FRI/INDUSTRY RESEARCH COOPERATIVES

MANAGEMENT OF EUCALYPTS COOPERATIVE

FOREST RESEARCH INSTITUTE
PRIVATE BAG
ROTORUA

VALIDATION OF THE NZFP FORESTS *EUCALYPTUS REGNANS* GROWTH MODEL

HEATHER MCKENZIE
FOREST RESEARCH INSTITUTE

REPORT NO. 7 MARCH 1990

MANAGEMENT OF EUCALYPTS COOPERATIVE

VALIDATION OF THE NZFP FORESTS *EUCALYPTUS REGNANS* GROWTH MODEL

HEATHER MCKENZIE
FOREST RESEARCH INSTITUTE

REPORT NO. 7 **MARCH 1990**

FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

Validation of the NZFP Forests *Eucalyptus regnans* growth model

In 1988 the NZFP Forests *E.regnans* growth model was contributed to the Management of Eucalypts Cooperative. Since its formation the Cooperative has concentrated on gathering data on *E. regnans* growth over a wide range of sites and stockings in a new series of permanent sample plots and by continuing measurement of the FRI regime trial. This report shows the data that has been collected and uses it to validate the NZFP Forests model.

The model does not have a thinning function so that data from thinned plots is divided into before and after thinning datasets. This reduces time intervals over which to run the model. As with the model data base there is little data beyond age 15 years.

For the sample plots as a group the error as a % of final basal area or height is reasonable although there is a tendency to overpredict in some regions.

For the regime trial which has been measured for 10 years the error as a % of final basal area or height is high if the initial values are set at age 3 years. The predictions improve with time and are reasonable when the initial age is 8 years.

The model will be useful for members wishing to predict growth for unthinned stands up to about age 15 if the tendency to overpredict is taken into account.

It is recommended that the Cooperative continue to collect data to provide the basis for a new growth model. The next model should include thinning functions, allowance for site quality and extend beyond age 15. Additional plots covering a range of stockings located in one stand would be valuable.

1 Introduction

1.1 Cooperative Objective.

The objectives of the Cooperative are:

To investigate the growth and yield of a selected number of eucalypt species, over as wide a geographical range and as wide a range of silvicultural regimes as practicable.

First to develop, and to disseminate to members a eucalypt data base. Second, to develop a eucalypt growth and yield model based on that data base.

The formation of the cooperative has seen the *E.regnans* database extended from one replicated regime trial and four other plots to include 74 new plots over the planted range of the species in New Zealand. These plots have had too few measurements to use for growth modelling so access to an independently derived model is an important contribution to the objects of the cooperative. The validation of this model provides an opportunity to disseminate a summary of the *E. regnans* data in the database.

2 The NZFP Forests Model

2.1 NZFP Forests *E. regnans* Database.

In 1988 the NZFP Forests *Eucalyptus regnans* growth model was contributed to the Management of Eucalypts Cooperative (Hayward 1988). The data used for the model is only available in graphical form. It can be summarised as follows:

2.1.1 Age

The plots were established at age 3 or 4 and measured for 10 or 11 years.

2.1.2 Stocking

The stocking varied from approximately 400 s/ha to 2500 s/ha at age 3 or 4. Thinning at age 4, 7 or 14 has apparently occurred in a few plots. There is a reduction in stocking due to mortality. For instance a plot of 1900 s/ha at age 3 would appear to loose 700 s/ha over the next 10 years whilst a plot of 900 s/ha would loose 200 s/ha over the same period.

2.1.3 Mean Top Height

The majority of plots were between 8 and 12 m Mean Top Height (MTH) at age 4 and by age 14 the spread was from 25 to almost 40 m. This appeared to be a result of the height growth dropping off in some plots. This would indicate that there may be a range of site indices but several more years measurement are required to show if this is the case.

2.1.4 Basal area

Basal area ranged from approximately 1 m^2/ha to 22 m^2/ha at age 4 and was 33 to 63 m^2/ha at age 14.

2.2 Elements of the Model

The model is described in the Management of Eucalypts Cooperative Report No. 4

The model is of the following form:

2.2.1 Basal Area

$$\ln G_2 = \frac{T_1}{T_2} \ln G_1 + \alpha_1\left(1 - \frac{T_1}{T_2}\right) + \alpha_2 N\left(1 - \frac{T_1}{T_2}\right)$$

where G_1 = Basal area/ha at age T_1

G_2 = Basal area/ha at age T_2

N = Initial stems/ha

$\alpha_1 \quad = 4.5352$

$\alpha_2 \quad = -0.0000937$

2.2.2 Mean Top Height

$$\ln H_2 = \left(\frac{T_1}{T_2}\right)^{\beta_1} \ln H_1 + \beta_2 \left(1 - \left(\frac{T_1}{T_2}\right)^{\beta_1}\right)$$

where H_1 = Plot Mean Top Height at age T_1

H_2 = Plot Mean Top Height at age T_2

β_1 = 0.5356

β_2 = 4.7541

2.2.3 Volume

$$V = \gamma_1 G H e^{\frac{\gamma_2}{H}}$$

where V = Volume / ha

G = Basal area / ha

H = Mean Top Height

γ_1 = 0.4088

γ_2 = -1.4499

3 Validation

3.1 Data for validation

3.1.1 Time interval

Goulding (1979) discusses validation of growth models. Both permanent sample plot and detailed forest inventories can be used. He points out that for the former a 15-20 year span of measurement is desirable. Plots measured over shorter periods have considerable variability because of measurement and sampling error and, importantly do not allow growth patterns to be compared.

The data available for validation of the Hayward NZFP *E. regnans* growth model is limited to the Cooperative database that has been established since 1986 and the *E. regnans* regime trial established in 1978 as well as 2 plots with a similar period of regular remeasurement on a farm site. The data is divided into the regime trial and permanent sample plots (PSPs) and they are considered separately. Some plots have been measured for 3 or 4 years. However if a thinning has occurred the data must be broken into before and after thinning subsets because there is no thinning function in Hayward's model. For example plots that may have been measured for 3 years may become two sets of data each of 1 and 2 year intervals. Figure 1 shows the time interval available plotted against initial age for the PSPs. The constraint on analysis in this case is that a large difference between predicted and actual growth may be the result of unusual growing conditions over the short period when the plots were measured.

3.1.2 Geographic Range

The data is of a quite different nature to that used for the growth model. The growth model data was collected systematically in the plantations of NZFP Forests over a period of time. They cover the geographic range of their plantations, stockings and age distribution. The Cooperative plots have been established in most of the areas of *E.regnans* known to exist in New Zealand and they reflect the age of these stands at present. The plots have a reasonable geographic distribution in the North Island (Figure 2) although the number of plots in some areas is low. The central North Island area is strongly represented with most plots within 50 km of Rotorua. The number of plots in any stand or area depends on the stand area and the resources available for measuring the plots. This has resulted in an arbitrary set of data in terms of location and number of plots in each area.

3.1.3 Age Distribution

The age distribution is not particularly good with little represented beyond age 15. This reflects the age of the stands in New Zealand. A survey of stands owned by members of the cooperative has resulted in the best possible sample.

3.1.4 Derivation of Plot variables

Height

The Mean Top Height (MTH_{100}) is used in all cases. MTH is derived from Mean Top Diameter (MTD). Mean tree diameter is calculated using the average basal area in a plot; MTD is the mean diameter of the largest 100 trees/ha by diameter. To derive MTH a sample of trees, usually 12, are measured and their heights regressed against diameter. MTH is then the height calculated from the MTD using this regression.

The plot diameter distribution and the sample of trees for height measurement both influence the estimate of MTH. In small samples such as the single plots used here, there will be more variability from this cause than in the larger sample used in Hayward's derivation. Therefore a large variation between the predicted height and that calculated for a particular plot should not necessarily be taken as showing that the model predicts height poorly. It may simply indicate an unusual diameter distribution or poor selection of sample trees.

Basal Area

Basal area is measured (not estimated) for each plot because the diameter of each tree is measured. The model can be most reliably tested for this.

3.1.5 PSP Data Base

In Figures 3 , 4 , 5 and 6 data for the PSPs is shown graphically by stocking, basal area, height and volume.

3.1.6 Regime Trial

The regime trial was planted in 1978. The objective was to evaluate 11 alternative silvicultural schedules covering options for sawlog, pulpwood and mixed objective regimes. The schedules were modified in 1986 to give a wider range of final crop stockings to strengthen the trial data for growth modelling purposes. Annual measurements commenced at age 4. The Regnans trial data is shown in Figures 7 , 8 , 9 and 10 by stocking, basal area, height and volume.

3.2 Analysis

3.2.1 Data identification

The ownership of plots is described in a way so that the ownership of them can not be identified. This is in accordance with the concern expressed when the Cooperative was founded that data be kept confidential. The data is thus identified by a computer generated plot identification number (plot-key) used in the FRI PSP system. The data was divided into the regime trial and the PSPs. Some PSPs had received a thinning and some treatments in the regime trial had been thinned once or twice. The model was used to predict the growth over periods between thinnings if they occurred. The before thinning data had 100000 added to the plot-key number and the post thinning data had 200000 added. Each owner will be able to identify their plots from the information given in Appendix 1.

3.2.2 Comparison of Model with Permanent Sample Plots

The NZFP Forests model is based on stands over 400 s/ha whilst the PSP data base includes a large proportion of plots under 400 s/ha if not at the first measurement then after a thinning. The model first is tested against data with stocking above and below 400 s/ha for an initial value.

Method

The difference between predicted and actual PSP values, divided by the time interval for the prediction to give an annual figure, were calculated. This enabled the results from a number of different trials to be compared. To enable comparison between plots with a wide range of heights and basal areas the errors were expressed as a percent of the final actual values. The data was then analysed graphically to determine how well the model predicted basal area and height. If large differences between actual and predicted were apparent any factors that were available such as initial stocking or height were analysed graphically in order to see if the cause of the difference could be identified. Please note: symbols and colours can vary depending on the sample included in the graph. Check the key for plot identity.

Volumes reported by the PSP system were not included in the validation because of inconsistency in volume computation methods. The model predicts stand volume from basal area and MTH, while the PSP volumes are based on tree volume calculations for a sample of trees (see below for details). Even when basal area and MTH were well predicted by the model there were substantial discrepancies with the PSP volumes[1]. Some extreme examples are shown in Table 1.

Table 1: Plots with high volume prediction error compared to height and basal area predictions

Plot Key	Basal area error % Actual	Height error % actual	Volume error % actual
13131	1.6	-1.0	32.0
13234	1.2	0.9	20.6
100069	0.5	0.1	16.6
200215	-1.0	0.9	-19.0

1 Application of Hayward's stand volume function to the actual basal area and height would give results consistent with the accuracy in prediction of basal area and height, but the comparison would add little to the validation.

The volume in the PSP plot is calculated as follows. The volume is calculated from diameter and height using Hayward's (1987) tree volume function for those trees with a height measurement. A volume-basal area regression is derived for these trees and applied to the total basal area of the plot to obtain total plot volume. Once again the sample of trees for the regression will influence the result. Inspection of one of the plots (100069) showed there was nothing unusual about the diameter distribution or height sample. The large discrepancy between the predicted stand volume and the volume calculated for the PSP may only reflect sampling error in the latter. A larger number of plots would be required to make a more meaningful comparison with the model's volume function.

Plots with stocking greater than 400 s/ha.

Basal area and height error as a % of actual graphed, against actual PSP values (Figure 11 and Figure 12) show that height is tending to be over predicted. The number of plots that have height over predicted may reflect the existence of several plots in a stand where the model does not work well. Where there are several plots in close proximity they had a similar error %. However plots 1000067, 1000068 and 1000069, which are all in close proximity in one stand, varied from 0.2 through -9.9 to -18.4 %.

Basal area is well predicted for the plots as a group.

Plots with stocking less than 400 s/ha.

Basal area and height error as a % of actual, graphed against actual PSP values (Figure 13 and Figure 14) show that height is tending to be over predicted again and in fact the cluster of plots below the line are in Kinleith forest. Although the model was derived from data in Kinleith forest this result is from new plots that have been thinned below the range the model covers. The selection of trees of good form in the plot could have reduced the height.

Basal area was predicted better than for the over 400 s/ha group of plots.

All plots by stocking

Figures 15 and 16 show the error % of actual basal area and height graphed against stocking for all the plots. No relationship is evident so further analysis was not undertaken.

All plots by Age

Figures 17 and 18 show the error % of actual basal area and height graphed against initial age for all the plots. The prediction of basal area improves with the age of the trees in the plot. The pattern is not so clear for height.

