

**GENETIC GAIN MULTIPLIERS :
UTILITY AND EFFICIENCY**

**R. WOOLLONS
S.D. CARSON**

REPORT No 78.

February 1999

Note: Confidential to Participants of the Stand Growth Modelling Programme
This is an unpublished report and MUST NOT be cited as a literature
reference.

EXECUTIVE SUMMARY

Genetic gain data was reviewed in order to re-evaluate the necessity to use growth rate multipliers for prediction of yield from genetically improved seedlots. As before, it was concluded that a growth rate multiplier was not necessary for prediction of top height, but seedlots rated GF14 and above were clearly on a different trajectory than climbing select seedlots (rated GF7), and unbiased predictions of basal area could only be obtained by using a multiplier. However, clear differentiation of open-pollinated (GF14) and control-pollinated seedlots (those rated >GF19) was not observed for all seedlots for which data was available. Because definitive data is available for only two seedlots, examination of the performance of additional control-pollinated seedlots at additional trial sites is clearly warranted.

INTRODUCTION

Late in 1997 Richard Woollons and Sue Carson approached the Stand Growth Modelling Co-operative with a request to uplift growth data in order to review the nature and extent of stand growth divergence caused by high GF-rated *Pinus radiata* stock. The main question addressed was, "To what extent were current FRI Growth models underestimating stand growth if not modified by 'multipliers' (Carson *et al.*, 1994, 1997)?" Conversely, could assumptions of genetic gain over all sites and additive extra production through all successive and higher GF ratings be substantiated?

Some work was assayed in early 1998, which Sue Carson presented to the Cooperative in February, 1998, but Richard Woollons was unable to attend the meeting. The data have now been augmented by 1998 measurements and the analyses have been reworked by the first author and are presented here.

DATABASE

The data comes from the series of trials established over 1978/ 79 as described by Carson *et al.*, 1994.

Six trials have been examined :

Aupouri (Auckland Sands AK1058)
Kaingaroa (CNI RO 2103/1, RO 2103/ 2 : Sawlog and Pulpwood Regimes)
Mohaka (Napier WN 377)
Golden Downs (Nelson NN 530)
Waimate (Canterbury CY 421)

There were originally two Southland sites as well, but snow and wind damage has limited the use of the plots and they are not used here.

The silviculture and structure of the various trials is described by Carson *et al.*, 1994.

There are 4 GF ratings represented in the various trials: GF2, GF7, GF14 and GF22 but replication varies with treatment and measurement schedule.

There are generally 6 (six) replications of GF7 and GF14 but only 3 replications of GF2 and GF22. Moreover the latter have only been assessed since 1993 with 6 measures available.

Diameter and height measures are available for all plots.

GROWTH MODEL DIVERGENCE

When considering whether a growth model should be modified to cater for additional growth divergence through superior genetic stock, it is important to understand to how most growth and yield systems (Garcia, 1984: Woollons and Haywood, 1985) operate.

Irrespective of whether a univariate or multivariate system is operative, a key element of both is the usage of projection equations to predict basal area / ha and mean-top-height growth.

$$Y = f(Y_1, T, T_1) \quad (1)$$

where in (1)

$$Y, Y_1 = \text{yield at ages } T \text{ and } T_1$$

So T_1 and Y_1 are the INPUT age and yield, the latter assumed to be known; Y and T represent the predicted yield, required at age T .

For example, a simple projection model for basal area/ ha is:

$$G = \exp(\log(G_1)(T_1/T) + 5(1 - (T_1/T))) \quad (2)$$

If we survey a stand at age 10 (T_1) and find there is 25 m²/ ha present, what is the estimated basal area /ha (G) at age 25 (T) ?

$$\text{So} \quad G = \exp(\log(25)(10/25) + 5(1 - (10/25)))$$

$$\text{giving} \quad G = 72.8 \text{ m}^2/\text{ha}$$

Therefore, a projection equation can handle families of growth paths, catering for a range (higher or lower) of input traits (basal area or height). These families of growth paths are NOT parallel but diverge or converge dependent on age and current yield, reflecting well-known biometrical and silvicultural principles (see Figure 1).

Thus, it is perfectly feasible that increased production through genetics could be modelled in growth systems WITHOUT modification. Given that a valid (higher) input yield is available, then this alone may be sufficient to depict the consequent growth trajectory. Alternately, the higher GF ratings may be on disjoint growth paths alien to the parent model growth assumptions. In this case, additional parameters are necessary to account for the phenomena. The purpose of this investigation was to determine which approach is best used to predict the increase in growth of genetically improved *Pinus radiata* in New Zealand.

MEAN TOP HEIGHT

To explore the height growth of the four GF stock- types, several height projection equations were examined.

The model:

$$H = \exp(\log(H_1)(T_1/T)^\beta + \alpha(1 - (T_1/T)^\beta)) \quad (3)$$

where in (3)

H_1 , H = mean top height at ages T_1 , T

overall, gave an excellent fit of the data, unbiased for the four stock-types and the large majority of the locations (see Appendices 1 to 3).

BASAL AREA/ HA

Graphs of the net basal area/ ha development and time are shown in Appendices 4 – 8. There is large variation in the degree of divergence and absolute gains by GF material, ranging from a very large difference between the size of the GF7 and GF14 seedlots at Napier to much smaller size differences between these seedlots at Aupouri and Kaingaora (1). These graphs must be viewed with caution, however, because there are some stocking differences which are confounded with seedlot differences.

NOTE: the GF2 at Aupouri is mislabelled and the GF rating is uncertain.

GF2 material was dropped from the analyses.

Basal area / ha growth was first examined by use of ORTHOGONAL POLYNOMIALS, which summarise the increment of any plot by fitting successively a straight-line, a quadratic curve, and then a cubic curve. Six measures are available (ages 14 to 20) for GF 7, 14 and 22 material. The point of the orthogonal polynomials is to reduce the dimension of the data from six to one.

Of the three functions we would expect the so-called linear component to be the strongest and it can be interpreted to be an expression of periodic annual increment. The quadratic and the cubic components are measures of curvature and reflect the degree by which each plot is adopting an sigmoid path through time. (With data no older than 20 years, these components will be relatively small).

The three components can be analysed as an Analysis of Variance. (see Tables 1 and 2).

The linear and quadratic components give very strong Regional effects and GF ratings are significant for the linear component. There are no overall interactions.

Examination of the least-squares means (not shown) confirm these, while suggesting that GF22 growth rates are more variable relative to GF14 increments. However, the estimates of genetic gain multipliers (growth rates) for the different sites (Carson *et al.* 1997) are not more variable across sites for GF22 than for GF14. In fact, a constant growth rate increase (as has been assumed in the implementation of the multipliers) would result in predictions much like the data that was observed, that is, a slightly larger variance in the absolute size differences among seedlots with the highest growth potential.

The three components of the functions fitted are not independent and measures of their joint effects can be obtained through Mahalanobis's distance. The 'distances' represent conservative measures of growth rate (divergence)

$$D^2(i | j) = (Y_i - Y_j)^T S^{-1} (Y_i - Y_j)$$

We have: (values in brackets = Prob {Distance = 0})

	<u>GF7 to GF14</u>	<u>GF14 to GF22</u>	<u>GF7 to GF22</u>
Aupouri	0.37 (n.s.)	3.32 (0.1016)	5.61 (0.0168)
Canterbury	4.10 (0.1228)	3.31 (n.s.)	0.19 (n.s.)
Napier	2.48 (0.0743)	6.48 (0.0086)	12.36 (0.0001)
Kaingaroa (1)	1.82 (n.s.)	0.33 (n.s.)	2.15 (0.1094)
Kaingaroa (2)	0.70 (n.s.)	1.96 (0.1368)	0.79 (n.s.)
Nelson	1.02 (n.s.)	14.25 (0.0525)	22.09 (0.0015)

Thus, based on growth rates over ages 14 to 20, and allowing for variation within sites, several growth paths are estimated to be equivalent.

