DOUGLAS FIR CENTRAL NORTH ISLAND GROWTH MODEL

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Executive Summary

DFCNIGM2 is a compatible growth and yield model developed by Mr Liu Xu at the University of Canterbury for simulating growth and yield of even-aged stands of Douglas Fir growing in the Central North Island of New Zealand. The data consist of over 2500 plot measurements from 244 permanent sample plots located in Kaingaroa, Whakarewarewa, Waimihia, Whirinaki, Horohoro, Karioi and Pureora forests. A wide range of ages (10 to 90 years), stockings (200 to 7000/ha), altitudes (200 to more than 900 m) and thinning histories (up to 3) was available for analysis.

Preliminary investigations indicated that growth and yield trends should be characterised individually for three localities (Whakarewarewa, Karioi and Kaingaroa + the rest), two levels of <u>Phaeocryptopus</u> infection (diseased or not) and two thinning histories (thinned or not), but that there was no justification for differentiating groups on the basis of altitude nor of initial stocking. As the disease is well established throughout the Central North Island, the branch specifying no disease should be interpreted only as a guide to what growth potential was and could be. It should not be used for today's forecasting.

Each branch through the model has a specific set of equations for:

net basal area/ha on age;

total stem volume/ha in terms of height and basal area;

merchantable volume/ha in terms of total stem volume; except for mortality and mean top height, equations are the same for all branches.

From inputs to an IBM compatible personal computer of starting age, mean top height (or site index), basal area/ha, stems/ha and indices of thinning and disease histories, growth simulations with or without further thinning can be conducted. At any age (but preferably between 15 and 70 years) reliable forecasts of mean top height, stocking, basal area/ha, mean dbhob, total stem volume/ha and merchantable volume/ha can be output on the screen and the printer. Separate estimates are provided for thinning removals and main crop residuals for any specified age of thinning.

The individual equations take the following form

Top Height :

$$h_{100,2} = h_{100,1}((1-\exp(-\alpha T_2))/(1-\exp(-\alpha T_1)))^{\beta}$$

Basal Area:

(a) unthinned stands

$$G_2 = 1/((1/G_1)(T_1/T_2)^{\beta} + \alpha(1-(T_1/T_2)^{\beta}))$$

(b) thinned Stands

$$G_2 = 1/((1/G_1)(T_1/T_2)^{\Gamma} + \alpha(1-(T_1/T_2)^{\Gamma}) + \beta X(1-(T_1/T_2)^{\Gamma}))$$

(c) after a thinning specified in stems/ha removed

$$G = \alpha G_o^{\beta}(1-(1-N/N_o)^{\Gamma})^{\delta}$$

Total Stem Volume:

(a) diseased Stands, thinned

$$V_t = \alpha+\beta G+\Gamma h_{100}+\delta G h_{100}$$

(b) diseased, unthinned stands

$$V_t = \beta G+\Gamma h_{100}+\delta G h_{100}$$

(c) no disease

$$V_t = \alpha+\delta G h_{100}$$

Merchantable Volume:

$$V_m = \alpha V_t^{\beta}\exp(-\Gamma(15/d_g^{\delta}))$$

Mortality:

$$N_2 = N_1(T_1/T_2)^{\beta(T2-T1)(\alpha\Delta G+\Gamma S)}\exp((T2-T1)(\alpha\Delta G+\Gamma S))$$

Where, in the standard IUFRO notation,

$h_{100,i}$: mean top height at age T_i ($i > 0$);
T_i: stand age;
G_i: basal area/ha at age T_i ($_i > 0$);
G_o: basal area/ha before thinning;
ΔG: periodic mean annual increment in basal area/ha;
N_i: stems/ha at age T_i ($_i > 0$);
V_t: total stem volume/ha;
V_m: merchantable volume/ha to 15 cm top;
α, β, Γ, δ are parameters estimated by non-linear least squares or weighted least squares (PROC NLIN or PROC REG in the SAS package).

Site index, mean top height at age 40 years for Douglas Fir, can be derived from setting T_1 = 40 years in the first equation. All of the residuals lie within ± 2 m, only one equation for all kinds of stands being needed. This analysis confirms the good estimation of the Burkhart and Tennent equations for Douglas Fir, but the one developed here is to be preferred because, in addition to being a good fit, it allows site index to be derived explicitly and more easily.

The various basal area/ha equations are also very reliable, being unbiased and with all of the residuals lying within ± 2 m^2/ha for thinned stands and ± 3 m^2/ha for unthinned stands. For estimating basal area after thinning with a stems/ha removal, 95 per cent of the predictions lie within ± 5 m^2/ha. Thinnings should therefore be specified preferably in terms of basal area/ha removed.

The total stem volume equation has nearly all its residuals within ± 20 m^3/ha for diseased, thinned stands; ± 40 m^3/ha for diseased, unthinned stands; and ± 30 m^3/ha for undiseased stands. The merchantable volume equation has most of its residuals within ± 23, 44 and 33 m^3/ha for diseased thinned, diseased unthinned and undiseased stand respectively.

Thus, DFCNIGM2, produces accurate and precise yield forecasts for each of the types of Douglas Fir stand in the Central North Island on an IBM PC compatible using the same sorts of inputs as FRI radiata pine growth models.

contents

Chapter 1. Introduction

This report describes the background to, and the nature, running and reliability of a set of growth and yield models for Douglas fir in the Central North Island. Douglas Fir (Pseudotsuga menziesii (Mirbel) Franco) plantations occupy 63 130 hectares of New Zealand's landscape (More than 27 000 ha occur in the study region), making up the second largest portion of exotic forest estate in this country. It has good timber qualities (Hellawell, 1978) or at least as good as those of radiata pine (James and Bunn, 1978). Yet much less research has been done on this species compared with Pinus radiata. The main reason for this might be that it is infected by Phaeocryptopus gaeumannii (Hood and Kershaw, 1975), an ascomycetous fungus that parasitises needles of Douglas Fir and subsequently reduces its growth rate (Beekhuis, 1978). However, as large amounts of resource exist and new plantings are still being added to it each year, it would be unwise not to recognise the importance of the management of this species. Sound forest management decision making has always depended on accurate growth and yield forecasts. Thus, development of computerised growth and yield models for Douglas fir is essential for good future management of a major part of New Zealand's plantation resource

Mountfort (1978) developed a growth and yield model for Douglas Fir plantations in Kaingaroa forest, but it had several theoretical and practical deficiencies and so an updated new model is needed.

Data used in the study come from the forests of Kaingaroa, Whakarewarewa, Waimihia, Whirinaki, Horohoro, Karioi and Pureora, but data only from Kaingaroa, Waimihia, Pureora and Whirinaki forests were used in the main modelling. Data from other forests had too great variations to be included in the current model and the number of measurements was too small to allow separate models to be developed.

Data were divided into classes according to factors that could influence the growth of the stand; for example, locality, thinning, disease infection, stocking level, etc. The grouping was done subjectively and then further checked by analysis of variance and comparing the coefficients for the fitted equations in each class. Those class attributes which were not significantly different from each other were then combined.

For each group described above, several linear and non_linear equations were fitted using SAS. The error mean squares, $S^2_{x.y}$, the coefficient of determination, R^2 , and residual patterns of those fitted equations were compared to choose equations that gave the best fit. In addition, the fitted equations were also evaluated for separate biological categories; and the goodness of fit of the equations was further judged by univariate analysis and extremes and mean of the residuals. The final groupings were: diseased thinned stands, diseased unthinned stands and undiseased stands. Each group has its own basal area equation to project future basal area/ha, a stand volume equation to convert projected basal area/ha and mean top height to volume/ha, a merchantable volume

/ha equation which gives future merchantable volume as a proportion of total volume. All three, however, share the same mortality and mean top height equations. Quadratic mean diameter of projected stands is calculated from the projected basal area/ha and number of trees/ha in the usual manner.

The fitted equations have been incorporated in a computer program DFCNIGM2, Douglas Fir Central North Island Growth Model version 2, which allows yield projections to be made using an IBM PC compatible.

The inputs needed are site index and/or mean top height at a given starting age, basal area/ha and stocking/ha at that age, together with disease and thinning status. Outputs are mean top height, stocking/ha, basal area/ha, mean dbhob, total stem volume/ha and merchantable volume/ha. Thinning may be conducted in terms of either basal area/ha or number of stems/ha left, but preferably the former. As all stands in the Central North Island are likely to have some infection of _Phaeocryptopus_, the undiseased option should be used only as an indicator of potential and not for preparing yield forecasts in today's environment.

Chapter 2 Data and Data Analysis

2.1. Data

The data were derived from permanent sample plot remeasurements [McEwen (1976)]. Procedures for taking measurements and making data entries are explained in detail in the Rotorua Conservancy PSP Manual and the Permanent Sample Plot Data Entry routines provided by the Forest Research Institute, Rotorua New Zealand (Klitscher,1983).

Table (2.1.1) and (2.1.2) are summaries of the measurements by forests, basal area classes, age classes, initial stocking classes and thinning operations.

Table (2.1.1), a summary of the whole data set used in this study, shows the following.

(1) A total of 244 PSP plots, which results in 2565 observations and 2320 increments (not shown on the table) are available for study.

(2) most of the measurements (75%) come from Kaingaroa forest. The numbers of measurements available in forests of Whakarewarewa, Whirinaki, Horohoro, Karioi and Pureora are 128, 70, 3, 125 and 107 respectively. In terms of increments, the numbers of observations will be even less. They are not sufficiently large to allow separate models to be developed and their exclusion or inclusion in the Kaingaroa group will be judged by not only the sample size but some other factors, such as location, soil types and site quality.

(3) there are only a few measurements for age classes 10 and 80 and so the age range in the data set can be said to be between 15 and 70 years, for all practical purposes;

(4) an adequate range of stocking levels is represented within the data set, particularly for Kaingaroa, Waimihia, Whirinaki and Pureora forests.

Thinning operations are summarized in table (2.1.2). In the data, there are stands left unthinned and thinned up to four times (one plot only). On average the stands were thinned three time between age 25 and 40 with a final stocking of 559, 290 and 225 respectively. Intervals of thinning are 5 years between first and second thinnings and 4 years between second and third thinnings.

Table (2.1.1) Distribuation of plot observations

conser-vancy	forest	No. of plots	age class	basal area class	stems/ha class <200	201-400	401-600	601-800	801-1000	1001-1200	1201-1400	1401-1600	1601-1800	>1800	sum by B.A. class	sum by age class	sum by forest	sum by conser-vancy
RO	WAKA	12	20	20						1			3		4			
				40					1						1	5		
			30	20						3					3			
				40				3	1						4	7		
			40	40		2	2	2							6			
				60			1	3							4	10		
			50	40	3	3									6			
				60		9	6								15			
				100					1	2		1			4	25		
			60	40	9										9			
				60	4	18									22			
				80		1	2								3			
				100					1						1	35		
			70	40	7										7			
				60	15	13									28			
				80		2									2	37		
			80	60	5	3									8	8		
			90	60	1										1	1	128	
	KANG	163	10	20			1	1				2		2	6	6		
			20	20	4	134	37	48	8	8	13	12	1	2	267			
				40		6	15	64	12	26	33	42	1	25	224			
				60							2	1		13	16	507		
			30	20	12	54	12								78			
				40	17	108	66	53	4	16	14	6	4	4	292			
				60			14	31	14	15	18	23	13	34	162			
				80					1	2	3	5	11	5	27	559		
			40	40	7	28	14	1							50			
				60		22	25	7	1			1			56			
				80			6	5	2	4	2	3		1	23			
				100				1	9	9	2				21			
				120						1					1	151		
			50	20	3										3			
				40	26	16									42			
				60	9	90	37	4	4						144			
				80		20	46	13	5	8					92			
				100			4	15	17	6					42			
				120			2	4	6	7					19	342		
			60	40	37	28	3								68			
				60	37	123	7								167			
				80	1	20	22	1							44			
				100				10	5						15			
				120				2							2	296		
			70	40	11	1									12			
				60	7	21									28			
				80		4									4			
				100				1							1	45		
			80			1									1	1	1907	

Table (2.1.1) (cont.) Distribuation of plot observations

conser-vancy	forest	No. of plots	age class	basal area class	stems/ha class <200	201-400	401-600	601-800	801-1000	1001-1200	1201-1400	1401-1600	1601-1800	>1800	sum by B.A. class	sum by age class	sum by forest	sum by conser-vancy
	WAIM	21	20	40				1	2						3			
				60							1				1			
				80									1		1	5		
			30	40		1	3								4			
				60			3	2	2		2				9			
				80						4		1	1		6			
				100							1	1	1		3	22		
			40	40	2	16	3								21			
				60		12	31	2							45			
				80			13	4	2	2	2				23			
				100					7	1	5	4			17	106		
			50	40	11	10									21			
				60	3	22	6								31			
				80		3	17	2							22			
				100			4	1			1				6			
				120							1				1	81		
			60	40	3										3			
				60	1	4									5			
				80		2									2			
				100			1								1	11	225	
	WIRI	9	20	20			1								1			
				40			6								6			
				60										3	3	10		
			30	40			7			3			1		11			
				60			2	2	3			3	3	2	15			
				80			1				1	1	1	11	15	41		
			40	40			2								2			
				60		2	1	6	1						10			
				80				1		2	1		1	2	7	19	70	
	HORO	1	30	20	3										3	3	3	2333
WN	KROI	21	30	40			1								1			
				60			1	2	1	1					5			
				80							1				1			
				100							1				1	8		
			40	40		1									1			
				60		4	1	1	2	3					11			
				80		1		1							2			
				100							1				1			
				120						1	2				3	18		
			50	60	2	2									4			
				80		6	1	3	2						12			
				100		1	5		1						7			
				120			3	2	12	6					23			
				140				4	14	10					28			
				160					1	3					4	78		
			60	100			6								6			
				120			1								1			

Table (2.1.1) (cont.) Distribuation of plot observations

conser- vancy	forest	No. of plots	age class	basal area class	stems/ha class <200	201- 400	401- 600	601- 800	801- 1000	1001- 1200	1201- 1400	1401- 1600	1601- 1800	>1800	sum by B.A. class	sum by age class	sum. by forest	sum by conser- vancy
				140				2	3						5			
				160			1	1	6	1					9	21	125	125
AK	PURE	17	10	20										1	1	1		
			20	20		10	2	7					1		20			
				40						1		2	4	3	10			
				60							1			1	2	32		
			30	20		8	1	1							10			
				40		3	11	4							18			
				60			4	3	3	4	1		3		18			
				80							2	3	1	3	9	55		
			40	40		11	2								13			
				60			1	1							2			
				80					2		1			1	4	19	107	107
sum		244			240	846	464	322	156	150	112	111	48	116	2565	2565	2565	2565
% of total observation:					9.4	33	18.1	12.6	6.1	5.9	4.4	4.3	1.9	4.5				

Table (2.1.2) Summary of thinning operations.

thinnings	0	1st	2nd	3rd	4th
no. of plots	64	133	29	17	1
no. of obs	693	1331	219	72	4
max. N/ha removed	0	2599	1503	336	128
min. N/ha removed	0	25	10	20	128
mean N/ha removed	0	846	269	164	128
mean residual stockings	1150	559	290	225	148
thinning intervals:					
maximum (yrs)		0	11	6	4
minimum (yrs)		0	2	2	
mean (yrs)		0	5	4	

The growth state of the stands, for example average volume/ha, mean dbh and mean top height at a given age, is shown in Table (2.1.3).

Table (2.1.3) Statistics of the stands (n = 2319)

variables	maximum	minimum	mean
age	82	9	35
nett G m^2/ha	158.2	3.3	44.9
nett V m^3/ha	1949.1	11.5	481.1
nett V_m m^3/ha	1861.6	0.6	425.1
dbhob (cm)	66.8	5.8	32.5
h_{100} (m)	46.3	9.0	25.0
Gmai (m^2 ha^{-1} an^{-1}.)	5.6	0.02	1.7
Vmai (m^3/ha an.)	147.5	0.14	24.5
N/ha	4941	44	638
initial N/ha	6944	1376	2509

The table shows that the stands were established in a very high initial stocking level of up to 6944 stems per hectare with a average of 2500 stems/ha. The stands then were left unthinned or thinned up to 4 times to an average stems per hectare varying from 170 to 600 (there is only one plot having 44 stems/ha and because of its luck of replication, it is ignored). When the stands reach an age of 35 years, on average, it will have a diameter of about 33 cm and mean top height of about 25 m and produce a basal area of 45 m^2/ha, volume 481 m^3/ha. Those values may be lower now than the table shows since this data set includes some pre-disease measurements.

2.2 Sources of Variation

The following factors were expected to affect growth and thus had to be accommodated in the model fitting process:

(1) disease infection;
(2) locality;
(3) altitude;

(4) spacing;
(5) thinning;
(6) growth period.

Each factor was thoroughly considered and the results of the analysis reported in the following subsections.

2.2.1. Disease

Douglas fir plantations are infected by needle-cast fungus P. gaeumannii. How to model diseased and undiseased stands became a major component of this study. It was originally proposed that this could be done in one of the following ways:

a. group disease infection into classes and express infection level as a variable in the yield equations;

b. fit separate equations for each distinct group of infection level;

c. derive a disease index and use it in the way described in a and b; or

d. fit yield equations to diseased and healthy data to the extent that time of infection was known to have occurred

Approaches a, b and c needed information about the disease on a plot or individual tree basis; unfortunately it was subsequently found that comprehensive information about the disease is not available and, despite much research, could not be found.

Approach c was tried in this study using 1963 as the threshold for disease occurrence (Manley, 1985) and basal area per hectare as the index of response subject to local divergences. But no obvious improvement resulted, probably because 1963 was a somewhat arbitrary choice; i.e. there were no exact records indicating that 1963 was the time when growth reduction due to disease had occurred in all plots. Even if 1963 were the time when growth reduction first occurred, it would not have occurred in all plots at the same time.

Approach d was adopted in this study. Results show considerable yield difference between diseased and un-diseased stands. From the Auckland region down to Timaru (possibly further) all Douglas Fir plantations in New Zealand have now been infected by the disease (Hood and Kershaw, 1975). Thus the aim of employing this approach was to provide a way for managers and those interested in the management of the plantations, to use local information to best effect.

2.2.2. Locality

Locality was divided into three groups:

a. Whakarewarewa;

b. Karioi;

c. Kaingaroa, Waimihia, Whirinaki and Pureora.

The reasoning behind such grouping is set out below.

The measurements represent 7 forests in the Central North Island of New Zealand. Those forests are Horohoro, Kaingaroa, Karioi, Pureora, Waimihia, Whakarewarewa and Whirinaki.

There were only two observations for Horohoro forest and this group was ignored. So 6 forests were left to consider.

Kaingaroa, Waimihia and Whirinaki were regarded as one group because they are essentially in the same location. This reduced the total number of groups to 4: Kaingaroa, Whakarewarewa, Karioi and Pureora. The question on whether or not observations from these four groups could be combined was then addressed.

Examining a graph of mean top height against age [Fig (2.2.2.1); on the graph, 1 to 7 represent forests of Horohoro, Kaingaroa, Karioi, Pureora, Waimihia, Whakarewarewa and Whirinaki respectively and this will apply to all graphs in this report], it seemed that all the groups can be combined. If mean top height differed markedly among forests, then each forest could form a growth pattern on its own on the graph. Observations of all forests, however, were spread over the graph evenly and no separate pattern was discernible.

Nonlinear regression analysis was also performed on the whole data set using the Chapman-Richards equation, which fitted very well [Fig (2.2.2.2)]. This has the same implication as the graphical analysis above. The Chapman-Richards equation was used since it produced the best fit out of several functional forms tried for this data set.

Next, the same equation form was fitted to each group separately. Table (2.2.2.1) contains statistics of the equation for each group. It can be seen that coefficients for Whakarewarewa and Karioi are different from that of the Kaingaroa group, so Whakarewarewa and Karioi were separated out of the Kaingaroa group.

But, the numbers of measurements available for Whakarewarewa and Karioi are 93 and 100 respectively, which is too small to reflect the intrinsic growth of those forests successfully and to judge their inclusion in the model.

Table (2.2.2.1) coefficients of the height equations

Forest	estimates of α	estimates of β	std error of α	std error of β	msse	n
KANG	0.03532	1.62024	0.00119	0.03802	0.3045	1867
WAKA	0.03122	1.28723	0.00796	0.28756	0.8430	93
KROI	0.01607	1.45898	0.00646	0.22620	0.5461	100
PURE	0.03720	1.51538	0.01052	0.19376	0.7983	81

Pureora is separated geographically from Kaingaroa forest, but coefficients for the equations indicated that these two groups should be combined. If there were sufficiently large numbers of measurements for Pureora forest (a total of 81 measurements is currently available), the conclusion could be different. To some extent, therefore, caution should be exercised when the model is applied to Pureora.

Finally, The above grouping is also suggested by Tennent (pers. comm.)

Although localities were divided into three groups,there were sufficient numbers of observations only for the Kaingaroa group to fit reliable growth and yield equations.

