

Forest Research Output

No. 32828

**INFLUENCE OF SITE AND GENETICS ON
BRANCH DIAMETER AT TIME OF PRUNING**

J.C. GRACE

REPORT No 98.

September 2001

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This is an unpublished report and **MUST NOT** be cited as a literature reference.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

Diameter of the largest branch removed by pruning was measured in many of the trials managed by the Stand Growth Modelling Cooperative. Within an experiment, stocking had a major effect on the plot mean value, however there was little variation due to seedlot. At a regional level, the relationship with stocking tended to be consistent between experiments. At a given stocking, the plot mean values tended to be higher on the poorer sites and smaller on the better quality sites. The relationship with stocking was not consistent between regions. In some regions, plot mean values increased rapidly with decreasing stocking. In other regions the trend was much less.

As a result of these analyses, regional level coefficients will be implemented in the branch model, BLOSSIM, to account for the variation in branch development between regions.

INFLUENCE OF SITE AND GENETICS ON BRANCH DIAMETER AT TIME OF PRUNING

J.C. GRACE

INTRODUCTION

Models developed to represent a biological process vary greatly in complexity from simple empirical models that provide the best-fit to observed data to detailed process-based or functional/structural models that predict the biological processes affecting tree growth. The branch model, BLOSSIM, has been designed as an attempt to bridge the gap between “best-fit” models and very detailed process-based models (Grace *et al* 1999). The structure of the model is based on our understanding of the branching process. Empirical relationships have then been fit to observed data.

This is a different modelling approach to that used in developing models of branch index (BIX) (Kimberley and Knowles, 1993). Branch Index is predicted using an empirical function of stand variables measured or predicted at critical points during the rotation, for example diameter at breast height (DBH) at age 20 years and dominant height at the time of the last thinning. The authors contend that DBH at age 20 years adequately accounts for the effects of site fertility and stocking. This model can be classified as a “best-fit” model, but is not helpful in understanding the mechanism of branch development for the following reason:

Growth occurs when the tree produces more photosynthate than is needed to keep it alive. The photosynthate produced is determined to a large extent by the amount and distribution of foliage within the tree crown. The branch diameters are determined to a large extent by their weight, which depends on the length and distribution of foliage. Hence in reality, stem diameter is a result of the branching, rather than branch diameter being the result of the stem diameter.

One hypothesis implemented in BLOSSIM, is that branch diameter growth is driven by a series of multiplicative potentials (SGMC Report No. 90), these potentials are:

- Branch – to account for different branch diameters within a cluster
- Cluster – to account for difference in cluster size within an annual shoot
- Tree – to account for differences between trees
- Stocking – to account effect of stocking.
- Site – to account for site influences
- Genetic – to account for genetic differences

It is anticipated that a better understanding of how different factors influencing branch growth will be obtained by using this series of potentials. It will also provide a good platform for hypothesis testing and incorporation of other fundamental research.

The first four potentials (branch, cluster, tree and stocking) appear to account for the variation in branch diameter within a tree and with varying stocking in Experiment RO696 (SGMC Report No. 90).

Since 1987, a series of trials have been planted to quantify the effects of genetics, stocking and site on tree growth (SGMC Report No. 70). To date, the only branch information collected has been the diameter of the largest branch removed by pruning.

The objective of this report is to document the analysis of these data to provide a preliminary understanding of the effect of genetics, site and stocking on branching and to determine preliminary estimates for the genetic, site and stocking potentials for all growth modelling regions.

METHODS

Genetic, site and stocking potentials have been developed using a stepwise approach. The data analysed were plot mean values for the diameter of the largest branch on a tree removed by pruning.