All plots by location

The maintenance of confidentiality makes a full description impossible. However plot owners will be able to identify their own plots and compare them with the other plots.

Height and basal area tended to be overpredicted in most central North Island, Bay of Plenty forests but the there was a mix of over and underprediction for some. The over prediction was more consistent for plots on the eastern side of the North Island. Whilst there was no pattern for basal area in Taranaki and Southland the height was over predicted in these regions.

3.2.3 Comparison of Model with Regnans Trial

3.2.4 Method

The error as a % of the actual basal area or height have been graphed against the initial height for the prediction Figures 19 and 20 . This separates the different thinnings. The colour code indicates to what age the prediction was run. Initial age was not used as it produces a column of marks that are difficult to separate. The use of height spreads the points out on the graph.

3.2.5 Basal area

In Figure 19 the blue crosses represent plots that were measured at age 4 and thinned at age 5. The error over that period is up to 30% of actual basal area. The green crosses under 11m initial height represent those plots not thinned again or unthinned. This means the model was run from age 4 or 5 until age 11. The prediction is very much better with an error % of less that 10 generally. The red crosses represent the prediction of the model when run from age 5 to 8 when thinnnings occurred. The green crosses above initial height 14 are for thinning at age 8 to 11. The model is predicting basal area much better with the error % of actual final basal area generally less than 10%.

3.2.6 Height

A similar pattern emerges for height in Figure 20. except that the error as a % of actual final is less than 10. The model predicts height well over the period 8 to 11 years.

4 Discussion

The changing behaviour of the regnans trial over time should be a warning that a year or two of measurement is not ideal for validating a growth model. The results of the validation are however quite encouraging in terms of usefulness. When the model is used to predict growth for all the PSP data then there is a good prediction of basal area for the plots as a group although height tends to be overpredicted. If members wish to use the model they would be advised to use sufficient plots to provide a good estimate of initial basal area and height and use the results with caution until more data can be collected particularly in their region. How well the model predicts over long periods of time particularly past age 15 is not known as the model and validation data do not extend past this age. The older the stand used to set initial values, the better the prediction is likely to be.

5 Recommendations

The NZFP *E.regnans* growth model may be quite useful to members for predicting growth in their stands to about age 15. The error range, + or - 20 %, is similar to that found in validation of a *P.radiata* model (West et al 1987). However the height prediction component of the model is likely to overpredict so that allowance should be made for that. The most serious deficiencies are the lack of a thinning function and the age limit for applicability. The data being collected by the Cooperative covers a much wider range of silvicultural schedules and will over time produce data on older stands. A new model to incorporate an extended range of data would have much wider applicability. Continuation of the collection of data from the Cooperative plots will increase their usefulness for this purpose. Two members of the cooperative have established series of plots within stands that are thinned to a range of stockings. These will be useful for growth modelling as the effect of site will be much reduced and the effect of the thinning can be analysed.

6 List of Figures

FIGURE 1 – TIME INTERVAL FOR SAMPLE PLOTS

(BETWEEN THINNINGS FOR THINNED PLOTS)

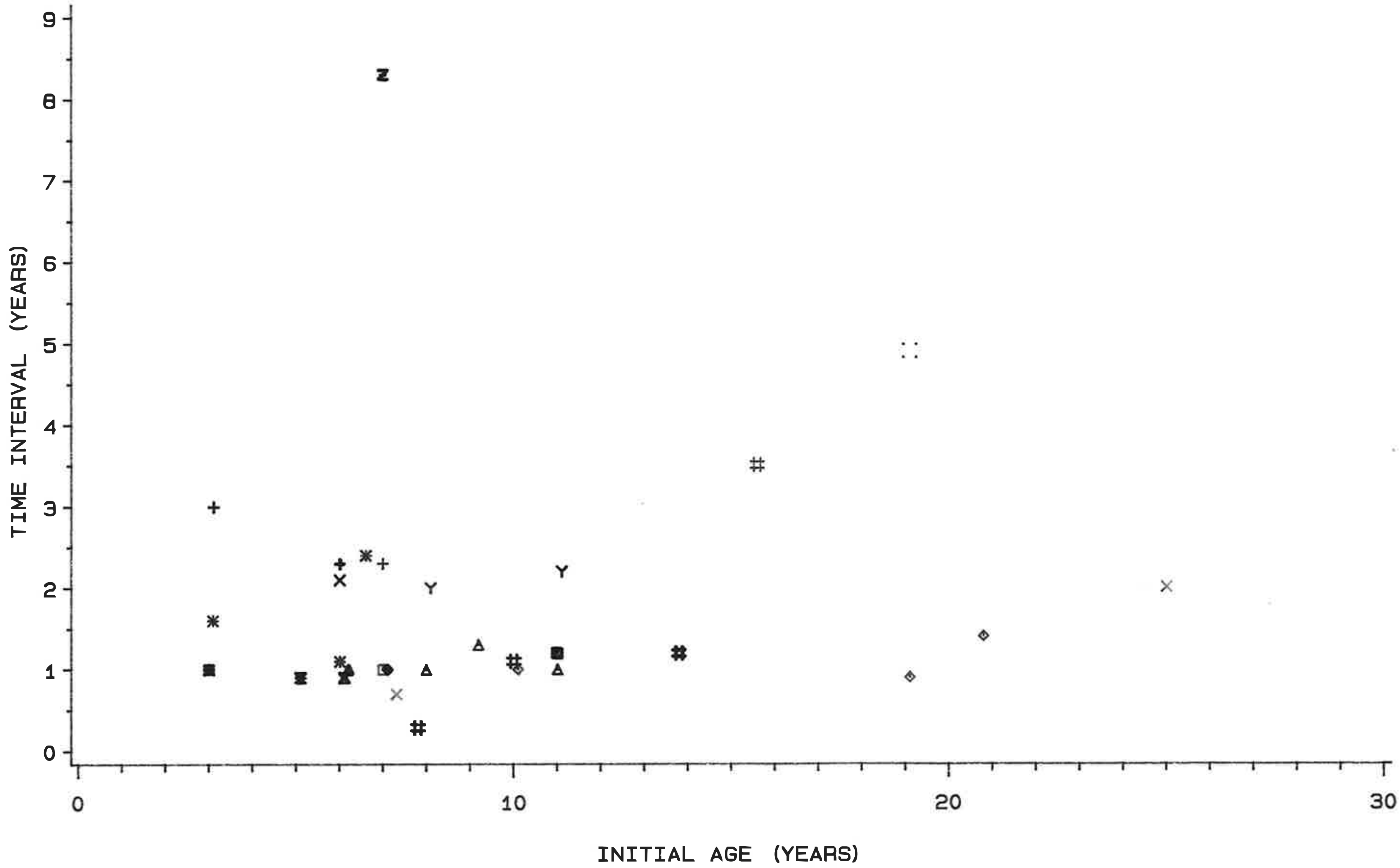
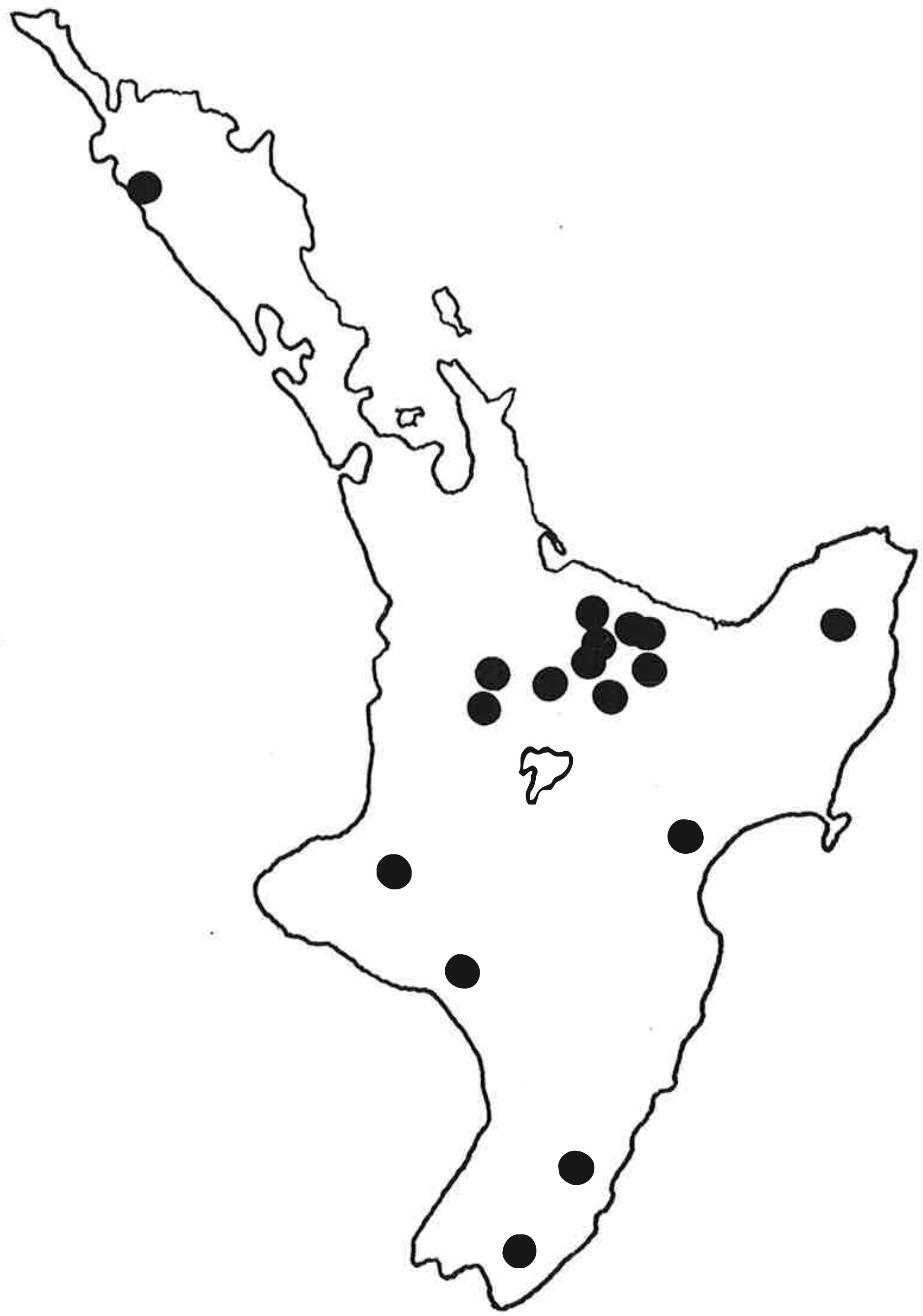