PLOT OF MEAN TOP HEIGHT ON AGE

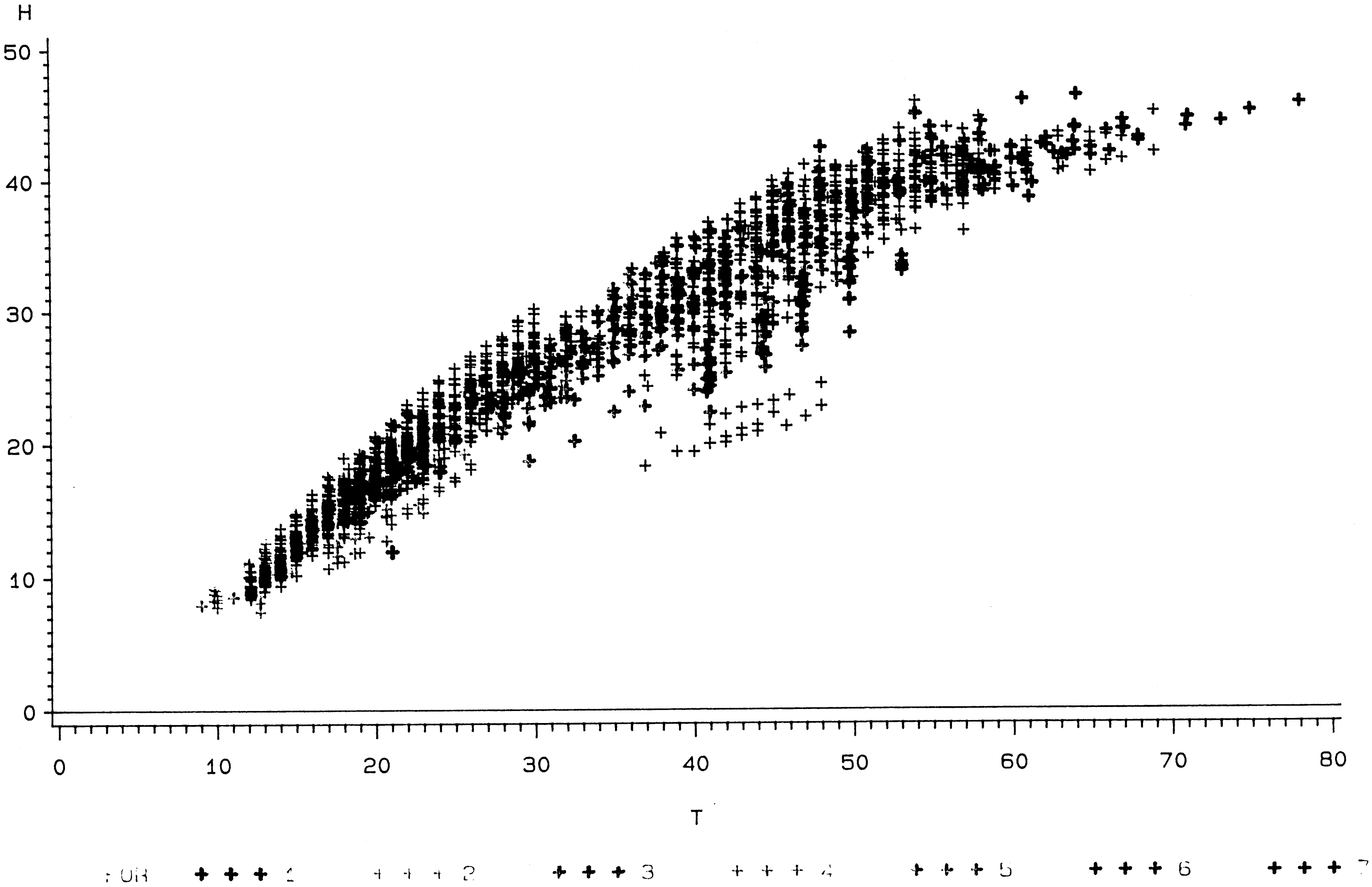

FIG (2.2.2.1): CENTRAL NORTH ISLAND PLANTATIONS

RESIDUAL PLOT OF SITE INDEX EQUATION

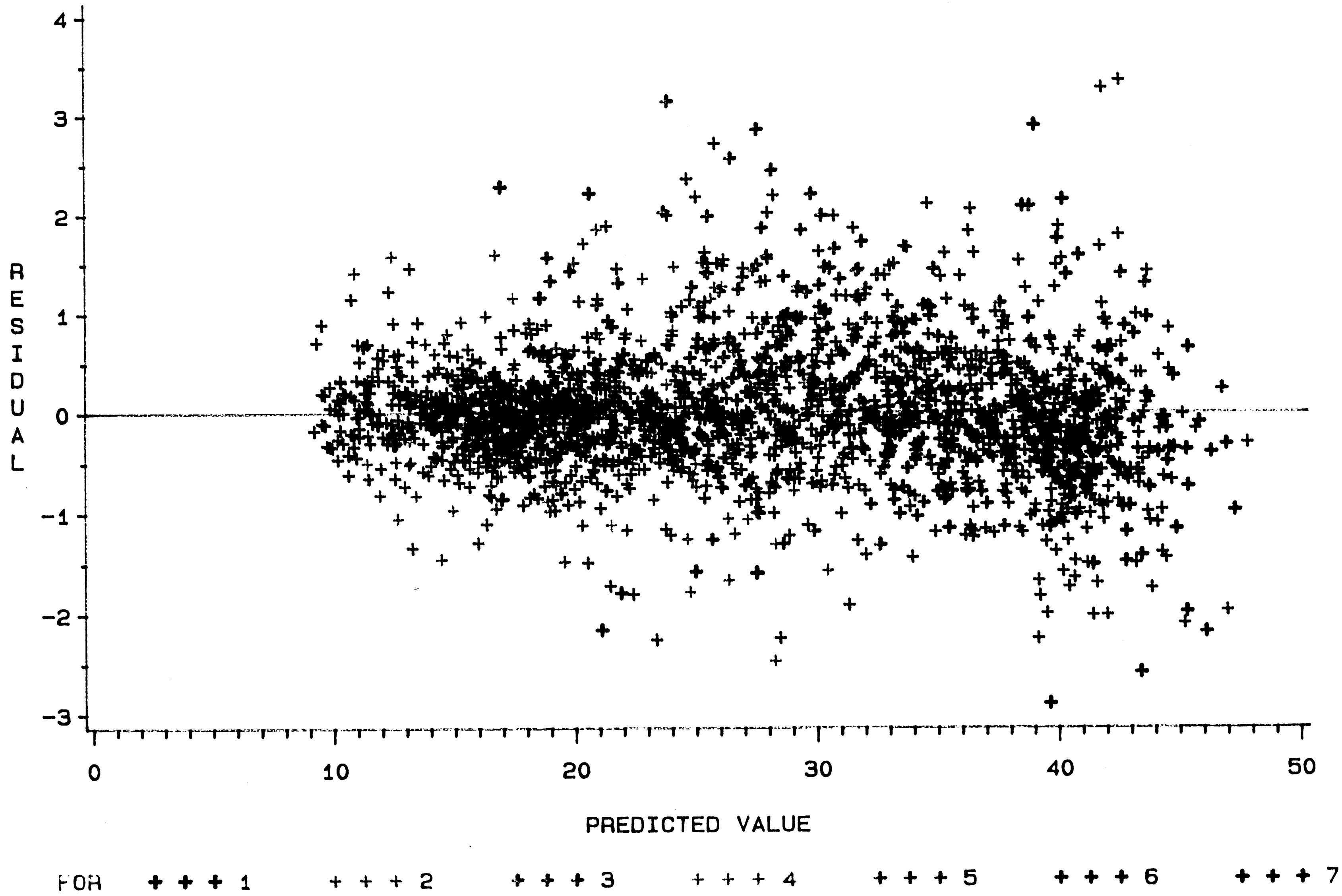

FIG (2.2.2.2): CRNTRAL NORTH ISLAND PLANTATIONS

2.2.3. Altitude

Table (2.2.3.1) provides a distribution of measurements for each forest by altitude class. Most sites (except Kaingaroa) do not have a sufficient number of measurements to cover the range of altitude, and so well defined trends are not clearly discernible.

Woollons (1985) used altitude as an independent variable in site index equation when he revised Clutter and Allison's model (1974). In this study, we have also tried to express altitude as an independent variable in the site index equation. For the Whakarewarewa and Karioi groups, predicted mean top height increases with altitude when altitude is introduced into the site index equation as an independent variable. For the Kaingaroa group, the equation gives logical prediction, i.e. predicted mean top height decreases with altitude. but the residual sum of squares was reduced by only 1.7% (it was not reduced at all when the equation was fitted to the whole data set). Thus, it was concluded that the influence of altitude is not important for the range of altitudes covered by this data set. Ultimately, altitude was not considered in fitting site index equations.

Table (2.2.3.1) Number of measurements by forest and altitude class.

Forest	Number of Measurements Per Altitude Class						
	100	200	300_500	600	700	800	>900
KANG		12	1311	251	95	24	
KROI							104
PURE				39	41	5	
WAIM				44	159		
WAKA			89	17			
WIRI			28				

2.2.4. Spacing

There were six classes of initial spacing in the data set as shown in Table (2.2.4.1). Whether or not there is any difference among initial stocking levels is tested by fitting a basal area equation, in this case the Schumacher equation, to each initial stocking level and the asymptotic standard errors are compared. The Schumacher equation was used because it resulted in very good fit for basal area projection and converged more easily than the Hossfeld equation, which produced a even better fit and was used as the final basal area projection model.

The numbers of observations in classes 2778, 4444 and 6944 were too small to fit separate equations. Classes 2315, 2778 and 3086 can be combined as regression coefficients of these two classes were nearly identical. Thus two main groups were considered: 1736 and 2315 to 3086. Table (2.2.4.2) gives the coefficients for these basal area projection equations fitted for the two groups and for all groups combined. The standard errors of the combined group were reduced compared with that of the two other groups individually. It was, as hoped, that forthcoming predictive flexibility could also be increased if the models were fitted to all initial stocking regimes combined.

Table (2.2.4.1) Distribution of measurements by forest and initial stocking level.

Forest	Initial stocking levels						
	1736	2315	2778	3086	4444	6944	total
HORO	0	0	0	2	0	0	2
KANG	579	392	0	771	0	1	1743
KROI	104	0	0	0	0	0	104
PURE	0	0	0	80	10	0	90
WAIM	203	0	0	0	0	0	203
WAKA	11	0	0	63	0	42	116
WIRI	0	0	17	44	0	0	61
total	897	392	17	960	10	43	2319

Table (2.2.4.2) Comparison of initial stocking level

$\log(G_{2)} = \log(G_1)(T_1/T_2)^{\beta} + \alpha(1-(T_1/T_2)^{\beta})$ .....(3.2.4.1)

Groups	Estimates of α	β	STD Errors of α	β	n
2315-3086	4.6342635	1.2658073	0.0212909	0.0216382	911
1736	5.7733959	0.5219554	0.2115409	0.0587559	287
combined	4.733519	1.1701647	0.0196016	0.0192757	1201

2.2.5. Thinning

During the process of developing DFCNIGM2, separate equations were fitted for unthinned stands, thinned once, thinned twice and thinned a third time. The equation used was again the Schumacher. Table (2.2.5.1) shows the coefficients of the equation fitted for each group. As can be seen from the table, confidence intervals for the equations of all groups except the first included 0 and/ or are not statistically significant. One equation each was therefore fitted for thinned and unthinned data to mirror the effect of thinnings on subsequent growth and yield.

Table (2.2.5.1) Comparison of thinning regimes

thinnings	Estimates		STD Errors	up, low	asymptote	n
0	α	5.013515	0.003207	4.950495	5.076535	451
	β	0.913518	0.030118	0.854327	0.972709	
1st	α	5.094112	0.039819	5.015981	5.172243	1117
	β	0.925192	0.023233	0.879605	0.970778	
2nd	α	7.944781	2.168825	3.660029	12.229531	154
	β	0.277587	0.148315	-0.015426	0.570600	
3rd	α	8.506121	4.568573	-0.653307	17.665550	55
	β	0.224252	0.219989	-0.216799	0.665303	
4th	α	4.687444	0.427290	3.677055	5.697832	8
	β	0.900876	0.463699	-0.195609	1.997361	
2nd-4th	α	7.239693	1.334872	4.608755	9.870632	217
	β	0.315333	0.124774	0.069413	0.561254	
0th-4th	α	5.094091	0.038693	5.018185	5.169998	1334
	β	0.910657	0.013612	0.864334	0.956978	

2.2.6. Growth period

The Schumacher equation was fitted to 10 year growth intervals and Table (2.2.6.1) contains the statistics of those equations.

Yield equations could be fitted for each growth period that is distinct with its parameters or other statistics (Knoebel <u>et al</u>., 1986) but this approach will not adopted here because:

(a) if different equations were fitted to different growth periods of the same stand, the curves drawn from two adjacent equations would not join together to form a smooth sigmoid curve that a population of plantation should basically follow;

(b) in Table (2.2.6.1), the differences among the coefficients for all intervals are not great noting that numbers of observations in intervals of $T \leq 10$ and $T > 70$ are too small for drawing any conclusion in these two classes;

(c) ages have been expressed in all key projection equations and the effect of growth period on yield will be reflected by those variables.

Table (2.2.6.1) Statistics of basal area equation for different growth periods

Intervals		Estimates	STD Errors	confid. intervals Lower	Upper	n
$0 < T \leq 10$	α	4.43586	0.12614	4.12720	4.74452	7
	β	1.40373	0.12414	1.09996	1.70750	
$10 < T \leq 20$	α	4.90324	0.03677	4.83099	4.97548	520
	β	1.00450	0.02694	0.95158	1.05742	
$20 < T \leq 30$	α	4.83180	0.03255	4.76785	4.89576	529
	β	1.12723	0.03594	1.05664	1.19783	
$30 < T \leq 40$	α	5.13215	0.08075	4.97265	5.29164	159
	β	0.92183	0.08073	0.76238	1.08128	
$40 < T \leq 50$	α	5.04950	0.06266	4.92632	5.17287	319
	β	0.87578	0.05946	0.75879	0.99278	
$50 < T \leq 60$	α	5.55236	0.21413	5.13036	5.97435	223
	β	0.48970	0.06833	0.35504	0.62436	
$60 < T \leq 70$	α	7.63929	2.33725	2.82567	12.4529	26
	β	0.27166	0.17136	-0.08126	0.62457	

2.3 Conclusions Regarding the Preliminary Data Analysis

(1) In terms of disease, data could be reliably divided into only two groups: healthy and diseased,

(2) Localities are divided into three groups: Whakarewarewa, Karioi and Kaingaroa group, but only the Kaingaroa group is modelled specifically,

(3) For this data set, the altitude effect is not significant,

(4) All initial stocking levels are combined,

(5) Thinnings were modelled through fitting separate equations for thinned and unthinned data,

(6) Growth periods are split at time of any thinnings and reflected by the independent variable T_1, the ages of the stand.

Chapter 3 Models and Their Properties

3.1. Site Index Equations

3.1.1. Calibration of Existing Site Index Equations

Burkhart and Tennent developed a site index equation for Kaingaroa forest in 1977, but the authors were unable to say whether or not this equation could be applicable outside Kaingaroa. Calibration of the applicability of Burkhart's equation was first carried out, therefore.

Mean top heights were estimated for each measurement in Kaingaroa forest, using Burkhart's equation and by the new one provided here. Residuals pertaining to these estimates were then plotted to detect possible bias. Figures (3.1.1.1), (3.1.1.2) and (3.1.1.3) are the residual patterns of Burkhart's equation for the three site groups: Kaingaroa, Whakarewarewa and Karioi. These figures show that the existing site index equation gives good estimation for Kaingaroa forest, but not so good for others. This led to the attempt to develop new site index equations for these other two forests.

3.1.2. Choice of methods

Clutter and others (1983) generalized the methods for fitting site index equation into three kinds:

A. guide curves;
B. difference equations;
C. parameter predictions.

To ensure that the most appropriate method was used to fit the equations, several forms have been fitted to the data to compare those 3 methods. Some equations gave good fit in one method, some in the other. The Schumacher equation,

$$h_{100,2} = \exp(\alpha+\beta/T_2) \qquad (3.1.2.1)$$

for instance, resulted in a good fit for guide curve case, while the Chapman_Richards equation,

$$h_{100,2} = h_{100,1}((1-\exp(-\alpha T_2))/(1-\exp(-\alpha T_1)))^{\beta} \qquad (3.1.2.2)$$

gave the best fit in the difference equation case.

For all the above,

$h_{100,1}$ = mean top height at T_1;
$h_{100,2}$ = mean top height at T_2;
T_1, T_2 = initial and remeasurement age;
exp = natural logarithm;
α, β = coefficients to be estimated from data.

This initial modelling seems to suggest that there is no particular method that is best for all situations; rather, the goodness of fit of a model depends on the nature of the data set and how good the model is in representing it in the specific circumstances.