A pooled basal area/ ha projection equation:

$$G = \exp(\log(G_1)(T_1/T)^\beta + \alpha(1 - (T_1/T)^\beta)) \quad (4)$$

where in (4)

$$G, G_1 = \text{net basal area/ ha at ages } T_1, T$$

was fitted to the data. The residual patterns are shown in Appendices 9 and 10. Clearly, the model is biased by location and GF rating.

A model :

$$G = \exp(\log(G_1)(T_1/T)^{\beta + 1dum14 + 2dum22}) + \alpha(1 - (T_1/T)^{\beta + 1dum14 + 2dum22})) \quad (5)$$

where in (5)

dum14, dum22 are dummy variables = 1 when GF14 or GF22 are present
= 0 otherwise

was fitted to each location (except Canterbury, for want of sufficient data).

Residual patterns for GF ratings were satisfactory for all locations.

Estimated values of the dummy variable coefficients are :

	ε_1 (GF14)	ε_2 (GF22)
Aupouri	0.014	0.073
Kaingaroa(1)	0.159	0.239
Kaingaroa(2)	0.119	0.125
Napier	0.136	0.285
Nelson	0.105	0.318

NB: these coefficients are related to, but for mathematical reasons are NOT equivalent to the multipliers calculated by Carson *et al.*, 1994 or 1997.

DISCUSSION

The analyses assayed for mean top height are clear-cut: a single projection equation suffices to depict top height growth and does not require embellishment to account for the higher GF rated stock. This is equivalent to concluding that no multipliers are required for height. This is essentially in agreement with Carson *et al.*, 1997 who concluded:-

‘Predictions of mean top height were not effected when the growth rate multipliers were added to the growth model equations’.

Results obtained for basal area are more complex.

There is evidence here that the growth paths of basal area / ha for the higher GF ratings, are diverging relative to GF7 trajectories. Results from the orthogonal polynomial analyses are very conservative and are limited (necessarily) to the last

six years but they are useful for emphasising the variation (in growth) present, both among and within locations. The basal area projection models substantiate that disparate growth has occurred and additional parameters are required to account for this.

Unfortunately, it is also clear that seedlots greater than GF19 (control-pollinated seedlots) do not always out perform GF14. To date, data from only a very few seedlots over GF19 are available, and only two are well represented, the GF22 from which the multipliers were estimated and the GF21 in the 'silvicultural series' detailed by Carson *et al.*, 1997 and 1999. The increase in performance of the GF22 over the GF14 is clear, especially on high growth sites, but a substantial increase in performance of the GF21 relative to GF14 is not apparent, either for volume or height. Carson *et al.*, 1997 comment:-

'The control-pollinated seedlot was rated a GF21, but relative to the open-pollinated seedlot (GF14) did not perform as well as the control-pollinated seedlot rated GF22 in the 1978 genetic gain trials (Carson *et al.*, 1997)'

During 1998 CHH Forests reviewed all the available results for additional seedlots over GF19 from both the Modelling and Breeding Cooperatives as well as data from Company Trials. The Report is not tabled here but part of the summary is: -

'Open-pollinated seedlots are consistently ahead of GF7 climbing select seedlings by both yield and form traits'

'Control-pollinated seedlots GF21 and GF22 while on average ahead of open-pollinated lots are much more variable in yield performance'

'There is evidence that neither control nor open pollinated seedlots perform particularly well on lesser producing sites.'

Given that the absolute size of genetic gains (in yield) are likely to be closely associated with growth-path-divergence, these findings are germane to discussion here. Divergence has been established but varies by location and shows greater variance for different controlled pollinated seedlots. Insufficient data is available to date to do anything other than assume nation-wide growth-rate multipliers. Additional data may or may not support this approach, but regional differences, if they exist, are likely to be relatively small, rather than large.

Given the results above, the question arises as to how best to estimate long-term volume gains from highly rated GF-material at his point in time. With respect to further research, the GF22 multiplier which is implemented in the SGMC models was estimated using data from only one seedlot which is represented on only a

limited number of sites. Therefore, examination of the performance of additional control-pollinated stock (GF > 19) relative to lower ranked is clearly warranted. In addition, the confounding of growth and form in the GF rating may be contributing to the increased variability of these higher ranked seedlots, and any further analyses should use the breeding value for growth (which is not confounded with breeding value for form traits), rather than GF ratings.

With respect to operational use of the multipliers, a valid INPUT basal area is clearly required, indicative and representative of faster early growth because of the superior rated seedlot, *per. se.* Given the results above it would be prudent to only use inventory data, where the faster early growth is a *fait accompli*.

Second, a 'multiplier' must be chosen, to account for the likely divergent basal area growth. At present, the FRI Models are programmed to linearly interpolate or extrapolate established 'benchmark' multipliers for GF14 and GF22. This is clearly a speculative practice because 1) the estimates are based on only six sites and on only a limited amount of data (plots and measurements) from the one seedlot greater than GF19, and 2) the one additional seedlot with >GF19 which is well represented in large-plot trials (the GF21 in the 1987 Silviculture/Breeds trials) is performing about the same as the GF14 (open-pollinated orchard) seedlot.

One conservative alternative may be to ALWAYS choose the GF14 multiplier (given the seedlot IS open pollinated material or higher) and input inventoried data, but otherwise desist from extrapolating the multiplier anymore. Clearly, data on a larger representation of highly rated seedlots is required in order obtain a reliable genetic gain multiplier for control pollinated seedlots. Data on 12 additional control-pollinated seedlots (rated >GF19) is becoming available from measurement of the 1984 Genetic Gain trial and the Silviculture/Breeds trials. In addition, there is opportunity for the SGM C to measure additional highly rated seedlots represented in large-plot trials planted in 1992-1994.

Special care should be taken on lower productivity sites where the evidence is that environmental effects are large so that absolute differences between seedlots are substantially reduced. On low productivity sites, the same increase in growth rate as on high productivity sites results in a smaller difference among seedlots. This is similar to raising or lowering the capital earning a fixed compound interest rate in a bank account. However, while the absolute increases in yield are relative to the productivity of the site, the cost of producing control pollinated stock is relatively fixed. This is analogous to a fixed fee charged for depositing funds into the bank account. The benefit of any genetic gain must always be weighed against the cost of producing that gain, and perhaps high and low productivity sites would lead to different conclusions as to the desirability of investment in very highly improved stock solely for the improvement of yield.

References

- Carson, S.D., Dunlop, J. and Garcia, O., 1997. Second estimation of genetic gain multipliers using data from 1978-1980 large block genetic gain trials. FRI/ Industry Research Cooperative : Stand Growth Modelling Cooperative Report No. 53 (unpublished)
- Carson, S.D., Garcia, O., Kimberley, M. O., and Skinner, J., 1994. Genetic gain in radiata pine expressed as growth rate multipliers. FRI/ Industry Research Cooperative : Stand Growth Modelling Cooperative Report No. 35 (unpublished)
- Carson, S. D., O. Garcia, and J. D. Hayes. 1999. Realised gain and prediction of yield with improved *Pinus radiata* in New Zealand. Forest Science. (In press).
- Carson, S. D., Kimberley, M., Hayes, J. D., and Carson, M. J., 1997 The effect of silviculture on genetic gain in growth of *Pinus radiata* at one-third rotation. FRI/ Industry Research Cooperative : Stand Growth Modelling Cooperative Report No. 57 (unpublished)
- Carson, S. D., M. O. Kimberley, J. D. Hayes, M. J. Carson. 1999. The effect of silviculture on genetic gain in growth of *Pinus radiata* at one-third rotation. Canadian Journal of Forestry Research (submitted).
- Garcia, O., 1984. New class of Growth Models for even-aged stands: *Pinus radiata* in Golden Downs forest. N. Z. Jour. For. Sci. 14: 65-86.
- Woollons, R. C. and Hayward W. J., 1985. Revision of a Growth and Yield Model for radiata pine in New Zealand. For. Ecol. and Manage 11: 191-202.