FIGURE 2 - LOCATION OF NORTH ISLAND PLOTS



● PLOT OR PLOTS

FIGURE 3 – REGNANS SAMPLE PLOTS

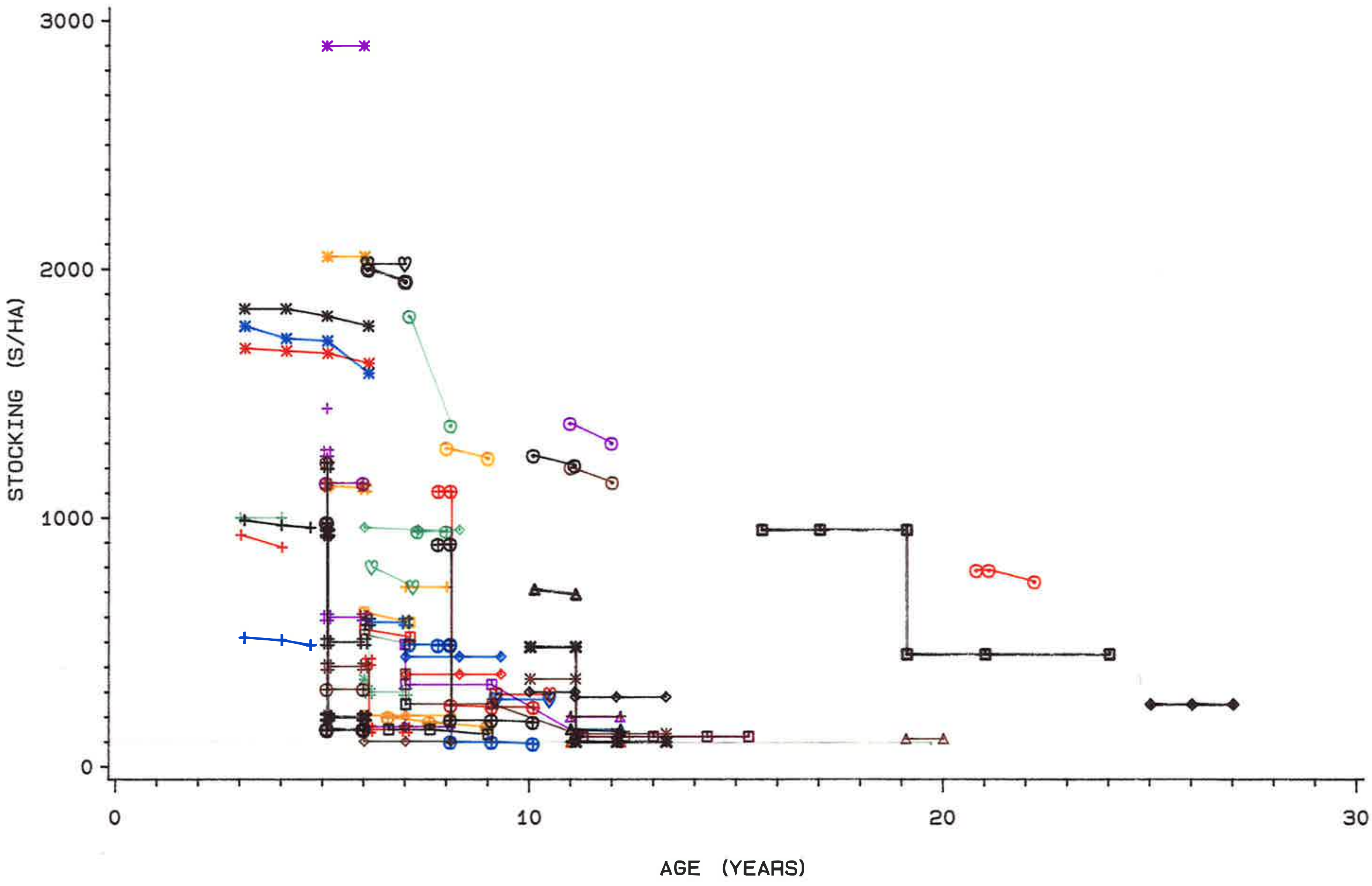


FIGURE 4 – REGNANS SAMPLE PLOTS

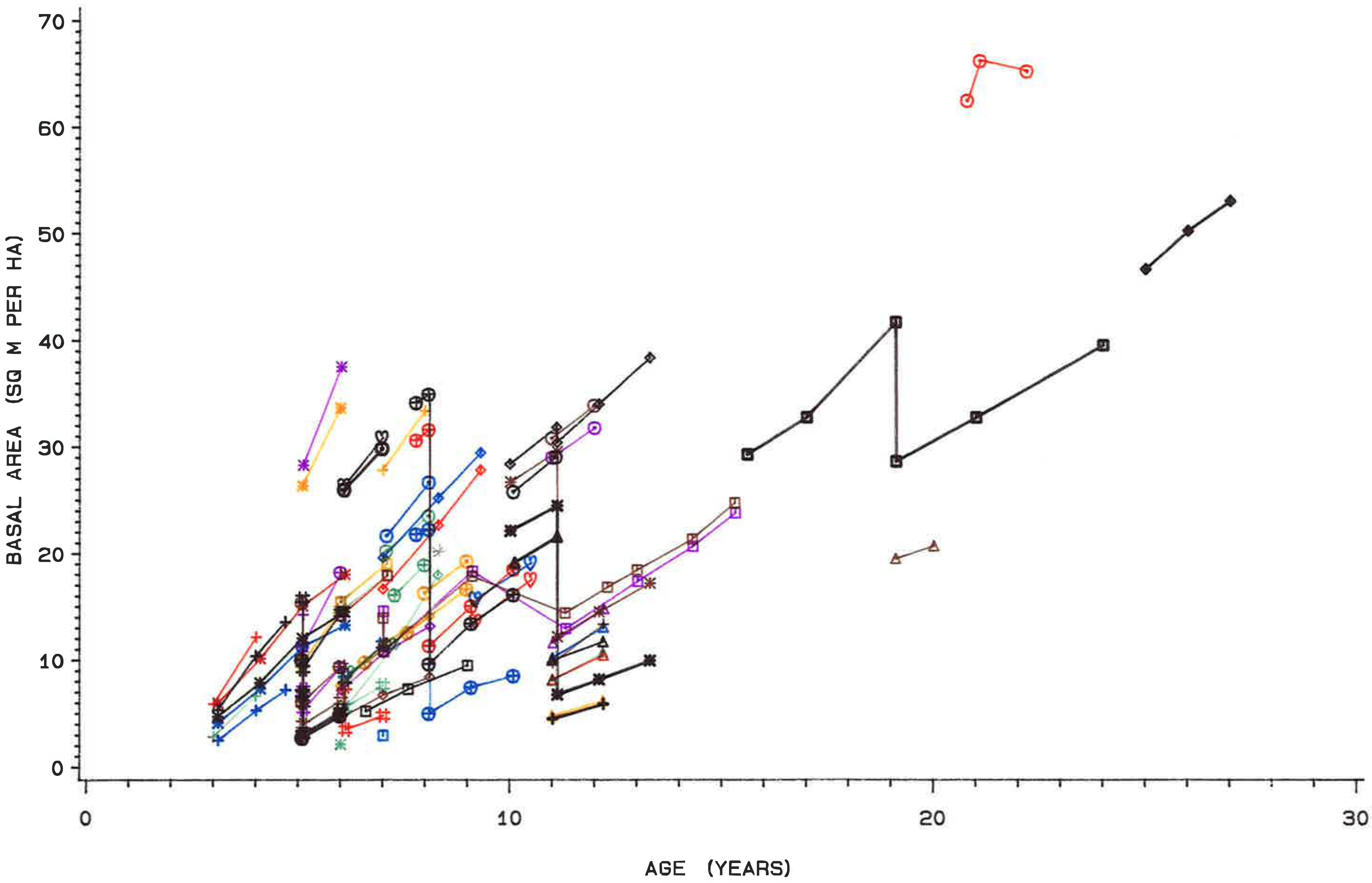


FIGURE 5 — REGNANS SAMPLE PLOTS

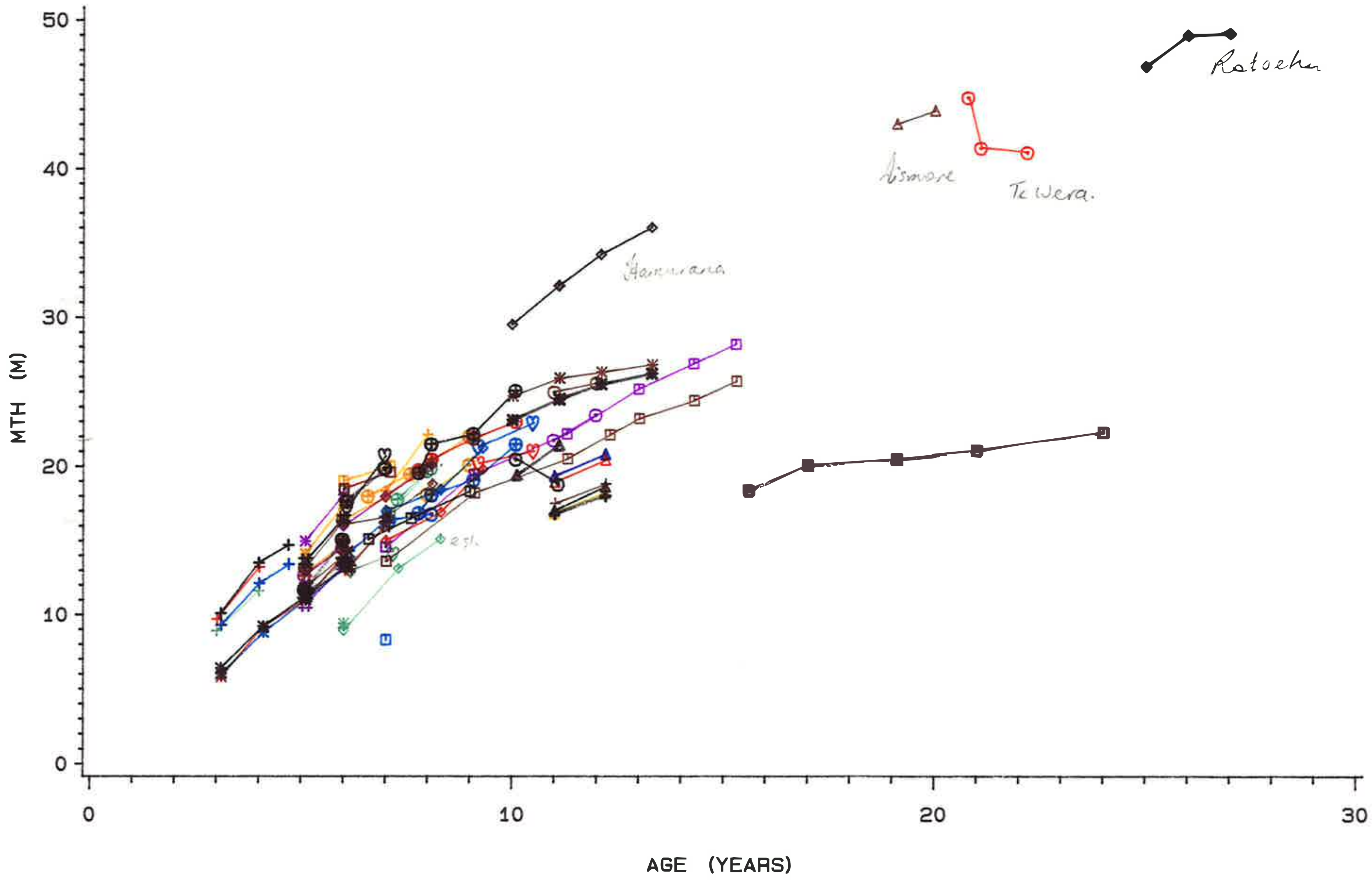


FIGURE 6 — REGNANS SAMPLE PLOTS

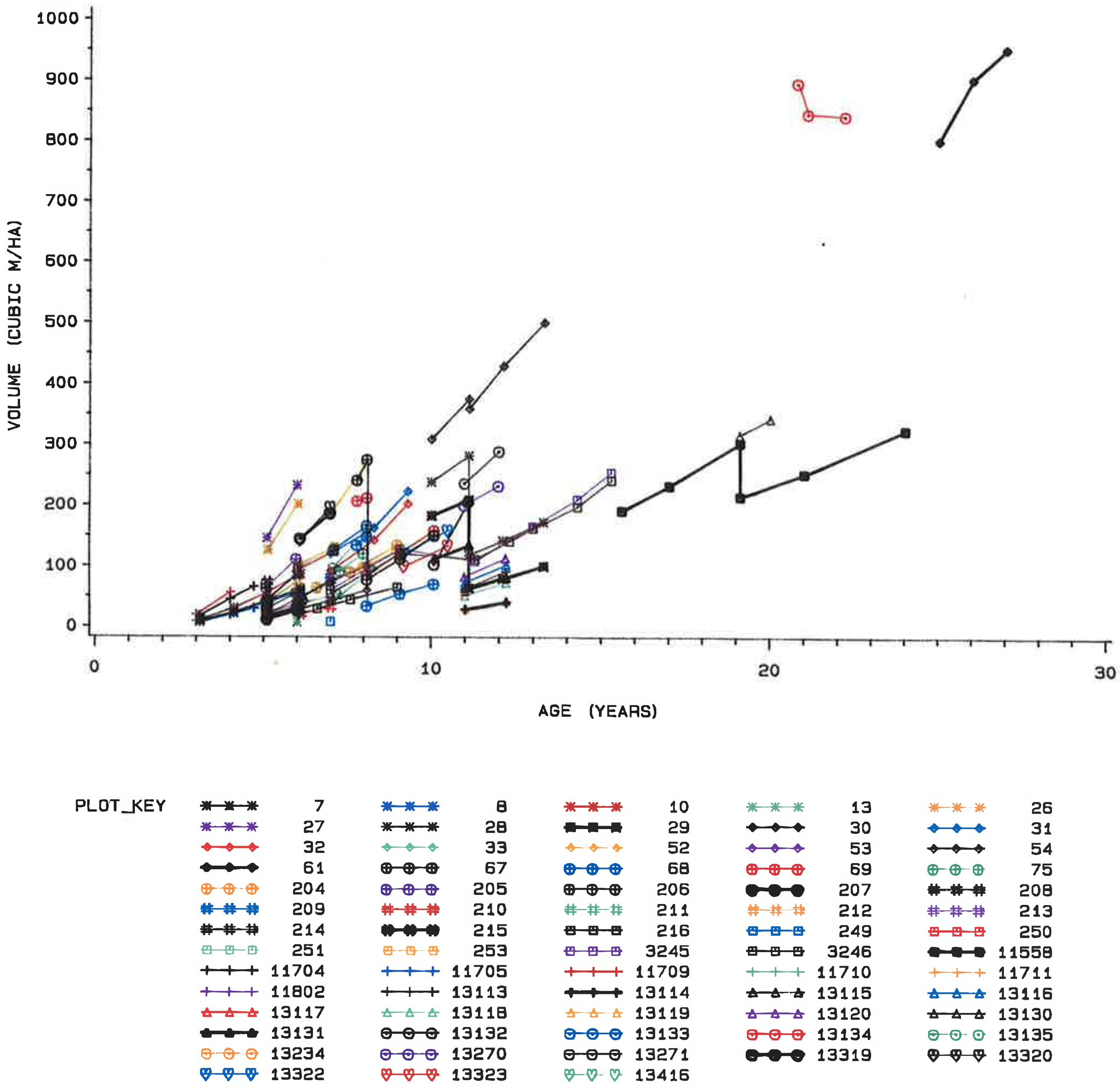


FIGURE 7 – REGIME TRIAL STOCKING CHANGES

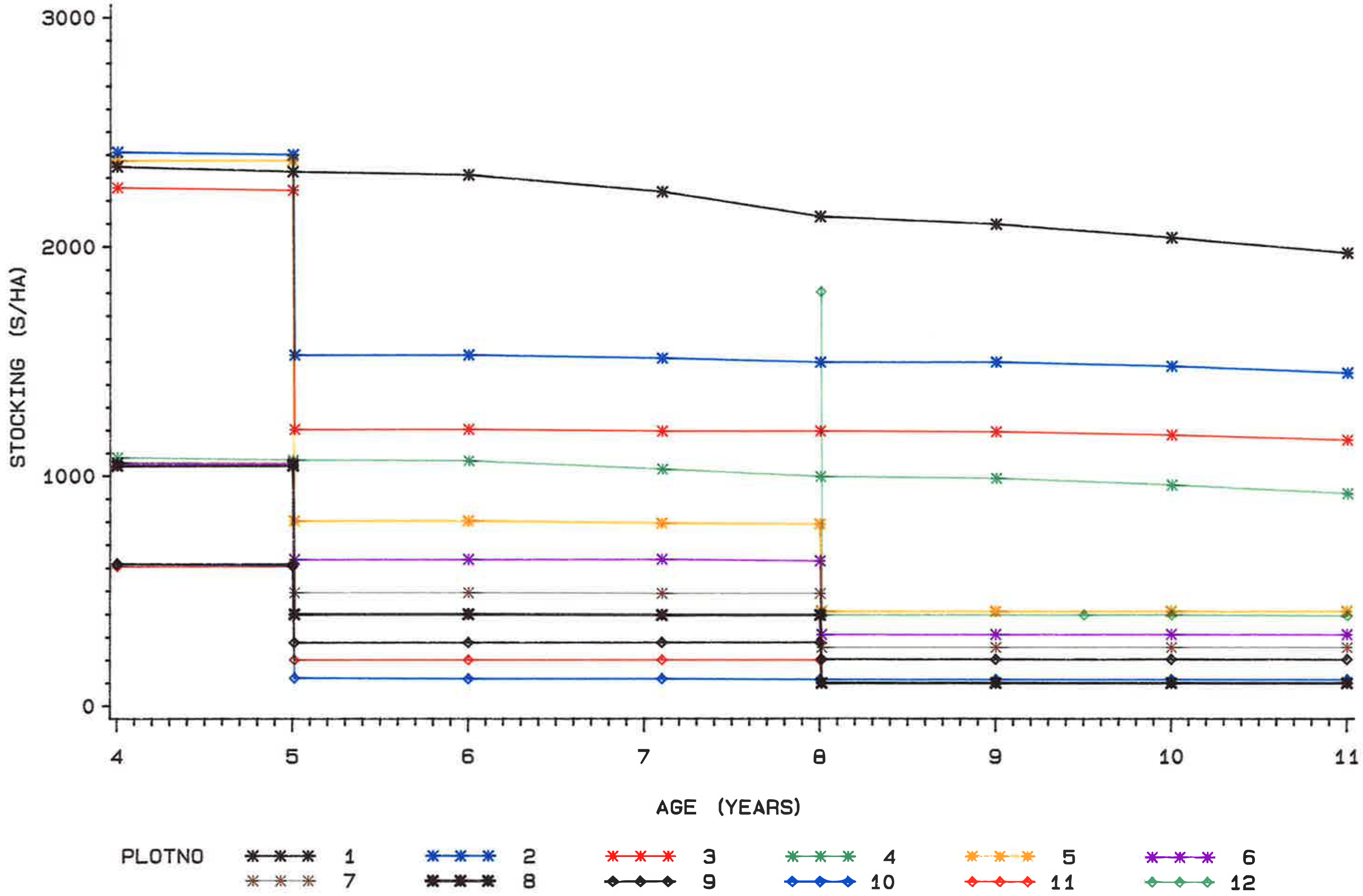


FIGURE 8 – REGIME TRIAL BASAL AREA GROWTH

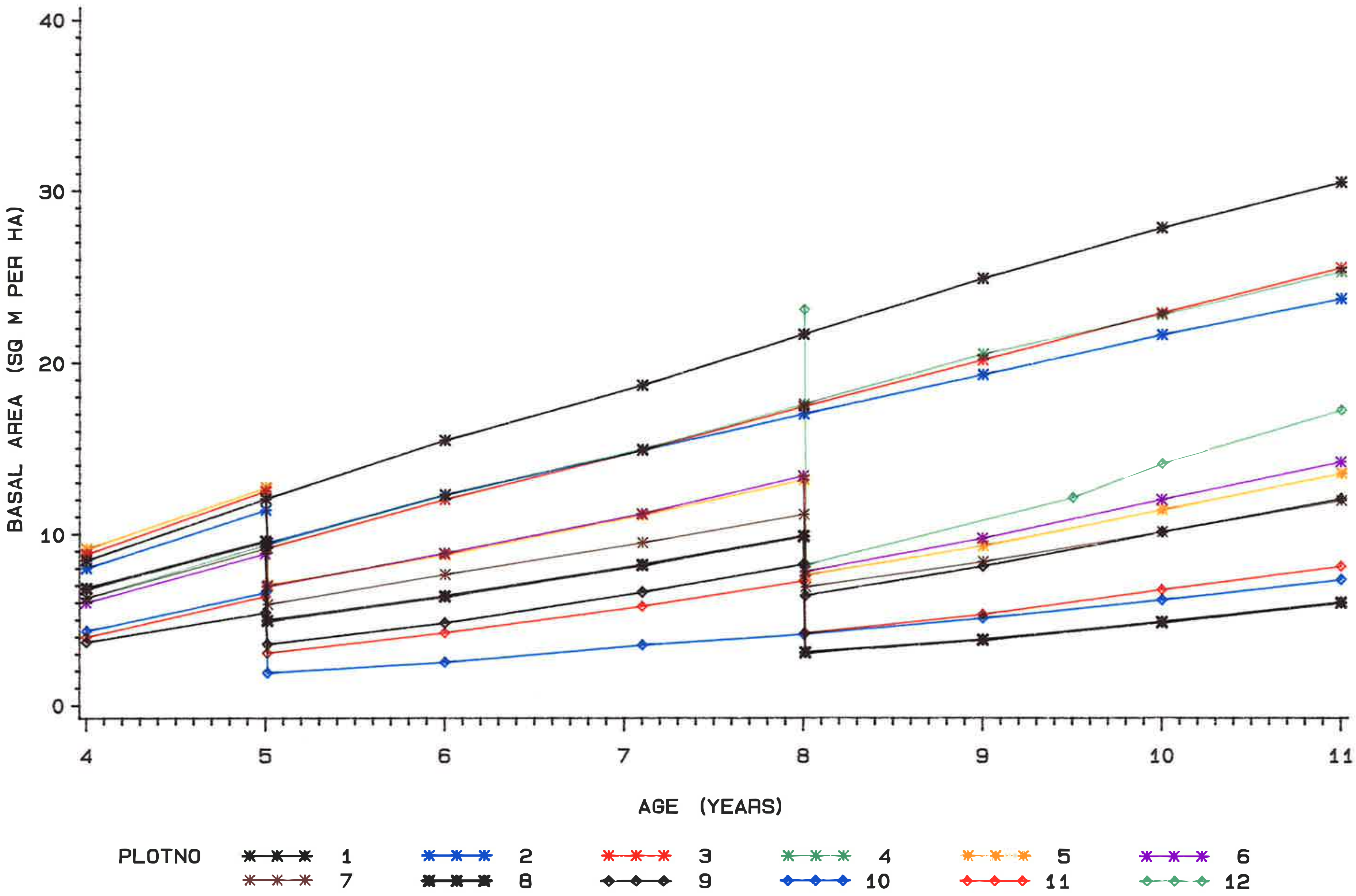


FIGURE 9 — REGIME TRIAL HEIGHT GROWTH

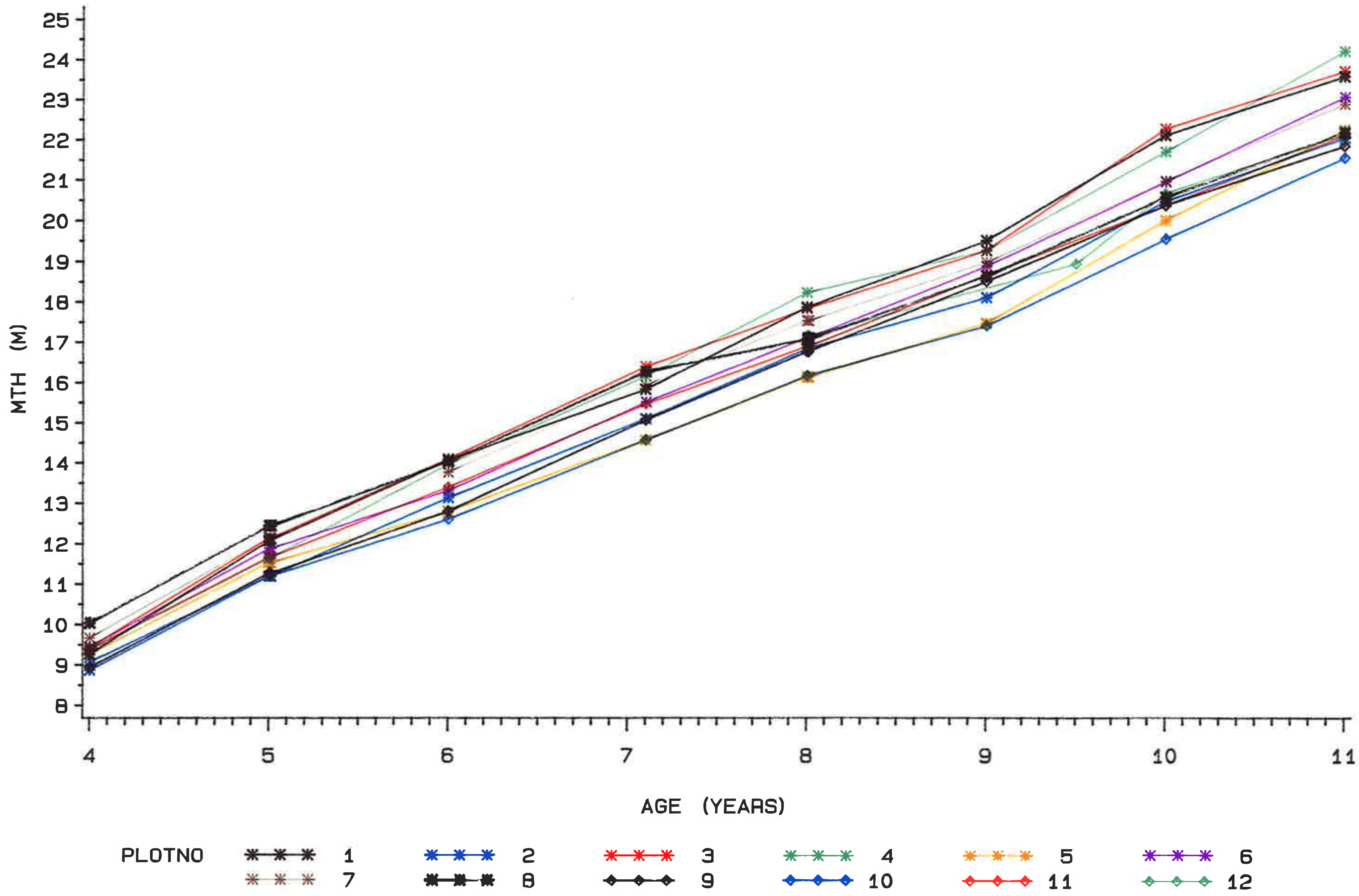


FIGURE 10 – REGIME TRIAL VOLUME GROWTH

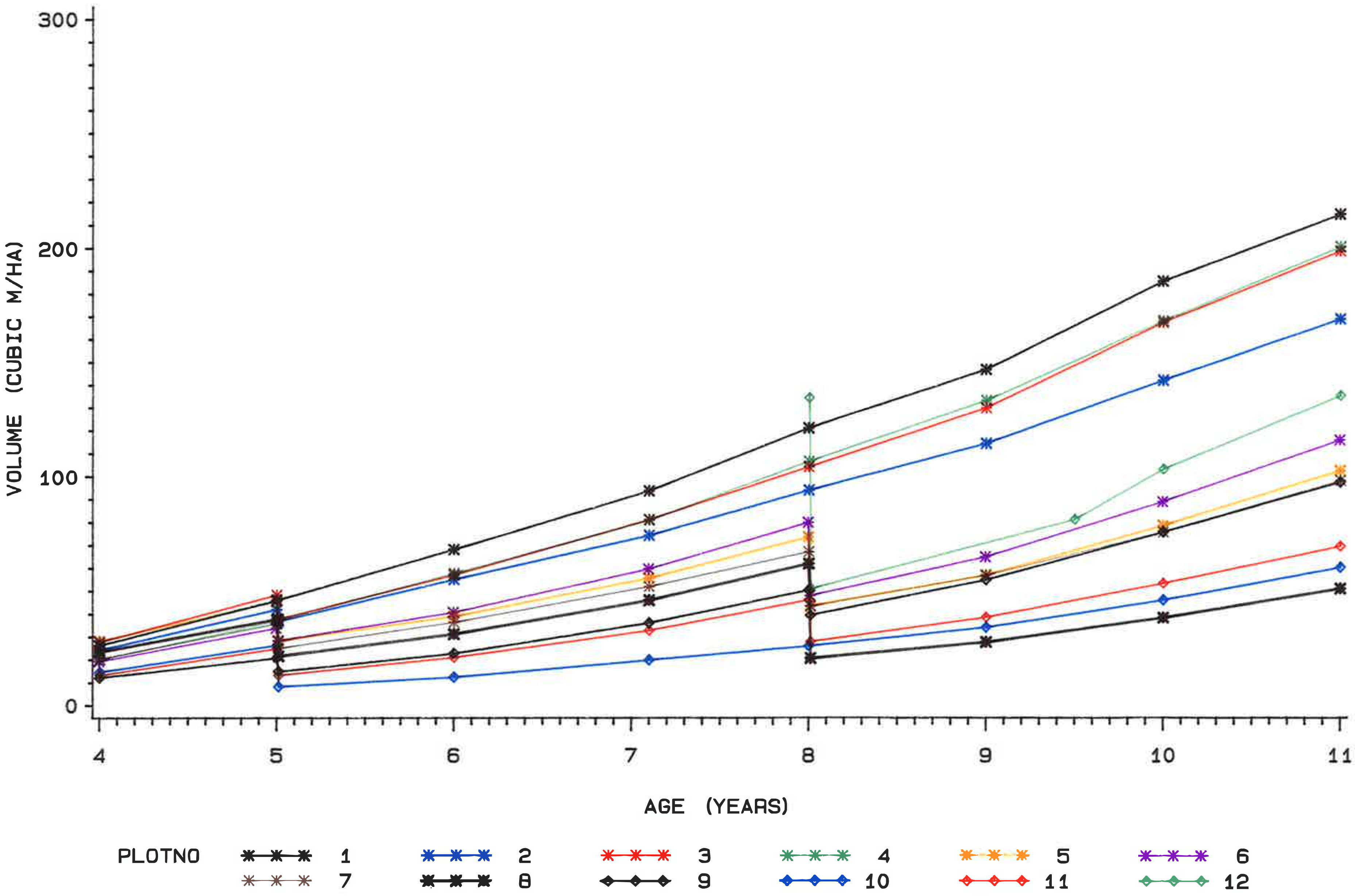


FIGURE 11 – SAMPLE PLOTS BASAL AREA ERROR

INITIAL VALUE GREATER THAN 400 S/HA
AT FIRST MEASUREMENT OR AFTER A THINNING

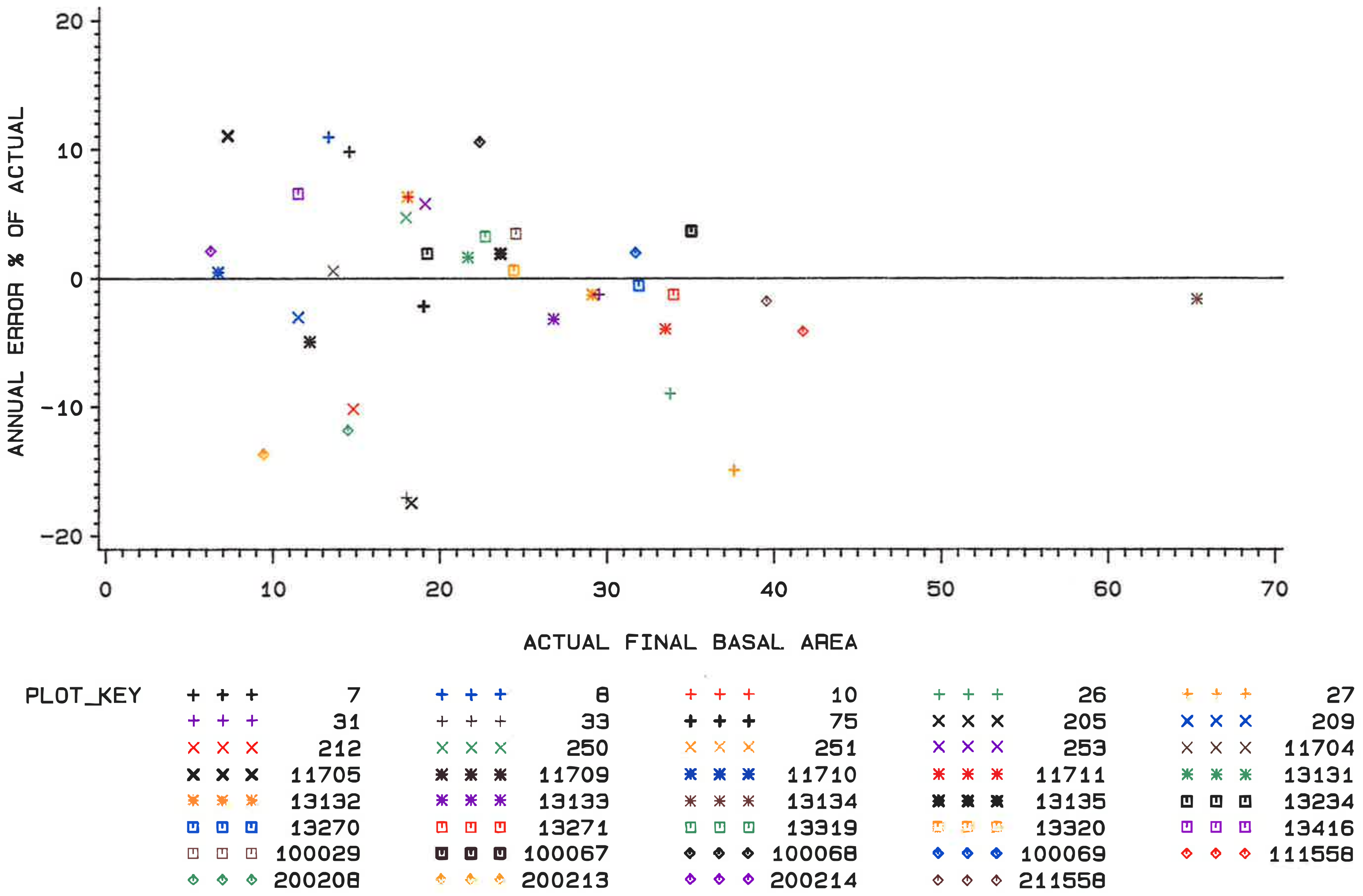


