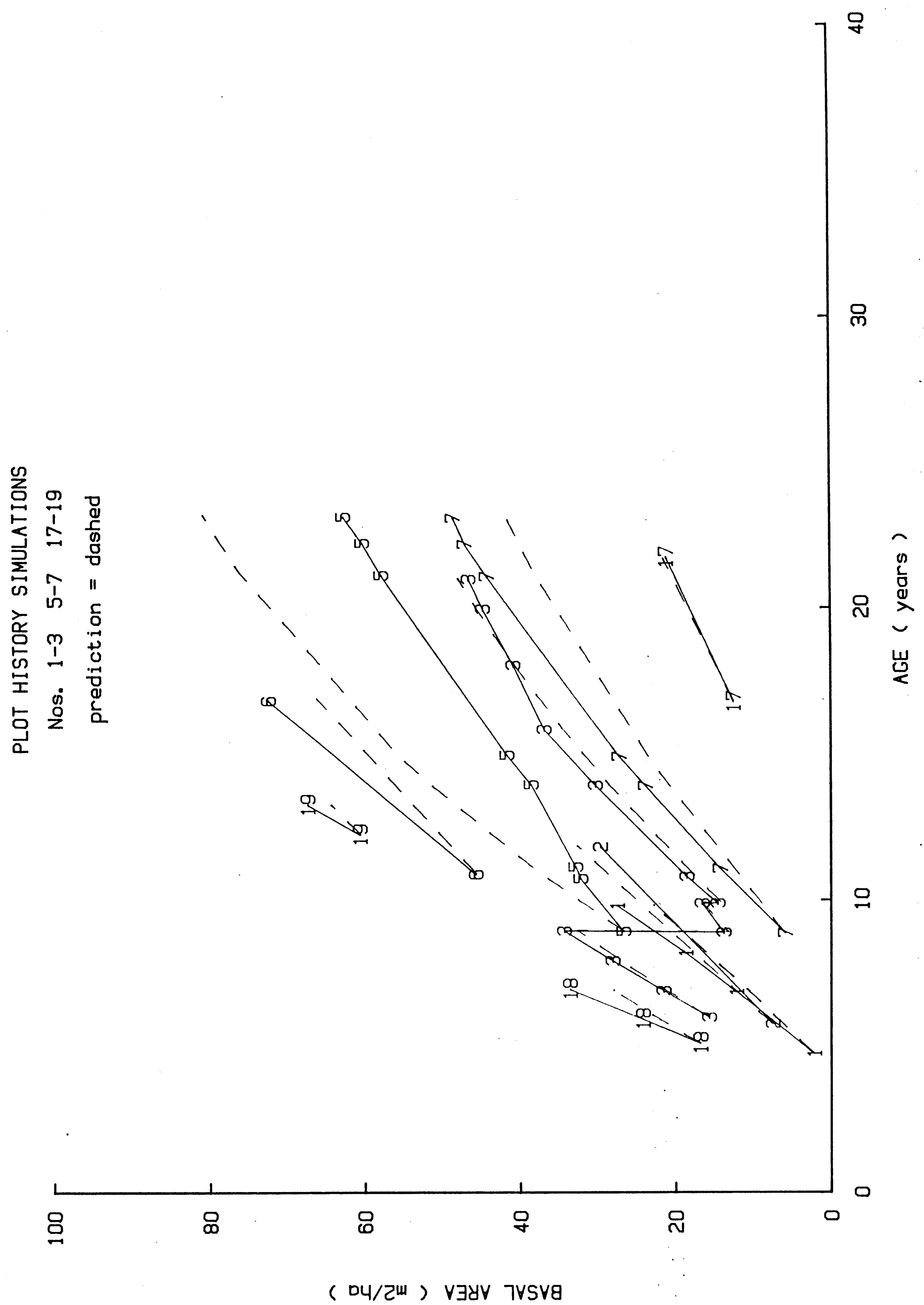

Figure 11. Plot history simulations, part 1 of 4.

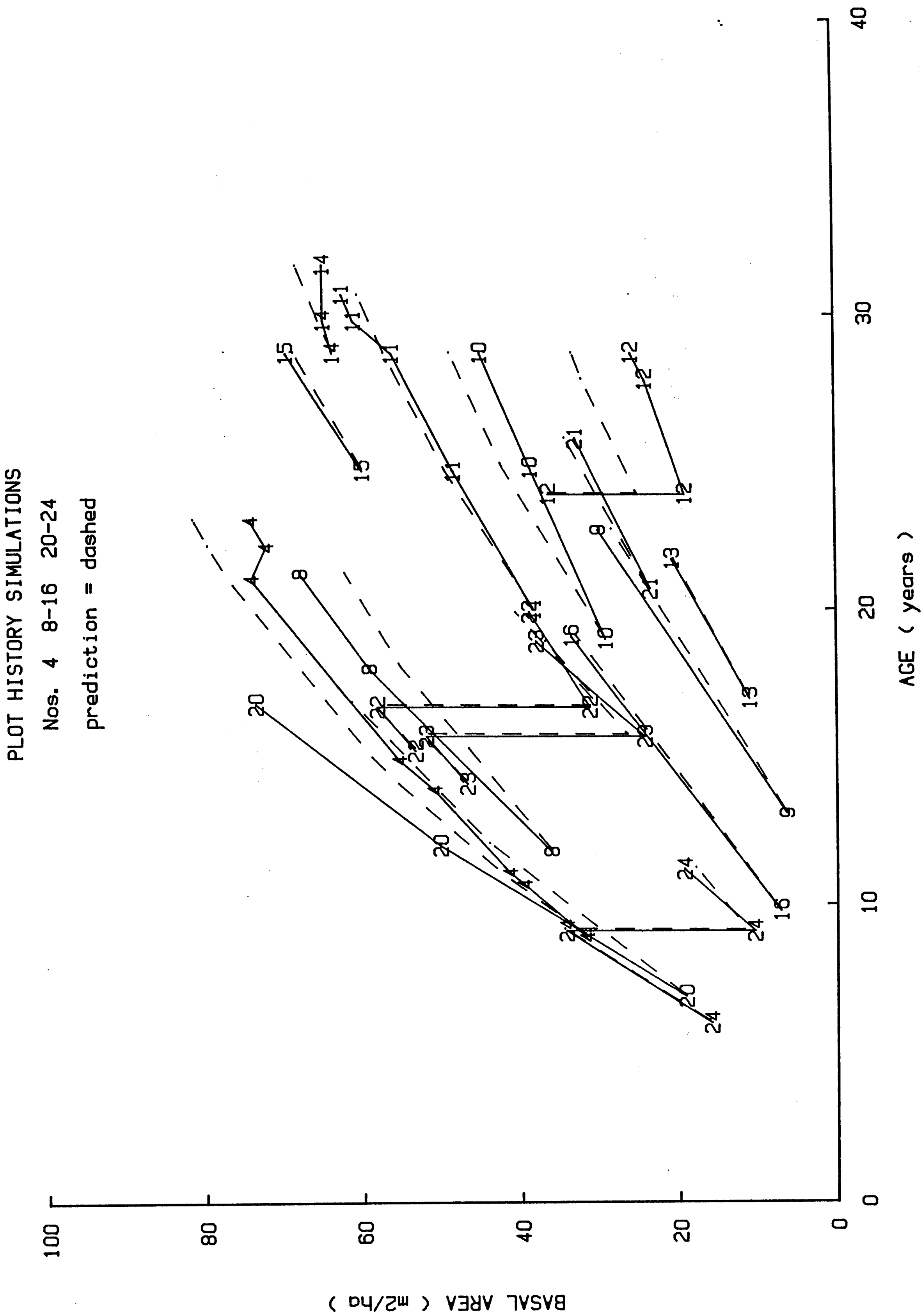

Figure 12. Plot history simulations, part 2 of 4.