Family of Basal — Area / ha Curves Through Time

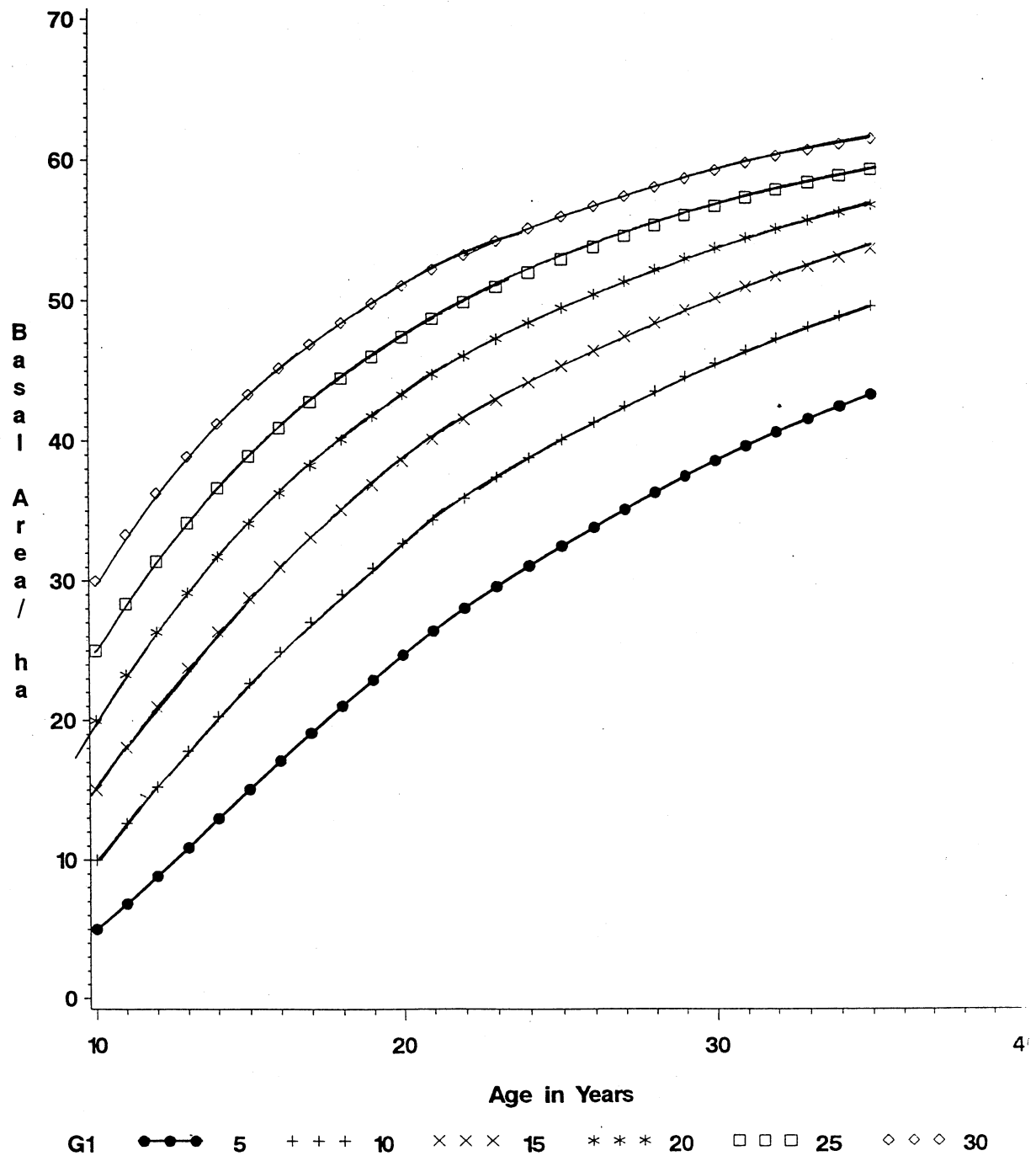


Figure 1

General Linear Models Procedure

Dependent Variable: GLIN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	27574.161	1622.009	8.14	0.0001
Error	72	14354.033	199.362		
Corrected Total	89	41928.195			

R-Square	C.V.	Root MSE	GLIN Mean
0.657652	19.47852	14.120	72.488

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REGION	5	21684.393	4336.879	21.75	0.0001
GF	2	5064.239	2532.120	12.70	0.0001
REGION*GF	10	2819.837	281.984	1.41	0.1915

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
gf_lin	1	5052.4676	5052.4676	25.34	0.0001
gf_qua	1	18.4815	18.4815	0.09	0.7616

184
09:39 Monday, January 11, 1999

General Linear Models Procedure

Dependent Variable: GQUA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	5194.4776	305.5575	5.20	0.0001
Error	72	4231.3768	58.7691		
Corrected Total	89	9425.8544			

R-Square	C.V.	Root MSE	GQUA Mean
0.551088	-78.33211	7.6661	-9.7867

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REGION	5	4658.8516	931.7703	15.85	0.0001
GF	2	85.3148	42.6574	0.73	0.4874
REGION*GF	10	267.4180	26.7418	0.46	0.9131

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
gf_lin	1	6.415063	6.415063	0.11	0.7421
gf_qua	1	73.195320	73.195320	1.25	0.2681