FIGURE 12 – SAMPLE PLOTS HEIGHT ERROR

INITIAL VALUE GREATER THAN 400 S/HA
AT FIRST MEASUREMENT OR AFTER A THINNING

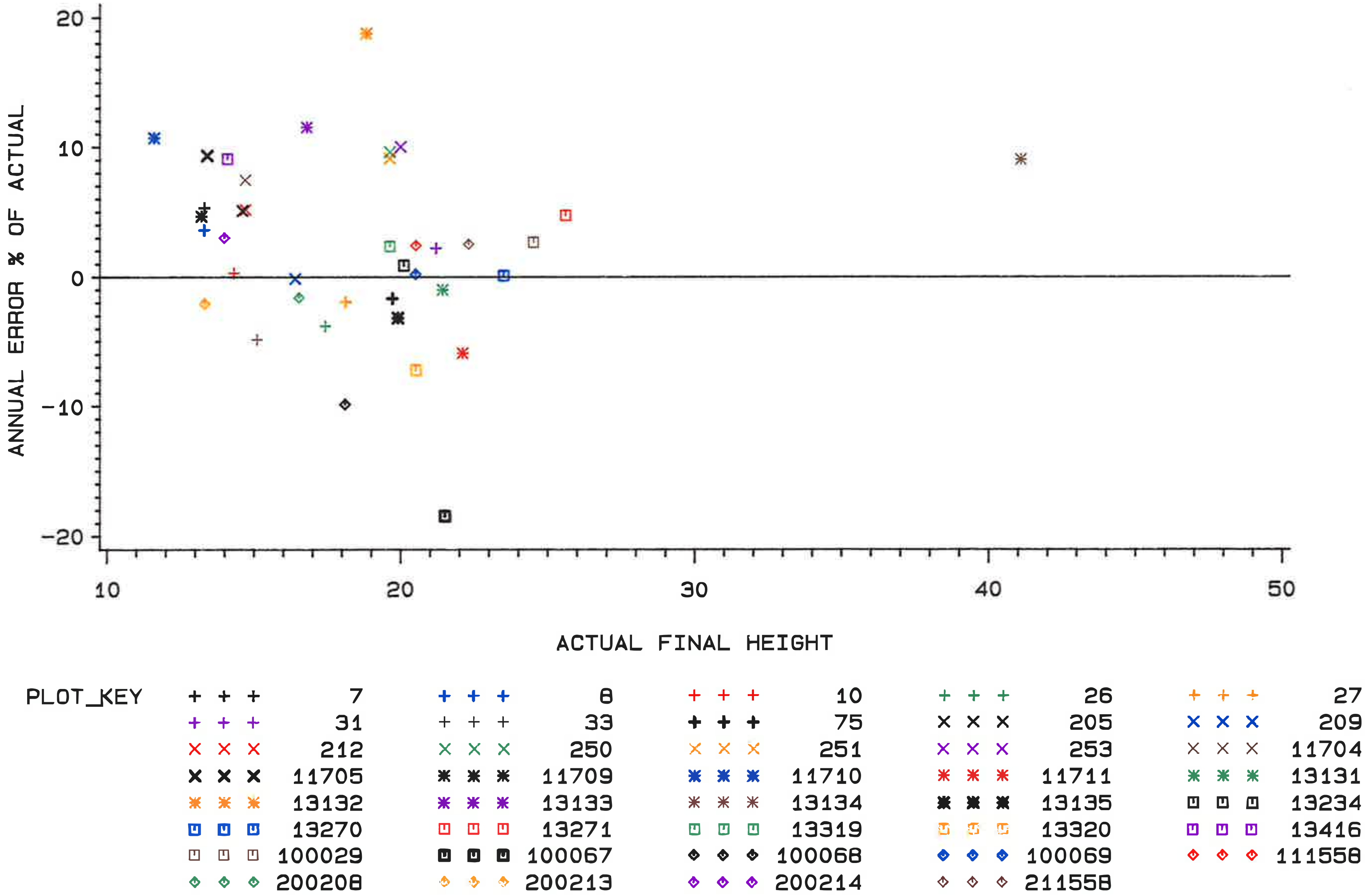


FIGURE 13 – SAMPLE PLOTS BASAL AREA ERROR

INITIAL VALUE LESS THAN 400 S/HA
AT FIRST MEASUREMENT OR AFTER A THINNING

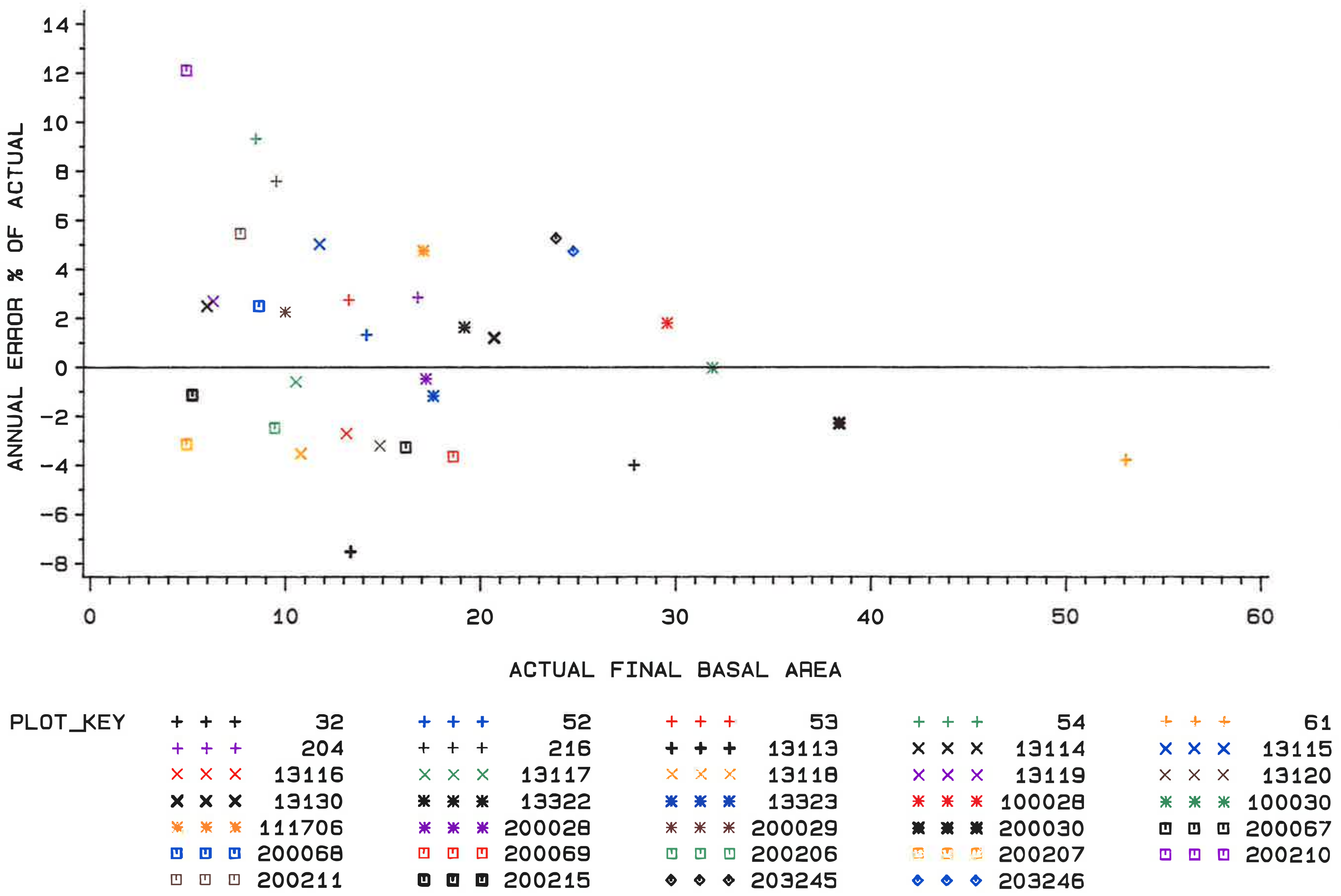


FIGURE 14 – SAMPLE PLOTS HEIGHT ERROR

INITIAL VALUE LESS THAN 400 S/HA
AT FIRST MEASUREMENT OR AFTER A THINNING

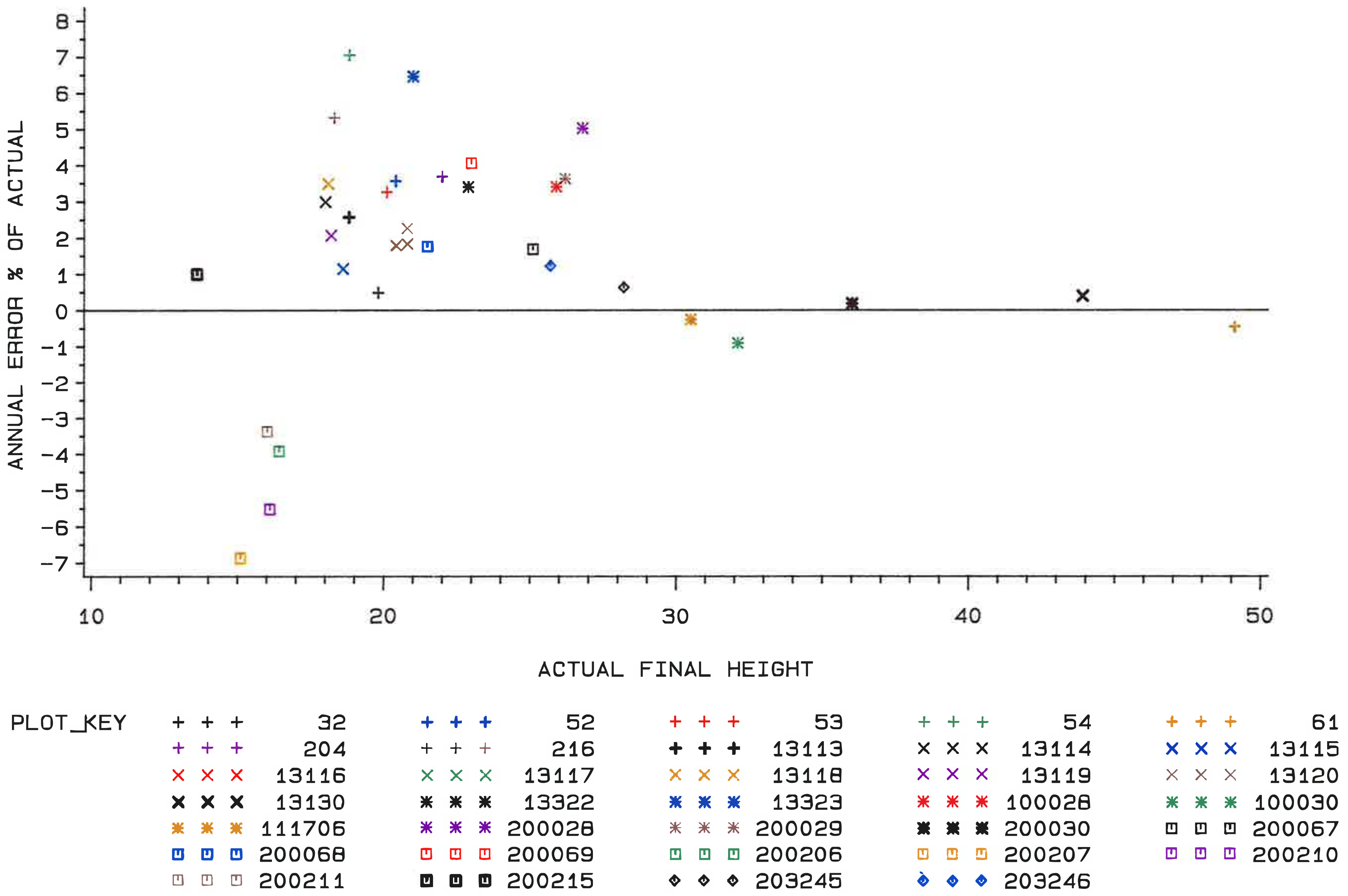


FIGURE 15 – SAMPLE PLOTS BASAL AREA ERROR

INITIAL VALUE SET AT FIRST MEASUREMENT OR AFTER A THINNING

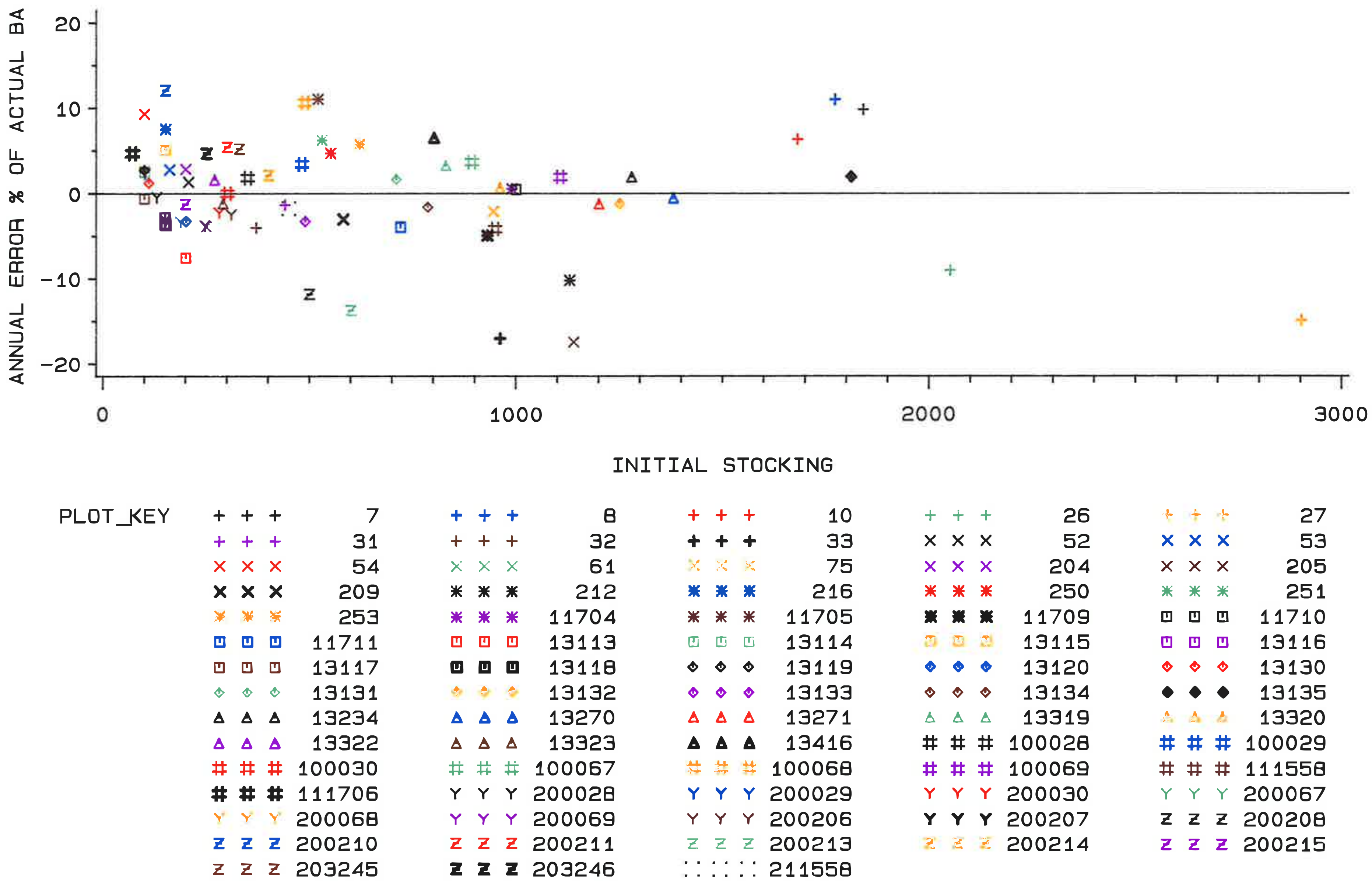


FIGURE 16 – SAMPLE PLOTS HEIGHT ERROR

INITIAL VALUE SET AT FIRST MEASUREMENT OR AFTER A THINNING

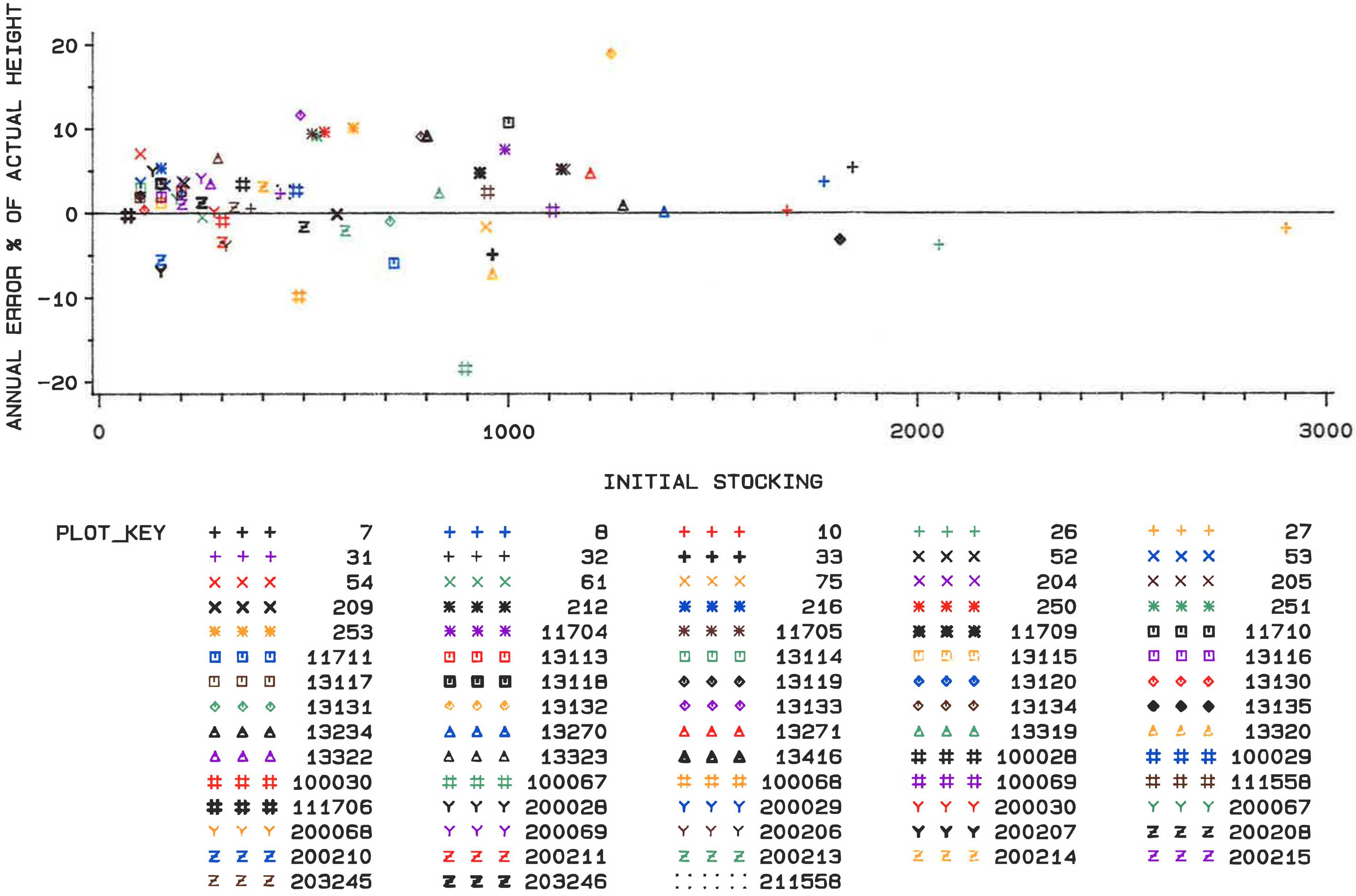


FIGURE 17 – SAMPLE PLOTS BASAL AREA ERROR

INITIAL VALUE SET AT FIRST MEASUREMENT OR AFTER A THINNING