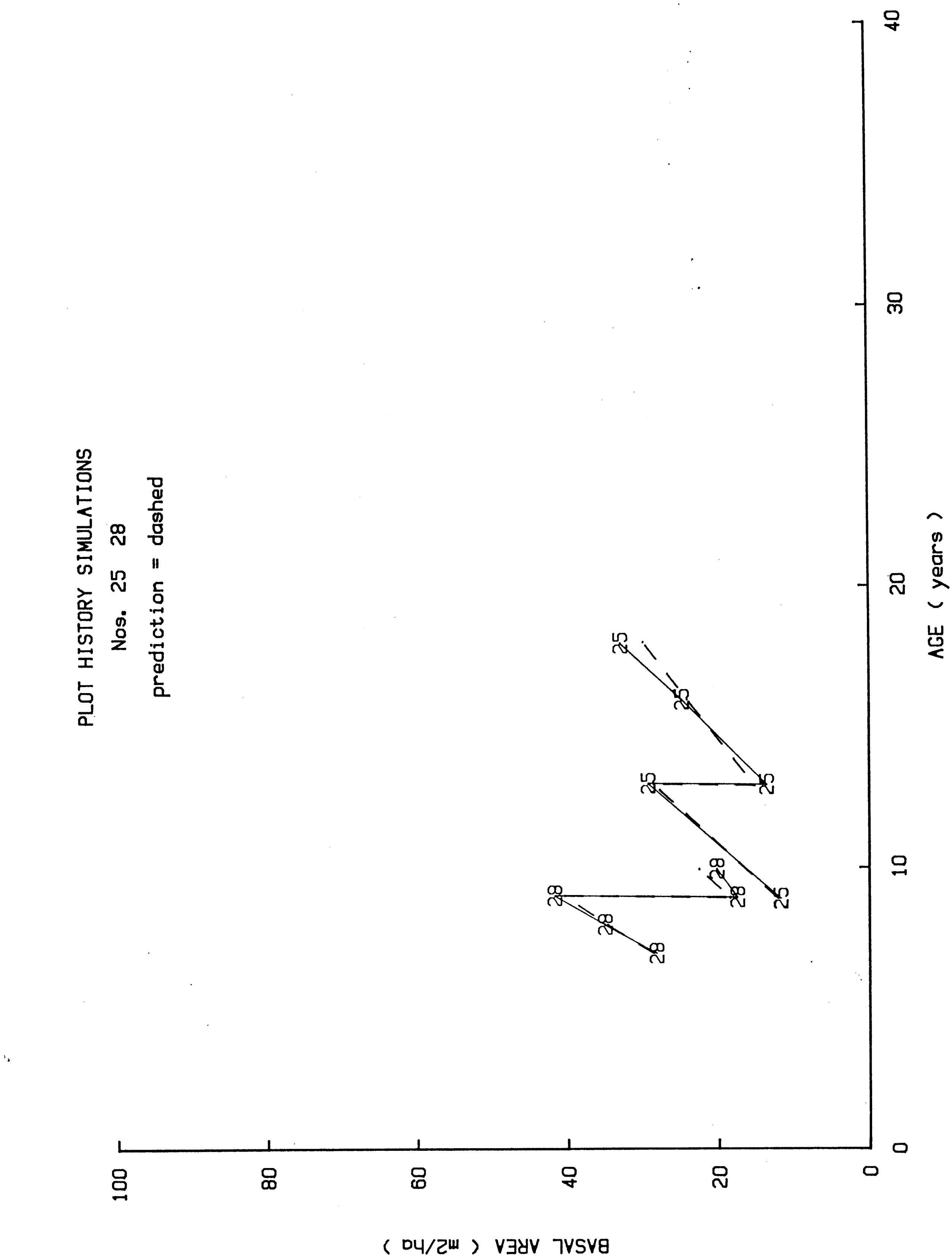

Figure 13. Plot history simulations, part 3 of 4.

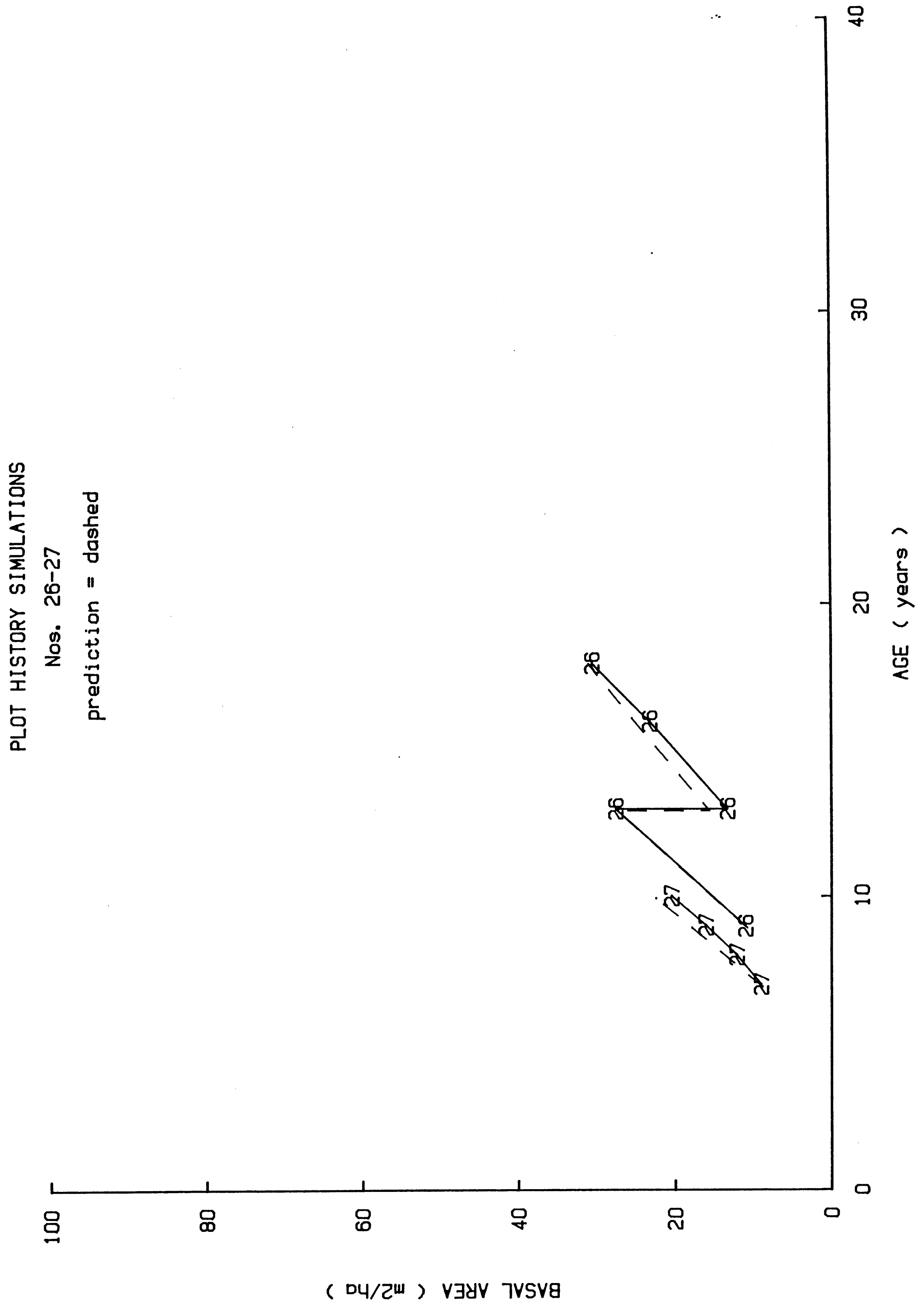

Figure 14. Plot history simulations, part 4 of 4.