First each SGMC trial has been analysed individually to determine the variability in diameter for the largest branch removed by pruning between different seedlots at one location (STEP 1). Secondly, all experiments within a growth modelling region have been compared (STEP 2). Finally preliminary genetic, site and stocking potentials are derived (STEP 3). These potentials were derived by assuming that these plot mean values represent the average tree (i.e. tree potential is 1), the average fully grown cluster (i.e. cluster potential is 1) and the largest branch in a cluster (i.e. branch potential is 1). This is not ideal for several reasons. First we have to assume that this branch is representative of the tree and is not the result of a malformation such as a fork or spike knot. Secondly this branch is likely to have been alive at the time of pruning and may not have reached its final size. Thirdly this branch is likely to represent the largest branch in approximately 1-2 annual shoots, whereas the cluster potential is obtained from the mean diameter of the largest branch in each cluster that has reached its maximum size (SGMC Report No.90). The experiments with relevant data are summarised in Table 1.

Table 1. Experiments Analysed.

Growth Modelling Region	Site Category	Forest	Seedlots	Tree Age at time of pruning (years)	Experiment
Sands	Medium	Woodhill	GF7, GF14, GF19, GF21, LI28(GF13)	5.7	FR7
Sands	Low	Sandtoft	GF6, GF14, GF16, GF25, LI25(GF13)	6.4	FR121/9
Clays	High	Tairua	GF7, GF14, GF16, GF25	4.4	FR121/4
Clays	Medium	Tungrove	GF7, GF14, GF16, GF25, LI25(GF13)	5.3	FR121/1
Clays	High BA	Mamaramui	GF14, GF17, GF22, LI23(GF9)	4.4	FR54
CNI	High	Tarawera	GF7, GF14, GF16, GF25, LI25(GF13)	5.0	FR121/6
CNI	Medium	Kaingaroa Cpt. 1187	GF2, GF16, GF18, GF22, GF23, GF25	4.8	FR85
CNI	Medium	Atiamuri	GF7, GF14, GF16, GF25, LI25(GF13)	4.9	FR121/2
CNI	Low	Kaingaroa, Cpt. 481	GF7, GF14, GF21, LI28(GF13)	6.9	FR9
CNI	High BA	Kawerau	GF2, GF16, GF25	4.4	FR84
East Coast	Medium	Mangatu	GF6, GF14, GF16, GF25, LI25(GF13)	4.8	FR121/8
East Coast	High BA	Huanui	GF7, GF14, GF16, GF25	4.6	FR121/7
Hawkes Bay	High	Tikokino	GF17, GF19, LI20(GF7)	5.7	FR57
Hawkes Bay	High	Tikokino	GF2, GF16, GF23, GF25	5.6	FR77
Hawkes Bay	Medium	Gwavas	GF2, GF16, GF23, GF25	5.8	FR78
Hawkes Bay	Low	Gwavas	GF7, GF14, GF16, GF25 LI25(GF13)	5.7	FR121/3
Nelson	High	Golden Downs	GF6, GF14, GF16, GF25, LI25(GF13)	5.9	FR121/13
Nelson	Medium	Golden Downs	GF2, GF16, GF23, LI27(GF6)	5.9	FR86
Nelson	Low	Ditchlings	GF7, GF14, GF21, LI28(GF13)	5.8	FR11
Canterbury	High	Ashley	GF6, GF14, GF16, GF25, LI25(GF13)	5.5	FR121/12
Canterbury	Medium	Dalethorpe	GF14, GF17, GF22, LI23(GF9)	7.0	FR56
Canterbury	Low	Eyrewell	GF16, GF17, GF22	6.7	FR55
Canterbury	Low	Shellocks	GF6, GF14, GF16, GF25, LI25(GF13)	7.8	FR121/11
Southland	Low	Blue Mountains	GF6, GF14, GF16, GF25, LI25(GF13)	7.9	FR121/10
Southland	High BA	Otago Coast	GF7, GF14, GF21, LI28(GF13)	7.0	FR12

STEP 1 – VARIATION BETWEEN SEEDLOTS WITHIN AN EXPERIMENT

Methods

For each plot within an experiment, the mean value for diameter of the largest branch on a tree removed by pruning was extracted from the Permanent Sample Plot System. These mean values were plotted against stems/ha before silviculture with the points labelled by seedlot.