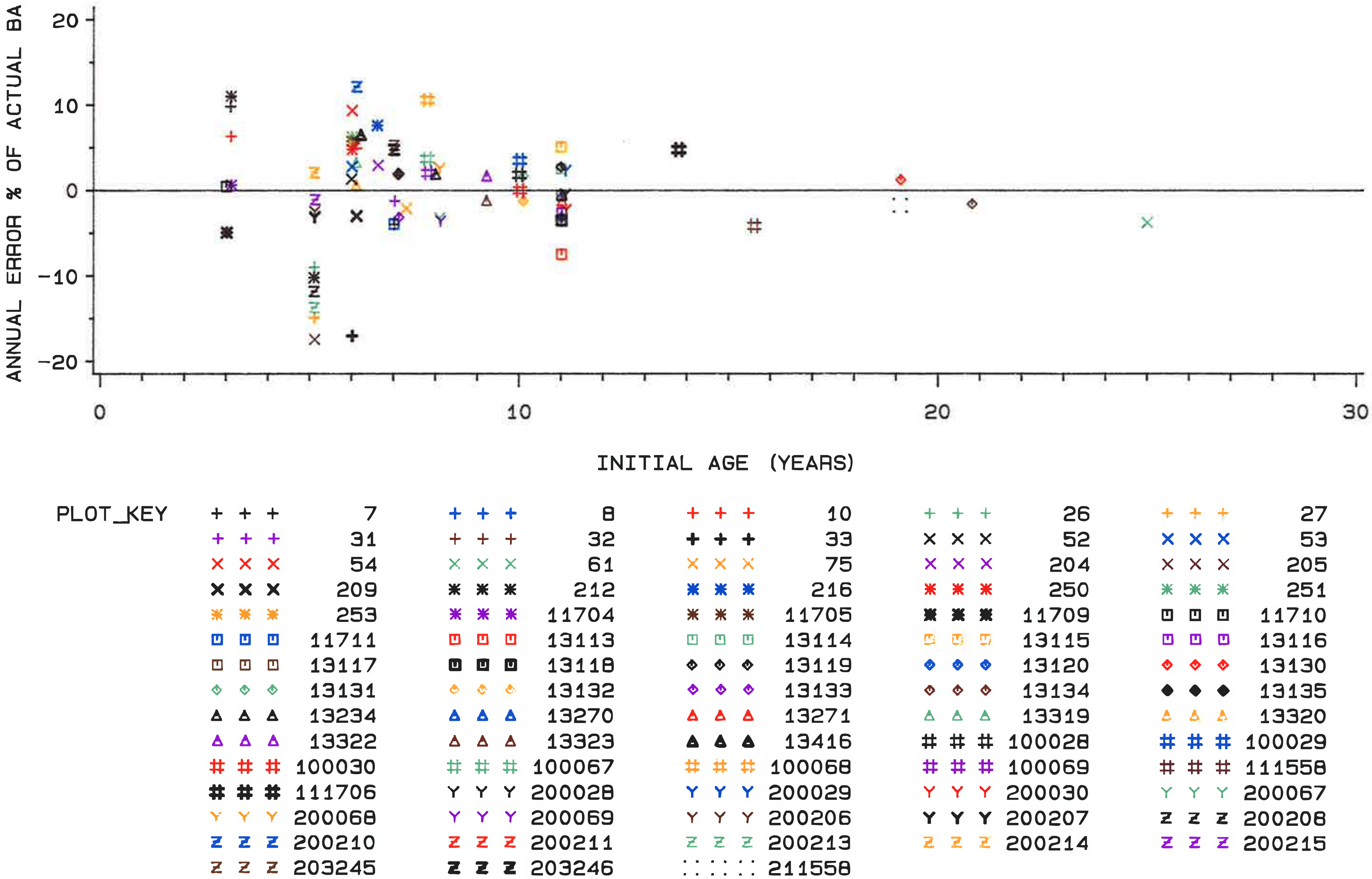


FIGURE 18 – SAMPLE PLOTS HEIGHT ERROR

INITIAL VALUE SET AT FIRST MEASUREMENT OR AFTER A THINNING

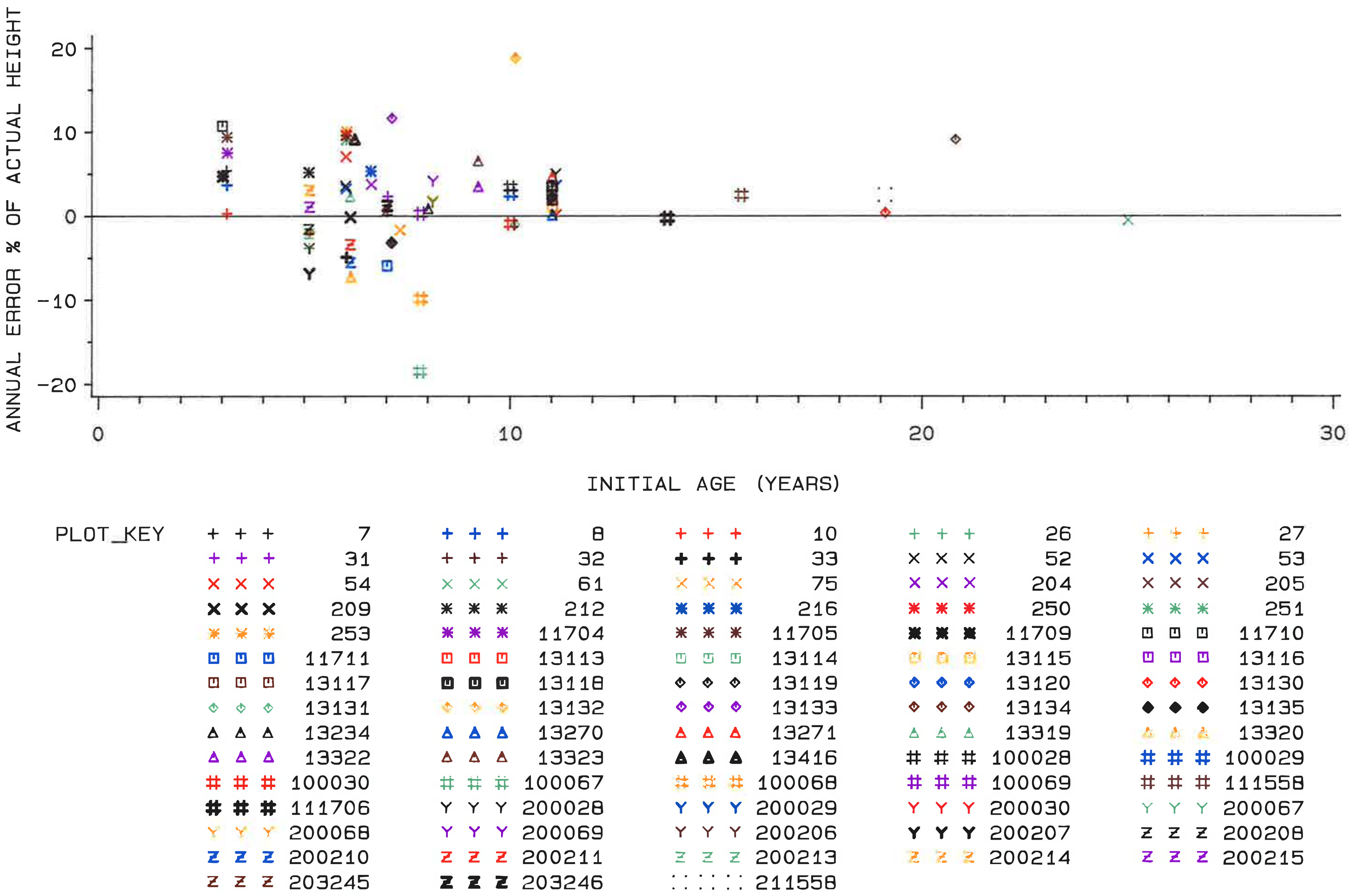


FIGURE 19 – TRIAL BASAL AREA ERROR

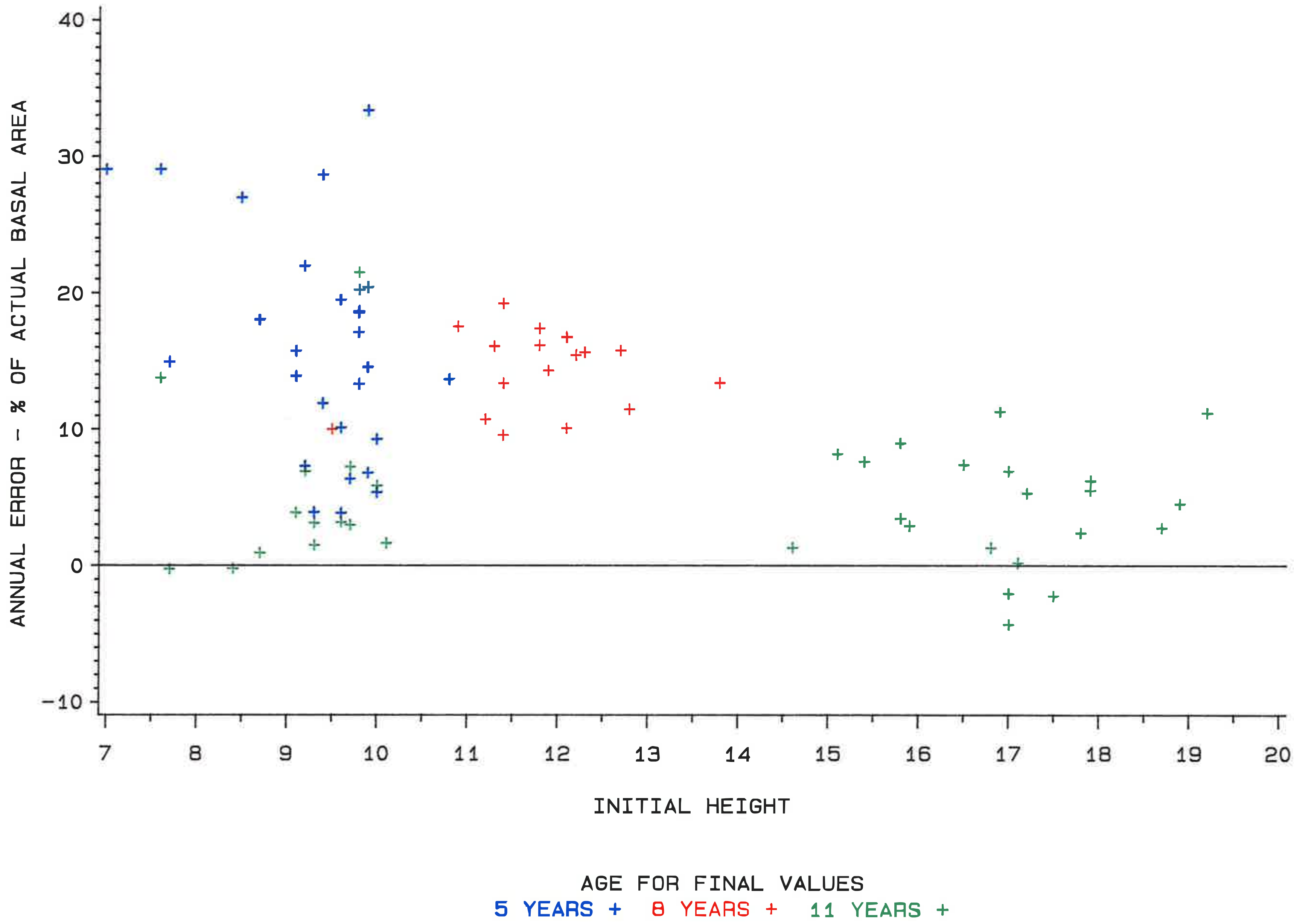
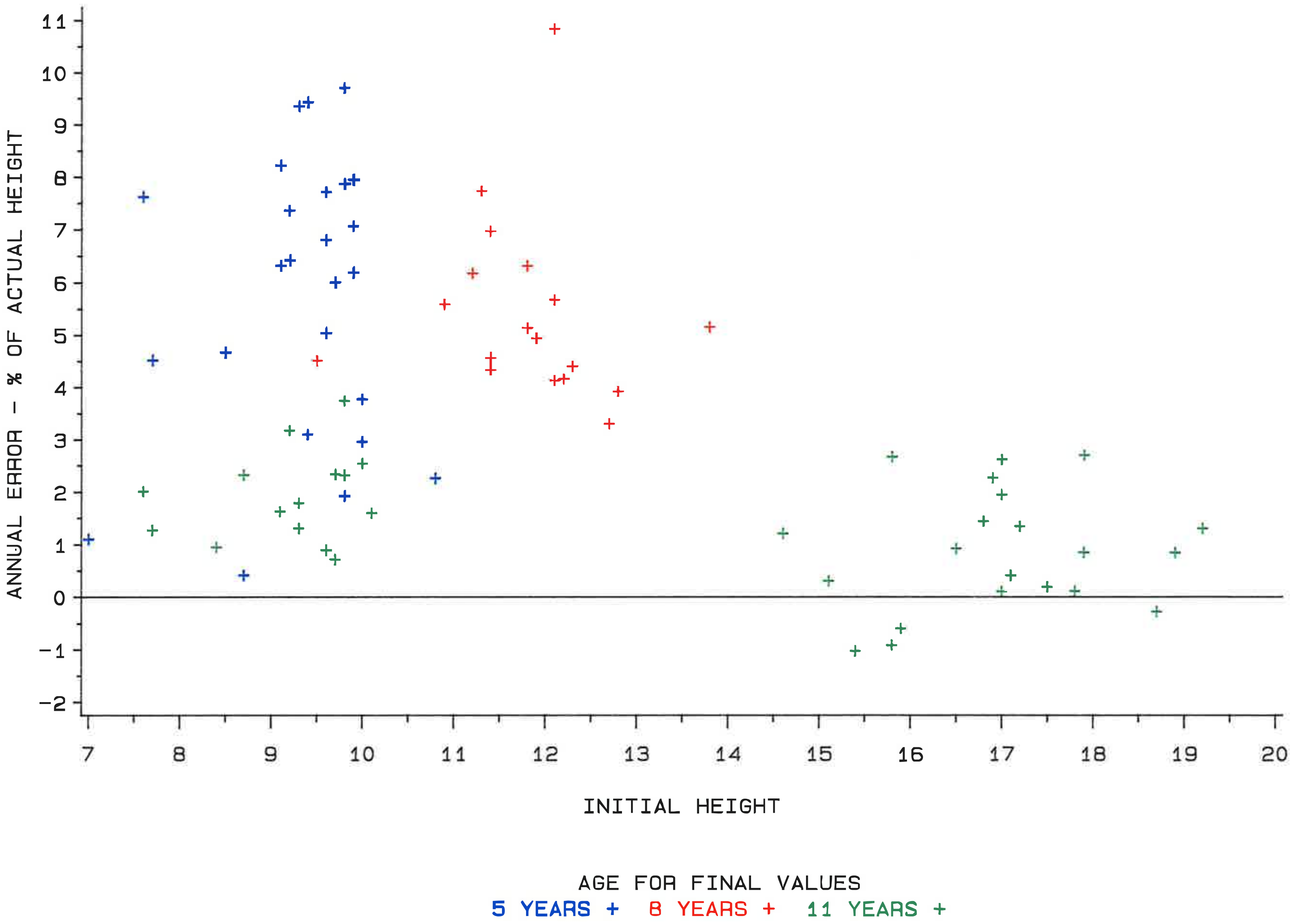


FIGURE 20 – TRIAL HEIGHT ERROR



7 References

Goulding C.J., 1979. Validation of growth models used in forest management. *N.Z. Journal of Forestry, 24(1): 108-124*

Hayward W., 1987. Volume and Taper of *Eucalyptus regnans* grown in the central North Island of New Zealand. *New Zealand Journal of Forestry Science 17(1):109-20.*

Hayward W., 1988. Eucalyptus regnans growth model Management of Eucalypts. *Cooperative Report No.4*

West G.G., Eggleston N.J., and McLanachan J., 1987. Further Developments and Validation of the EARLY growth model *FRI Bulletin No 129*