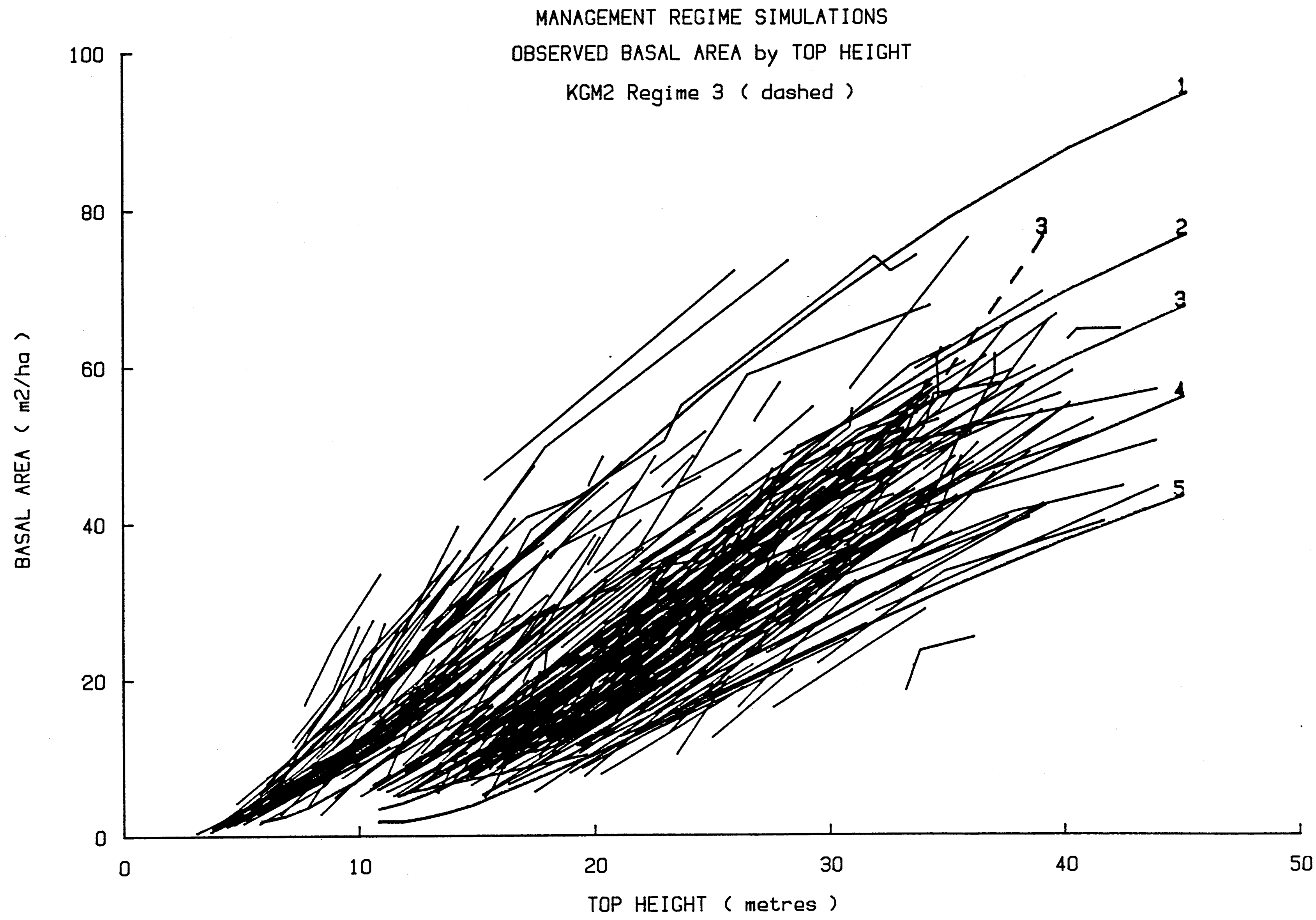

Figure 15. Management regime simulations -- basal area by top height.

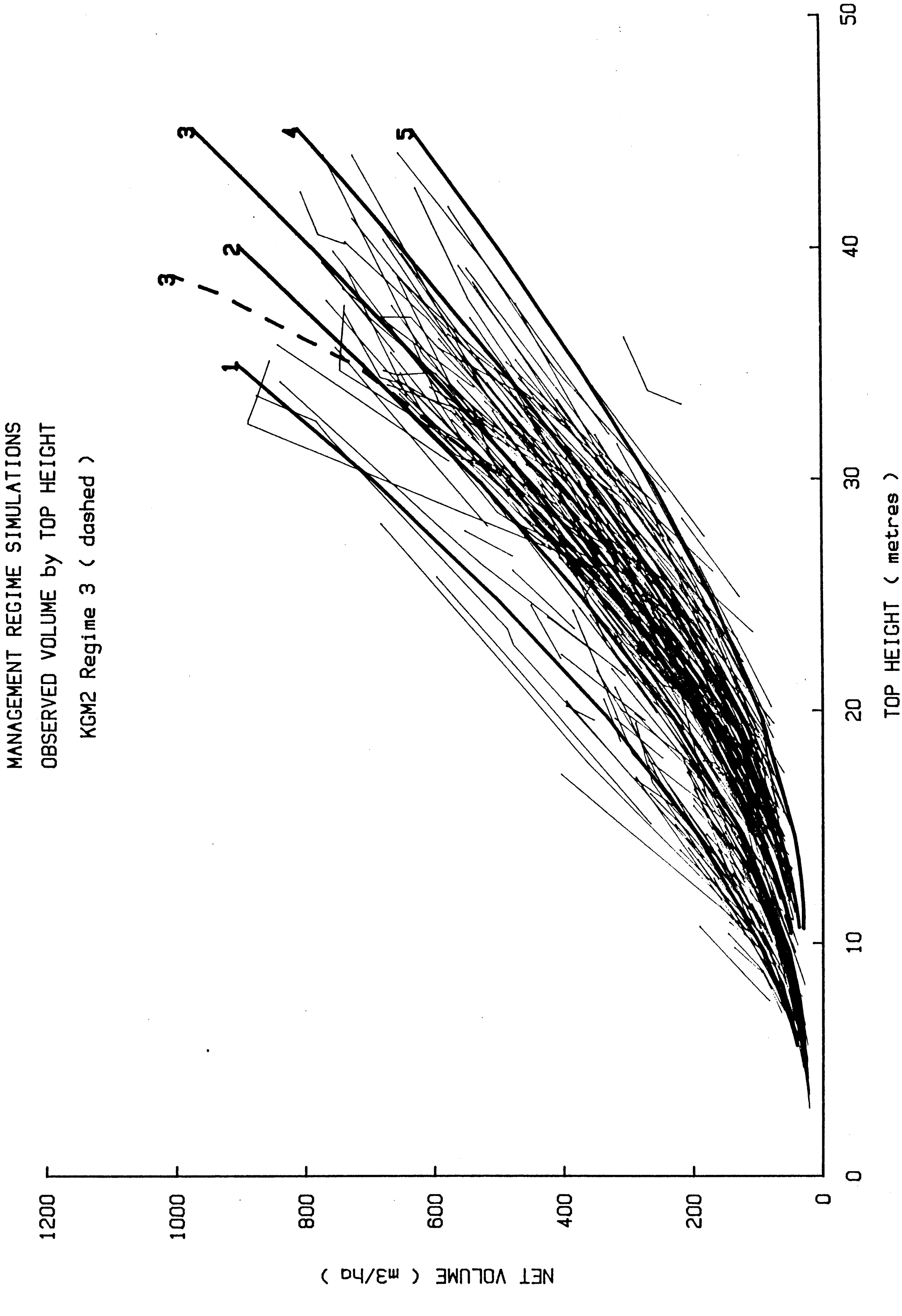

Figure 16. Management regime simulations -- volume by top height.