The model, Eqn.1, was fitted to the data from each experiment using the SAS procedure PROC NLIN.

$$bd = a \times \left(\sqrt{\frac{10000}{s}} \right)^b \quad (1)$$

where:

bd is the plot mean value for the diameter of the largest branch on a tree removed by pruning
 s is the stems/ha before any silviculture (this will be less than the planting stocking if there has been any mortality)
 a, b are model coefficients

$\left(\sqrt{\frac{10000}{s}} \right)$ represents the average distance between trees, and can be considered an approximation for branch length at canopy closure. Since branch diameter is correlated with its length (see e.g. SGM Report No. 28), this term can be considered to represent the effect of stocking on branch diameter.

The correlation between residuals and predicted values was calculated at an experiment level (to check that Eqn.1 is appropriate) and for each seedlot within an experiment (to determine whether the same value of b is appropriate for each seedlot). The residuals were also analysed (using the Duncan test) to determine whether there were significant differences between the seedlots.

Results

Experiments FR77, FR78, FR84, FR85 and FR86 had a very narrow range of stocking. As a consequence of this, the coefficient, b , was not significantly different from zero (4 experiments) or the model did not converge (1 experiment).

There was a much wider range of stockings in experiments FR57, FR121/1, FR121/2, FR121/6, FR121/8 and FR121/12, but still the coefficient, b , was not significantly different from zero.

For these 11 experiments, the Duncan test was applied directly to the plot mean values for diameter of the largest branch on a tree removed by pruning (as there was no need to remove the effect of stocking). The long-internode seedlots generally, but not always, had the largest mean values. There was generally no significant difference in the mean value of bd between seedlots. For FR78 and FR84 there was a significant difference between the mean value of bd for the seedlot with the largest branches and the seedlot with the smallest branches. The difference was approximately 0.5 cm in both cases.

For the other 14 experiments the coefficient b was significantly different from zero. There was no significant correlation between residuals and predicted values at an experiment level indicating that Eqn.1 was appropriate for describing the relationship between bd and stocking. The correlation between residuals and predicted values was significant for only two seedlots (GF17 in FR86 and GF25 in FR121/9). Given the number of seedlots considered, it is reasonable to assume that the coefficient b is unlikely to vary with seedlot. The long-internode seedlots generally, but not always, had the most positive mean residual (i.e. the branch diameter tends to be larger for the long-internode seedlots compared to the other seedlots). If the long-internode seedlots and seedlots with only 1 plot were ignored then there was no significant difference between the seedlots in an experiment (except in 1 case FR121/9).

Discussion

From these analyses it is considered that Eqn.1 adequately defines the relationship between stocking and the plot mean value for the diameter of the largest branch on a tree removed by pruning. The shape of the relationship varied between experiments. Within an experiment the shape of the relationship tended not to vary with seedlot, and apart from the long internode seedlots there was generally no difference between seedlots in plot mean value for the diameter of the largest branch on a tree removed by pruning.

For modelling purposes, a judgement needs to be made as to whether the assumption that the coefficients a and b are independent of seedlot within an experiment is valid. The assumption is considered valid if long-internode seedlots are excluded (as only a very few tests showed significant differences between seedlots).

STEP 2 - VARIATION BETWEEN EXPERIMENTS WITHIN A REGION

Methods

Data pertaining to the long-internode seedlots have not been considered in the following analysis for the reasons stated above (in Step 1).

The model, Eqn.1, was fitted to the data from each region. The correlation between residuals and predicted values was calculated at a regional level and for each experiment within the region. The residuals were analysed (using the Duncan test) to determine whether there were significant differences between the experiments.

Eqn.1 was also fitted to the complete dataset. The correlation between residuals and predicted values was calculated for each region. The residuals were analysed (using the Duncan test) to determine whether there were significant differences between regions.

Results

For the complete dataset, there was significant correlation between residuals and predicted values for some regions, indicating that one model for the whole country is not appropriate.

Graphs showing measured values of bd versus stocking for each region are shown Figures 1-8. The predicted coefficients when the Eqn.1 was fitted to the data by regions are shown in Table 2. There was no significant correlation between residuals and predicted values at a regional level.