RESIDUAL PLOT OF SITE INDEX EQUATION

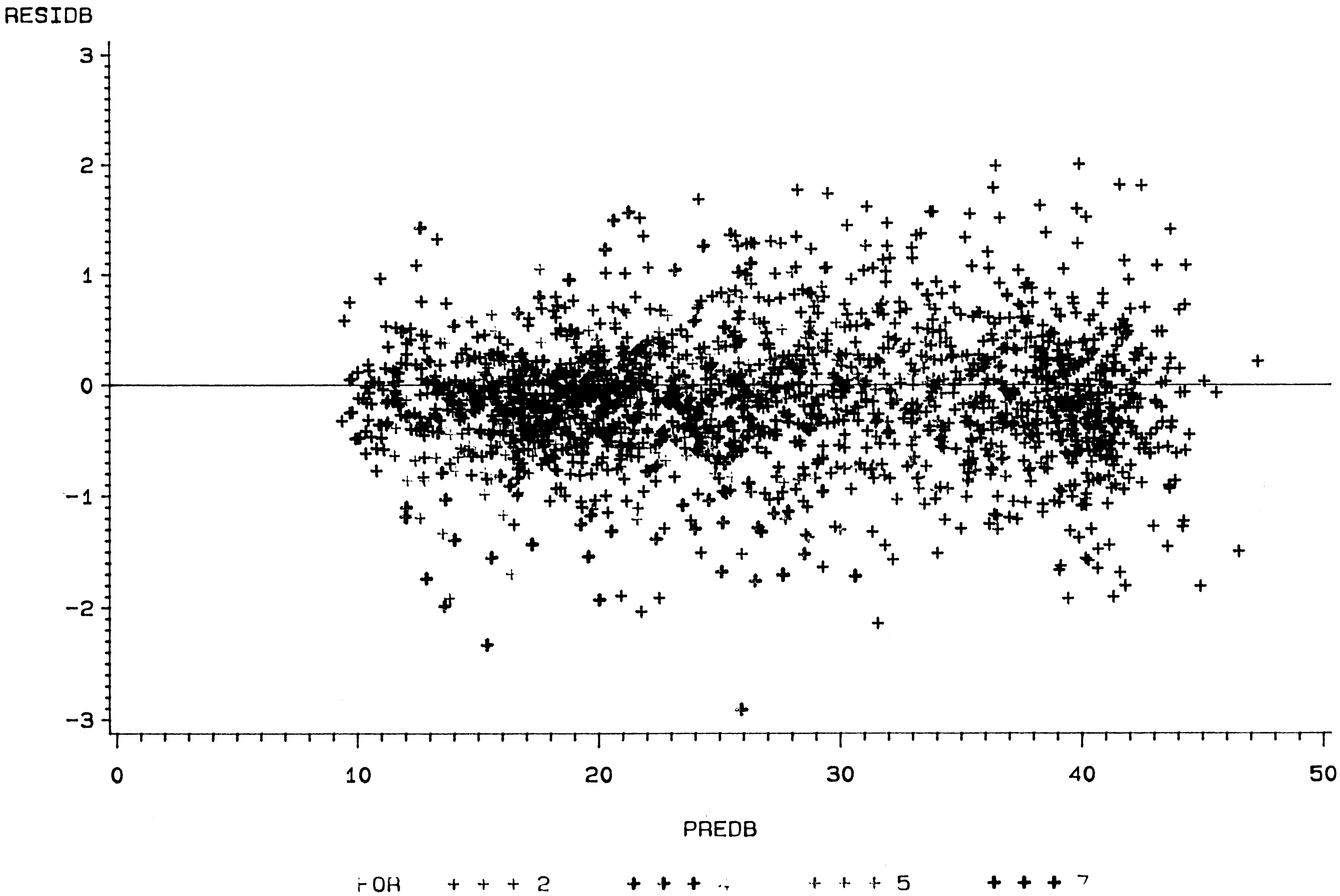

FIG (3.1.1.1) EXISTING EQUATION FOR KAINGAROA

RESIDUAL PLOT OF MEAN TOP HEIGHT

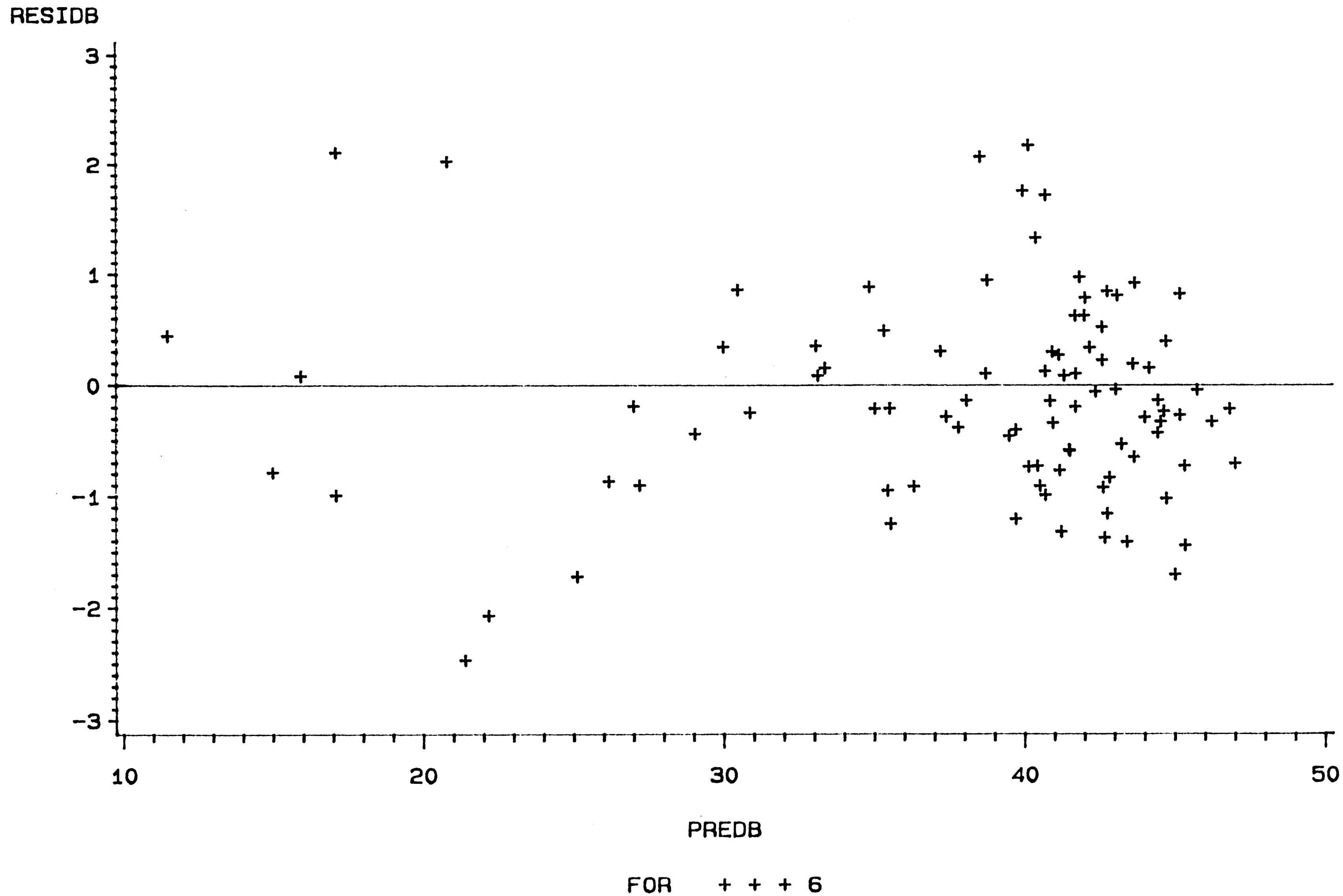

FIG (3.1.1.2) EXISTING EQUATION FOR WHAKAREWAREWA

RESIDUAL PLOT OF MEAN TOP HEIGHT

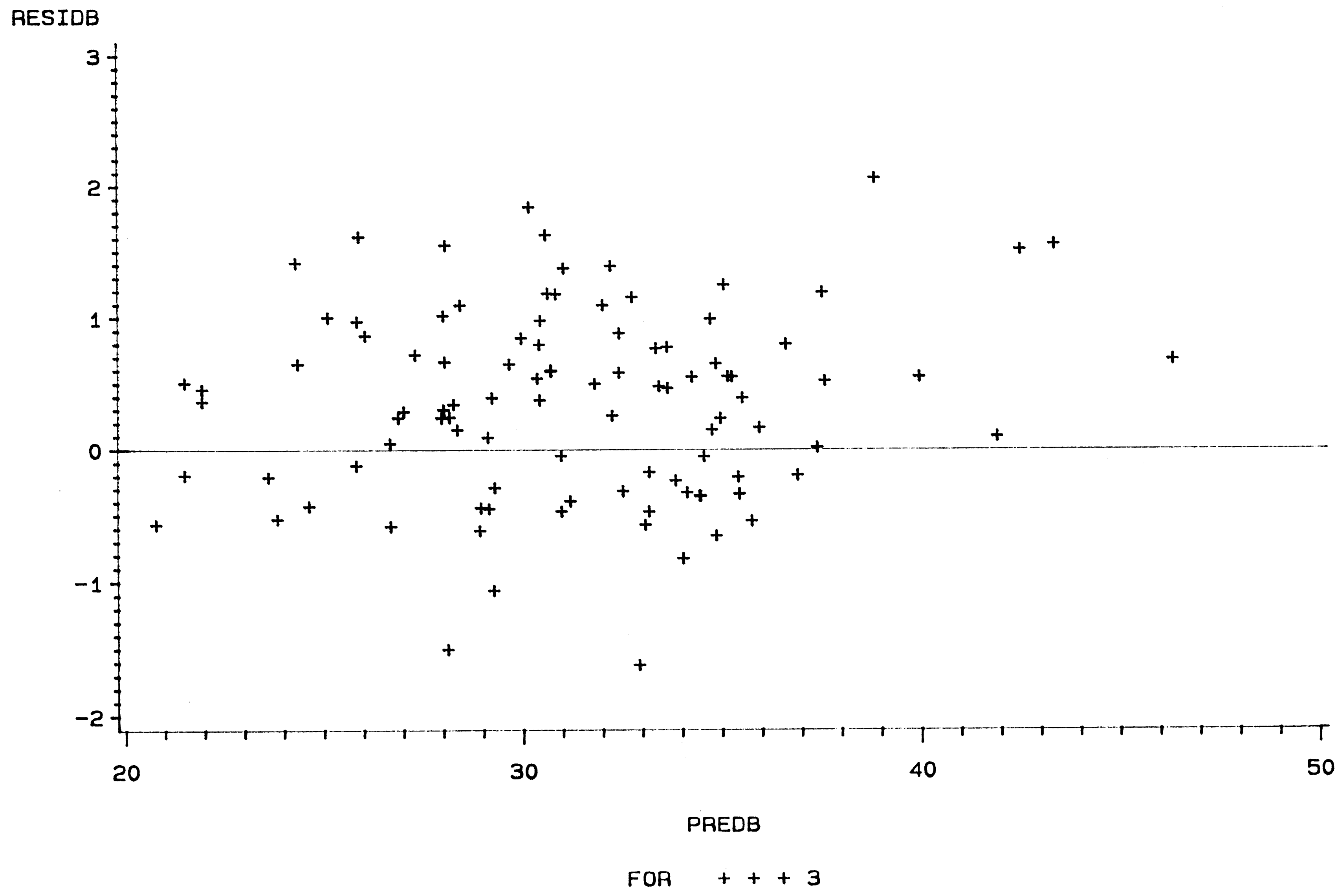

FIG (3.1.1.3) EXISTING EQUATION FOR KARIOI

3.1.3. Fitting site index equations

Some previous research showed that mean top height of Douglas Fir stands was not affected by the disease (Manley 1985). For this large data set, plotting of mean top height against age resulted in the same conclusion [Fig. (2.2.2.1)]. The mean top height equations were then fitted to data without considering disease infection.

Equation (3.1.2.2) was fitted to previously defined groups. Table (3.1.3.1) contains the coefficients and associated statistics of site index equations for those groups.

Table (3.1.3.1) Statistics of new site index equations

Forest	Estimates of α	Estimates of β	STD error of α	STD error of β	n
KANG	0.0333941	1.5530098	0.0011704	0.0331478	1947
WAKA	0.0312229	1.2872249	0.0079595	0.2875633	93
KROI	0.0160797	1.4589794	0.0064647	0.2262033	100

Fig (3.1.3.1), (3.1.3.2), (3.1.3.3) are the residual patterns for the new equations. They indicate that the equation fitted for Kaingaroa gave a good estimation, but the estimations from the other two equations were not so good, mainly on account of fewer data. Comparison of the residual patterns for the new site index equations with that of the existing equation [Fig. (3.1.1.1), (3.1.1.2) (3.1.1.3)], shows that:

(1) both the new equation and Burkhart + Tennent's equation give good estimation for Kaingaroa forest;

(2) the new equations give almost identical estimations to Burkhart + Tennent's for all three groups: Kaingaroa, Whakarewarewa and Karioi;

(3) from (1) and (2), it is reasonable to conclude that both the new equations and the existing equation could give good estimation for Whakarewarewa and Karioi forests. The "bias" shown on graphs, may be due to the number of measurements for these two groups being too small to reflect their intrinsic growth pattern. As will be seen in the next section, the numbers of measurements for fitting basal area equations are also very small. Because of this, Whakarewarewa and Karioi groups will not be considered separately from here on.

When T_2 in equation (3.1.2.2) is set equal to T_0, the index age, $h_{100,2}$ is the site index by definition. i.e.

$$S = h_{100,1}((1-\exp(-\alpha T_0))/(1-\exp(-\alpha T_1)))^{\beta} \qquad (3.1.3.1)$$

with an index age 40 (Burkhart and Tennent, 1977; Mountfort, 1978)

Fig (3.1.3.4) shows the site index curves drawn based on this equation.

Although the existing equation can give good estimation to

Kaingaroa forest it was decided to use the new site index equations in the models for the following reasons:

a. the new equation gives a good estimation almost identical to that given by Burkhart + Tennent's equation;

b. the new equation is more convenient to use as it can be explicitly solved for S, the site index.

c. the new equation covers the forests of Kaingaroa, Pureora, Waimihia and Whirinaki while the existing one is applicable to Kaingaroa only.

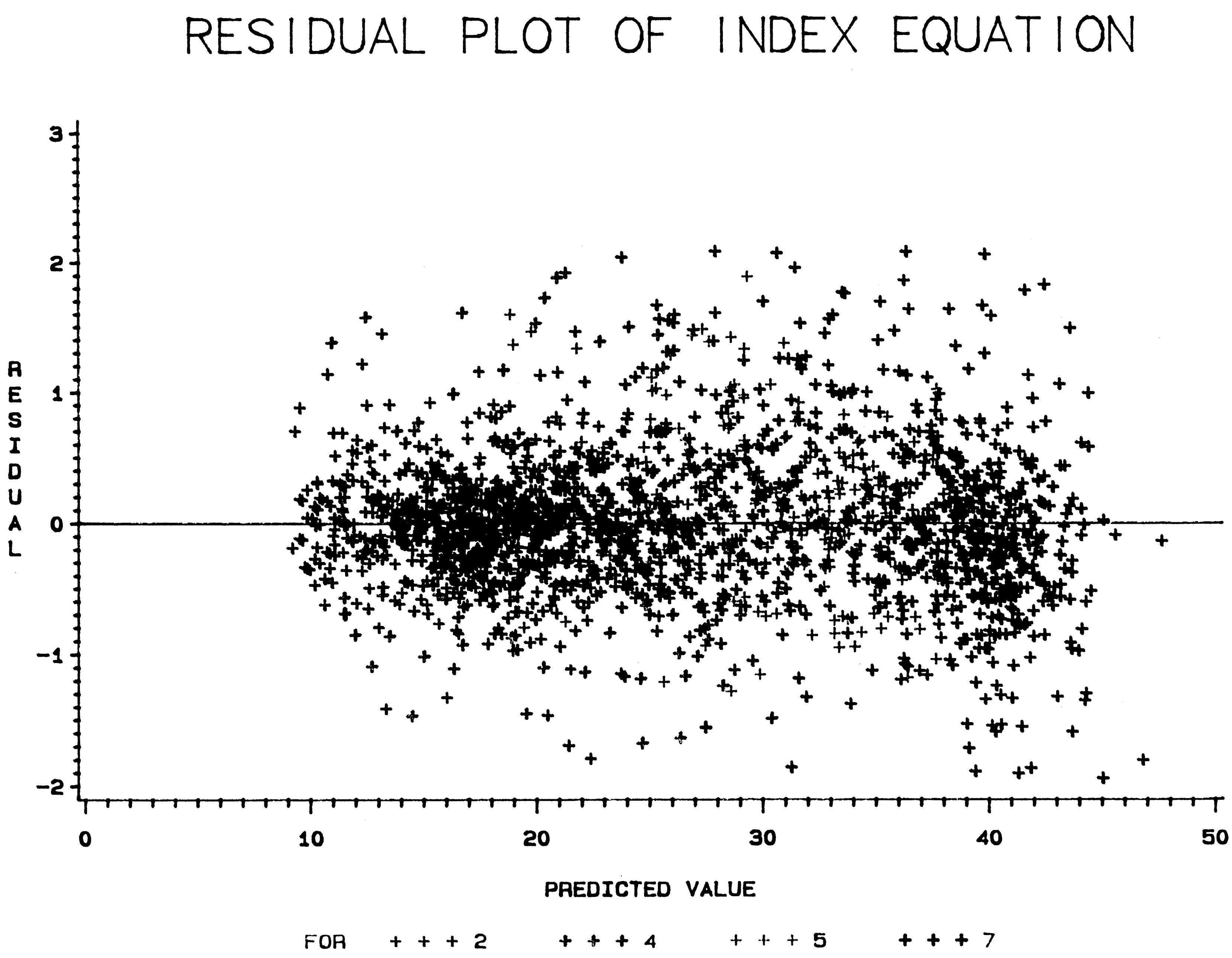

FIG (3.1.3.1): KAINGAROA GROUP

RESIDUAL PLOT OF INDEX EQUATION

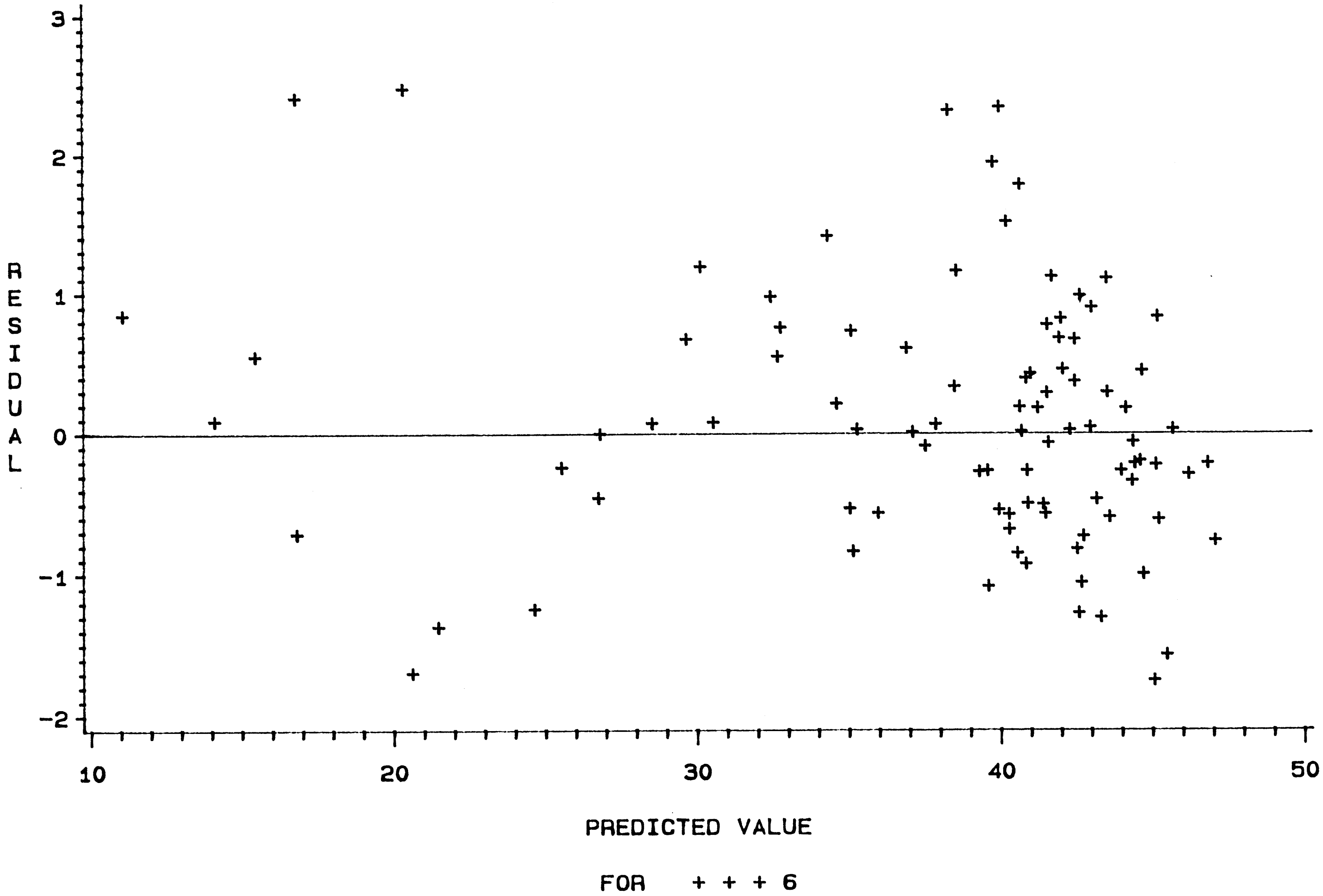

FIG (3.1.1.2): WHAKAREWAREWA GROUP

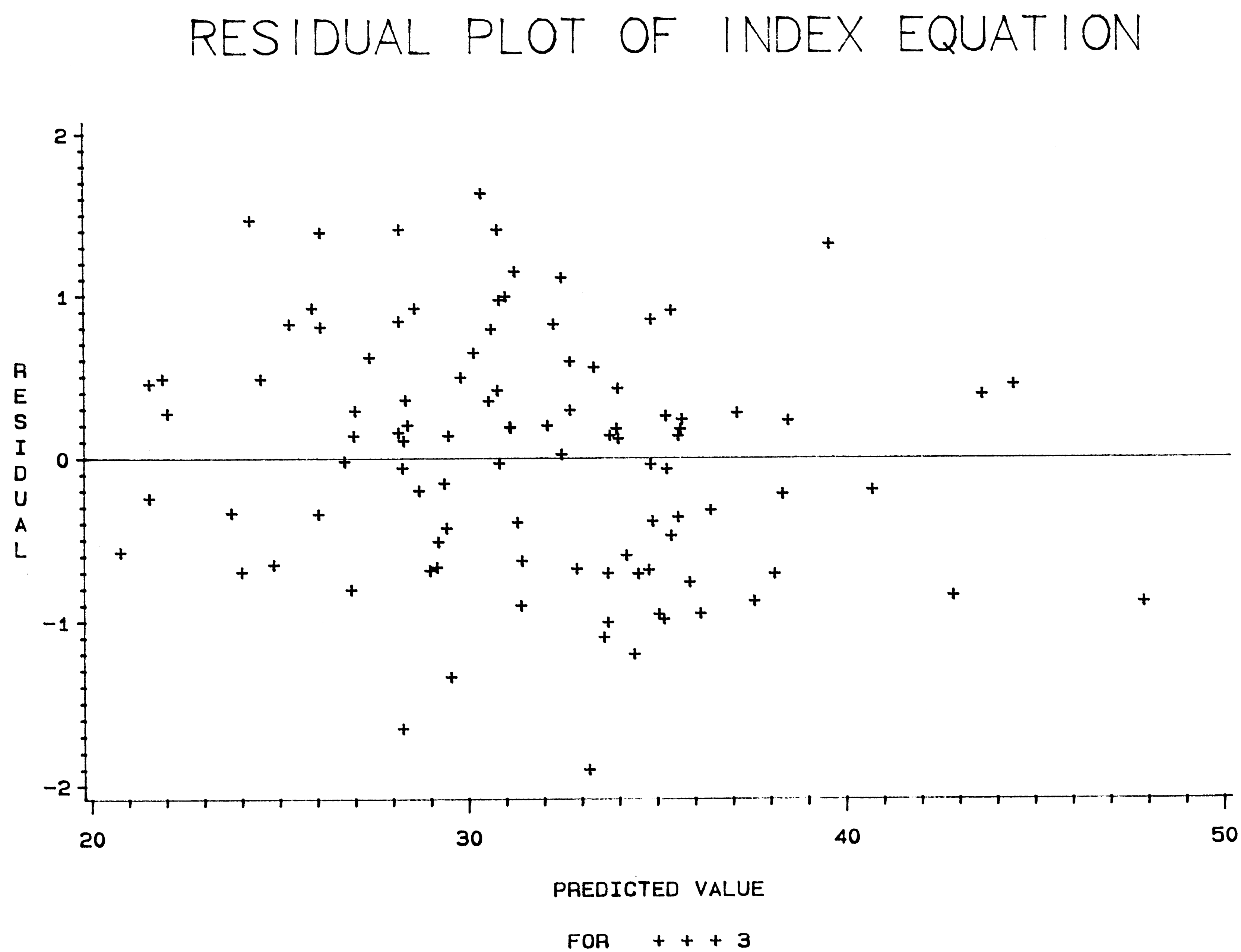

FIG (3.1.3.3): KARIOI GROUP

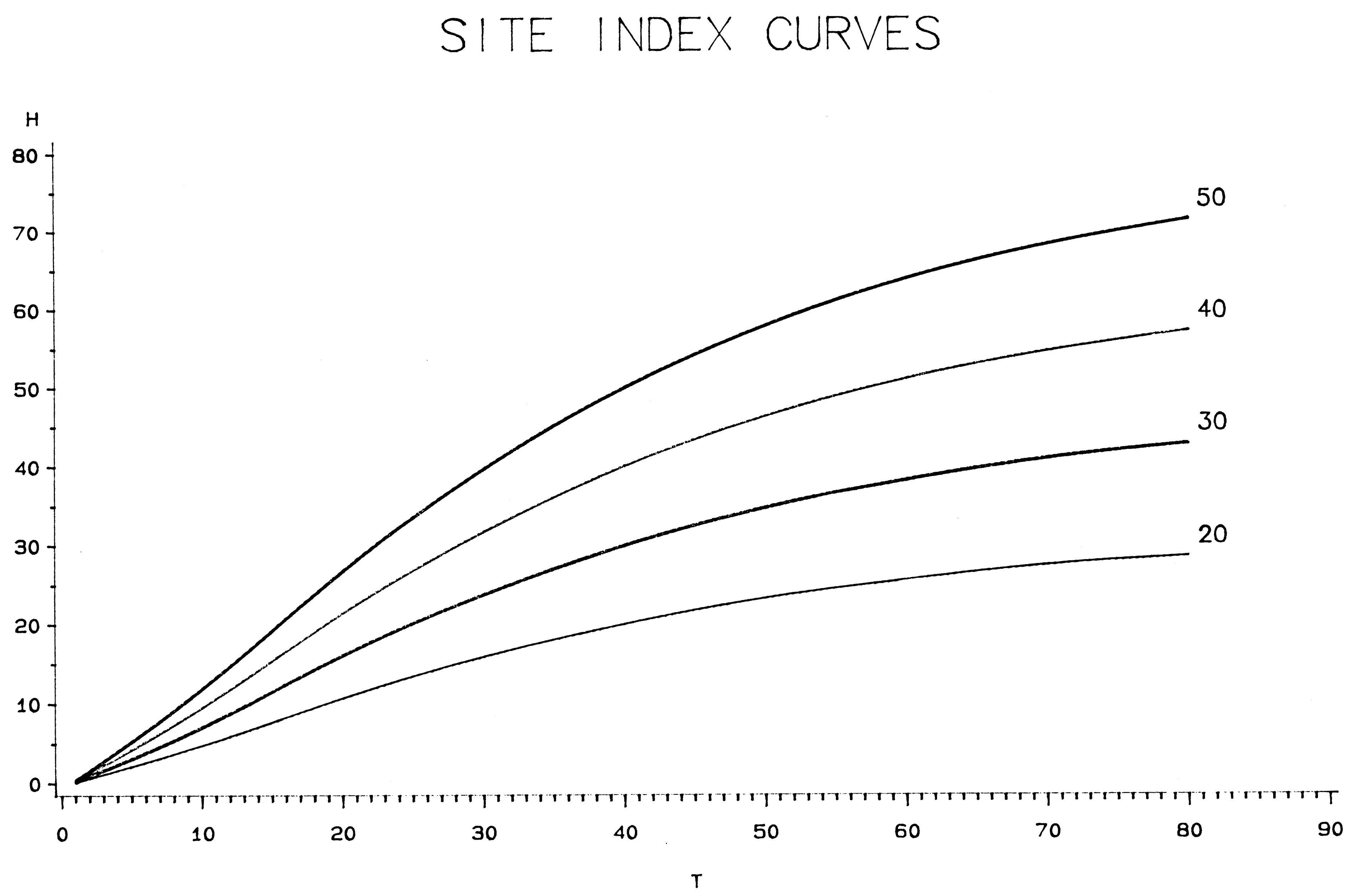

FIG (3.1.3.4): KAINGAROA REGION PLANTATIONS

3.2. Basal area projection

3.2.1 Basal area projection equations

Table (3.2.1.1) shows the numbers of observations available for fitting the basal area projection equation.

Table (3.2.1.1) Distribution of measurements by forest and thinnings

pre-1963						
Forest	Un-thinned	1st thinning	2nd thinning	3rd thinning	all 3 thinnings	sum
Horohoro	0	0	0	0	0	0
Kaingaroa	41	58	26	3	87	128
Karioi	4	4	2	0	6	10
Pureora	0	0	0	0	0	0
Waimihia	7	6	3	0	9	16
Waka.	15	11	1	0	12	27
Whirinaki	0	0	0	0	0	0
sum	67	79	32	3	114	181

Table (3.2.1.1) (continued)

post-1963						
Forest	Un-thinned	1st thinning	2nd thinning	3rd thinning	all 3 thinnings	sum
Horohoro	1	0	0	0	0	1
Kaingaroa	316	937	90	47	1074	1390
Karioi	78	0	0	2	2	80
Pureora	25	28	3	0	31	56
Waimihia	43	66	13	9	88	131
Waka.	12	42	10	2	54	66
Whirinaki	18	8	0	0	8	26
sum	493	1081	116	60	1257	1750

Because of the small numbers in other groups, only the Kaingaroa group (Kaingaroa, Waimihia, Whirinaki and Pureora) was considered here.