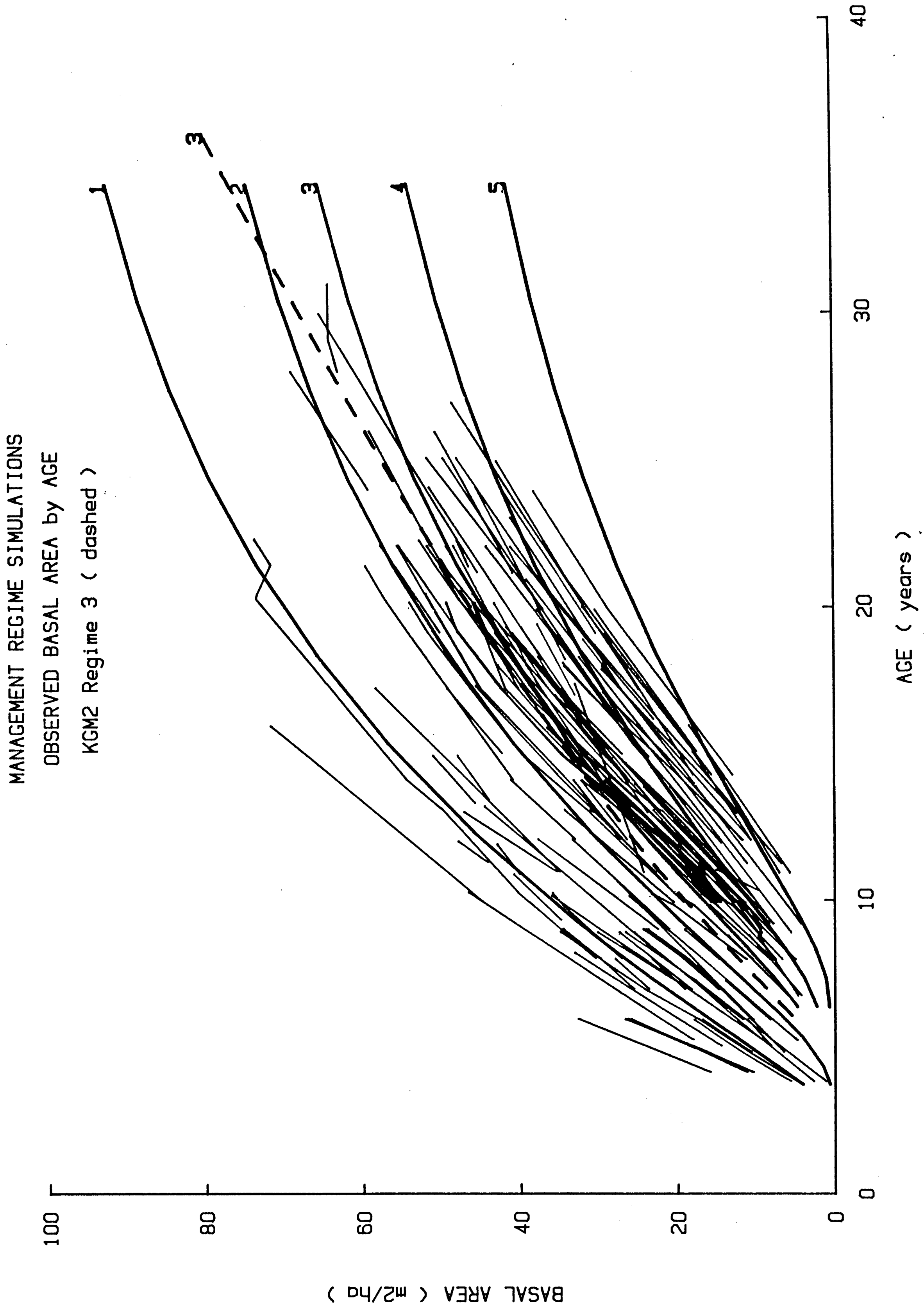

Figure 17. Management regime simulations -- basal area by age.

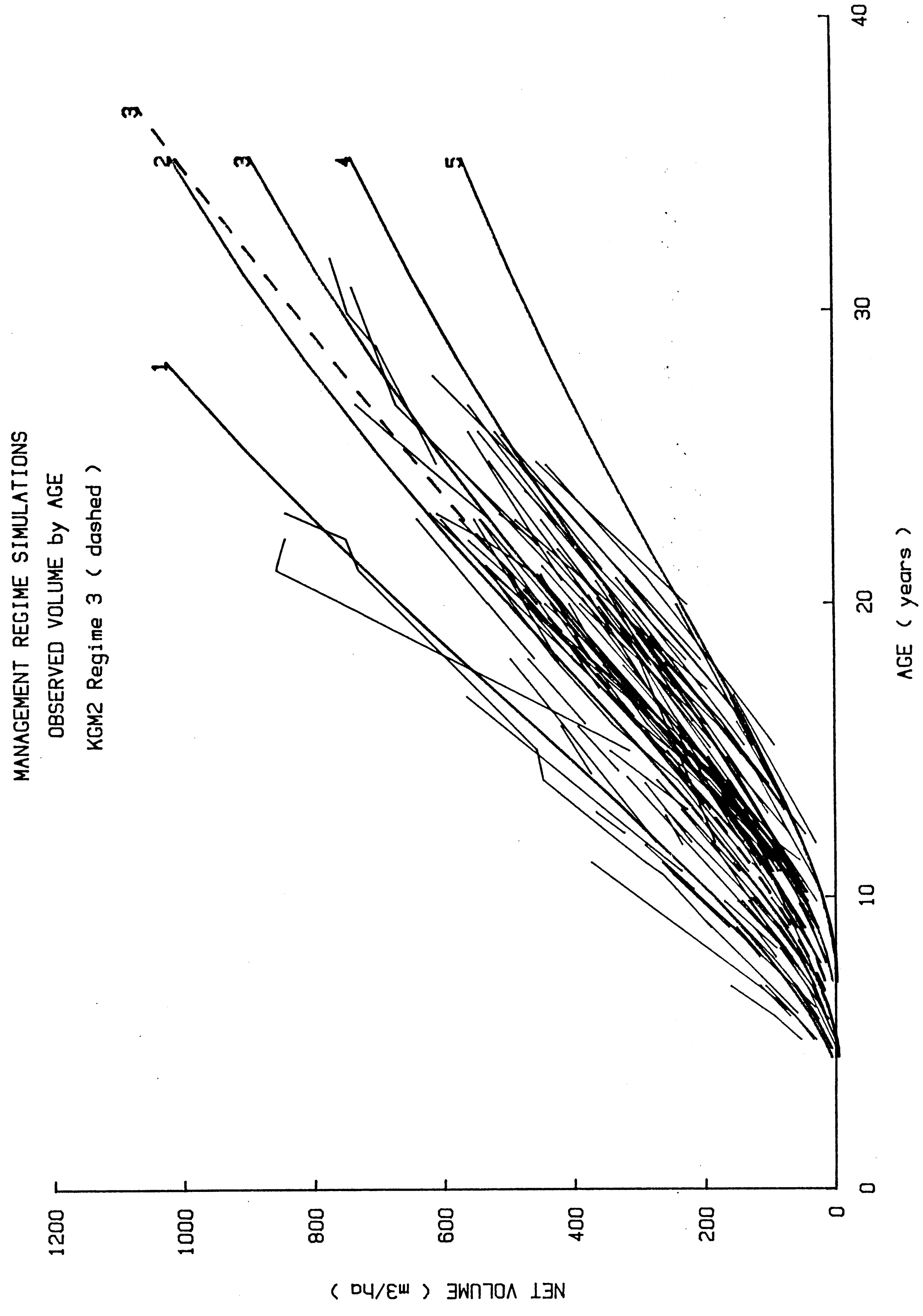

Figure 18. Management regime simulations -- volume by age.