Appendix 1: Plot Identification

Plot key	Cons	Expt	Sub Expt	Plot	Sub plot	Location
7	RO	2085	1	1	0	Kaingaroa Cpt 59
8	RO	2085	1	2	0	Kaingaroa Cpt 59
10	RO	2085	1	5	0	Kaingaroa Cpt 59
26	RO	2085	16	17	0	Waiariki
27	RO	2085	16	18	0	Waiariki
31	WN	378	4	25	0	Esk Cpt 80
32	WN	378	4	26	0	Esk Cpt 80
33	WN	378	4	27	0	Esk Cpt 82
52	RO	2085	2	1	0	Hereperu Cpt 20
53	RO	2085	2	2	0	Hereperu Cpt 20
54	RO	2085	2	3	0	Hereperu Cpt 20
61	RO	2085	4	4	0	Rotoehu Cpt 83
75	AK	270	2	1	0	Waipoua Cpt 66
204	RO	2085	3	2	0	Tokomaru Cpt 250
205	RO	2085	14	1	0	Kinleith 6336
209	RO	2085	14	5	0	Kinleith 5270
212	RO	2085	14	8	0	Kinleith 5185
216	RO	2085	3	1	0	Tokomaru Cpt 250
250	RO	2085	9	1	0	Pinnacles Cpt 737
251	RO	2085	9	2	0	Pinnacles Cpt 737
253	RO	2085	9	4	0	Pinnacles Cpt 737
11704	RO	2085	5	1	0	Kawerau Pouturu
11705	RO	2085	5	2	0	Kawerau Pouturu