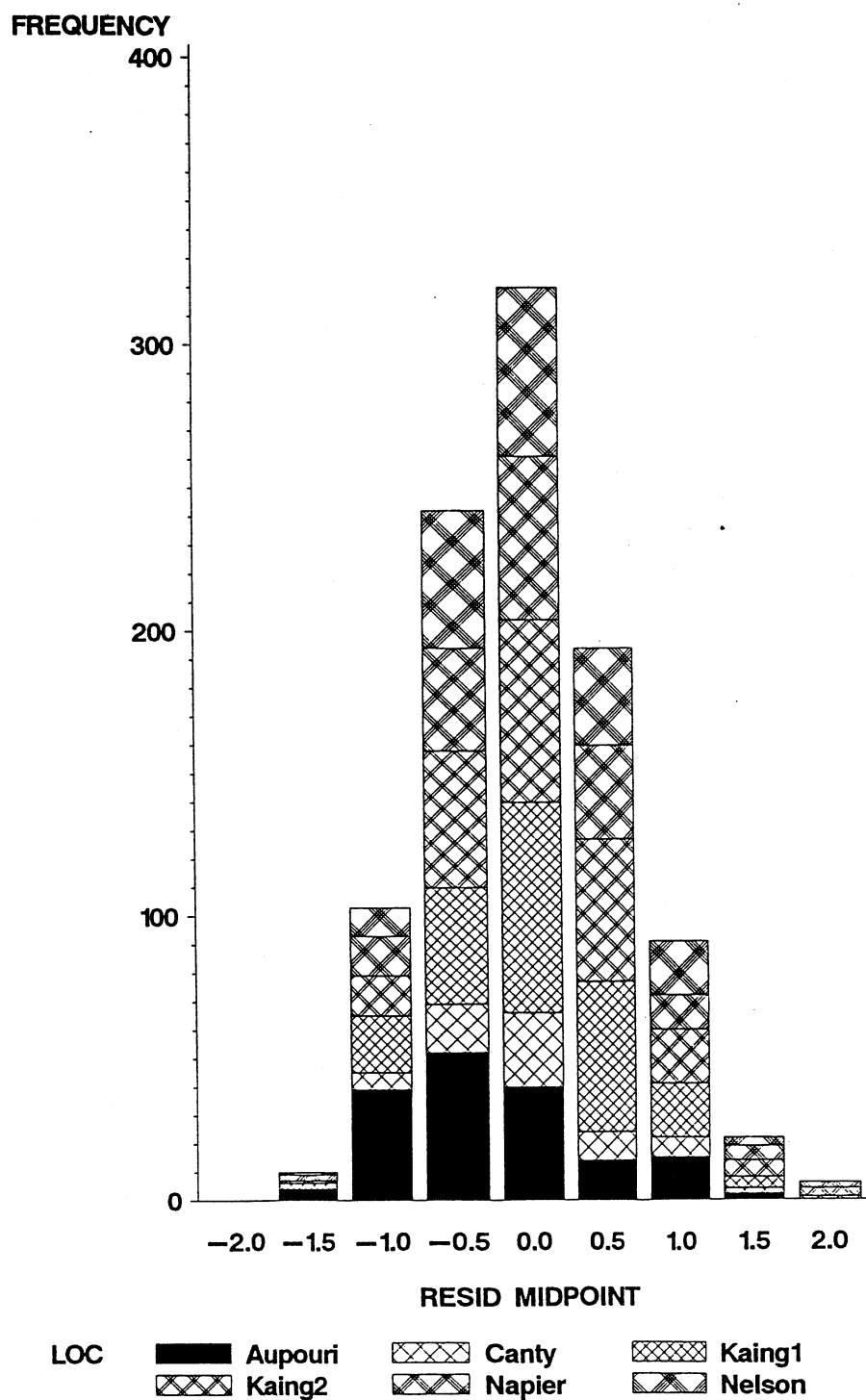
Table 1

General Linear Models Procedure
Least Squares Means

	REGION	GF	GLIN LSMEAN	GQUA LSMEAN	GCUB LSMEAN
<i>AUPONCE</i>	AK	7	51.638333	0.3250000	-0.21666667
	AK	14	59.751667	1.5850000	-0.56000000
	AK	22	76.763333	-0.2966667	-0.04666667
<i>CANY</i>	CY	7	82.390000	-24.5233333	-1.61000000
	CY	14	97.023333	-28.1966667	-0.31000000
	CY	22	86.640000	-22.4400000	-1.52666667
<i>NELSON</i>	NN	7	68.493333	-6.9266667	0.38833333
	NN	14	78.790000	-8.1266667	0.10666667
	NN	22	93.630000	-13.1366667	-1.35333333
<i>ROTO(1)</i>	RO	7	63.156667	-6.1233333	0.21500000
	RO	14	75.991667	-8.3950000	0.01666667
	RO	22	79.125000	-6.5150000	-0.97000000
<i>ROTO(2)</i>	RO1	7	50.353333	-15.3100000	0.47500000
	RO1	14	48.723333	-17.5300000	1.81666667
	RO1	22	56.960000	-17.1400000	-0.29166667
<i>NATIER</i>	WN	7	82.056667	-5.5833333	0.63333333
	WN	14	91.745000	-11.3250000	0.25000000
	WN	22	124.616667	-2.8766667	-0.31333333