The Hossfeld function was finally used as an appropriate basal area projection equation after analyzing it and several others. The Hossfeld is given by

$$Y = (\alpha T^{r}) / (\alpha \beta + T^{r}) \qquad \text{(3.2.1.1)}$$

Differentiating (3.2.1.1) with respect to T gives the growth equation:

$$dY / dT = \alpha \beta \Gamma Y / T(\alpha \beta + T^{r}) \qquad \text{(3.2.1.2)}$$

Difference equation forms of (3.2.1.1) are:
polymorphic

$$Y_2 = 1/\{(T_1/T_2)^r(1/Y_1)+(1/\alpha)[1-(T_1/T_2)^r] +X(1/\beta)[1-(T_1/T_2)^r]\} \qquad (3.2.1.3)$$

anamorphic

$$Y_2 = 1/((1/Y_1)+\alpha(1/T_2^r-1/T_1^r)+\beta X(1/T_2^r-1/T_1^r)) \qquad (3.2.1.4)$$

This equation is not known extensively in western countries, even though it has more desirable properties than the Schumacher equation.

(a) It is a sigmoid growth curve, with an upper asymptote, α,

$$Y = \lim\ (\alpha T^r)\ /\ (\alpha\beta+T^r) = \alpha \qquad (3.2.1.5)$$

and an inflexion point

$$Y_{inflex} = \alpha(\Gamma-1)/2\Gamma \text{ at } T = ((\alpha\beta(\alpha-1))\ /\ \alpha + 1)) \qquad (3.2.1.6)$$

(b) as T2 approaches T1, Y_2 approaches Y_1;

(c) as T2 approaches ∞, Y_2 approaches an upper asymptote, α; (Clutter et al., 1983; Clutter and Sullivan, 1972; Knoebel et al, 1986; Schumacher, 1939; and others).

(d) in addition, the Hossfeld function has this property: when T = 0, then Y = 0. in contrast, when T = 0, Y is not defined in the Schumacher equation. The yield equation, therefore, makes good biological as well as mathematical sense.

Although yield at age zero is not utilised in practice, (d) is a desirable property to have just as the upper asymptote is seldom utilised, particularly for plantations. The role of the lower and upper asymptote is to force the yield function, when fitted to data, to fall within boundaries that should exist in reality for a biological population.

For our data set, it also fitted slightly better than Schumacher equation.

Note that a thinning index was also introduced to the above equation, which not only simplified the model as a whole but also increased the precision.

For the diseased unthinned group the original Hossfeld equation was used:

$$G_2 = 1/((1/G_1)(T_1/T_2)^\beta + \alpha(1-(T_1/T_2)^\beta)) \qquad (3.2.1.7)$$

For the diseased thinned stands the equation was modified into:

$$G_2 = 1/((1/G_1)(T_1/T_2)^{\Gamma+\delta/T2} + \alpha(1-(T_1/T_2)^{\Gamma+\delta/T2}) + \beta X(1-(T_1/T_2)^{\Gamma+\delta T2})) \qquad (3.2.1.8)$$

And for healthy stands, the equation was

$$G_2 = 1/((1/G_1)(T_1/T_2)^{\Gamma} + \alpha(1-(T_1/T_2)^{\Gamma}) + \beta X(1-(T_1/T_2)^{\Gamma})) \qquad (3.2.1.9)$$

Where

G_1 = basal area/ha at age T_1;
G_2 = basal area/ha at age T_2;
α, β, Γ, δ = coefficients to be estimated from data.

Table (3.2.1.2) shows the coefficients for the best basal area equations fitted for the three groups.

Table (3.2.1.2) Statistics of basal area projection equations

G	Estimates of				STD error of				n
	α	β	Γ	δ	α	β	Γ	δ	
a	0.0037	0.0153	0.7566	30.0814	0.0005	0.0008	0.0520	0.7646	1308
b	0.0084		1.8508		0.0001		0.0370		438
c	0.0076	0.0013	2.5951		0.0004	0.0003	0.0675		156

Where

G ___ group;
a ___ post-1963 thinned;
b ___ post-1963 unthinned;
c ___ pre-1963 stand.

Fig (3.2.1.1) to (3.2.1.6) are the residual patterns for those fitted equations.

A paper by Woollons et al (1989) describing the use of the Hossfeld equation as a yield equation has been accepted for publication by the Japanese Association of Forest Statisticians.

3.2.2. Basal area/ha after thinning

Basal area/ha after thinning can be estimated from the following equation (Matney and Sullivan, 1982):

$$G = \alpha G_0^{\beta}(1-(1-N/N_0)^{\Gamma})^{\delta} \qquad (3.2.1.10)$$

Where

G = basal area/ha after thinning;
G_0 = basal area/ha before thinning;
N = stems/ha after thinning;
N_0 = stems/ha before thinning;
α, β, Γ, δ = coefficients.

If desired, this equation can be rearranged to get the number of trees/ha after thinning.

Table (3.2.2.1) presents the estimated coefficients and the standard errors of the estimates.

Fig (3.2.2.1) and (3.2.2.2) displays the residual pattern and residual bar chart of this equation. Although the residual pattern is acceptable, the bar chart shows a little bias. This is caused by the small number of measurements available for fitting this equation.

Table (3.2.2.1) Statistics of equations for BA/ha after thinning

	Estimates of	STD error of	n
α	1.575813766	0.15421165798	123
β	0.895126313	0.02522280853	
Γ	0.983393463	0.10315973274	
δ	0.646141197	0.03677562871	

In order to make precise projections, it is recommended that users should supply their own thinning index inputs preferably in terms of basal area/ha removed because:

(1) basal area/ha after thinning estimated from stocking is an average value, while a different type of thinning with different weights, times and ages could vary widely;

(2) due to the small number of observations,the residual bar chart of this equation shows some bias.

It is also recommended that users supply basal area/ha after thinning rather than stems/ha after thinning because the number of stems/ha is not closely associated with volume production, and is thus less important than basal area/ha.