However there was a significant correlation between residuals and predicted values for 5 experiments:

- FR55 (Canterbury)
- FR121/4 (Clays)
- FR121/2, FR121/6 (Central North Island)
- FR121/13 (Nelson)

Since regional models are necessary, the question arises as to whether these 5 experimental sites are representative of their region and chance that has caused a significant correlation in the residuals, or whether differences are real and more growth modelling regions are necessary. A previous analysis of growth data in Canterbury Region (SGMC Report No. 39) indicated that there was variation in growth patterns within the region. Hence the significant correlation for FR55 is likely to be due to real differences in growth between sites. An investigation of variation in growth patterns with site quality in each of the other regions would be needed to determine the reason for the trend in the other 4 experiments.

Table 2. Coefficients from fitted Eqn.1 to observed data.

Region	Predicted value of a and its approximate standard error	Predicted value of b and its approximate standard error
Canterbury	2.39 ± 0.40	0.25 ± 0.10
Clays	2.86 ± 0.33	0.24 ± 0.07
CNI	1.42 ± 0.15	0.56 ± 0.07
East Coast	2.71 ± 0.40	0.16 ± 0.09
Hawkes Bay	3.06 ± 0.40	0.16 ± 0.08
Nelson	1.47 ± 0.22	0.43 ± 0.10
Sands	1.91 ± 0.24	0.52 ± 0.09
Southland	2.84 ± 0.28	0.32 ± 0.06

The variation in b between regions is worth further thought. b is lowest for Hawkes Bay and East Coast Regions which are dry areas. The low variation in branch size with stocking is one possible reason for the continued the use of low final crop stockings in these regions.

The mean residuals by experiment within region were compared using a Duncan test. There were significant differences between experiments within a region (

Table 3). It is interesting to note that, within a region, the high quality sites tend to have the most negative residual (i.e. branches tend to be smaller than predicted). The low quality and high basal area sites tend to have the more positive residual (i.e. branches tend to be larger than predicted).

There are two possible causes for the pattern. The age of pruning could have a slight influence on the results. On the lower quality sites the age of pruning tends to be slightly later than on the better quality sites (at most just over 2 years) (Table 1). At these ages, the largest branch in the pruned zone is still likely to be alive and possibly increasing slightly in diameter. This may account for some of the variation in branch size. The other factor is that there may be site differences in branch diameter growth and final size. This was observed for branch index in

Kaingaroa Forest Branch index increased as site index decreased (Tombelson *et al*, 1990). The observed variability in the data is probably the result of both the factors.

The Sands Region stands out as being the reverse with the low quality site having small branches. This may be the result of the nitrogen availability as branch growth is reduced by nitrogen deficiency (Will, 1971).

Discussion

These results indicate that there tends to be one relationship between stocking and branch diameter at time of pruning in a region, but that the level tends to vary with site quality within a region. The difference between the highest and lowest mean residual is always less than 2 cm within a region and generally less than 1 cm with the poorer quality sites tending to have larger branches. The time of pruning may have contributed to this difference. Given the small number of experiments within a region, it is considered unwise to try and include within region variation at this stage. Model sensitivity analysis will indicate whether we need to model within region variation at a later stage.

Table 3. Mean residuals from fitted Eqn.1 to observed data at a regional level.

Region	Experiment	Site Quality	Mean Residual	Grouping (Duncan test) *
Canterbury	FR56/0	Medium	0.9	a
	FR121/11	Low	-0.2	b
	FR55/0	Low	-0.7	c
	FR121/12	High	-0.9	c
Clays	FR54/0	High BA	0.2	a
	FR121/1	Medium	-0.1	a b
	FR121/4	High	-0.5	b
CNI	FR9/0	Low	0.4	a
	FR84/0	High BA	0.2	a
	FR121/2	Medium	-0.2	b
	FR121/6	High	-0.4	b c
	FR85/0	Medium	-0.5	c
East Coast	FR121/7	High BA	0.1	a
	FR121/8	Medium	-0.1	a
Hawkes Bay	FR121/3	Low	0.4	a
	FR77/0	High	0.3	a
	FR78/0	Medium	-0.04	b
	FR57/0	High	-0.4	c
Nelson	FR11/0	Low	0.2	a
	FR86/0	Medium	-0.1	a
	FR121/13	High	-0.7	b
Sands	FR7/0	Medium	0.1	a
	FR121/9	low	-0.5	b
Southland	FR12/0	High BA	0.01	a
	FR121/10	Low	-0.07	a