11709	RO	2085	16	1	0	Hignett
11710	RO	2085	16	2	0	Hignett
11711	RO	2085	16	3	0	Royal
13113	SD	684	1	1	1	Longwoods Cpt 30
13114	SD	684	1	1	2	Longwoods Cpt 30

13115	SD	684	1	1	3	Longwoods Cpt 30
13116	SD	684	1	1	4	Longwoods Cpt 30
13117	SD	684	1	1	5	Longwoods Cpt 30
13118	SD	684	1	1	6	Longwoods Cpt 30
13119	SD	684	1	1	7	Longwoods Cpt 30
13120	SD	684	1	1	8	Longwoods Cpt 30
13130	WN	378	1	1	0	Lismore Cpt 53
13131	WN	378	1	2	0	Lismore Cpt 88
13132	WN	378	1	3	0	Lismore Cpt 88
13133	WN	378	2	1	0	Te Wera Cpt 156
13134	WN	378	2	2	0	Te Wera Cpt 65
13135	WN	378	2	3	0	Te Wera Cpt 168
13234	RO	2085	4	7	0	Rotoehu Cpt 7
13270	RO	2085	4	2	0	Rotoehu Cpt 2
13271	RO	2085	4	3	0	Rotoehu Cpt 2
13319	RO	2085	7	1	0	Whaka Cpt 6
13320	RO	2085	7	2	0	Whaka Cpt 6
13322	FR	39	1	2	0	Pureora Cpt 1
13323	FR	39	1	3	0	Pureora Cpt 1
13416	WN	378	5	602	1	Ngaumu Cpt 602
100028	RO	2085	16	19	0	Rotorua Blackwell