RESIDUAL PLOT OF BASAL AREA EQUATION

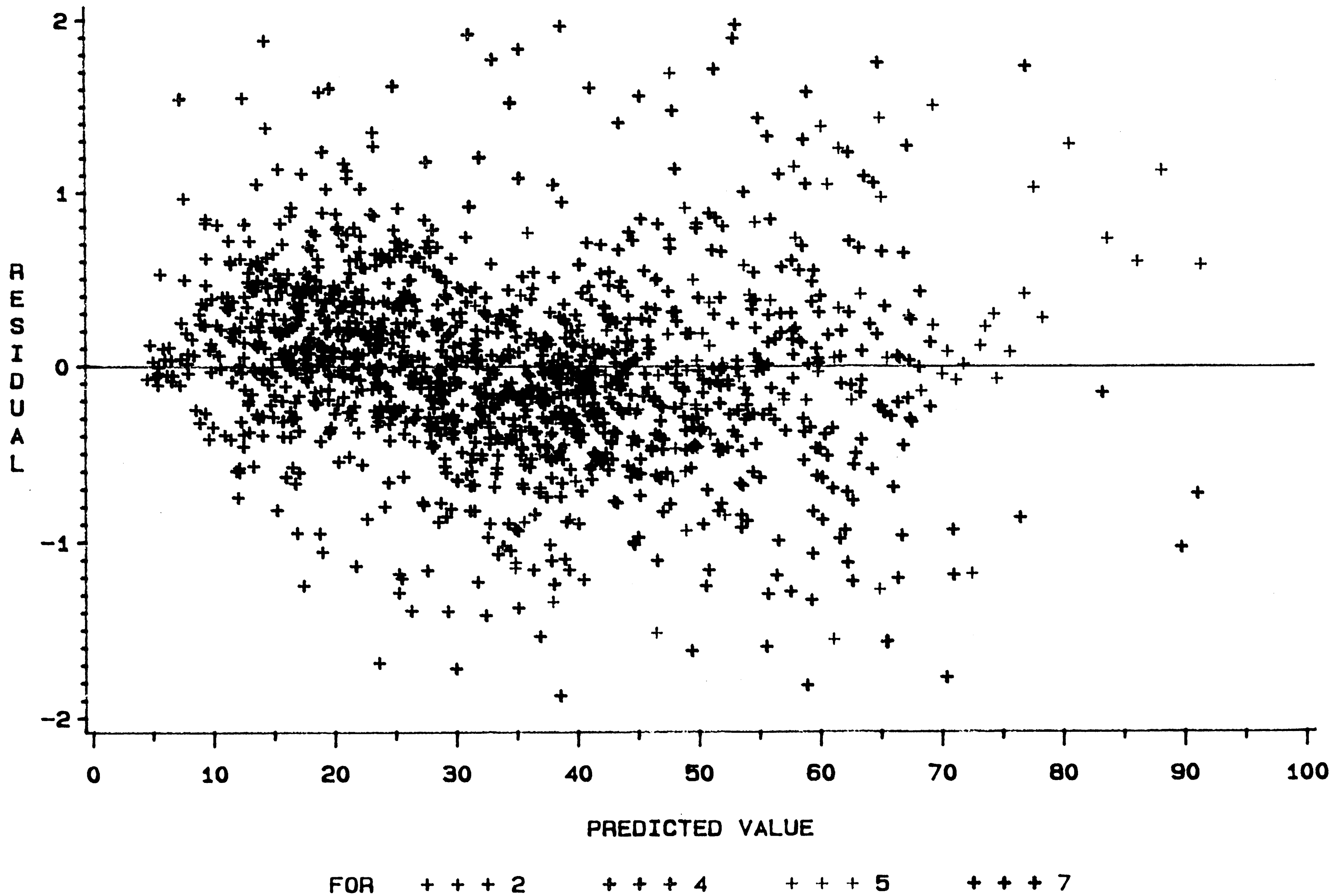

FIG (3.2.1.1): KAINGAROA DISEASED THINNED STANDS

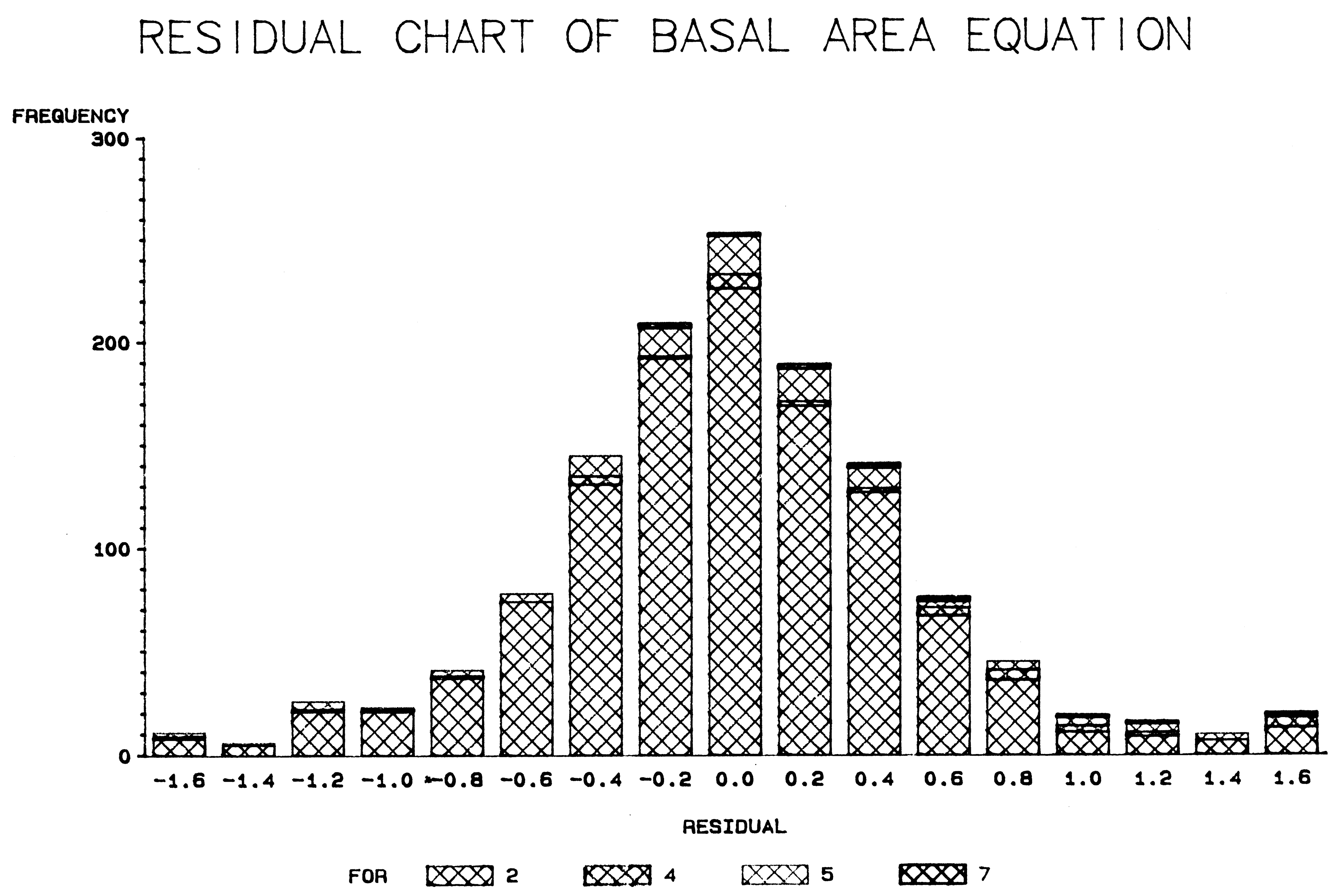

FIG (3.2.1.2): KAINGAROA DISEASED THINNED STANDS

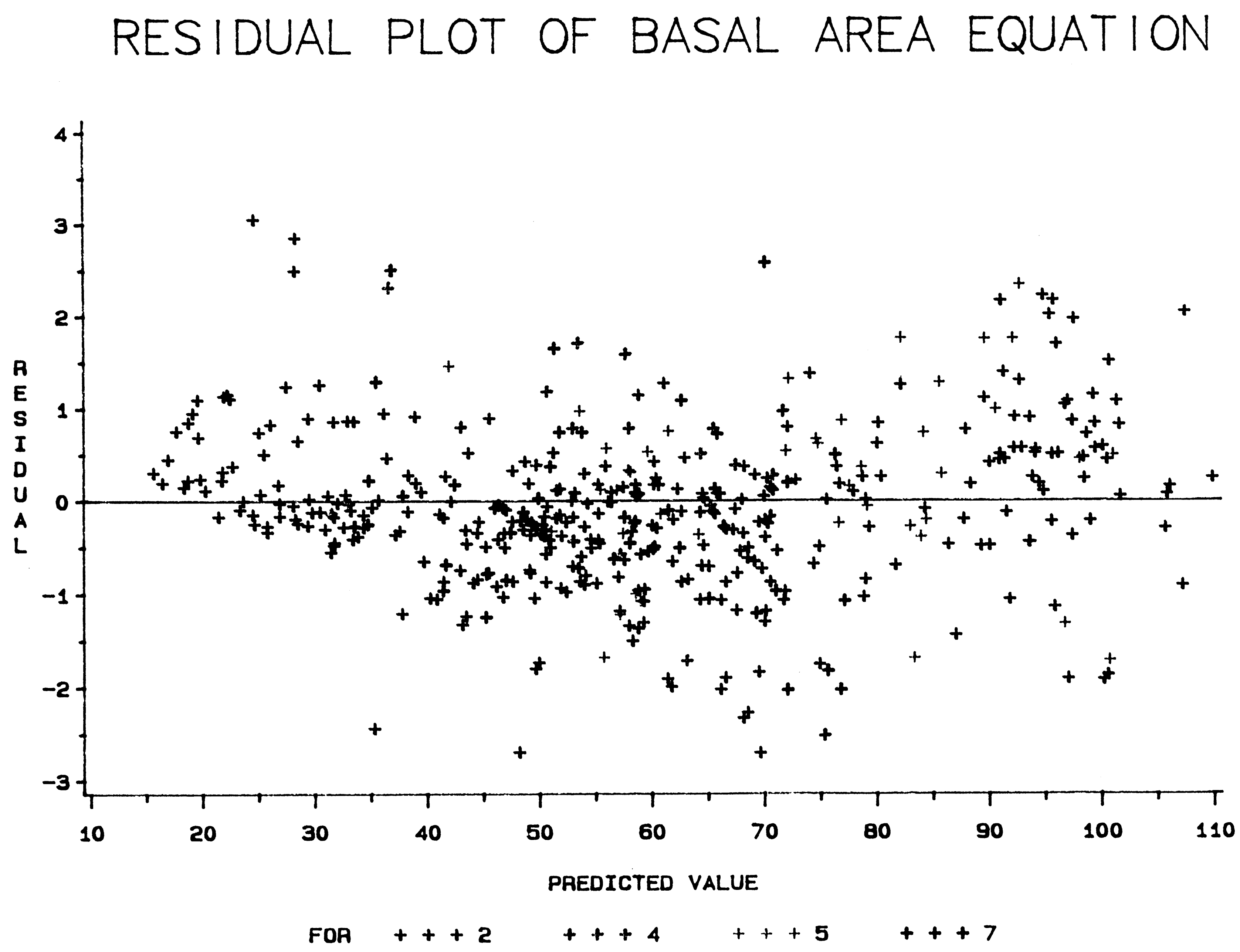

FIG (3.2.1.3): KANG DISEASED UNTHINNED STANDS

RESIDUAL CHART OF BASAL AREA EQUATION

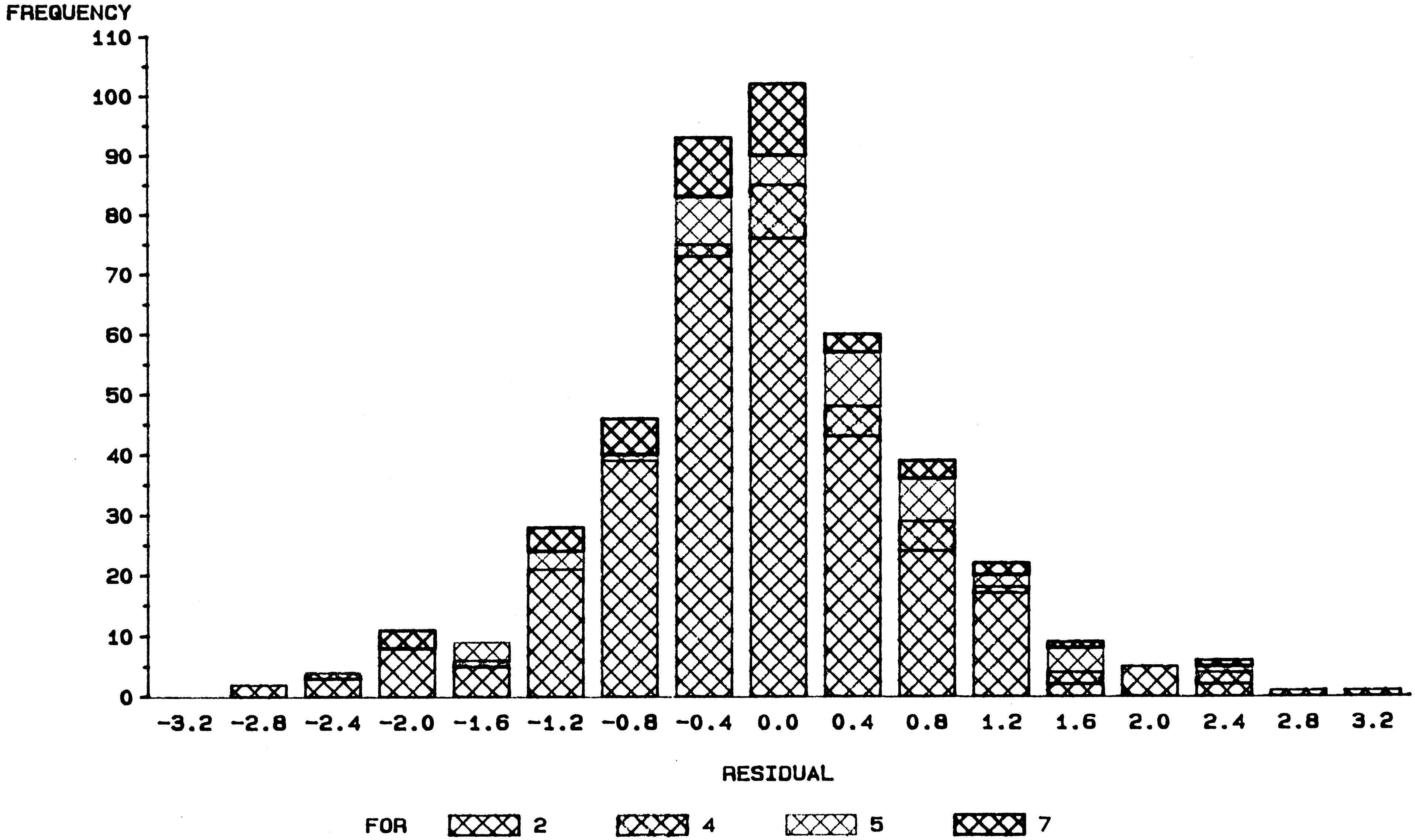

FIG (3.2.1.4): KANG DISEASED UNTHINNED STANDS

RESIDUAL PLOT OF BASAL AREA EQUATION

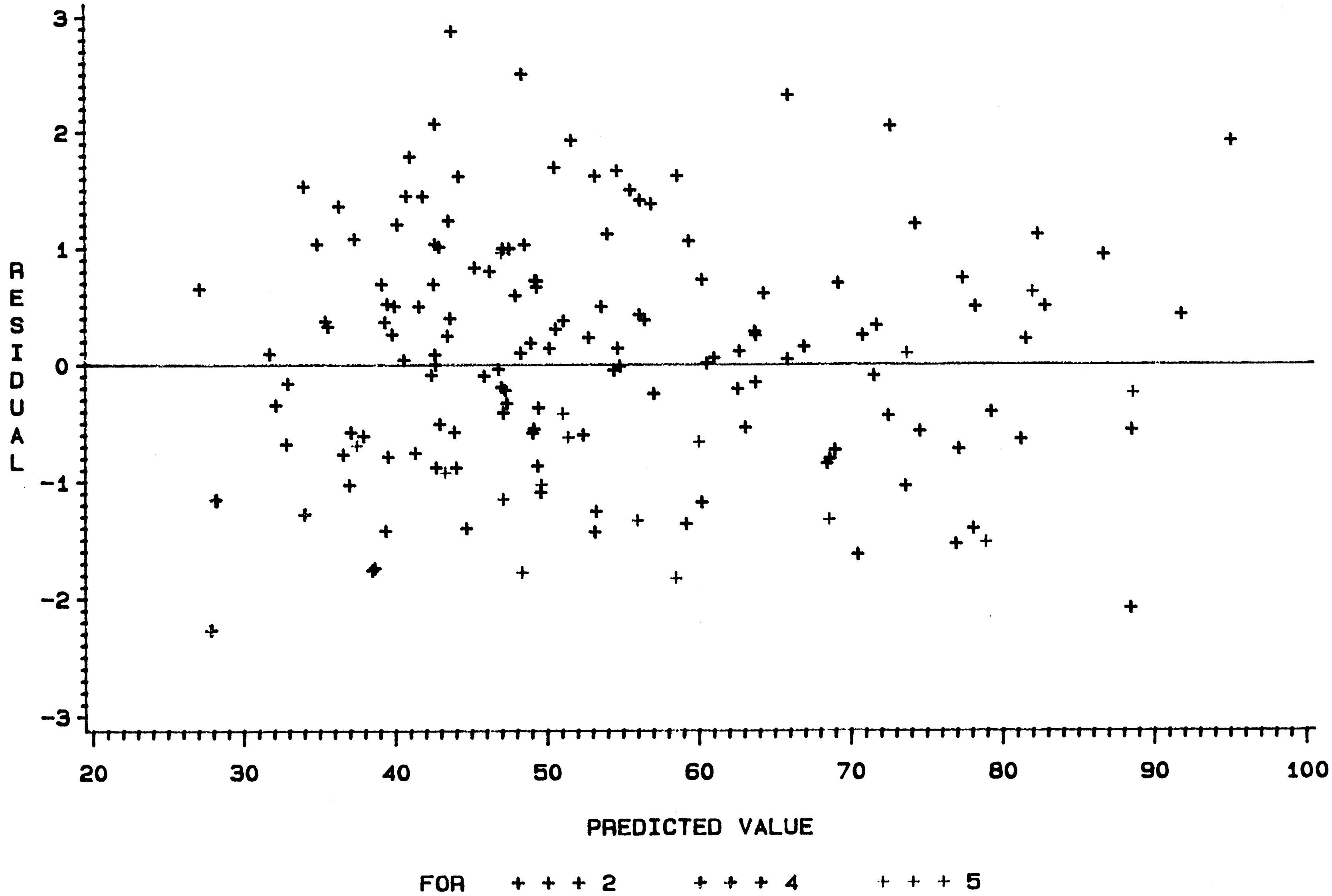

FIG (3.2.1.5): KAINGAROA UNDISEASED STANDS

RESIDUAL CHART OF BASAL AREA EQUATION

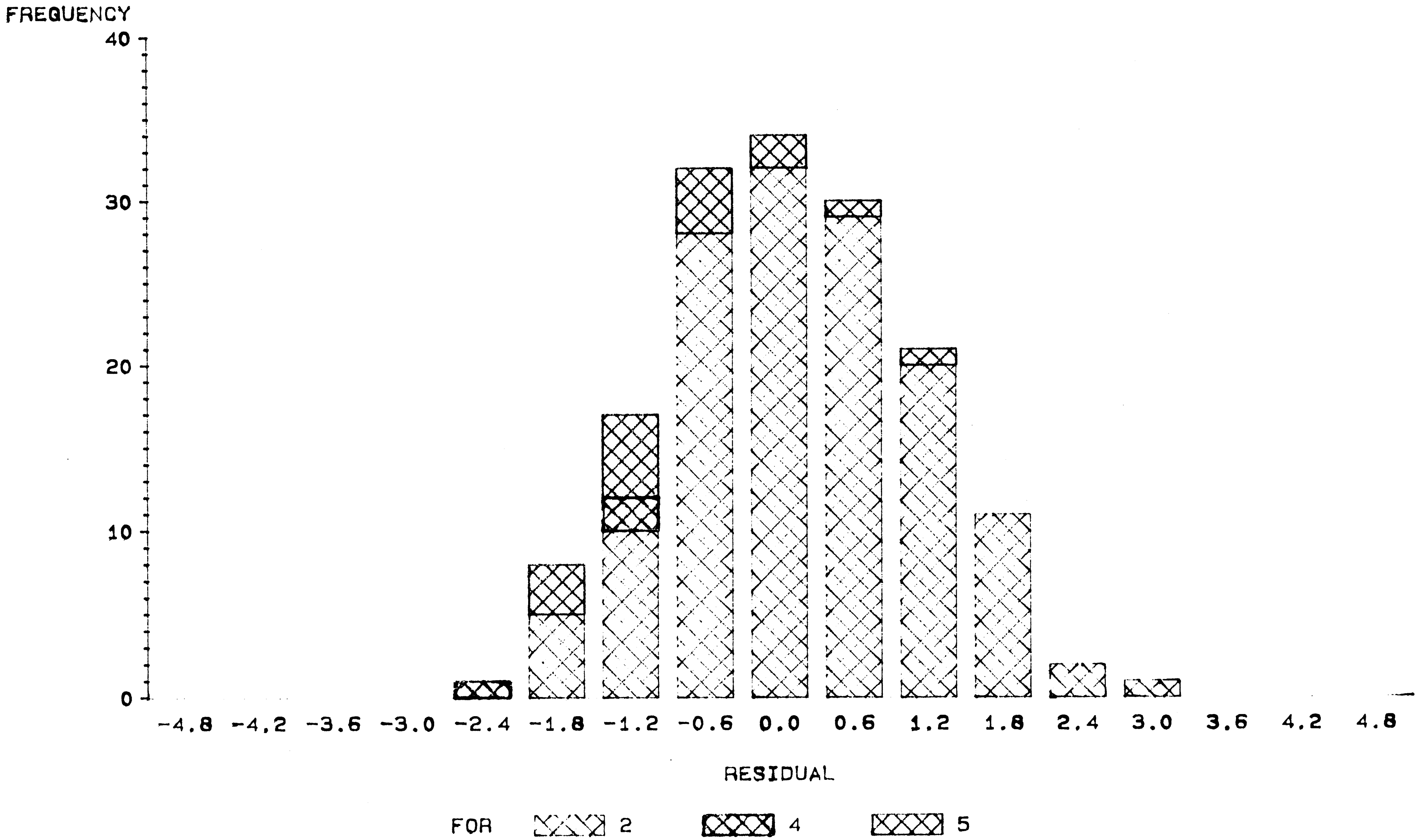

FIG (3.2.1.6): KAINGAROA UNDISEASED STANDS

RESIDUAL PLOT, G/HA AFTER THINNING EQUATION

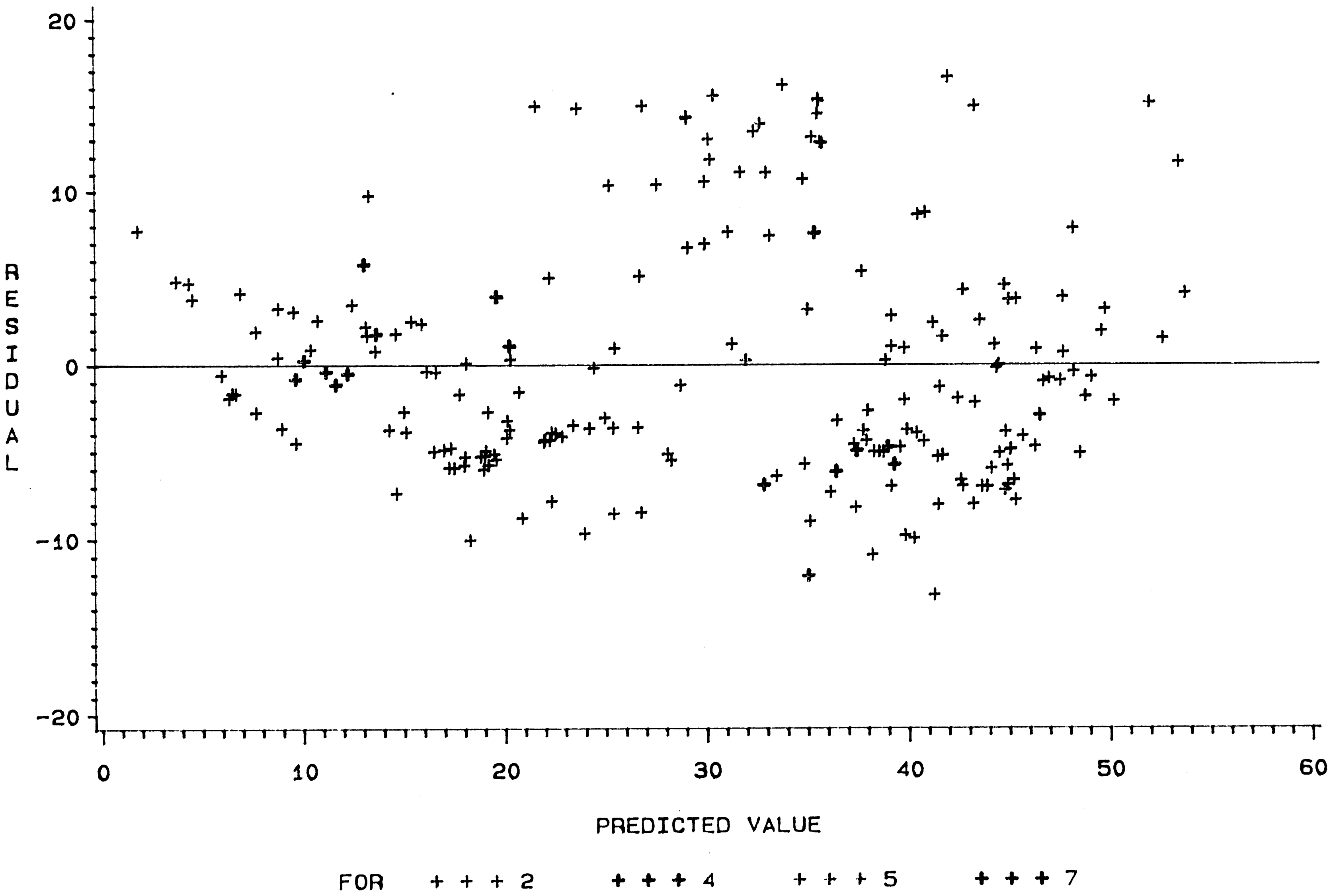

FIG (3.2.2.1): KAINGAROA REGION PLANTATIONS

RESIDUAL CHART, G/HA AFTER THINNING EQUATION

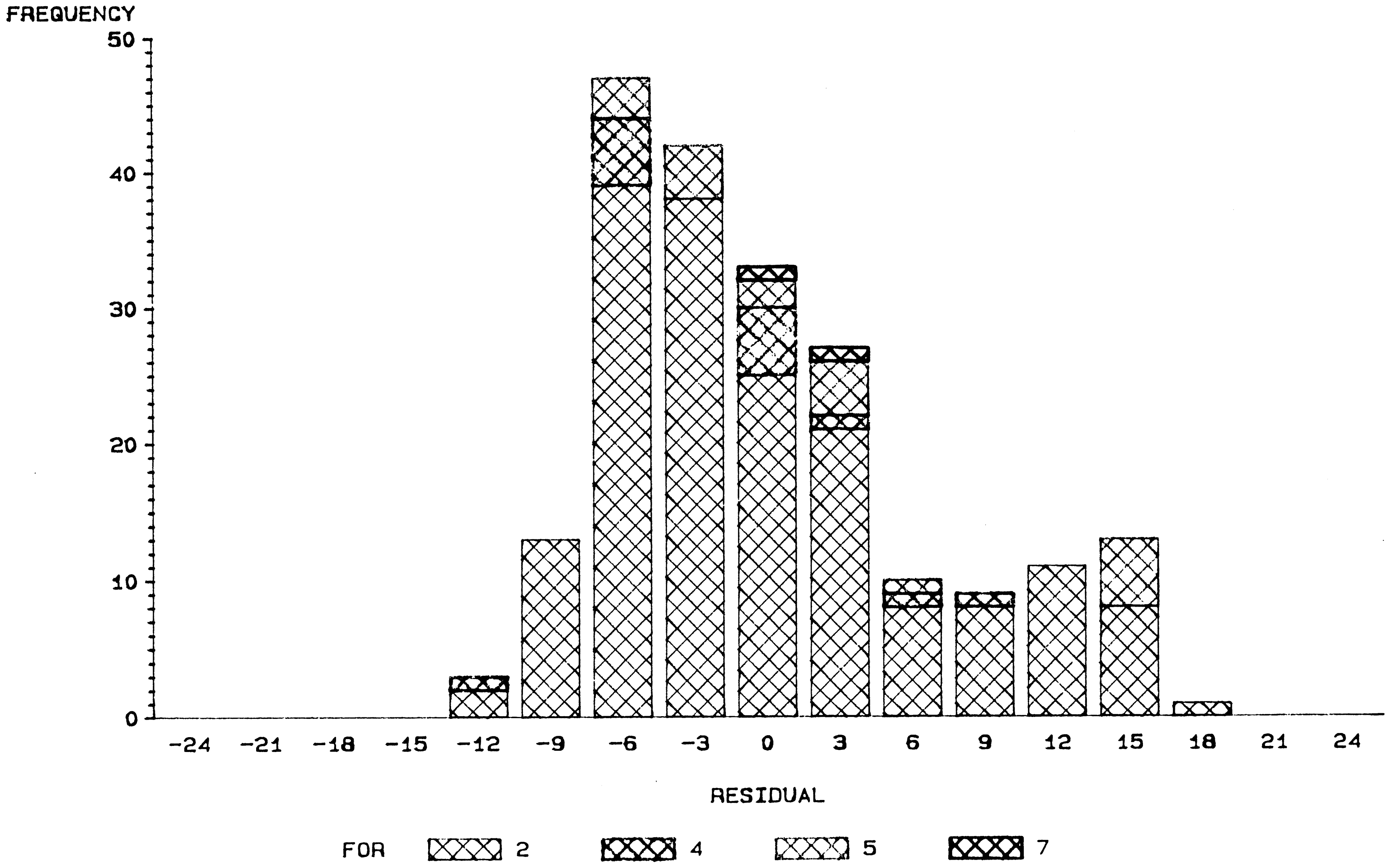

FIG (3.2.2.2): KAINGAROA REGION PLANTATIONS

3.3. Volume Equations

For diseased, thinned stands, the best volume equation solved with PROC REG using a weight of $(1/Gh_{100})^2$ was:

$$V = \alpha+\beta G+\Gamma h_{100}+\delta Gh_{100} \qquad (3.3.1)$$

Where
V = total volume (m^3/ha);
G = basal area (m^2/ha);
h_{100} = mean top height (m);
α, β, Γ, δ = coefficients to be estimated from the data.

For diseased unthinned stands, the corresponding equation was:

$$V = \beta G+\Gamma h_{100}+\delta Gh_{100} \qquad (3.3.2)$$

For undiseased stands, the corresponding equation was:

$$V = \alpha+\beta Gh_{100}) \qquad (3.3.3)$$

The IUFRO notation adopted in (3.3.1) to (3.3.3) is the same as defined previously.

Figure (3.3.1) to (3.3.6) are the residual patterns for the volume equations. In forecasting projected volume/ha, projected basal area/ha and mean top height are converted to volume.

Note that all three volume equations are independent of stocking.

Table (3.3.1) shows the values of the coefficients for the volume equations fitted for the previously defined three groups.

Table (3.3.1) Coefficients for the volume projection equations

G	Estimates of				STD error of				n
	α	β	Γ	δ	α	β	Γ	δ	
a	-1.6032	0.2502	0.7454	0.3314	0.4690	0.0391	0.0234	0.0012	1263
b			0.6620	0.3365			0.0498	0.0021	377
c			0.7040	0.3392			0.0447	0.0017	163