* Experiments with different letters have significantly different mean residuals

STEP 3 - STOCKING, SITE and GENETIC POTENTIALS

The site potential in BLOSSIM aims to account for the between-site variation in mean branch diameter (averaged over the largest branch in each cluster in the zone of the crown where branches have reached their maximum size). The data, analysed for this report, give a first indication of the likely site variability, but there are really insufficient sites in each region to confidently determine the effect of within-region site quality on this mean branch diameter. Hence a regional level site potential will be implemented. This assumption will need to be born in mind when testing the model and may need to be revisited at a later stage.

In SGMC Report No. 90, the term, $10000/s$, was considered initially as the stocking potential. Analyses indicated that the term needed to be raised to a power. The current analyses indicate that both coefficients a and b vary with site. Mathematically it will be neater to assume that:

a is the site potential

$\left(\sqrt{\frac{10000}{s}} \right)^b$ is the stocking potential

The genetic potential will be assumed to be 1 (at present) as these analyses showed little variation among seedlots (excluding long-internode seedlots).

The coefficients (Table 2) will be implemented in BLOSSIM for testing.

GENERAL DISCUSSION

The primary objective of this study was to derive preliminary estimates of the site potential for the branch model, BLOSSIM, by analysing data on the diameter of the largest branch removed by pruning. The analyses also provide a clear indication of the effect of site, silviculture and genetics on the diameter of the largest branch removed by pruning.

The analyses indicated that the influence of genetics on the diameter of the largest branch removed by pruning was small. In some instances the long-internode seedlots had significantly larger branch diameter. Apart from this, there was generally no significant difference between the different levels of genetic improvement.

Stocking had a significant influence on the diameter of the largest branch removed by pruning, however the shape of the relationship varied with site (Figure 9).

These results are logical and are supported by results in other studies.

The fact that genetics was the least significant of site, silviculture and genetics is in agreement with results obtained for both height and basal area growth in a subset of these trials (Carson *et al.*, 1999).

The term $\sqrt{(10000 / s)}$ was used in Eqn.1 as a stocking potential. This value is the average spacing between trees. King and Loucks (1978) suggest that the theoretical relationship between branch length and branch diameter at the branch base varied according to the forces acting on the branch. The fact that the coefficient b varied between regions suggests that branches may be subjected to different forces in different regions.

This study indicated that high quality sites tended to have larger branches than the lower quality sites. This is in agreement with results from a previous study (Tomblason *et al*, 1990) which showed that, at a given stocking, branch index was smaller on the higher quality site.

For a given stocking, the mean diameter of the largest branch removed by pruning varies with region. It is generally smallest in the Nelson area and largest in Southland. This tends to support casual observation that Southland has large branches (A. Cassie pers. comm.). The small branches in Nelson are likely to be attributable to nitrogen deficiencies (Will and Hodgkiss, 1977). Will (1971) indicates that large branches are likely to occur on fertile sites with an ample supply of nitrogen. This seems to be confirmed by the fact that the High Basal Area Sites tend to have large branch diameters.

REFERENCES

Stand Growth Modelling Cooperative Reports:

- No. 28: Grace, J.C. 1992: Branch Dynamics in Radiata Pine: Literature Review.
- No. 39: Grace, J.C. 1994: Relationship between environmental variables and radiata pine growth within the Canterbury growth modelling region.
- No. 70: Hayes, J.D.; Carson, S.D. 1998: Trials designed to quantify growth and yield gains from genetically improved radiata pine (third revision).
- No. 90: Grace, J.C. 2000: Branch diameter growth in radiata pine: hypothesis and prototype model.