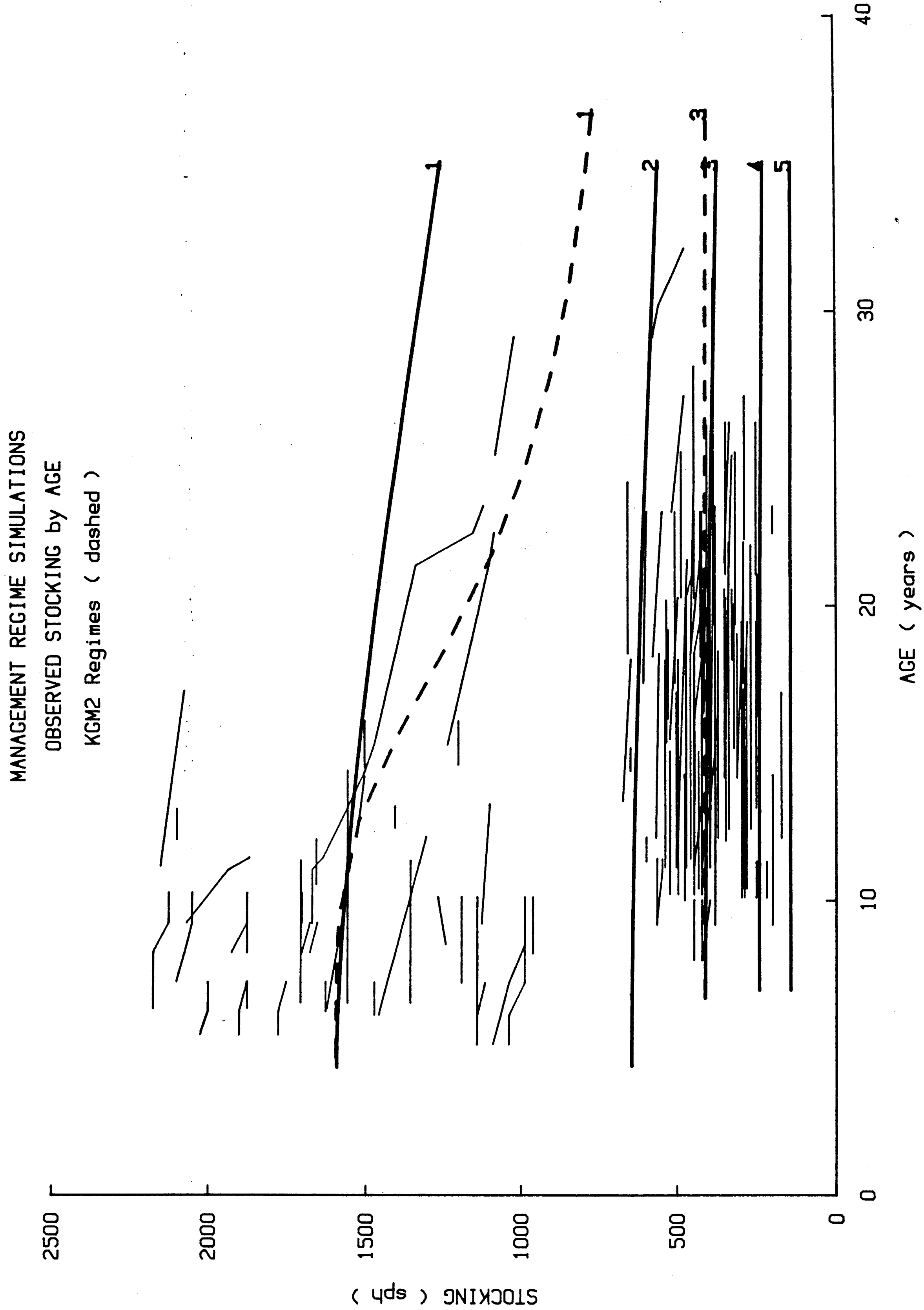

Figure 19. Management regime simulations -- stocking by age.

Table 14: Comparison of stand volume at age 30 from 5 regimes for the 'Clays' and KGM2 models

REGIME*	NET VOLUME FOR SITE INDEX = 30m	
	KGM2 (m^3)	CLAYS (% change from KGM2)
1	866m^3	+27
2	877	0
3	836	- 8
4	752	-17
5	693	-31

* 1. Plant 1540 stems/ha without management, clearfell at age 30.

2. As in 1, but thin at mean top height (MTH) 6m to 600 stems/ha.

3. As in 2, but perform a second thinning at MTH 11m to 370 stems/ha.

4. As in 3, but thin at MTH 11m to 200 stems/ha.

5. As in 3, but thin at MTH 11m to 100 stems/ha.

For both basal area (Figure 15) and volume (Figure 16) by top height, the 'clays' model does well to approximate the growth and yield trends in the data. In comparison, KGM2's prediction of basal area for regime 3 begins slightly higher than the 'clays', meets at about 25 metres top height, then, rises sharply continuously ascending, well above the 'clays' curve and away from the trend of the data. For volume, KGM2's prediction for regime 3 is slightly higher than the 'clays' up until about 25 metres top height; then rises, crossing the 'clays' regime 2 curve at about 32 metres top height, well away from the trend of the data.

With respect to age and basal area (Figure 17), the 'clays' curves are reasonable for regimes 1 - 3, however for regimes 4 - 5 (heavy thinning), the 'clays' curves flatten out relative to the data, particularly after age 12. For regime 3, KGM2's curve is slightly above the 'clays' curve up to age 20, after which the KGM2 curve continues to ascend, intersecting the 'clays' regime 2 curve at about age 32 (without any suggestion of flattening out).

With respect to age and volume (Figure 18), the trend of the 'clays' curves are similar to that experienced in the basal area curves. For regime 3, the KGM2 curve is midway between the 'clays' regime 2 and 3 up until age 28, after which the KGM2 curve continues to ascend approaching the 'clays' regime 2 curve at age 35 (without any suggestion of flattening out).

Stocking trends (mortality) in the data, and for 'clays' regimes 1 - 5 and KGM2 regimes 1 and 3 are presented in Figure 19. For regime 1 (unthinned), 'clays' and KGM2 exhibit vastly different curves beyond age 12. 'Clays' maintains a relatively high stocking level to age 35, while KGM2 predicts a significant drop in stocking to age 25, followed by a flattening trend to age 38. Due to a lack of data from plots with high initial stocking and measurements carried beyond age 15, it is difficult to judge the relative accuracy of either model. For regimes 2 - 5, both models predict similar stocking trends to age 35.

Table 14 provides a comparison of stand volume at age 30 from the 5 regimes for the 'clays' and KGM2 models. The comparative trend exhibited is for KGM2 to under-predict volume of unmanaged stands, while over-predicting volume in greater degrees with respect to increases in management intensity.

6.0 DISCUSSION

The objective of this report was to document the construction and evaluate the performance of the 'clays' growth model. This objective has been met, however the degree to which the performance of the model has been evaluated is less than optimum. A more in-depth evaluation of the model's performance is easily the subject of a stand-alone future report. The intent, herein was to touch on the models performance, knowing full-well that the 'draft' release of the model would generate rigorous 'performance testing' by the users. The author's intention is to collate information from the users to supplement future performance reports on the model.

The 'draft' release of the 'clays' model is supported by the view that the model behaves logically and well, and has no inherent deficiencies precluding it's use within the range of stand parameters as described herein.

7.0 ACKNOWLEDGEMENTS

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Mr Alan Thorn for categorising soil types to determine plot inclusion or exclusions;

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Mr Ian Hunter, and Drs Chris Goulding, Oscar Garcia, and Anthony Gilchrist for technical support and encouragement during the project.