RESIDUAL PLOT OF VOLUME EQUATION

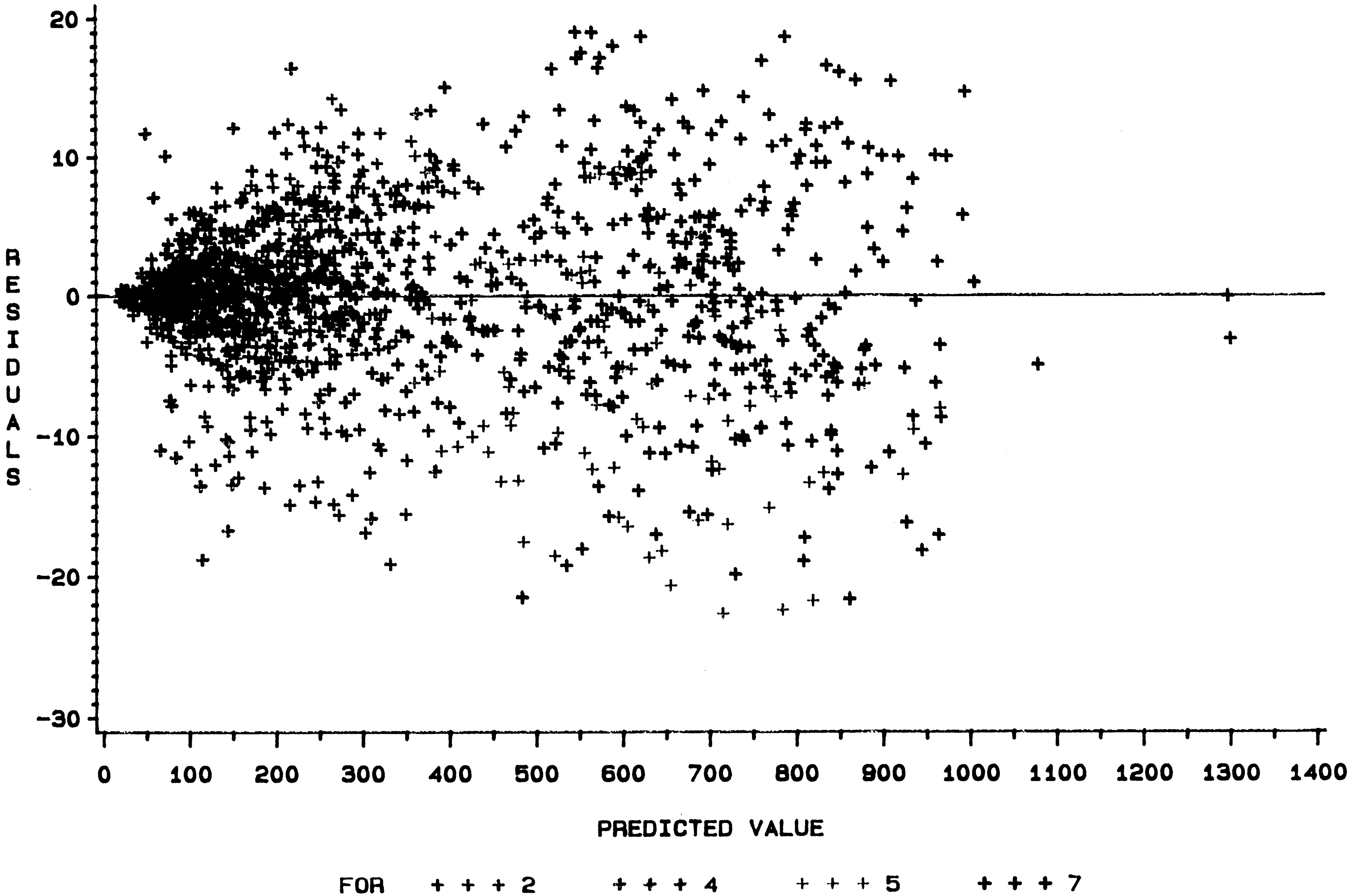

FIG (3.3.1): KAINGAROA DISEASED THINNED STANDS

RESIDUAL CHART OF VOLUME EQUATION

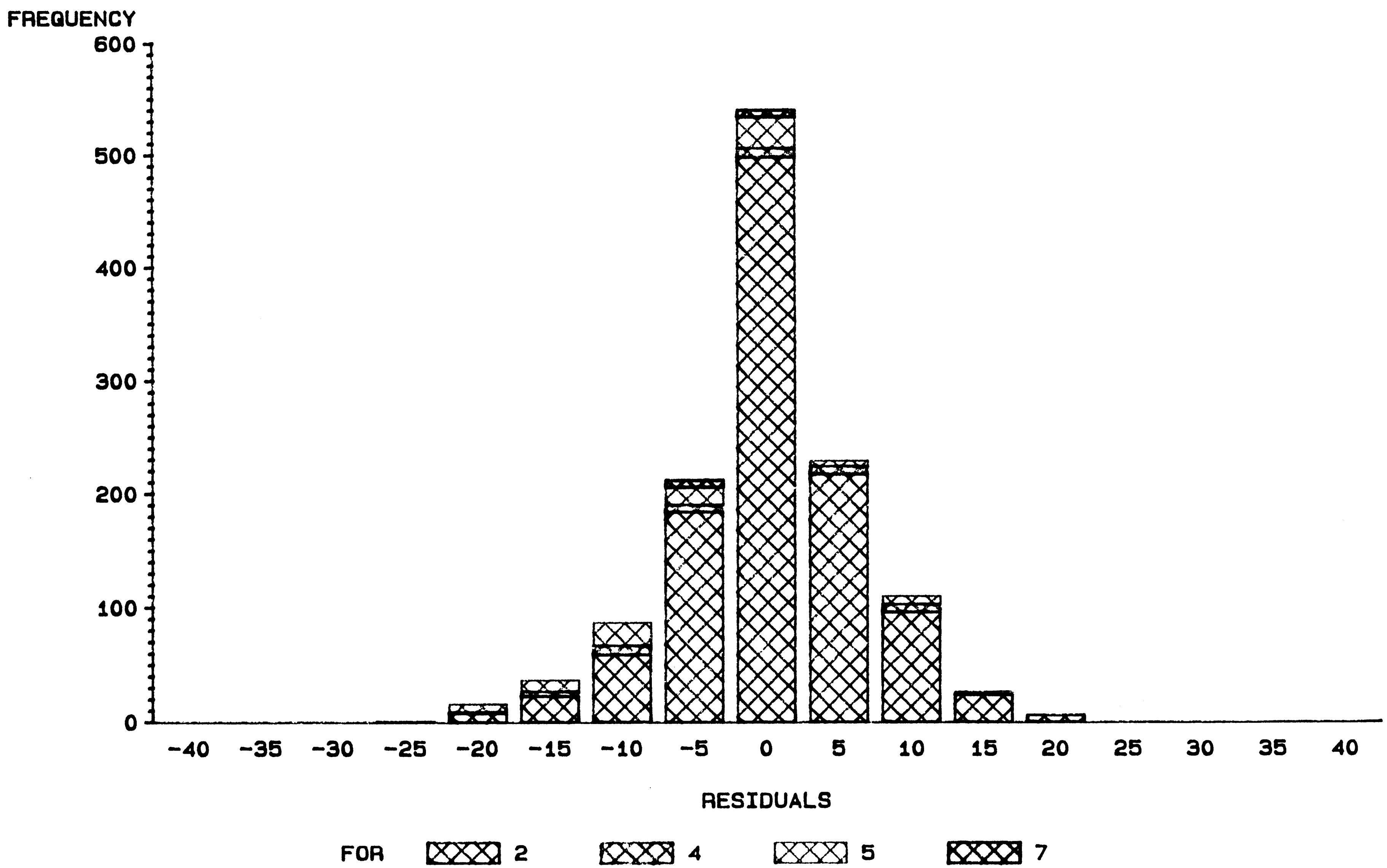

FIG (3.3.2):KAINGAROA DISEASED THINNED STANDS

RESIDUAL PLOT OF VOLUME EQUATION

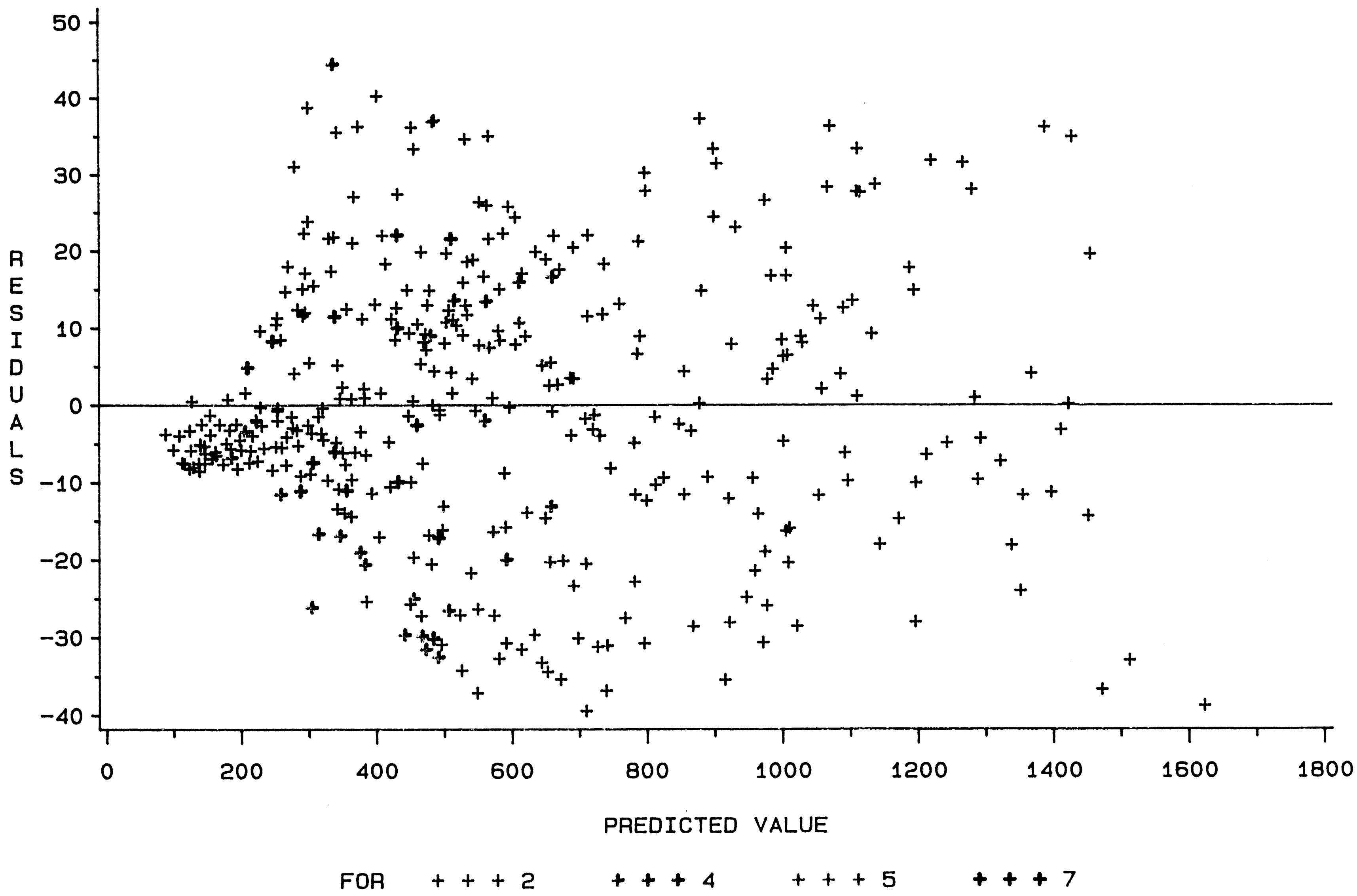

FIG (3.3.3): KAINGAROA DISEASED UNTHINNED STANDS

RESIDUAL CHART OF VOLUME EQUATION

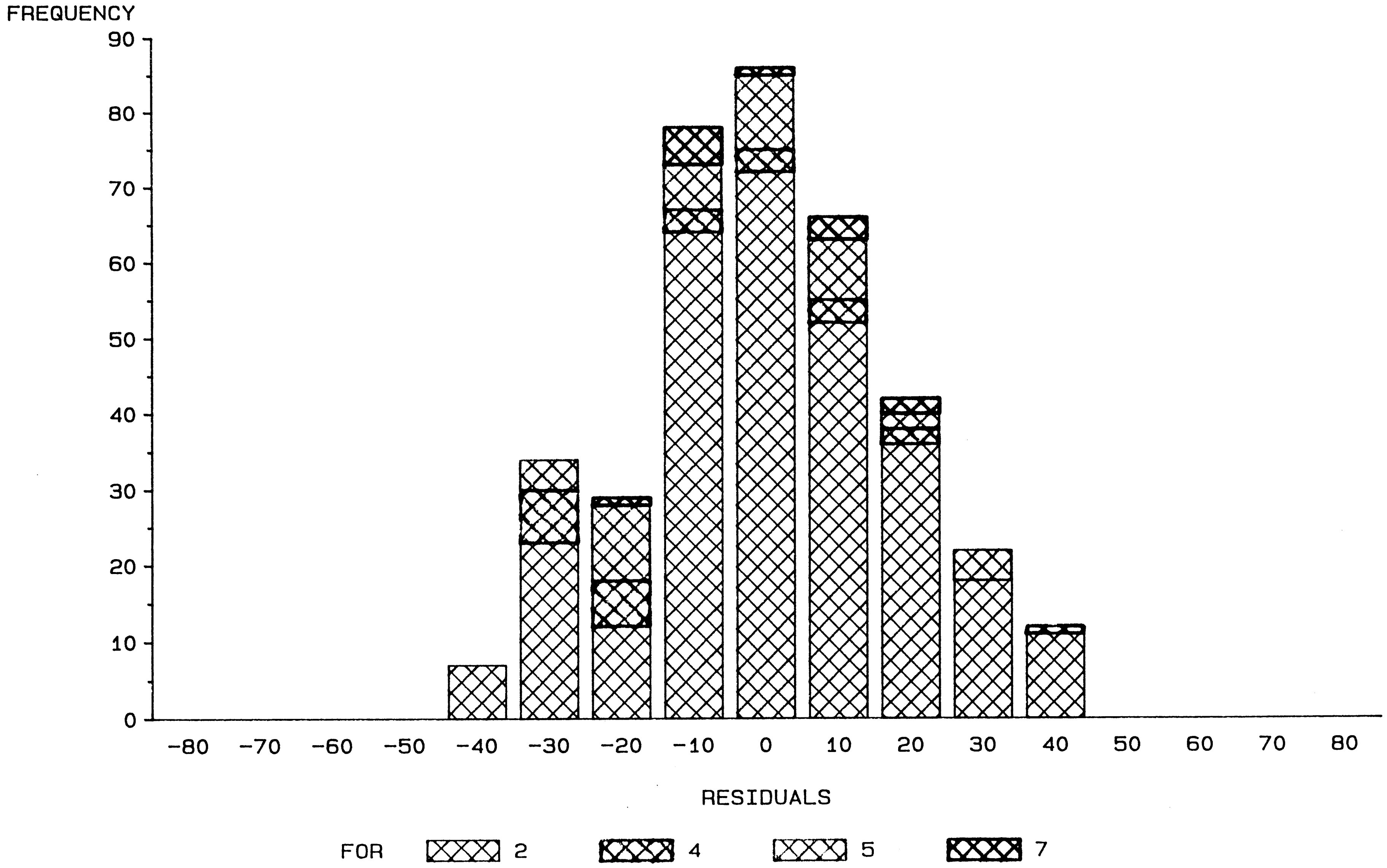

FIG (3.3.4):KAINGAROA DISEASED UNTHINNED STANDS

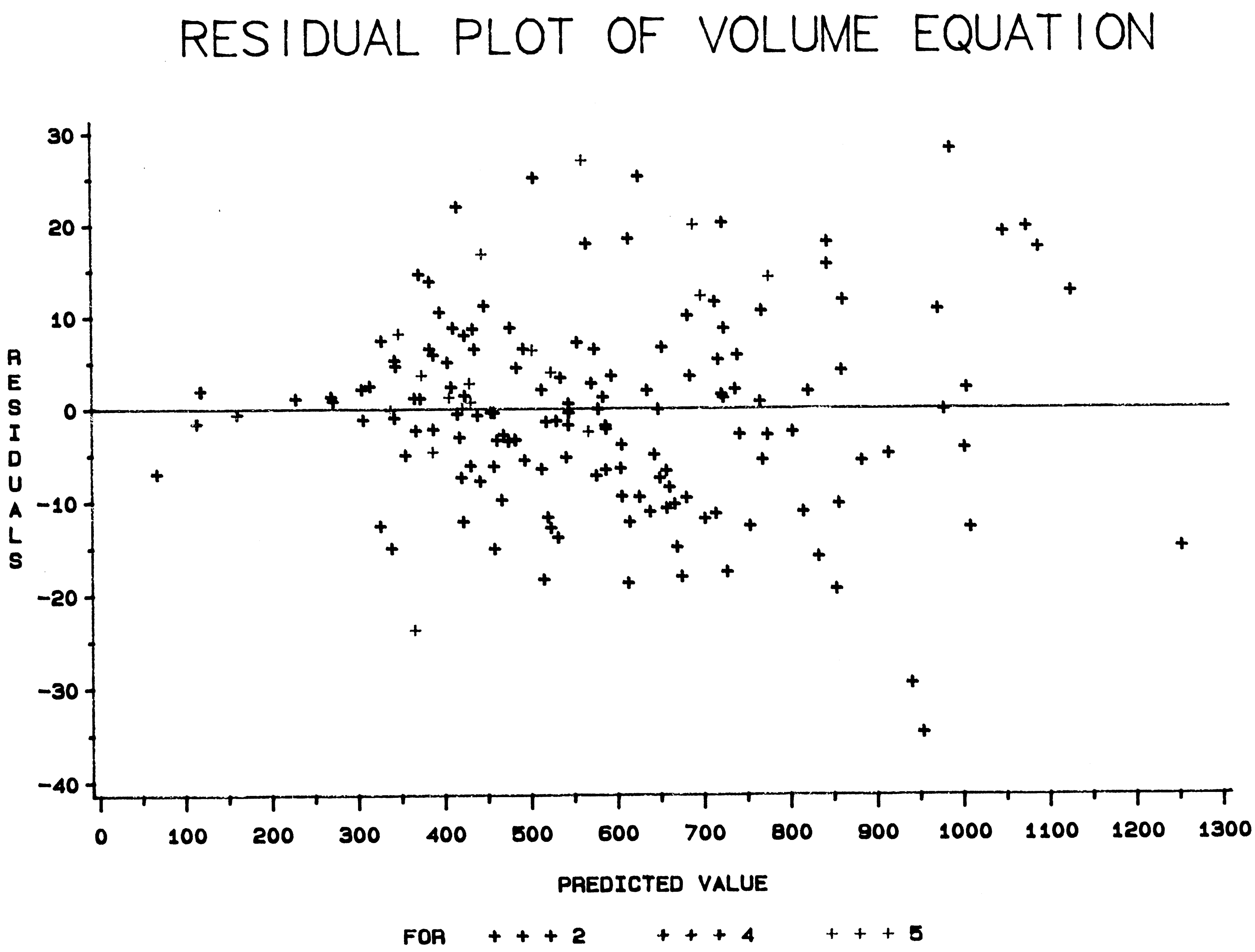

FIG (3.3.5): KAINGAROA UNDISEASED STANDS

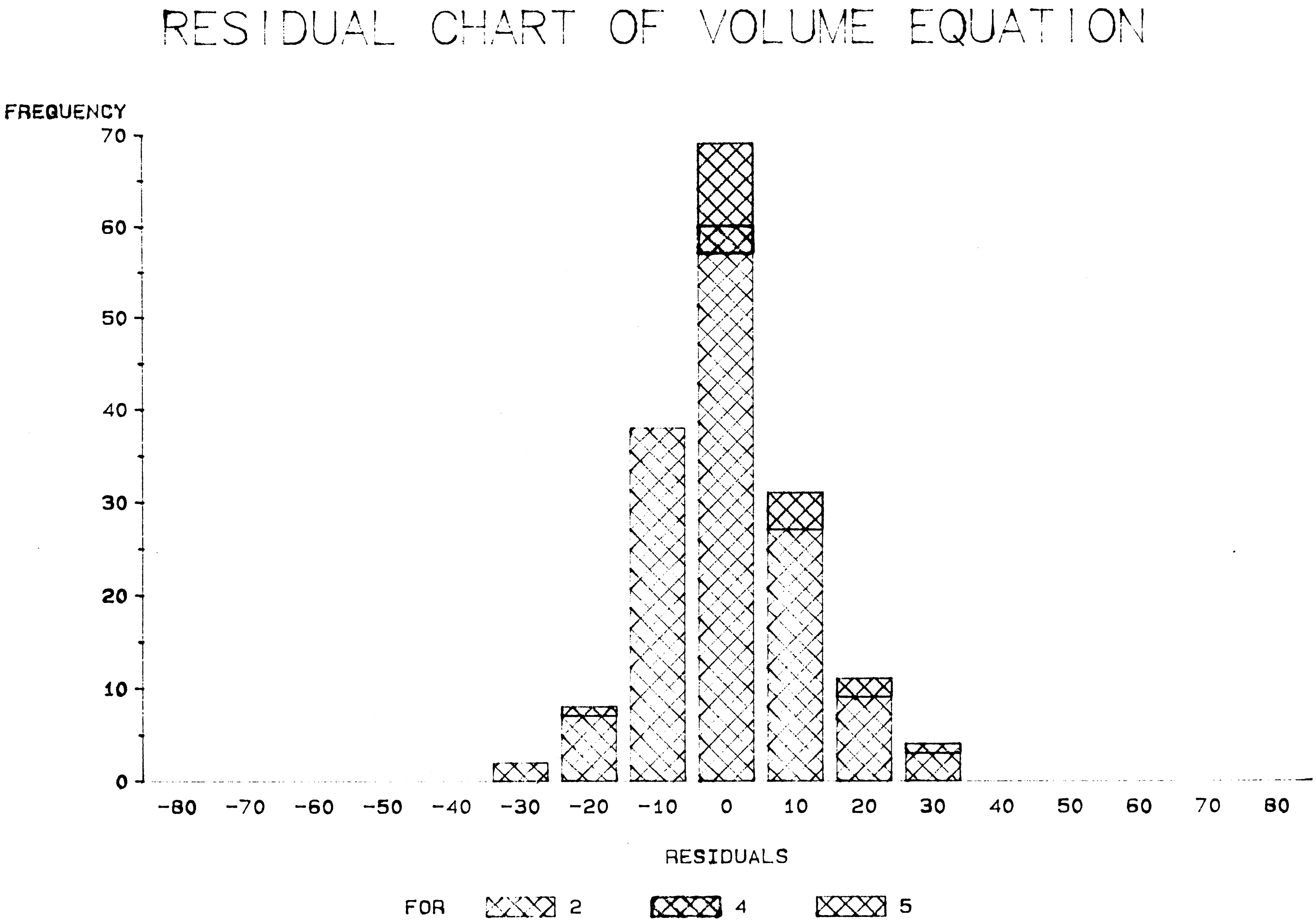

FIG (3.3.6):KAINGAROA UNDISEASED STANDS

3.4. Merchantable volume equations

The original data contained no information about merchantable volumes and so they had to be estimated from alignment charts constructed by Lewis (1954). Thus the estimation could be far less reliable than that estimated from actual measured data.

The three data groups have the same form of merchantable volume equation:

$$V_m = \alpha V_t^{\beta}\exp(-\Gamma(15/D^{\delta})) \qquad (3.4.1)$$

Where

Vm = merchantable volume (m^3/ha) to a 15 cm small end top diameter;

Vt = total volume (m^3/ha);

D = quadratic mean diameter (cm);

α, β, Γ, δ = coefficients to be estimated from data

Fitting this equation showed that:

(1) it results in an excellent fit [Fig. (3.4.1) to (3.4.6)];

(2) it always give logical estimation. i.e. the merchantable volume given by this equation is always less than total volume.

This equation could be useful for predicting merchantable volume for other species.

Table (3.4.1) shows the coefficients for the merchantable volume equations for the three groups.

Table (3.4.1) Coefficients of merchantable volume projection equations

G	Estimates of				STD error of				n
	α	β	Γ	δ	α	β	Γ	δ	
a	0.9862	1.0011	-462.71	3.1631	0.0014	0.0002	5.9968	0.0038	1274
b	0.9957	0.9999	-395.70	3.1096	0.0024	0.0003	9.0497	0.0078	380
c	1.0007	0.9999	-313.30	3.0298	0.0028	0.0004	17.594	0.0180	157