Other references:

- Kimberley, M.O.; Knowles, R.L. 1993. A model to predict branch index in radiata pine direct sawlog regimes. Forest and Farm Plantation Management Cooperative Report No. 1. New Zealand Forest Research Institute (unpublished). 11pp
- Carson, S.D.; Kimberley, M.O.; Hayes, J.D.; Carson, M.J. 1999. The effect of silviculture on genetic gain in growth of *Pinus radiata* at one-third rotation. Canadian Journal of Forest Research. 29: 1979-1984.
- Grace, J.C.; Pont, D.; Goulding, C.J.; Rawley, B. 1999: Modelling branch development for forest management. New Zealand Journal of Forestry Science 29(3): 391-408.
- King, D. and Loucks, O.L. 1978. The theory of tree bole and branch form. Rad. and Environ. Biophys. 15: 141-165.
- Tombleson, J.D.; Grace, J.C.; Inglis, C.S. 1990. Response of radiata pine branch characteristics to site and stocking. In: R.N. James and G.L. Tarlton (eds) New approaches to spacing and thinning in plantation forestry. FRI Bulletin 151 pp 229-232.
- Will, G.M. 1971: Nitrogen supply, apical dominance and branch growth in *Pinus radiata*. Plant and Soil 34: 515-517.
- Will, G.M.; Hodgkiss, P.D. 1977: Influence of nitrogen and phosphorus stresses on growth and form of radiata pine. New Zealand Journal of Forestry Science 7: 307-320.

Figure 1. Data for the Sands Growth Modelling Region.