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APPENDIX 1. REPRESENTED SOIL TYPES

Waitakere hill soils

Waikere clay and sandy loam (Maharangi friable sandy loam)

Waitakere hill soils

Rangiuru hill soils

Northern brown granular clay

Mangawheau sandy clay loam, sandy loam hill soil

Maramarua fine sandy loam, silty clay loam hill soils

Hamilton clay loam

Marua light brown clay brown loam, Omaiko soil suite

Hukerenui silt loam

Rangiora clay, clay loam, silty clay loam

Waipu clay

Wharekohe silt loam

Waipoua clay

APPENDIX 2: Plots by forest in the height model data-set

Whangapoua Forest

1	4010000100
2	4010000200
3	4010000300
4	4010000400
5	4010000600
6	4010000700
7	4010000800
8	4010000900
9	4010001000
10	4010001100
11	4010001300
12	4010001400
13	4010001600
14	2860100100
15	2860100200
16	2860100400
17	2860100500
18	2860100600
19	2860200100
20	2860200300
21	2860200400
22	2860200500
23	2860200600
24	2860200700
25	2860300100
26	2860300200
27	2860300400
28	2860300500
29	2860300600
30	2860300700
31	3690000399
32	3690000499
33	3690000799
34	3690000899
35	3690001199
36	3690001299
37	3690001400
38	3690001500
39	3690001600
40	3690001700
41	3690001800
42	3690001900
43	3690002000
44	3690002100
45	3690002200

Glenbervie Forest

1	5010100100
2	5010100200
3	5010100300
4	5010100400
5	5010100500
6	5010100600
7	5010100700
8	5010200200
9	5010300400
10	5010300800
11	5010301000
12	5010301200
13	5010301300
14	5010301600
15	5010400200
16	5010400499
17	5010400600
18	5010400999
19	5010401000
20	5010600100
21	5010600200
22	5010600600
23	5010601100
24	5010801000
25	2860400100
26	2860400200
27	2860400300
28	2860400400
29	2860400500
30	2860400600
31	2860400700

Maramarua Forest

1	5690100200
2	5690100300
3	5690100400
4	5690100500
5	5690100700
6	5690100800
7	5690101200
8	5700200100
9	5700200200
10	5700200400
11	5700200500
12	5700200600
13	5700200700
14	5700202300
15	2860500100
16	2860500200
17	2860500300
18	2860500400
19	2860500600
20	2860500700
21	2860500800

Riverhead Forest

1	4390000400
2	4390000700
3	4390000800
4	4390001100
5	7340200104
6	7340200105
7	7340200202
8	7340200206
9	7340200301
10	7340200303

Tairua Forest

1	7340300102
2	7340300104
3	7340300203
4	7340300207
5	7340300303
6	7340300307

Waitangi Forest

1	4820400800

APPENDIX 3: Plots by forest in the basal area/stocking model data-set ('99' series are 'new' plots as a result of area change; 25 plots are 'doubles', 19 plots are 'singles'.

Whangapoua Forest		Maramarua Forest		Glenbervie Forest	
1	4010000100	1	5690100100	1	5010100100
2	4010000200	2	5690100200	2	5010100200
3	4010000299	3	5690100300	3	5010100300
4	4010000300	4	5690100400	4	5010100400
5	4010000400	5	5690100500	5	5010100500
6	4010000600	6	5690100600	6	5010100600
7	4010000700	7	5690100700	7	5010100700
8	4010000800	8	5690100800	8	5010100800
9	4010000900	9	5690100900	9	5010200200
10	4010000999	10	5690101000	10	5010200300
11	4010001000	11	5690101100	11	5010200400
12	4010001100	12	5690101200	12	5010300100
13	4010001300	13	5690101300	13	5010300199
14	4010001400	14	5690101400	14	5010300300
15	4010001600	15	5690101500	15	5010300399
16	5380000100	16	5700200100	16	5010300400
17	5380000200	17	5700200200	17	5010300499
18	5380000400	18	5700200300	18	5010300500
19	2860100100	19	5700200400	19	5010300599
20	2860100200	20	5700200500	20	5010300600
21	2860100400	21	5700200600	21	5010300699
22	2860100500	22	5700200700	22	5010300700
23	2860100600	23	5700201000	23	5010300799
24	2860200100	24	5700201100	24	5010300800
25	2860200300	25	5700201300	25	5010300901
26	2860200400	26	5700201600	26	5010301000
27	2860200500	27	5700201700	27	5010301199
28	2860200600	28	5700202300	28	5010301200
29	2860200700	29	2860500100	29	5010301300
30	2860300100	30	2860500200	30	5010301399
31	2860300200	31	2860500300	31	5010301400
32	2860300400	32	2860500400	32	5010301499
33	2860300500	33	2860500600	33	5010301599
34	2860300600	34	2860500700	34	5010301600
35	2860300700	35	2860500800	35	5010400100
36	3690000399	36	6560000100	36	5010400200
37	3690000499	37	6560000200	37	5010400300
38	3690000599	38	6560000500	38	5010400399
39	3690000699	39	6560001000	39	5010400499
40	3690000799	40	6560001100	40	5010400599
41	3690000899	41	6560001200	41	5010400600
42	3690001199	42	6560001300	42	5010400699
43	3690001299	43	6560001700	43	5010400700
44	3690001300	44	6560002100	44	5010400900
45	3690001400	45	7420000100	45	5010400999
46	3690001500	46	7420000200	46	5010401000
47	3690001600	47	7420000300	47	5010401099
48	3690001700	48	7420000400	48	5010401199
49	3690001800	49	7420000500	49	5010401299
50	3690001900	50	7420000600	50	5010500100
51	3690002000	51	7420000700	51	5010500200
52	3690002100	52	7420000800	52	5010500499
53	3690002200	53	7420001100	53	5010600100
54	3690002300	54	7420001400	54	5010600200
55	3690002400	55	7420002100	55	5010600399
56	3690002500	56	7420002900	56	5010600499
				57	5010600599
				58	5010600600
				59	5010600700
				60	5010600800
				61	5010600999
				62	5010601100
				63	5010701100
				64	5010801000
				65	5010801200
				66	2860400100
				67	2860400200
				68	2860400299
				69	2860400300
				70	2860400399
				71	2860400400
				72	2860400499
				73	2860400500
				74	2860400599
				75	2860400600
				76	2860400699
				77	2860400700
				78	2860400799

APPENDIX 3: Continued

Tairua Forest

1 7340300102
2 7340300104
3 7340300203
4 7340300207
5 7340300303
6 7340300307

Riverhead Forest

1 4390000400
2 4390000700
3 4390000800
4 4390001100
5 7340200104
6 7340200105
7 7340200202
8 7340200206
9 7340200301
10 7340200303

Waipoua Forest

1 7110300700
2 7110300800
3 7110300899
4 7110300900
5 7110301000
6 7110301099
7 7110301100
8 7110301199
9 7110301200
10 7110301299

Waitangi Forest

1 4820300100
2 4820300301
3 4820400100
4 4820400800

Puhi Puhi Forest

1 4580200100
2 4580200300
3 4580200400
4 4580300600
5 4580300700
6 4580301200
7 4580400400
8 4580400499

APPENDIX 4: **Plots by forest in the thinning function analysis.**

Riverhead Forest

1	4390000200
2	4390000300
3	4390000400
4	4390000500
5	4390000600
6	4390000700
7	4390000800
8	4390000900
9	4390001000
10	4390001100
11	2860600100
12	2860600200
13	2860600300
14	2860600400
15	2860600500
16	2860600700
17	2860601000
18	2860601100
19	2860601500
20	2860601600
21	2860601700
22	2860601800
23	2860601900
24	2860602000
25	2860602100
26	2860602200

Glenbervie Forest

1	5010300400
2	5010301200
3	5010301300
4	5010301400
5	5010400100
6	5010400200
7	5010400600
8	5010400900
9	5010401000
10	5010600100
11	5010600501
12	5010600600
13	5010600999
14	5010601100
15	5010801000
16	2860400100
17	2860400200
18	2860400300
19	2860400400
20	2860400500
21	2860400600
22	2860400700

Whangapoua Forest

1	4010000200
2	4010000900
3	2860100100
4	2860100200
5	2860100400
6	2860100500
7	2860200100
8	2860200300
9	2860200500
10	2860200600
11	2860200700
12	2860300100
13	2860300200
14	2860300400
15	2860300500
16	2860300600

Waipoua Forest

1	7110301099
2	7110301199

Waitangi Forest

1	4820300301
2	4820300600
3	4820400100
4	4820400800

Maramarua Forest

1	5700202300
2	2860500100
3	2860500200
4	2860500300
5	2860500400
6	2860500600
7	2860500700
8	2860500800

APPENDIX 5: Plots by forest in the volume/basal area function analysis ('99' series are 'new' plots as a result of area changes; 53 plots are 'doubles'.