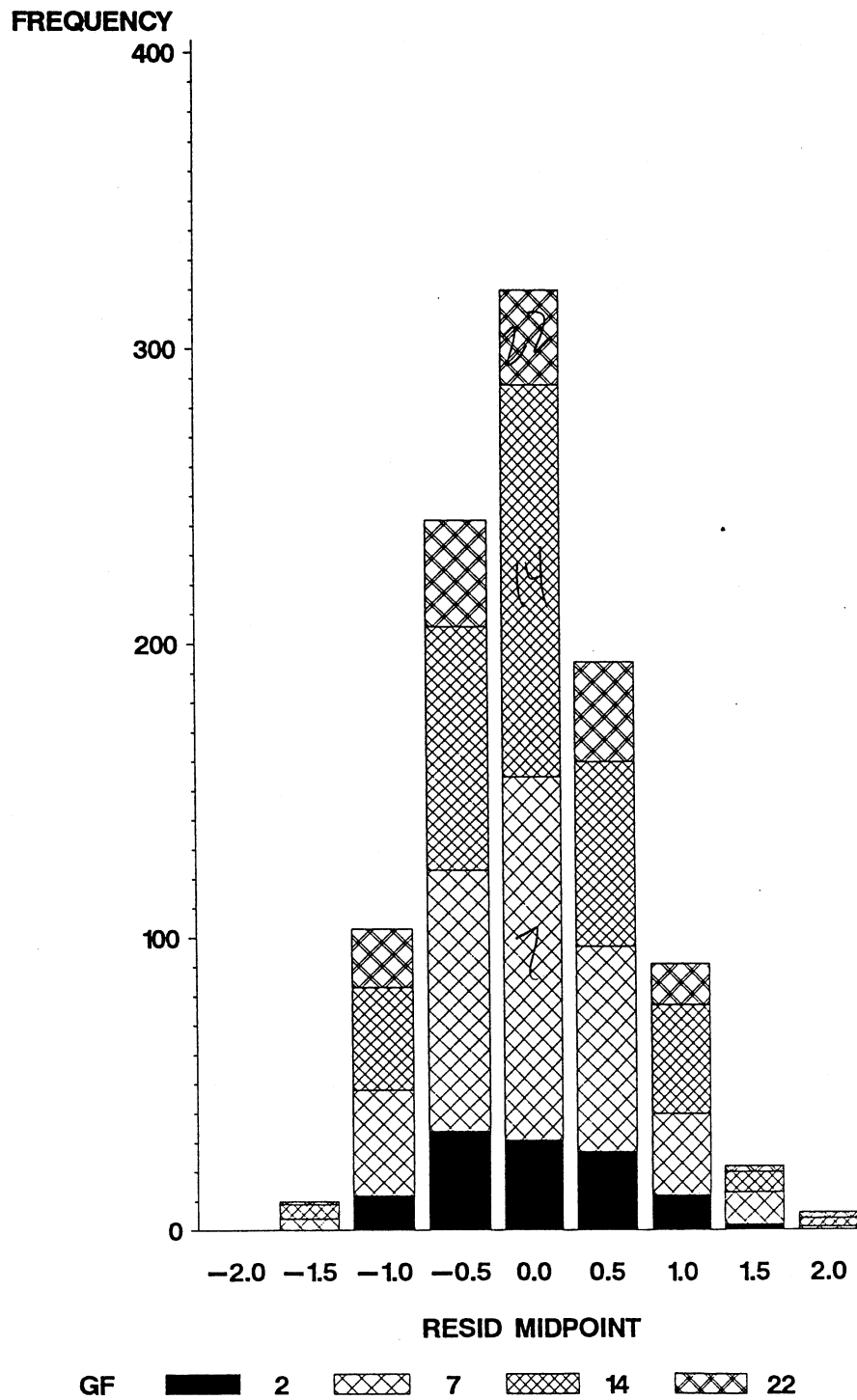
Table 2

TOP HEIGHT PROJECTION EQUATION



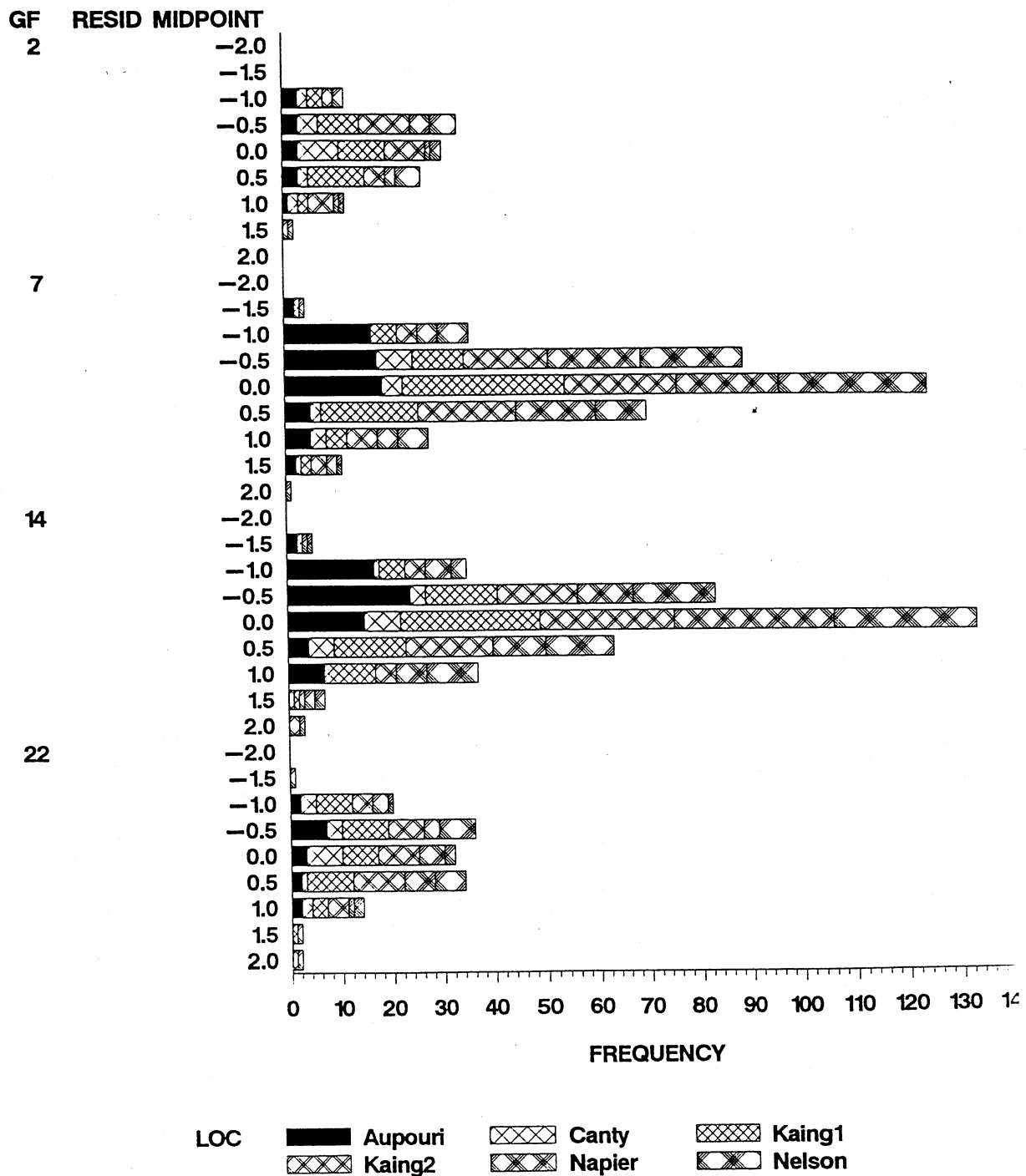
Appendix 1

TOP HEIGHT PROJECTION EQUATION