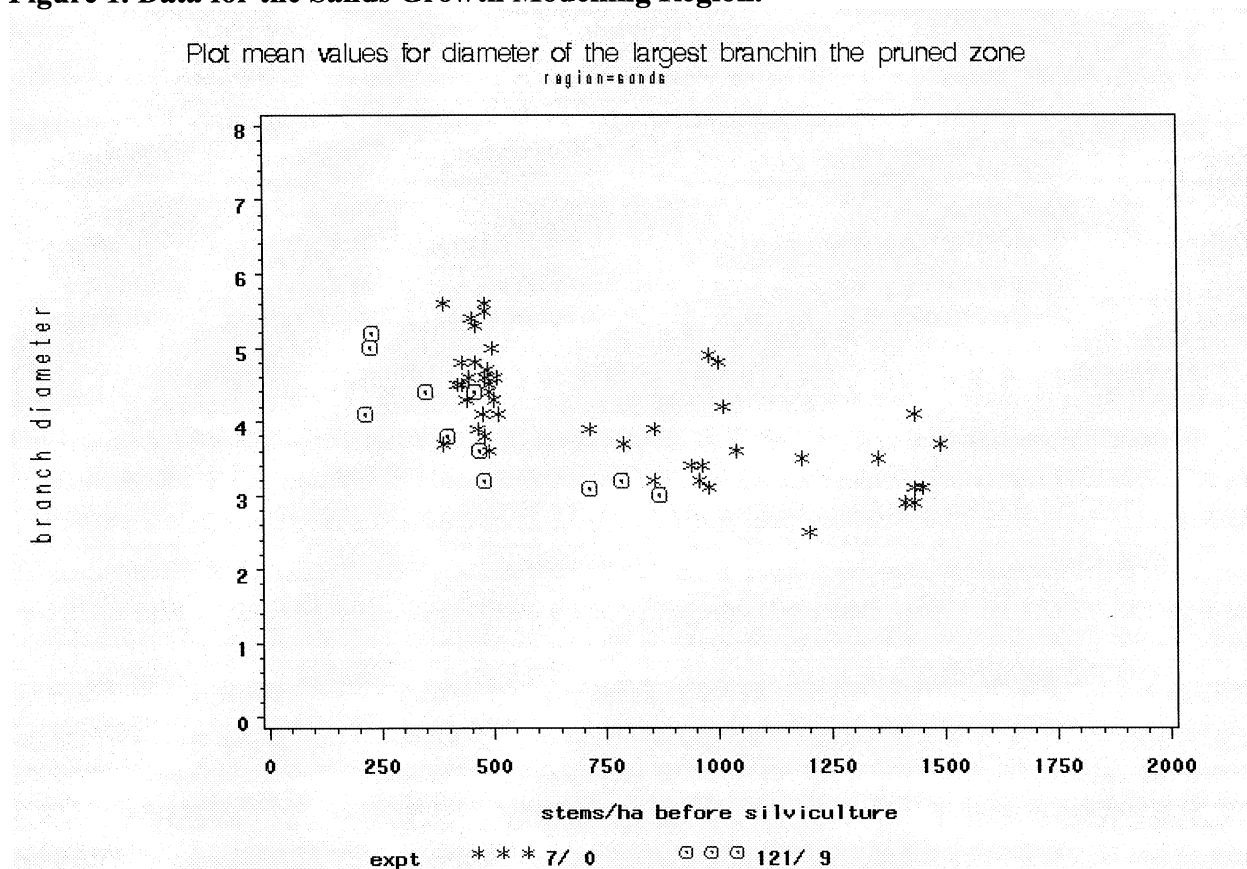


Figure 2. Data for the Clays Growth Modelling Region.

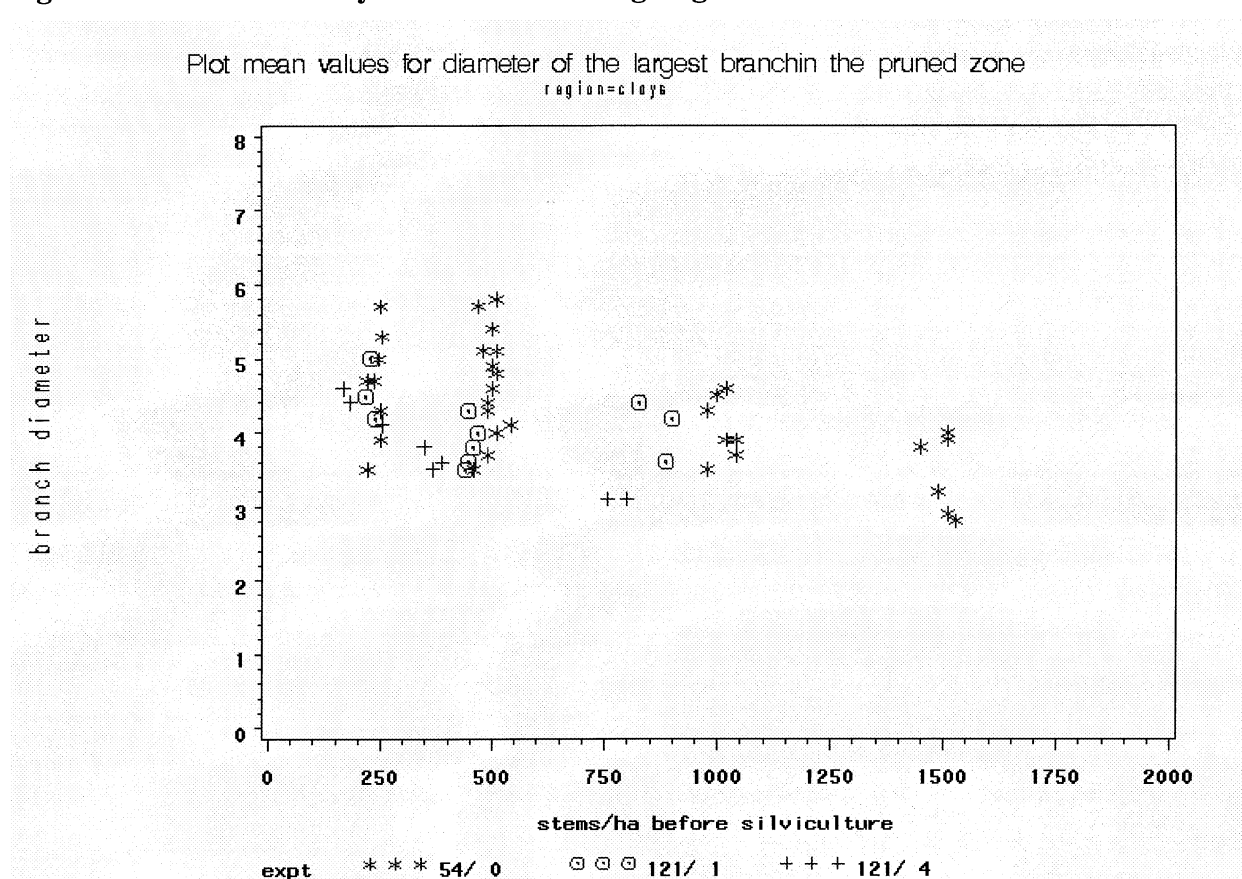


Figure 3. Data for the Central North Island Growth Modelling Region.