Glenbervie Forest

1	5010100100
2	5010100200
3	5010100300
4	5010100400
5	5010100500
6	5010100600
7	5010100700
8	5010100800
9	5010100900
10	5010200200
11	5010200300
12	5010200400
13	5010300100
14	5010300199
15	5010300300
16	5010300399
17	5010300400
18	5010300499
19	5010300500
20	5010300599
21	5010300600
22	5010300699
23	5010300700
24	5010300799
25	5010300800
26	5010300901
27	5010301000
28	5010301100
29	5010301199
30	5010301200
31	5010301299
32	5010301300
33	5010301399
34	5010301400
35	5010301499
36	5010301500
37	5010301599
38	5010301600
39	5010400100
40	5010400200
41	5010400299
42	5010400300
43	5010400399
44	5010400400
45	5010400499
46	5010400500
47	5010400599
48	5010400600
49	5010400699
50	5010400700
51	5010400800
52	5010400899
53	5010400900
54	5010400999
55	5010401000
56	5010401099
57	5010401100
58	5010401199
59	5010401200
60	5010401299
61	5010500100
62	5010500200
63	5010500300
64	5010500400
65	5010500499
66	5010600100
67	5010600199
68	5010600200
69	5010600300
70	5010600399
71	5010600400
72	5010600499
73	5010600501
74	5010600599
75	5010600600
76	5010600700
77	5010600799
78	5010600800
79	5010600899
80	5010600900
81	5010600999
82	5010601000
83	5010601099
84	5010601100
85	5010601199
86	5010700199
87	5010700200
88	5010700300
89	5010700400
90	5010700499
91	5010700500
92	5010700600
93	5010700700
94	5010700800
95	5010700900
96	5010701000
97	5010701099
98	5010701100
99	5010701200
100	5010701299
101	5010800200
102	5010800300
103	5010800600
104	5010800700
105	5010800800
106	5010801000
107	5010801200
108	7010000300
109	7010000400
110	7010000600
111	7010001500
112	2860400100
113	2860400200
114	2860400300
115	2860400400
116	2860400500
117	2860400600
118	2860400700

Maramarua Forest

1	5690100100
2	5690100200
3	5690100300
4	5690100400
5	5690100500
6	5690100600
7	5690100700
8	5690100800
9	5690100900
10	5690101000
11	5690101100
12	5690101200
13	5690101300
14	5690101400
15	5690101500
16	5700200100
17	5700200200
18	5700200300
19	5700200400
20	5700200500
21	5700200600
22	5700200700
23	5700201000
24	5700201100
25	5700201200
26	5700201300
27	5700201400
28	5700201500
29	5700201600
30	5700201700
31	5700201800
32	5700201900
33	5700202000
34	5700202100
35	5700202200
36	5700202300
37	2860500100
38	2860500200
39	2860500300
40	2860500400
41	2860500600
42	2860500700
43	2860500800
44	6560000100
45	6560000200
46	6560000400
47	6560000500
48	6560000600
49	6560000700
50	6560000800
51	6560001000
52	6560001100
53	6560001200
54	6560001300
55	6560001700
56	6560002100
57	6560002200
58	6560002300
59	7420000100
60	7420000200
61	7420000300
62	7420000400
63	7420000500
64	7420000600
65	7420000700
66	7420000800
67	7420001100
68	7420001200
69	7420001400
70	7420001700
71	7420002000
72	7420002100
73	7420002300
74	7420002600
75	7420002900

APPENDIX 5: Continued.

Whangapoua Forest	
1	4010000100
2	4010000200
3	4010000300
4	4010000400
5	4010000600
6	4010000700
7	4010000800
8	4010000900
9	4010001000
10	4010001100
11	4010001300
12	4010001400
13	4010001600
14	5380000100
15	5380000200
16	5380000300
17	5380000400
18	2860100100
19	2860100200
20	2860100400
21	2860100500
22	2860100600
23	2860200100
24	2860200300
25	2860200400
26	2860200500
27	2860200600
28	2860200700
29	2860300100
30	2860300200
31	2860300400
32	2860300500
33	2860300600
34	2860300700
35	3690000300
36	3690000399
37	3690000400
38	3690000499
39	3690000500
40	3690000599
41	3690000600
42	3690000699
43	3690000700
44	3690000799
45	3690000800
46	3690000899
47	3690001100
48	3690001199
49	3690001200
50	3690001299
51	3690001300
52	3690001400
53	3690001500
54	3690001600
55	3690001700
56	3690001800
57	3690001900
58	3690002000
59	3690002100
60	3690002200
61	3690002300
62	3690002400
63	3690002500
64	3690002600

Riverhead Forest	
1	4390000200
2	4390000300
3	4390000400
4	4390000500
5	4390000600
6	4390000700
7	4390000800
8	4390000900
9	4390001000
10	4390001100
11	2860600100
12	2860600200
13	2860600300
14	2860600400
15	2860600500
16	2860600700
17	2860601000
18	2860601100
19	2860601500
20	2860601600
21	2860601700
22	2860601800
23	2860601900
24	2860602000
25	2860602100
26	2860602200
27	7340200104
28	7340200105
29	7340200202
30	7340200206
31	7340200301
32	7340200303

Puhi Puhi Forest	
1	4580200100
2	4580200300
3	4580200400
4	4580200500
5	4580200599
6	4580200700
7	4580300200
8	4580300299
9	4580300300
10	4580300400
11	4580300500
12	4580300600
13	4580300700
14	4580301200
15	4580400400
16	4580400499

Waitangi Forest	
1	4820300100
2	4820300199
3	4820300299
4	4820300301
5	4820300500
6	4820300600
7	4820300701
8	4820400100
9	4820400200
10	4820400600
11	4820400700
12	4820400800
13	4820400899

Tairua Forest	
1	7340300102
2	7340300104
3	7340300203
4	7340300207
5	7340300303
6	7340300307

Waipoua Forest	
1	7110300700
2	7110300799
3	7110300800
4	7110300899
5	7110300900
6	7110300999
7	7110301000
8	7110301099
9	7110301100
10	7110301199
11	7110301200
12	7110301299

APPENDIX 6: Plots by forest in the 'young stand' function analysis.