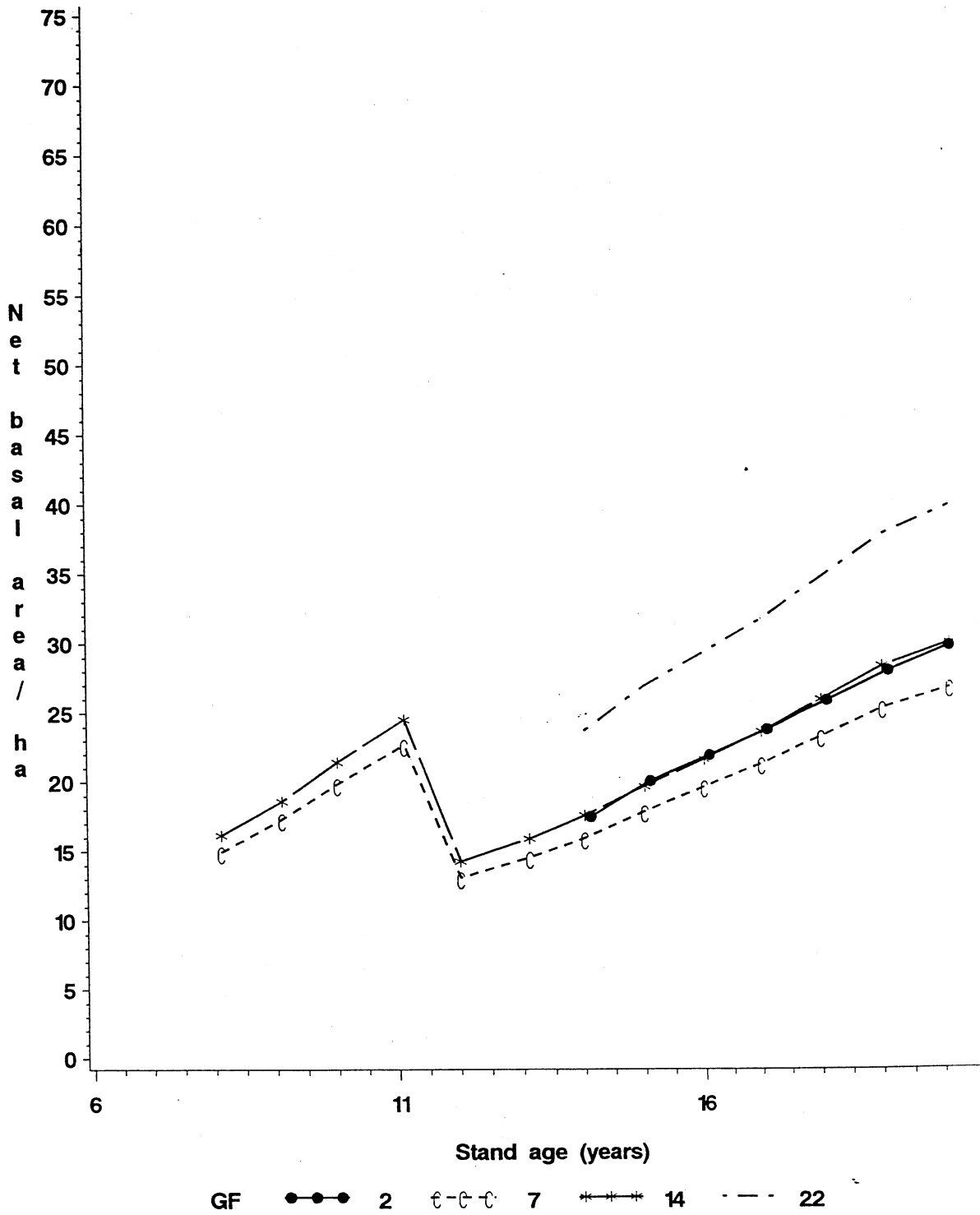
Appendix 2

TOP HEIGHT PROJECTION EQUATION



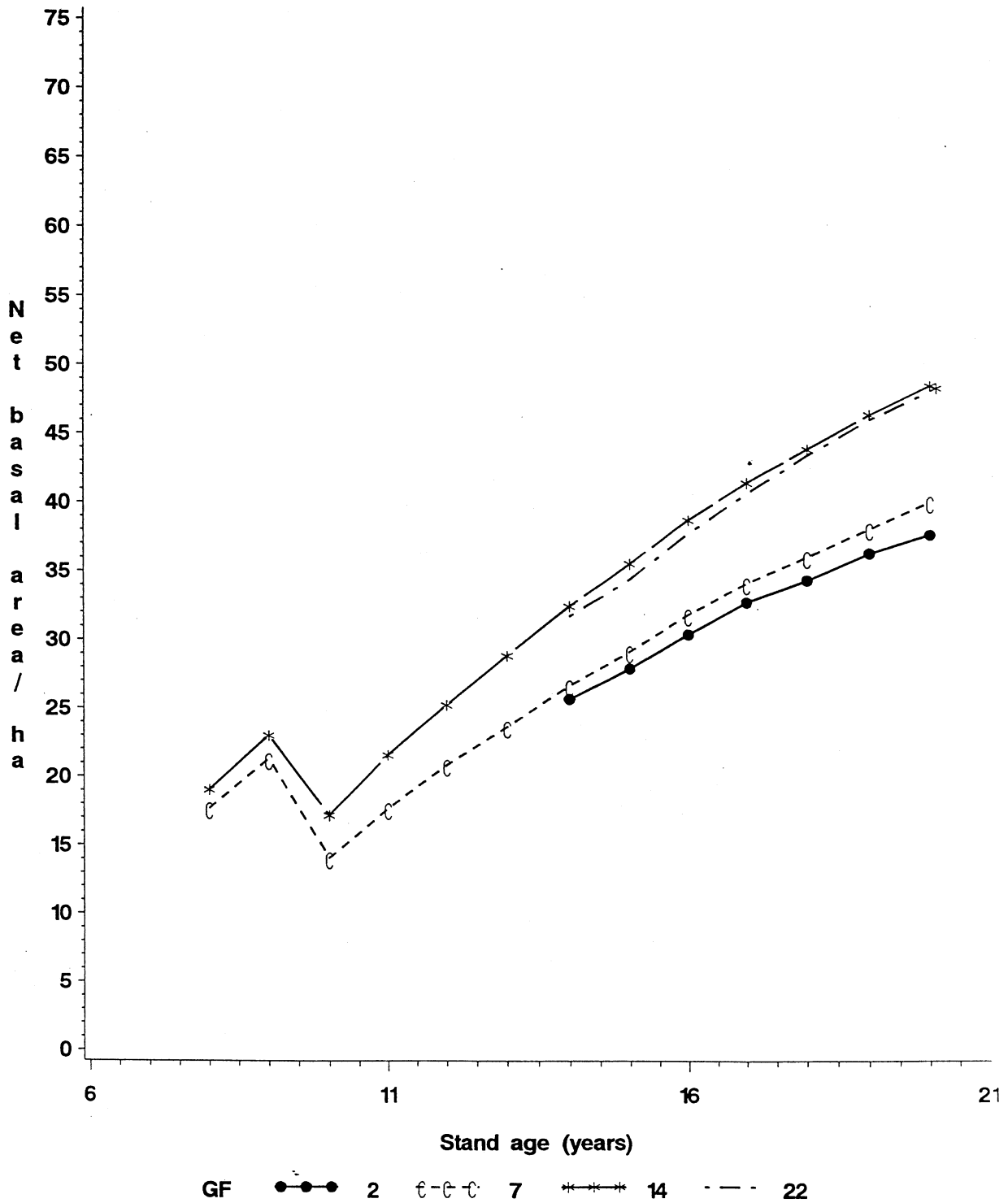
Appendix 3

LOC= Aupouri



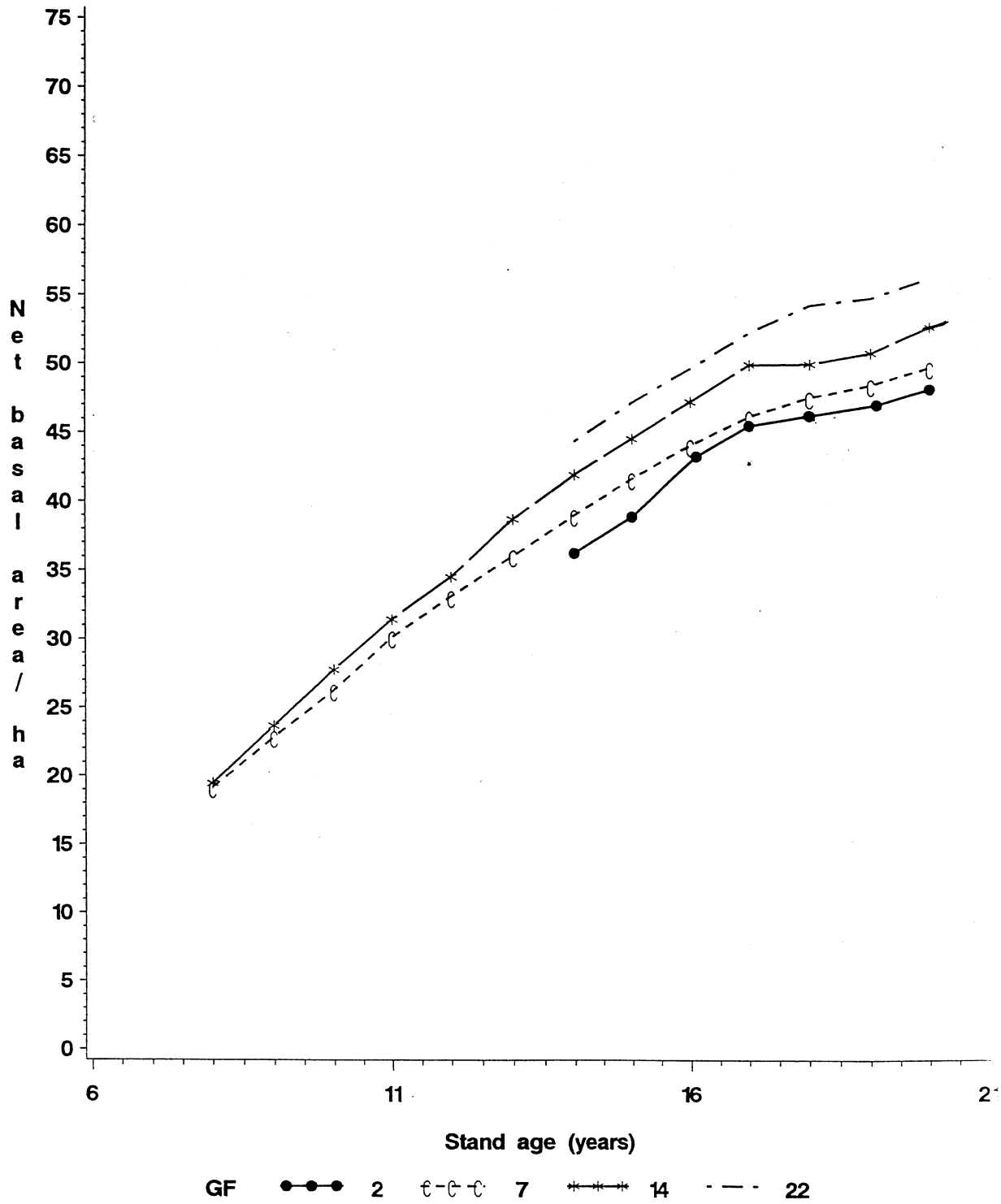