RESIDUAL PLOT OF MERCHANTABLE VOLUME EQUATION

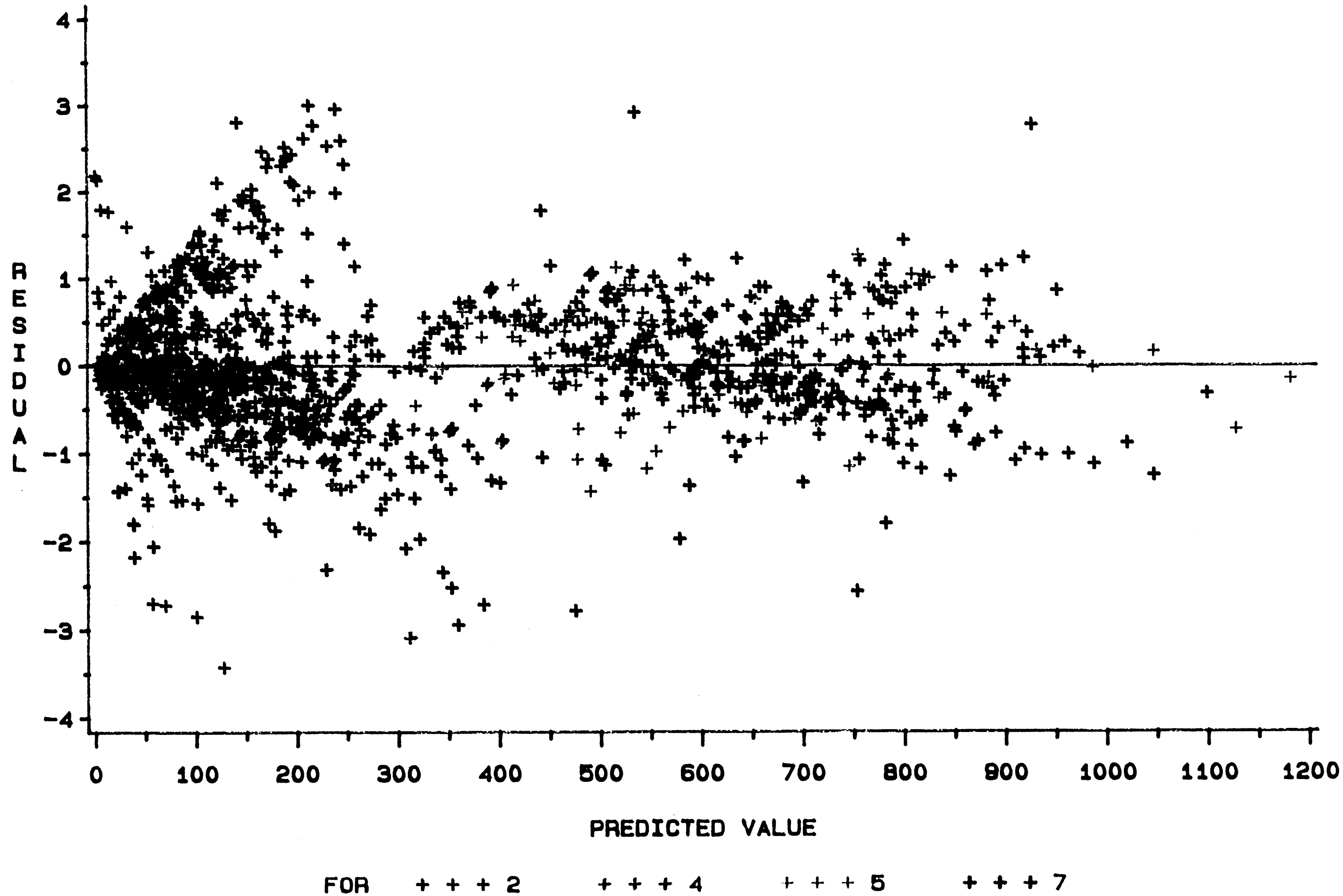

FIG (3.4.1): KAINGAROA DISEASED THINNED STANDS

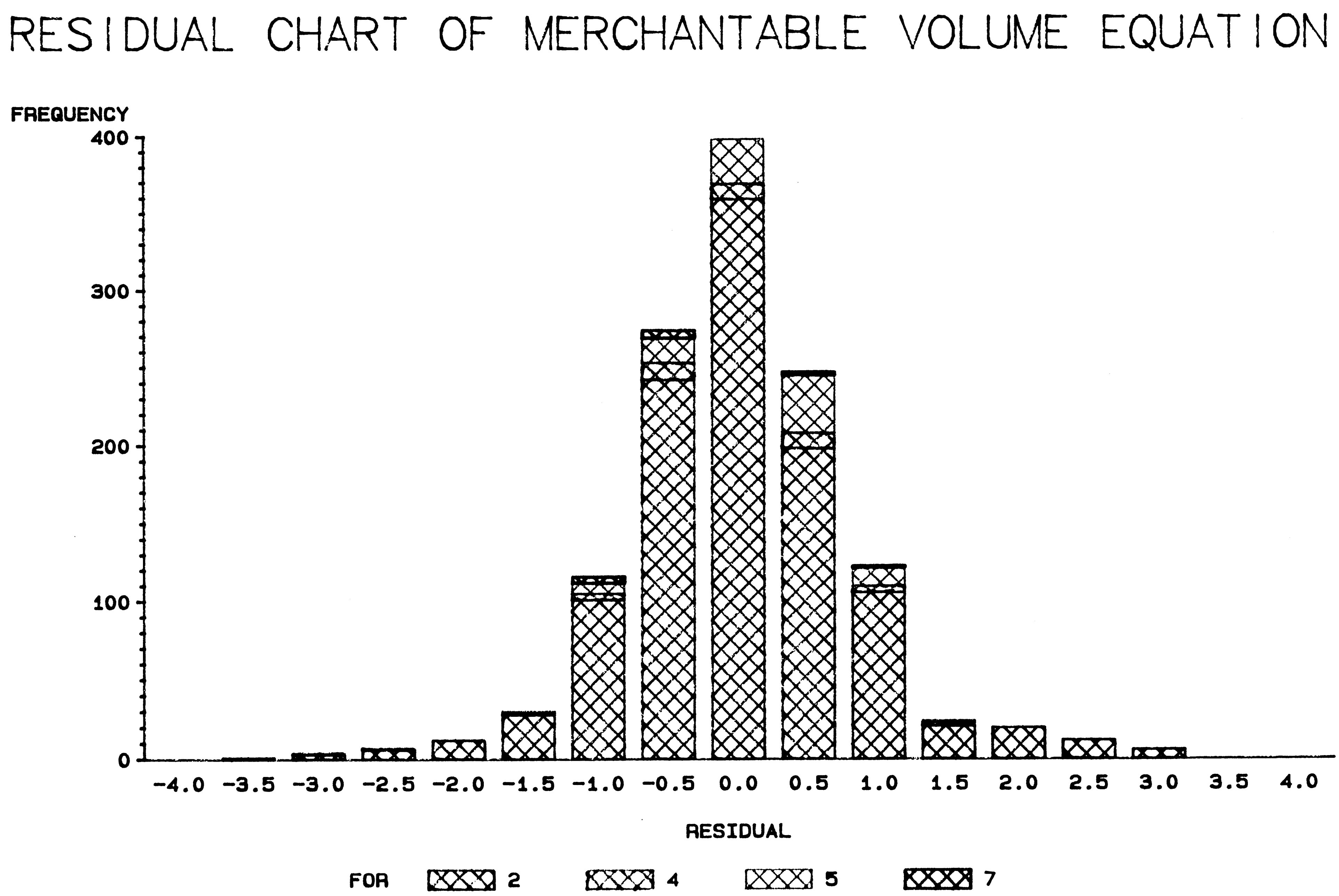

FIG (3.4.2): KAINGAROA DISEASED THINNED STANDS

RESIDUAL PLOT OF MERCHANTABLE VOLUME EQUATION

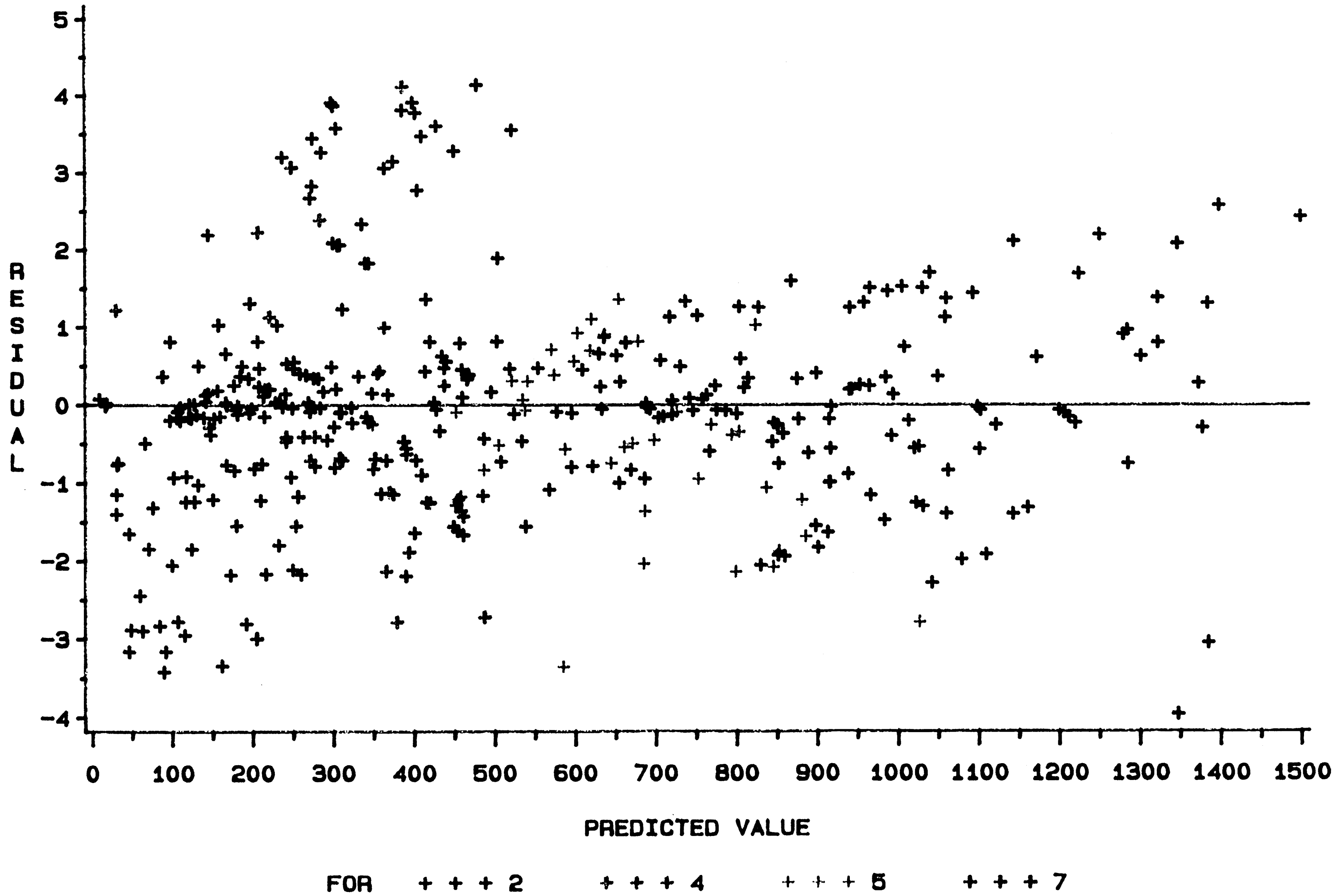

FIG (3.4.3): KAINGAROA DISEASED UNTHINNED STANDS

RESIDUAL CHART OF MERCHANTABLE VOLUME EQUATION

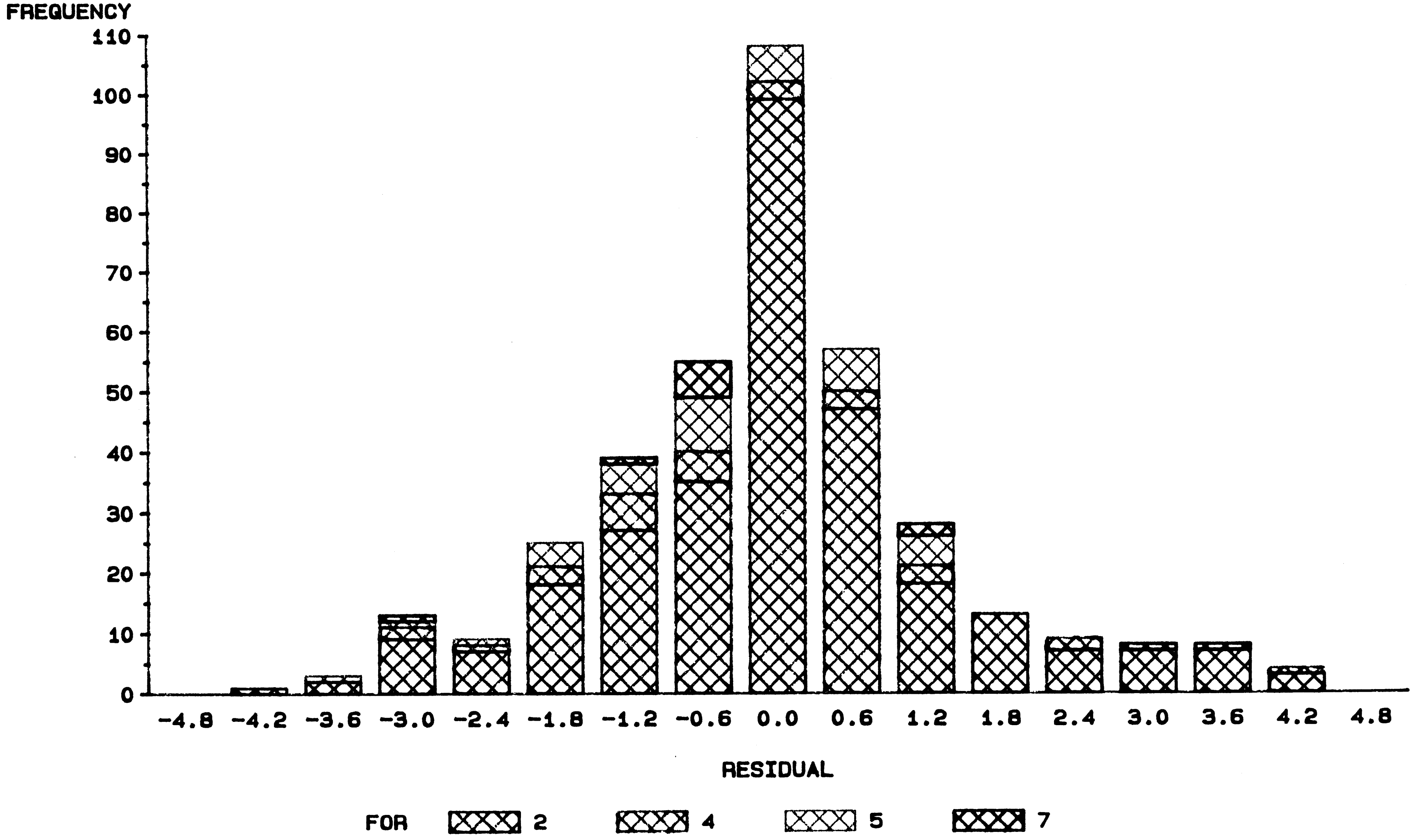

FIG (3.4.4): KAINGAROA DISEASED UNTHINNED STANDS

RESIDUAL PLOT OF MERCHANTABLE VOLUME EQUATION

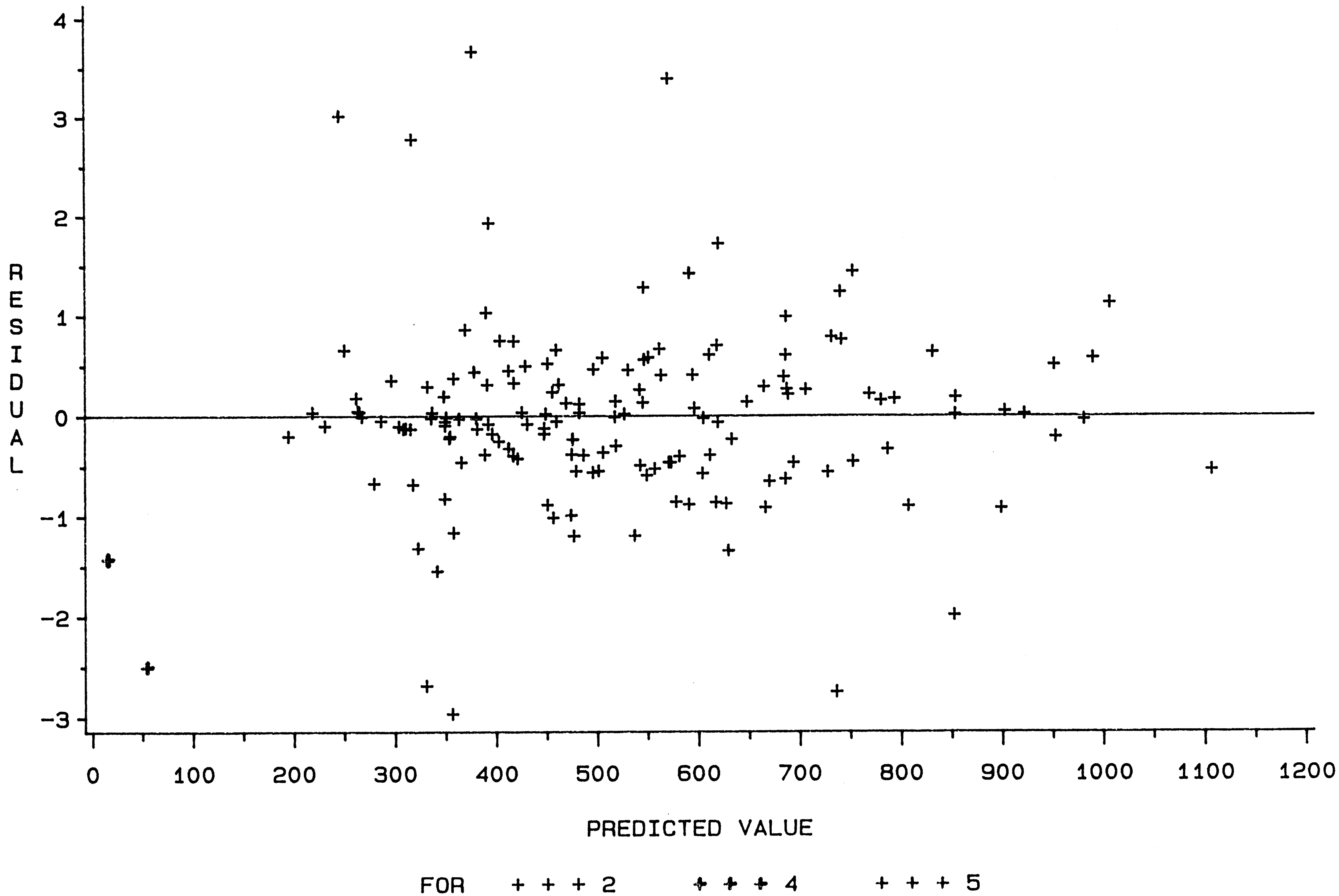

FIG (3.4.5): KAINGAROA UNDISEASED STANDS

RESIDUAL CHART OF MERCHANTABLE VOLUME EQUATION

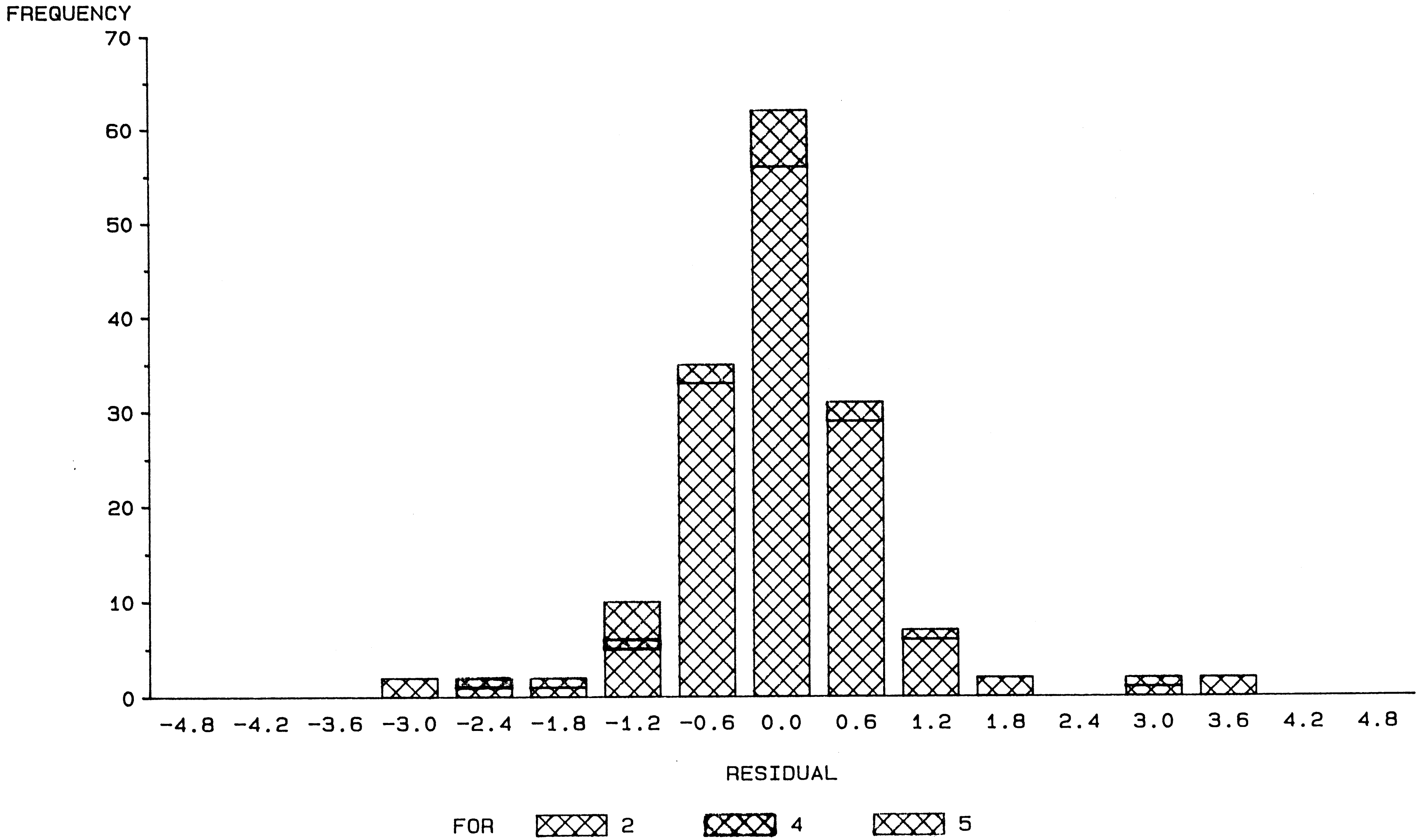

FIG (3.4.6): KAINGAROA UNDISEASED STANDS

3.5. Mortality Function

The mortality equation was formulated by first assuming a mortality rate of:

$$(dN/dT)/N = \beta_0+\beta_1 G+\beta_2/T+\beta_3 S \ldots\ldots\ldots\ldots (3.5.1)$$

then integration of (3.5.1) resulting in (3.5.2):

$$N_2 = N_1(T_2/T_1)^{\beta 2} e^{(T2-T1)(\beta 0+\beta 1G+\beta 3S)} \ldots (3.5.2)$$

The thinning index, X, was introduced into (3.5.2) the equation then became

$$N_2 = N_1(T_2/T_1)^{\beta 2} e^{(T2-T1)(\beta 0+\beta 1G+\beta 3S)X} \ldots (3.5.3)$$

(3.5.3) is further modified into

$$N_2 = N_1(T_2/T_1)^{\beta 2(T2-T1)(\beta 1\Delta G+\beta 3S+\beta 4d)X} \; e^{(T2-T1)(\beta 1\Delta G+\beta 3S+\beta 4d)X} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5.4)$$

The above procedure for deriving mortality equation had been proposed by Clutter et al (1983) and applied by other researchers such as Bailey et al (1985). But the equation formulated here is slightly different in that it contains: X, ΔG and additional power term, $\beta 2(T2-T1)(\beta 1\Delta G+\beta 3S+\beta 4d)X$, (where $X = 1-d_t/d_b$. d_t is the mean diameter of thinned trees, d_b is the mean diameter of the stand before thinning and ΔG is periodic basal area increment) which is the key to success in reducing the residual sums of squares.

The equation reduced the residual sums of squares by 37% comparing to the equation used in DFCNIGM1.

The estimates for this equation are given in following table:

Table (3.5.1) estimated statistics for mortality equation

parameters	estimates	STD errors	MSSE	n
β_1	0.000236748	0.00003740667	724.7	790
β_2	-2.038555111	0.08614757985		
β_3	-0.000532254	0.00006971255		
β_4	-0.021408309	0.00213324567		

The residual patterns of the mortality equation are shown on graphs Fig (3.5.1) and Fig (3.5.2).