Whangapoua Forest

1	4010000600
2	4010001000
3	4010001100
4	2860100100
5	2860100200
6	2860100400
7	2860100500
8	2860200100
9	2860200300
10	2860200500
11	2860200600
12	2860200700
13	3690000300
14	3690000400
15	3690000500
16	3690000600
17	3690000800
18	3690001100

Glenbervie Forest

1	5010300400
2	5010301300
3	5010301400
4	5010400100
5	5010400200
6	5010400300
7	5010400500
8	5010400600
9	5010400900
10	5010401000
11	5010500100
12	5010500300
13	5010600100
14	5010600200
15	5010600400
16	5010600501
17	5010600600
18	5010600800
19	5010601000
20	5010601100
21	5010700200
22	5010700300
23	7010000300
24	7010001500
25	2860400200
26	2860400300
27	2860400400
28	2860400500
29	2860400600
30	2860400700

Riverhead Forest

1	4390000300
2	4390000400
3	4390000500
4	4390000800
5	4390001000
6	4390001100
7	7340200105
8	7340200301
9	7340200303

Puhi Puhi Forest

1	4580200700
2	4580300200
3	4580300300
4	4580300500
5	4580300600
6	4580300700
7	4580400400

Appendix 7: Height Model - Log-likelihood values and parameter estimates

Version No.	Log Likeli- hood	Parameters**							
		a	b	c	σ_o	σ	σ_m	TO	HOC
1*	532.1	6.05	0.41(L)	0.91	0	-0.2E-42	0.08	0	-0.33
2	530.1	3.19(L)	0.12	0.95	0	0	0.09	0	-0.37
3	524.7	5.61	0.49(L)	0.80	0	-0.4E-7	0.08	0.09	0
4	523.1	5.20	0.59(L)	0.67	0	-0.6E-7	0.07	0	0
5	519.5	3.00(L)	0.19	0.68	0	-0.1E-55	0.07	0	0
6	511.2	7.11(L)	0.29	1.04	0	0.2E-47	0.10	0.19	0

*Selected as 'best'

** a = height asymptote/10 (m), [y-axis]
b = growth rate, [x-axis]
c = curve shape
σ_o = environmental variation at first observation.
σ = environmental variation at subsequent observations
σ_m = measurement error
TO = age at height zero
HOC = height at age zero **c
(L) = local parameter

Appendix 8: Basal area/stocking model 'T58' - parameter estimates for basal area (m^2/ha), stocking (stems/hectare) and height (m)

b:	=	6.16874
		0
		5.19314
		27.17421
a:	=	0
		0.78093
		42.72038
		1
lambda:=		-1.31629
		-1.35978E-2
		-1
		-27.17421

C:	=	0.43403	-0.04898	0.52361	-0.09195
		0	-0.37861	0	0
		0	0	0.91521	0
		0	0	0	-0.50286
A:	=	-1.3	-86.86113	0.16258	-47.48677
		2.06061	0	0	0
		0	0	-1	0
		0	0	0	-27.17421
P:	=	1	65.98940	-0.51402	-1.83645
		1.56547E-4	1	2.58022E-5	-2.73702E-4
		0	0	1	0
		0	0	0	1

Appendix 9. Thinning Function - residual mean squares and parameter estimates for basal area after thinning (m^2/ha)

Function	Residual Mean Square	Parameter estimates			
		a	b	c	d
1	2.39806	5.238	0.135	-0.082	0.665
2	2.39990	2.712	0	-0.011	-0.456
3	2.38434	2.732	0.060	0	-0.549
4	2.80376	0.914	-0.168	0.031	0
5*	2.37182	2.510	0	0	-0.455
6	3.25213	0.969	0	-0.060	0
7	2.80193	1.153	-0.176	0	0
8	3.18664	0.655	0	0	0

*Selected

Appendix 10: Plots included in the plot history simulations

Simulation No.	Plot No.
1	7340200104
2	4820400100
3	2860200500
4	4010001000
5	4010000600
6	4580300600
7	4010001600
8	3690000399
9	5700201300
10	5690100400
11	5010100200
12	5010100100
13	5700201600
14	5010100300
15	5010200300
16	3690001300
17	5700201700
18	2860400700
19	5010600600
20	5010600200
21	5010300599
22	5010300400
23	5010301300
24	5010801000
25	2860500100
26	2860500600
27	2860100500
28	2860200300

Appendix 11. Plot history simulations - stand parameters.

No	Forest	SI (m)	INITIAL AND FINAL STAND PARAMETERS Age (yrs)	Top Height (m)	Basal Area (m^2/ha)	Stocking (SPH)	THINNING HEIGHT 1	HEIGHT 2	RATIO 1	RATIO 2
1	RVHD	30.6	4.9 - 9.9	4.9 - 15.8	2.5 - 27.7	1125 - 1115	-			-
2	WAIT	24.1	5.9 - 11.9	6.0 - 18.2	7.8 - 29.9	1436 - 1415	-			-
3	WHAP	33.5	6.1 - 21.0	10.1 - 32.9	15.9 - 46.8	1654 - 346	15.6	17.3	0.410	0.882
4	WHAP	32.0	9.0 - 23.1	15.8 - 33.5	31.4 - 74.2	1647 - 1104	-			-
5	WHAP	34.0	9.0 - 23.1	16.4 - 35.0	26.8 - 62.7	1730 - 1054	-			-
6	PUHI	27.7	10.9 - 16.8	15.2 - 25.7	45.7 - 72.3	2125 - 2050	-			-
7	WHAP	30.9	9.0 - 23.1	15.6 - 33.2	6.3 - 48.8	198 - 198	-			-
8	WHAP	32.8	11.9 - 21.3	21.5 - 34.1	35.9 - 67.9	563 - 543	-			-
9	MARM	25.7	13.2 - 22.8	17.4 - 29.3	6.1 - 30.0	267 - 257	-			-
10	MARM	35.2	19.1 - 28.8	31.9 - 43.9	29.0 - 44.9	227 - 208	-			-
11	GLBV	27.5	20.1 - 30.8	26.8 - 34.6	38.2 - 62.5	573 - 524	-			-
12	GLBV	28.9	24.0 - 28.8	33.2 - 36.1	19.0 - 25.8	119 - 119	33.2		0.524	-
13	MARM	25.2	17.1 - 21.8	23.4 - 25.6	10.8 - 20.7	160 - 140	-			-
14	GLBV	32.3	28.8 - 31.8	40.0 - 42.2	63.7 - 65.0	573 - 474	-			-
15	GLBV	29.5	24.8 - 28.8	33.5 - 38.9	59.9 - 69.7	1067 - 1008	-			-
16	WHAN	28.8	9.9 - 19.2	14.7 - 29.6	6.9 - 33.4	296 - 296	-			-
17	MARM	27.5	16.9 - 21.8	24.9 - 28.3	13.0 - 21.5	100 - 100	-			-
18	GLBV	33.2	5.2 - 7.0	7.6 - 10.8	17.0 - 33.7	2000 - 1975	-			-

Appendix 11 (continued)

No	Forest	SI (m)	INITIAL AND FINAL STAND PARAMETERS Age (yrs)	Top Height (m)	Basal Area (m^2/ha)	Stocking (SPH)	THINNING HEIGHT 1	HEIGHT 2	RATIO 1	RATIO 2
19	GLBV	33.2	12.2 - 13.2	20.8 - 21.5	60.6 - 67.3	2030 - 2030	-			
20	GLBV	32.0	7.0 - 16.9	10.6 - 28.0	18.9 - 73.5	1535 - 1287	-			
21	GLBV	25.4	20.8 - 25.9	25.3 - 31.0	23.4 - 32.9	317 - 300	19.9		0.536	
22	GLBV	33.9	15.3 - 20.0	26.6 - 32.6	53.2 - 38.8	1210 - 346	27.7		0.534	
23	GLBV	32.1	14.2 - 19.0	22.2 - 30.5	46.6 - 37.9	1481 - 444	24.5		0.464	
24	GLBV	33.7	6.1 - 11.3	10.8 - 19.4	15.7 - 19.2	1600 - 300	15.3		0.299	
25	MARM	29.9	9.0 - 18.0	12.6 - 26.2	10.9 - 32.2	1160 - 420	18.1		0.452	
26	MARM	30.2	9.0 - 18.9	13.1 - 26.9	10.8 - 33.5	1062 - 444	19.0		0.478	
27	WHAN	31.6	7.0 - 10.0	8.7 - 14.7	8.8 - 20.3	1704 - 1679				
28	WHAN	34.4	7.0 - 10.0	13.1 - 18.6	27.3 - 19.4	1728 - 519	16.7		0.409	