Appendix 4

LOC= Kaing1



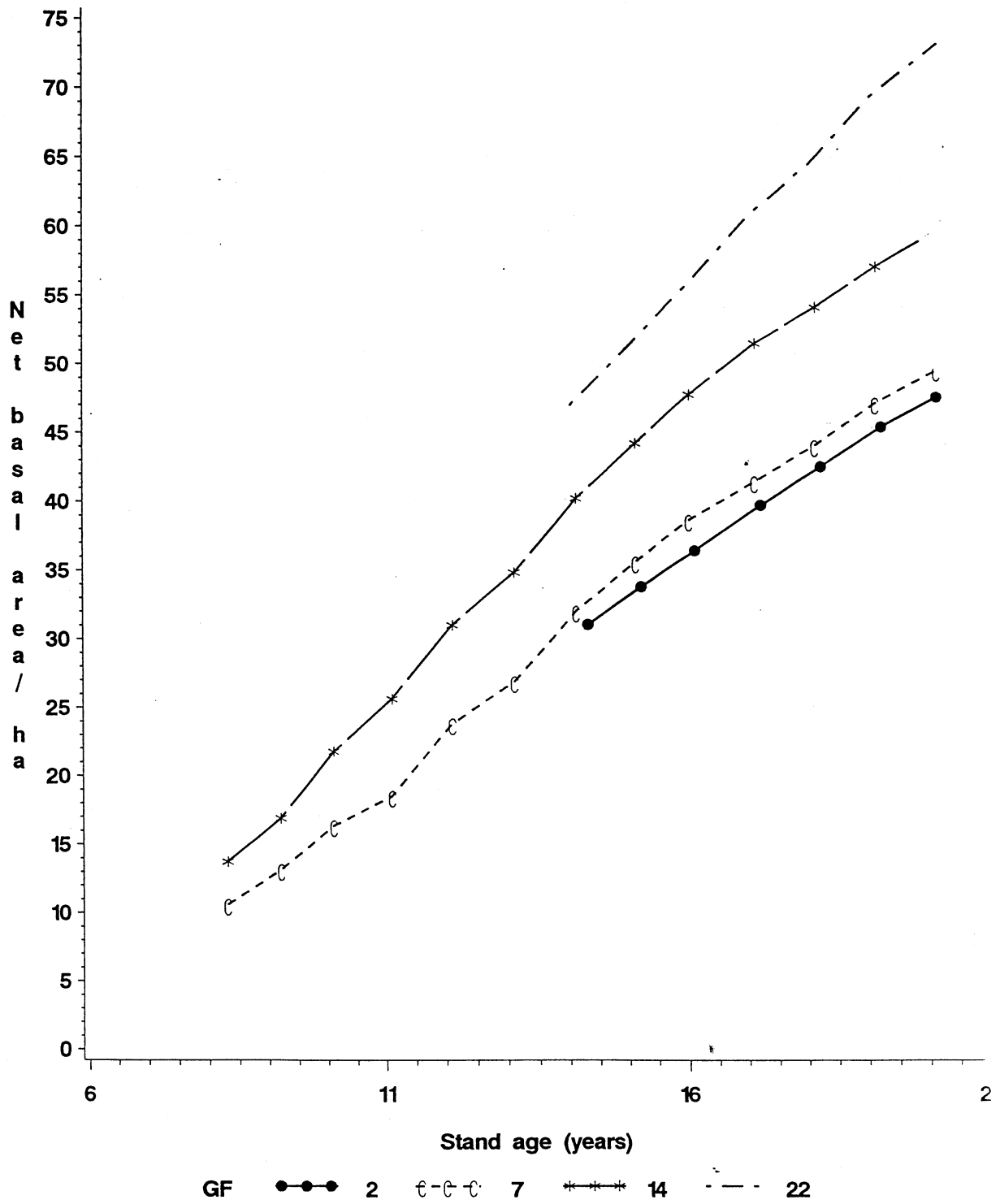
Appendix 5

LOC= Kaing2



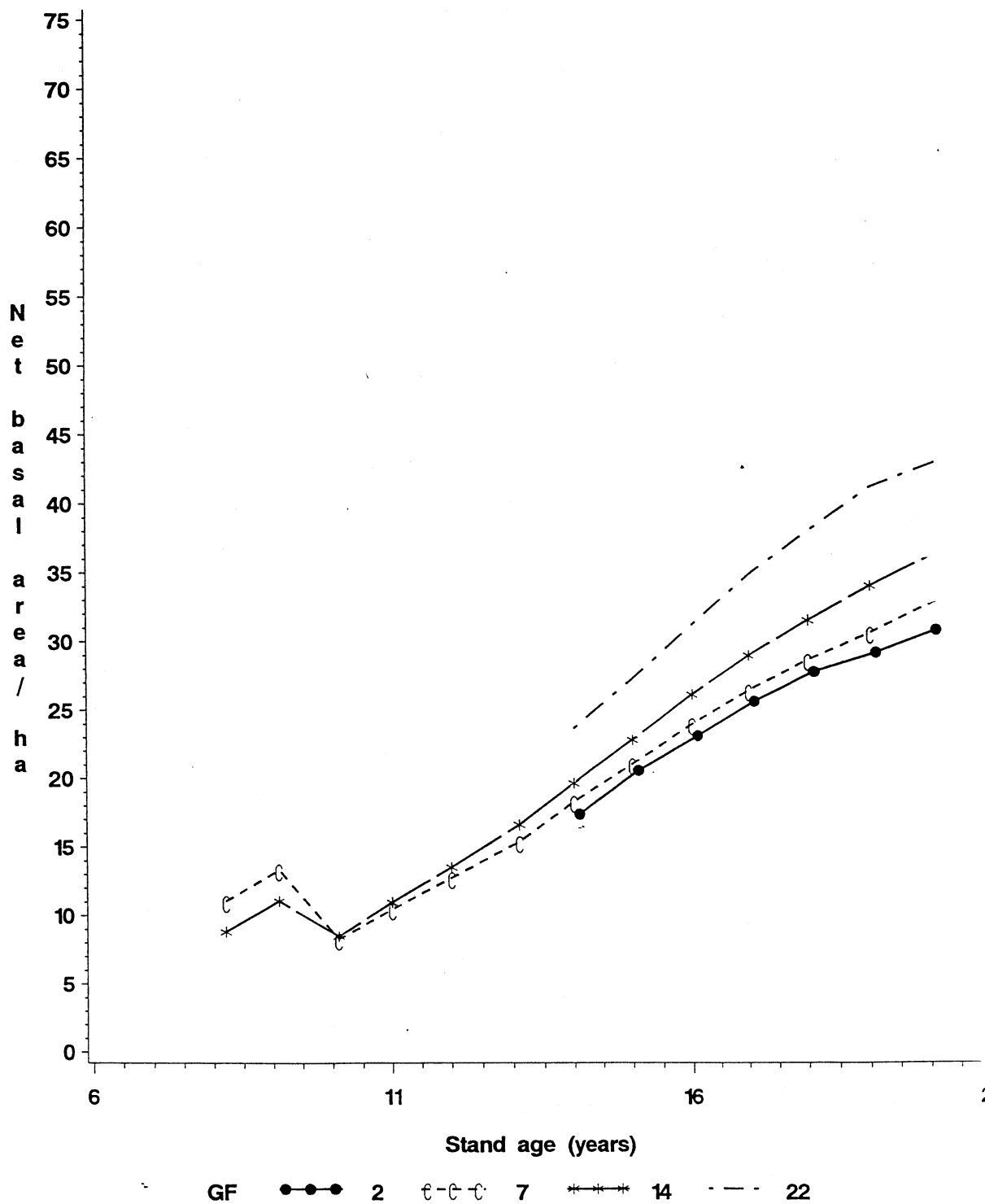
Appendix 6

LOC= Napier