RESIDUAL PLOT OF MORTALITY EQUATION

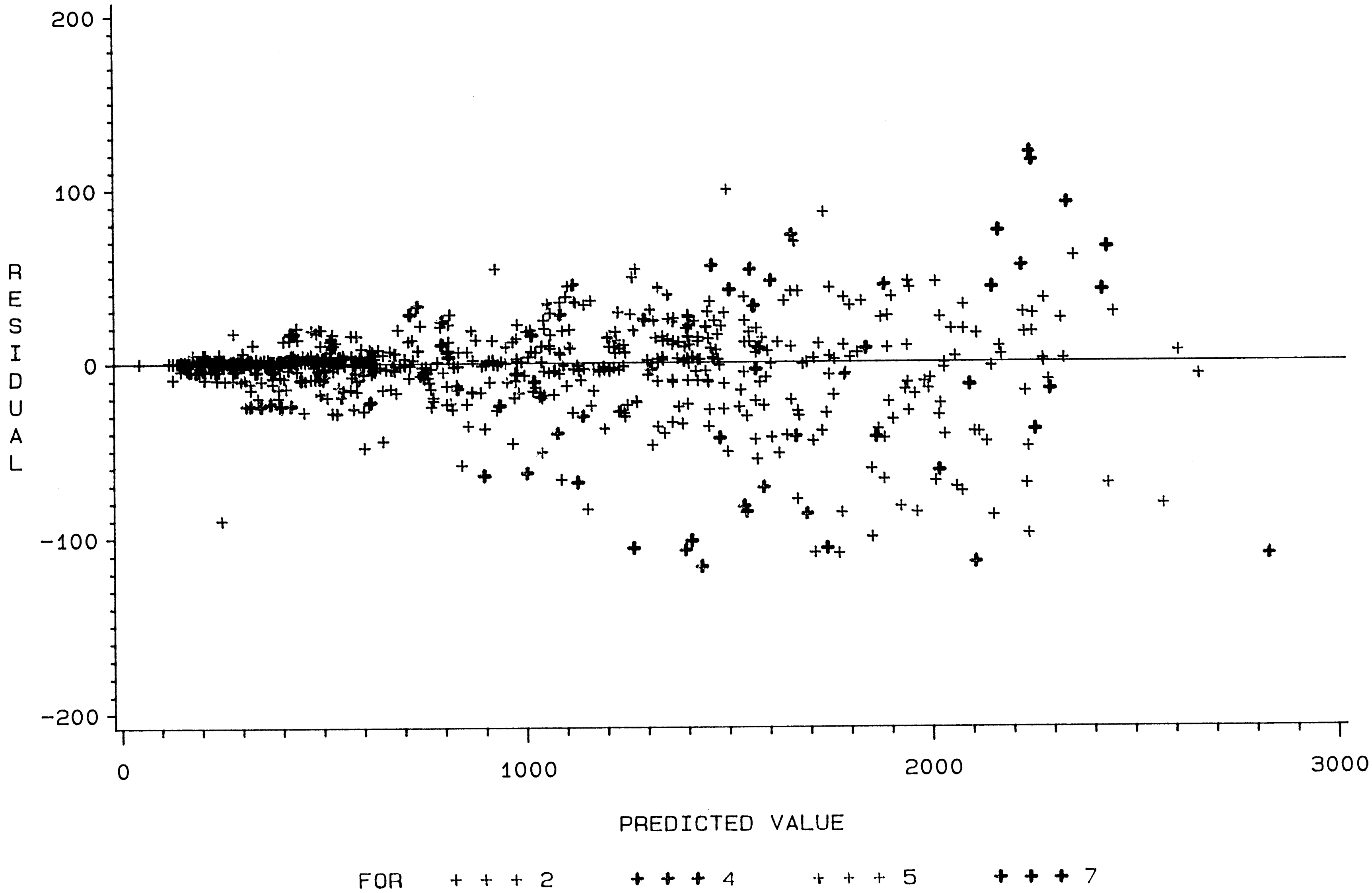

FIG (3.5.1): CENTRAL NORTH ISLAND PLANTATIONS

RESIDUAL CHART OF MORTALITY EQUATION

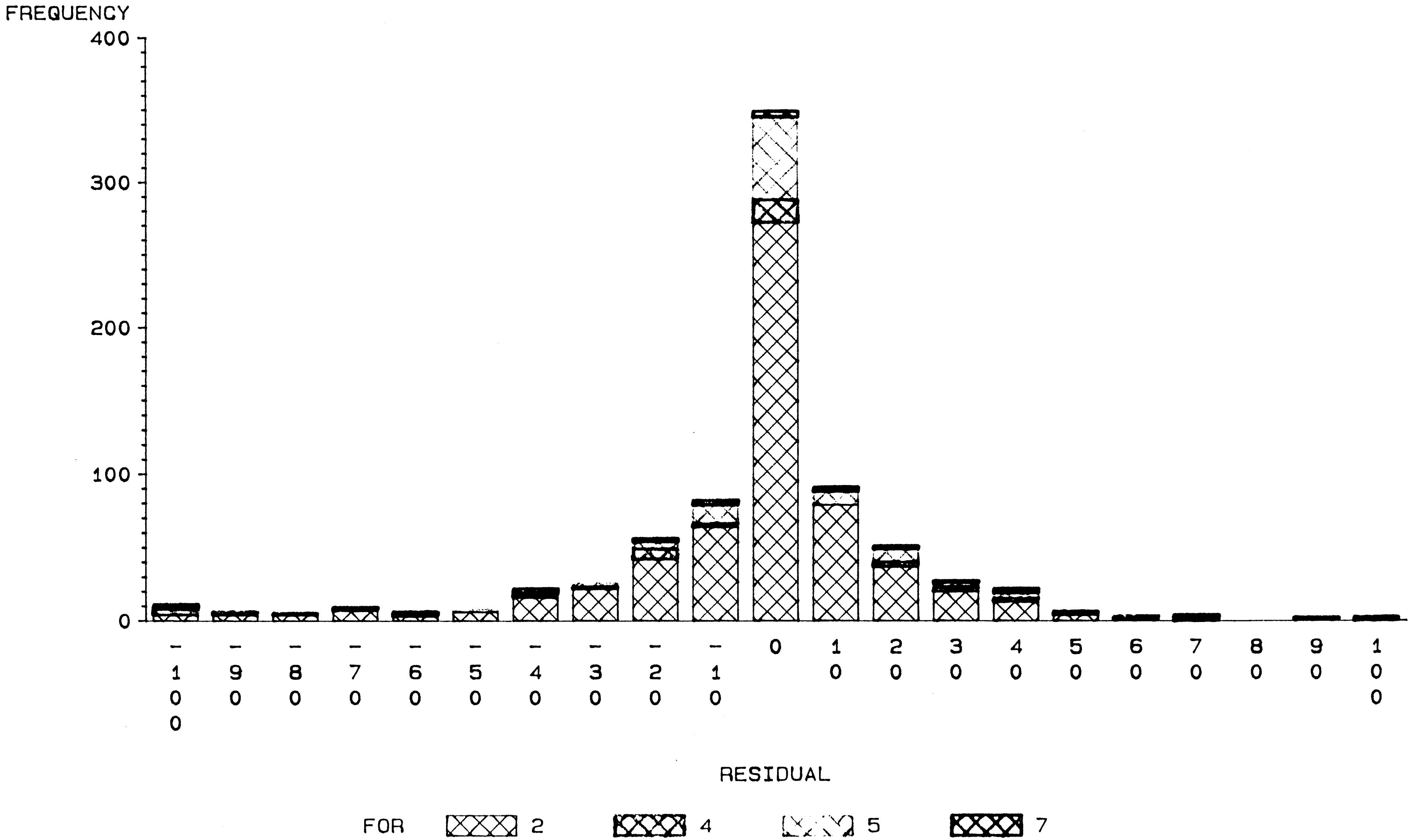

FIG (3.5.2): CENTRAL NORTH ISLAND PLANTATIONS

Chapter 4. Verification and Evaluation

4.1 Bias

There is no significant bias for the major equations in the model, namely mean top height, basal area/ha, stand volume/ha, merchantable volume/ha and mortality equations except in the cases where the numbers of observations available for fitting the equations are small.

Equation for estimating basal area/ha or number of trees/ha after thinning is slightly biased due to an insufficient number of measurements available for fitting the equations. This problem can be avoided if the user specifies the basal area/ha and number of stems/ha after thinning. It is recommended that the user specifies basal area/ha after thinning and lets the model estimate the residual number of trees/ha.

4.2 Limitations to applicability of the model

(1) The age range in the data set should be restricted to between 15 and 70 years of age. Thus this model should not be applied to stands whose age is outside those limits, in particular, the lower end of the range;

(2) The model applies strictly to forests of the Kaingaroa group, i.e. Kaingaroa, Pureora, Waimihia and Whirinaki. However, caution should be taken when it is applied to Pureora because of the reasons given in chapter 2.

4.3 Precision in projection

If an independent data set had been set aside from within the whole data set for validating the model, the modelling itself would have suffered adversely, because:

(a) the number of measurements left in Pureora, Waimihia and Whirinaki, would have been too small to represent growth reliably;

(b) the number of measurements for fitting post-1963 unthinned and pre-1963 sub-models would have been too small.

The whole data set then was used for construction and evaluation.

(1) Mean Top Height and Site Index

In section 3.1.3 it was pointed out that the new site index equation gave almost identical prediction of mean top height in terms of residual pattern to that by Burkhart and Tennent (1977). Table (4.3.1) is the summary statistics of the residual of the new site index equation.

Table (4.3.1) Residual (in m) statistics for site index equation

Number of obser-vations	Minimum residual value	Mean residual value	Maximum residual value	Standard deviation of residual	Absolute mean residual
1769	-1.94	0.008736	2.09	0.571352	0.42

Bias, represented by the mean residual value, is 0.008736 m, when ideally it should equal to 0, though average prediction errors will lie within 0.5 metres.

(2) Basal area/ha

Table (4.3.2) shows summary statistics for the residual values in the basal area equations. Bias is bigger for post-1963 unthinned and pre-1963 groups than for post 1963 thinned. This arises mainly because of the smaller number of observations in these two groups. In any case, prediction errors are no more than 3 m^2/ha, average prediction errors will lie within 1 m^2/ha.

Table (4.3.2) Residual (m^2/ha) statistics for basal area equations

Groups	Number of obser-vations	Minimum residual value	Mean residual value	Maximum residual value	Standard deviation of residuals	Absolute mean residual
a	1308	-1.87	0.0007	1.97	0.55	0.41
b	438	-2.70	0.0606	3.05	0.90	0.67
c	156	-2.27	0.0811	2.88	1.02	0.83

Where
a = post-1963 diseased thinned group;
b = post-1963 diseased unthinned group;
c = pre-1963 undiseased group.
and will apply right through this chapter.

(3) Volume /ha

Table (4.3.3) shows the summary statistics of residuals for the stand volume equations.

able (4.3.3) Residual (m^3/ha) statistics for volume equations

G	Number of obser-vations	Minimum residual value	Mean residual value	Maximum residual value	Standard deviation of residuals	Absolute mean residual
a	1263	-22.65	-0.0560	19.03	6.4757	4.7
b	377	-44.78	-0.5060	40.28	17.7613	13.7
c	163	-37.05	-0.4341	29.25	9.9363	7.1

The standard error of the intercept for the total volume equation in the post-1963 thinned group is nearly one third of the estimate and is a bit high. Residual bar chart for post-1963 unthinned is not so well-balanced [Fig. (3.3.4)]. Otherwise the total volume equations behave well.

(4) Merchantable Volume/ha

Table (4.3.4) shows the summary statistics of residuals for merchantable volume equations.

Table (4.3.4) Residual (m^3) statistics for merchantable volume equations

Groups	Number of observations	Minimum residual value	Mean residual value	Maximum residual value	Standard deviation of residual	Absolute mean residual
a	1274	-3.42	0.0045	3.00	0.7968	0.5843
b	380	-3.97	-0.0560	4.14	1.4181	1.0229
c	157	-2.96	-0.0187	3.67	0.9205	0.6065

In terms of error mean squares, residual pattern, bias and goodness-of-fit, the merchantable volume equation is one of the best equations to be found for this data set.

Note that the residual values for merchantable volume in Table 4.4 are very small. They should be, since they are based on total volume.

(5) Mortality

The minimum, maximum and mean of the residuals of the mortality equation are -117, 121 and -3 respectively with an average prediction error of 16 trees per hectare.

4.4 Projection logic in terms of common biological relationship

For a given site index (e.g. 31 m) and basal area (e.g. 45 m^2/ha) and initial stocking (e.g. 1000 trees/ha) volume increased as age increased [Table (4.4.1)].

For a given age (20), initial basal area/ha (45 m^2/ha) and the same stocking level as above, volume forecasts increased as site index increased [Table (4.4.2)].

For a given age (20) and site index (30) volume increased as basal area/ha increased [Table (4.4.3)]. This demonstrates that projection is biologically realistic.

Table (4.4.1) For a given site index, BA/ha and N/ha, volume increased as age increased.

Age (yrs)	Top height (m)	Stocking (N/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	M-volume (m^3/ha)
20	17.0	1000	45	290	213
25	20.8	1000	45	347	255
30	24.6	1000	45	405	297
35	28.0	1000	45	456	335
40	31.0	1000	45	502	369
45	33.6	1000	45	542	398
50	35.9	1000	45	576	423
55	37.9	1000	45	606	445
60	39.7	1000	45	632	465

Table (4.4.2) For a given age, BA/ha and N/ha, volume increased as site index increased.

Age (yrs)	Site index (m)	Stocking (N/ha)	Basal area (m_2/ha)	Volume (m^3/ha)	M-volume (m^3/ha)
20	20	1000	45	194	143
20	25	1000	45	235	173
20	30	1000	45	275	202
20	35	1000	45	316	232
20	40	1000	45	356	262
20	45	1000	45	397	292
20	50	1000	45	438	321

Table (4.4.3) For a given age, site and N/ha volume increased as basal area/ha increased.

Age (yrs)	Site index (m)	Stocking (N/ha)	Basal area (m^2/ha)	Volume (m^3/ha)	M-volume (m^3/ha)
20	30	1000	30	184	103
20	30	1000	35	215	136
20	30	1000	40	245	169
20	30	1000	45	275	202
20	30	1000	50	306	235
20	30	1000	55	336	268
20	30	1000	60	366	300

4.5 Thinning effect on yields

In order to analyze the effect of thinning on yield, three examples of thinning regimes are specified below (the regime for the comparison is given in brackets).

initial condition:
site index: 30 m;

initial age: 20 years;
initial basal area: 45 m^2/ha;
initial stocking: 1500 stems/ha.

(1) number of thinnings
thin to 20 m^2/ha at age 20;
project to age 30 and thin to 20 (50) m^2/ha;
project to age 40 and thin to 20 m^2/ha;
project to age 70.

(2) weight of thinning with the same initial conditions
thin to 20 m^2/ha at age 20 (20);
project to age 30 and thin to 20 (40) m^2/ha;
project to age 40 and thin to 20 (45) m^2/ha
project to age 70.

(3) time effect on thinning with the same initial conditions
project to age 20 (30) thin to 30 m^2/ha;
project to age 30 (40) thin to 40 m^2/ha;
project to age 40 (50) thin to 45 m^2/ha.
project to age 70.

The effect of number of thinnings, weight of thinning, and time of thinning on yields are shown on Tables (4.5.1) to (4.5.3).

Table (4.5.1) Effect of number of thinning on yields

Age	Total volume for stand thinned three times	Total volume for stand thinned once	Differences between the two
20	275	275	0
30	333	584	-251
40	343	699	-356
50	356	939	-583
60	494	1146	-652
70	625	1320	-695

Table (4.5.2) Effect of weight of thinning on yields

Age	Total volume of heavy thinning	Total volume of light thinning	Differences between the two
20	275	275	0
30	333	441	-108
40	343	587	-244
50	356	693	-337
60	494	881	-387
70	625	1045	-420

Table (4.5.3) Effect of time of thinning on yields

Age	Total volume of stand thinned earlier	Total volume of stand thinned later	Differences between the two
20	275	275	0
30	441	584	-143
40	587	470	117
50	693	629	64
60	881	731	150
70	1045	885	160

These tables show that:

(1) final yield decreases as the number of thinnings increases;

(2) final yield decreases as weight of thinning increases;

(3) final yield decreases if the same thinning is delayed.

4.6 Differences between yields projected for diseased and undiseased stands.

One should note, that it is hard to estimate by how much yields produced by the diseased and undiseased stands differ. It not only depends on whether or not the stands are diseased but also on some other stand conditions, such as age, number of thinnings, intensity of thinning, and time of thinning etc.

To give the reader a general idea of how much yield difference there is between diseased and undiseased stands, an average stand condition is specified below and a rough comparison made.

Initial stand condition:

initial age 20 years;
site index 30 m;
initial stocking 1500 stems/ha;
initial basal area 45 m^2/ha.

age and thinning conditions:

at age 20 thinned to 30 m^2/ha;
project to age 25 and thinned to 30 m^2/ha;
project to age 30 and thinned to 30 m^2/ha;
project to age 70

Based on the same condition specified above, projections are made for diseased and undiseased stands. Table (4.6.1) shows the differences in projected yields at specified ages.

Table (4.6.1). Yield differences between diseased and undiseased stands at specified stand conditions

Age	Volume of diseased stand	Volume of undiseased stand	Yield difference (m^3/ha)	Percentage difference (%)
20	275	268	7	2.6
30	338	395	-57	-14.4
40	470	612	-142	-23.2
50	673	989	-316	-32.0
60	859	1331	-472	-35.5
70	1022	1620	-598	-36.9

From Table (4.6.1) one can roughly say that for a young stand (30 years of age), a diseased stand produces about 15 % less volume than that of the same undiseased stand and it is about 35% less for old stands (60 years of age).

Note that in the above projections, the same amount of basal area/ha remains after thinning for diseased and undiseased stands. If the same amount of basal area/ha is removed in thinning for diseased and an undiseased stands, the difference will be much bigger because undiseased stand produces more volume in the same growth period than that of a diseased stand.

4.3. Feedback from users

Users are the ones who are most familiar with the forests and their growth and yield. Thus, their judgement about the projection precision of the model is important. The model is a tool developed for the users. The ways it requires the inputs and gives outputs ought to suit users' tastes. Thus, any feedback from the users is welcomed.

4.4. Possible refinement to the model

In order to get more detailed information about stand development and to improve precision, the following important refinements to the model are envisaged.

(1) a diameter distribution model is needed in order to economically evaluate thinning options and this can be done by disaggregating the stand level model to a compatible diameter distribution model using the parameter recovery procedure (Hyink, 1980. Frazier, 1981. Matney and Sullivan, 1982. Cao and others, 1982. Cao and Burkhart, 1984. Hyink and Moser 1983. Knoebel and others, 1986);

(2) although there is a lack of disease information, an improvement to the basal area projection equations is necessary and possible, using a disease index derived from individual tree information;

(3) the mortality function might also be improved.

These refinements, particularly (1) and (2) , involve manipulation of individual tree data and will be more laborious.

Appendix

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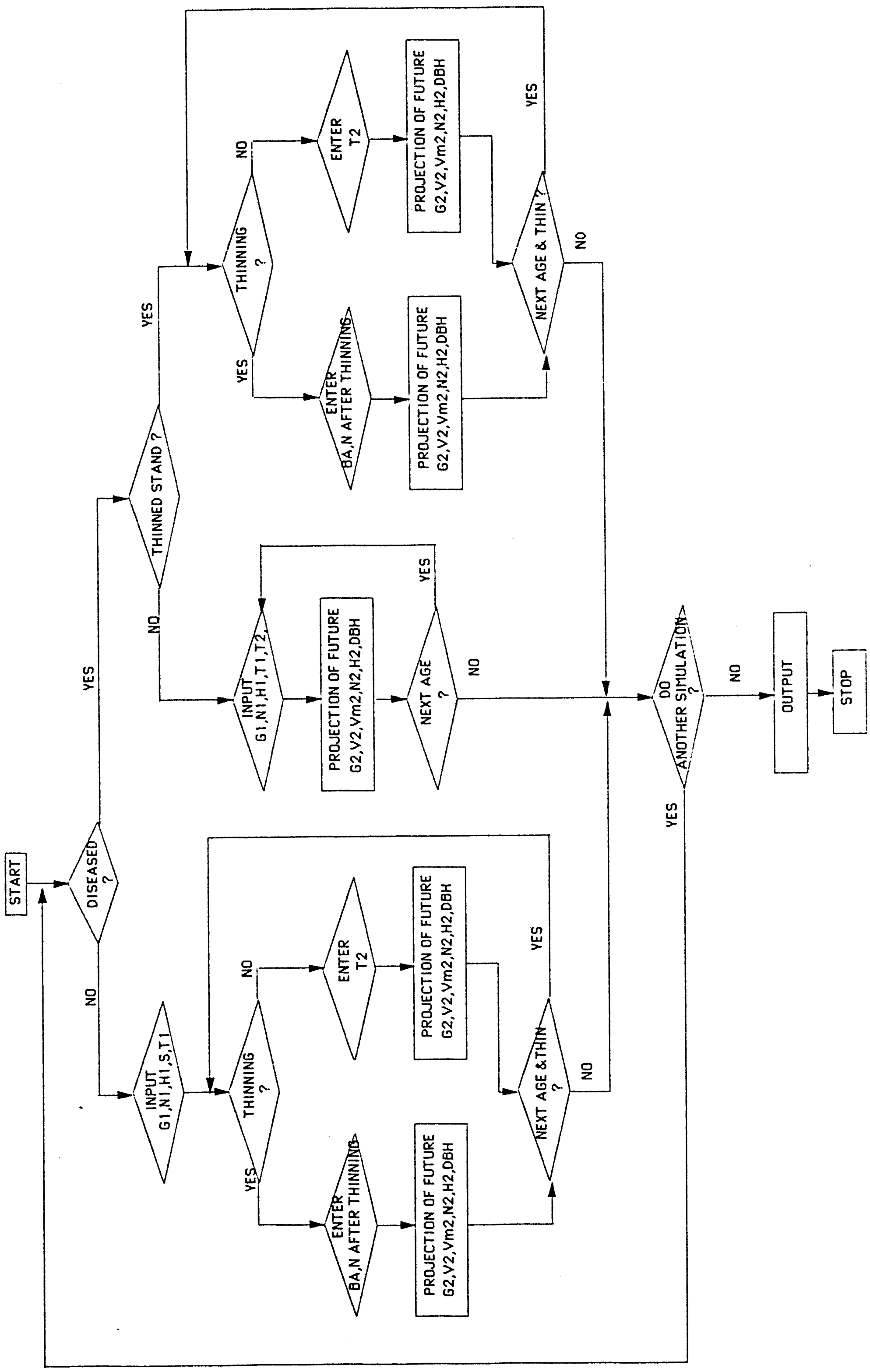
3. Computer Programme DFCNIGM2(floppy disk)



FLOW CHART FOR DFCNIGM (DOUGLAS FIR CENTRAL NORTH ISLAND GROWTH MODEL)

4. Instructions for running the programme

The DFCNIGM2 is started, at the DOS prompt, by entering DF. A short description of the model is then given, followed by a series of questions to which the user must respond. The first such prompt on the screen asks the user if a hardcopy (or printout on the printer) is required: if yes, Y is entered, N if not. The next request is for 2 or 3 numerical starting values, namely site index, age , mean top height at that age: if any of these values is unknown, enter 0 (zero). Given any 2 of these 3 values, the third can be derived and then displayed on the screen; if all these have non-zero values, a reconciliation for consistency is made, but then the program operates on the given mean top height and age entries. The remaining stand starting values are initial stocking (N/ha) and initial basal area/ha for the specified starting age, separated by a comma.

At this point, there are different branches to the program, depending upon the inputs entered. For stands infected with Swiss needle cast, Phaeocryptopus gaeumannii, a Y is entered at the prompt, N if not on either branch. The next question relates to whether or not the stand has been or will be thinned, both categories requiring a Y entry whereas for neither, N applies. For this Y subbranch, thinning can be simulated. For the N Sub-branch, thinning options are not available whatsoever.

Initial output at this point provides a summary of the starting values that have been just entered and then the start of the yield tabulations of mean top height, stocking/ha, basal area/ha, mean dbhob, total stem volume/ha and merchantable volume to a 15 cm top end diameter for input age. Output appears on the screen automatically and simultaneously on the printer if the response was Y to a hardcopy. The stand can then be grown forward year by year after entering an age in years, or thinned at any time through entering a T, or stopped if an S is entered.

Where T is the response, the following data should be supplied by the user: basal area/ha and/or number of stems/ha to remain after thinning. The former is the preferred option. Output then relates to thinnings removed in terms of stocking, basal area, mean dbhob, total stem and merchantable volumes. The simulation of the stand growth can then be conducted forwards through time.

The same options are available for the thinned, undiseased stands, while, for unthinned stands the forwards growth and yield simulations are available but not a thinning option. To carry out another simulation, Y can be used when prompted with the question.