100029	RO	2085	16	20	0	Rotorua Blackwell
100030	RO	2085	16	21	0	Rotorua Terry
100067	RO	2085	6	1	0	Tokoroa Kokako
100068	RO	2085	6	3	0	Tokoroa Kokako
100069	RO	2085	6	2	0	Tokoroa Kokako
111558	WN	275	0	3	0	Wairarapa Hiwinui
200028	RO	2085	16	19	0	Rotorua Blackwell
200029	RO	2085	16	20	0	Rotorua Blackwell
200030	RO	2085	16	21	0	Rotorua Terry
200067	RO	2085	6	1	0	Tokoroa Kokako

200068	RO	2085	6	3	0	Tokoroa Kokako
200069	RO	2085	6	2	0	Tokoroa Kokako
200206	RO	2085	14	2	0	Kinleith 6336
200207	RO	2085	14	3	0	Kinleith 6336
200208	RO	2085	14	4	0	Kinleith 6336
200210	RO	2085	14	6	0	Kinleith 5270
200211	RO	2085	14	7	0	Kinleith 5270
200213	RO	2085	14	9	0	Kinleith 5185
200214	RO	2085	14	10	0	Kinleith 5185
200215	RO	2085	14	11	0	Kinleith 5185
203245	WN	235	0	27	0	Esk Cpt 82
203246	WN	235	0	28	0	Esk Cpt 82
211558	WN	275	0	3	0	Wairarapa Hiwinui