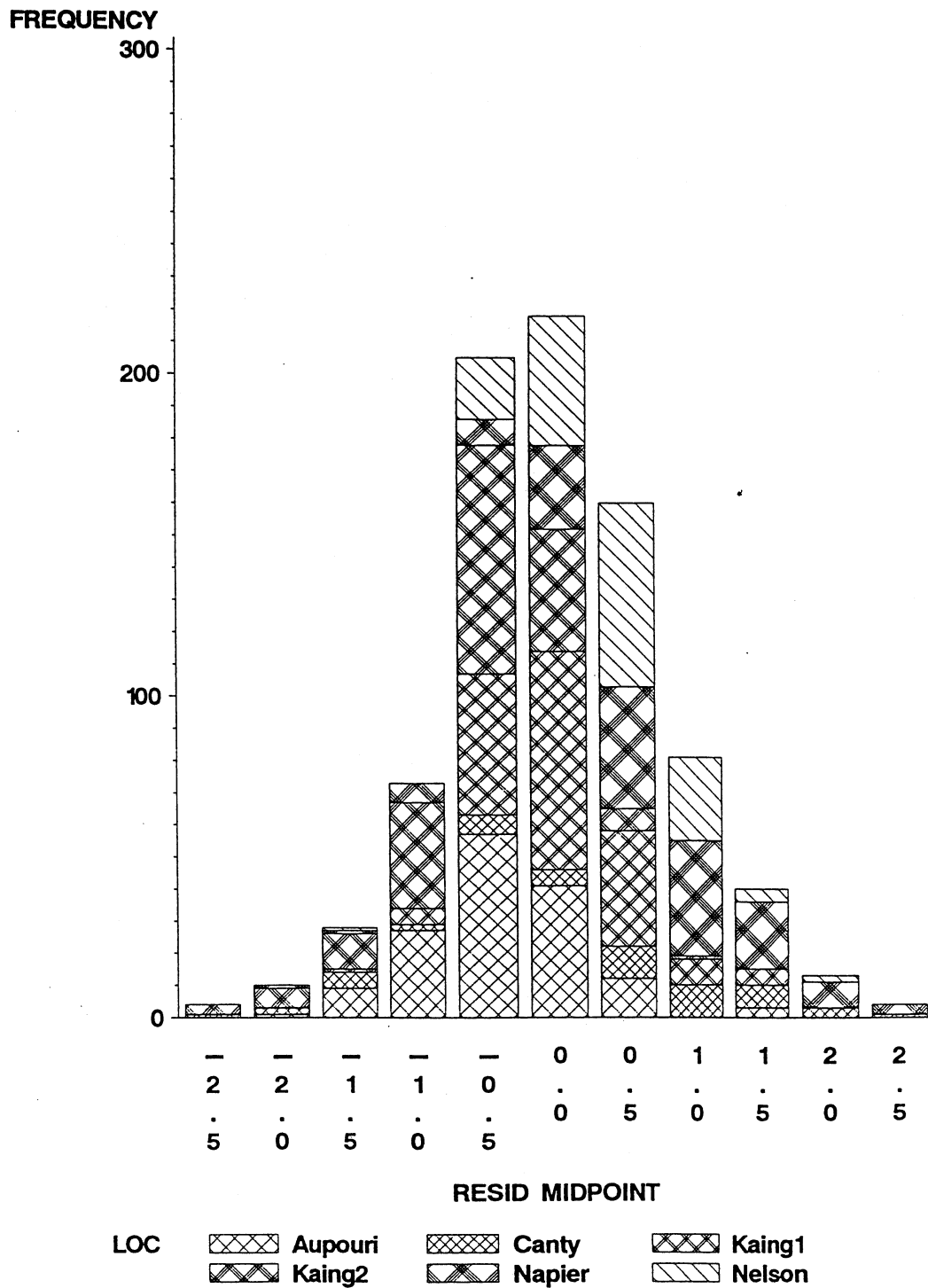
Appendix 7

LOC= Nelson



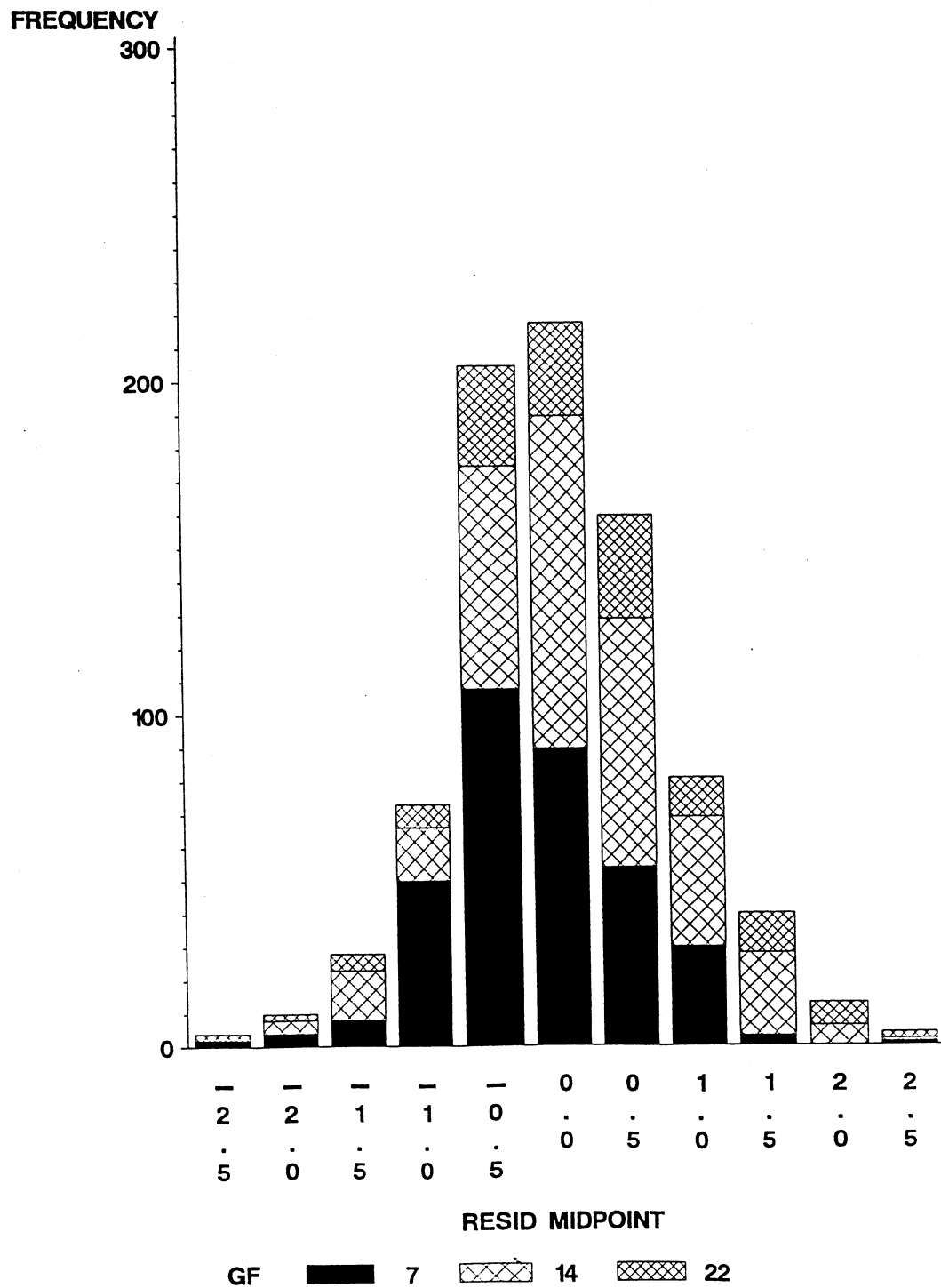
Appendix 8

Basic Basal—area/ ha Function



Appendix 9

Basic Basal Area MModel



Appendix 10