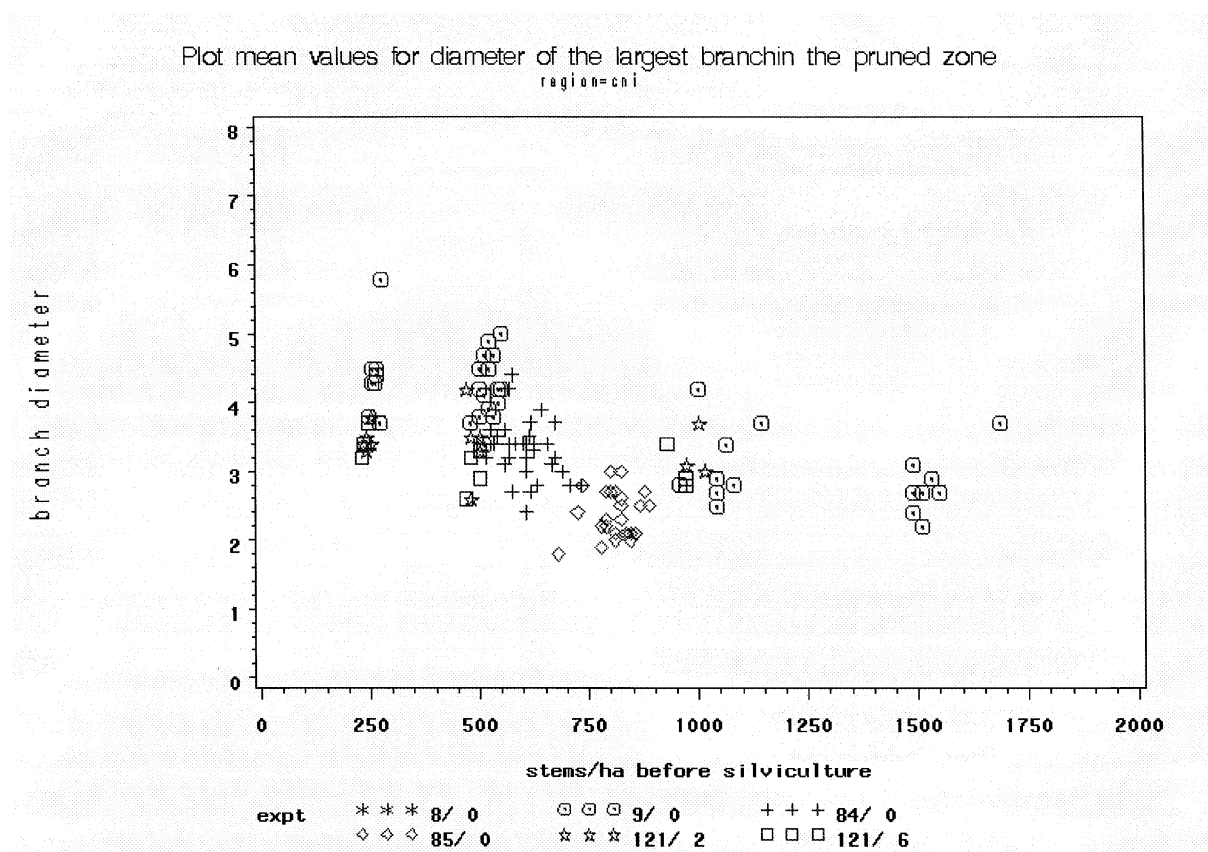


Figure 4. Data for the East Coast Growth Modelling Region.

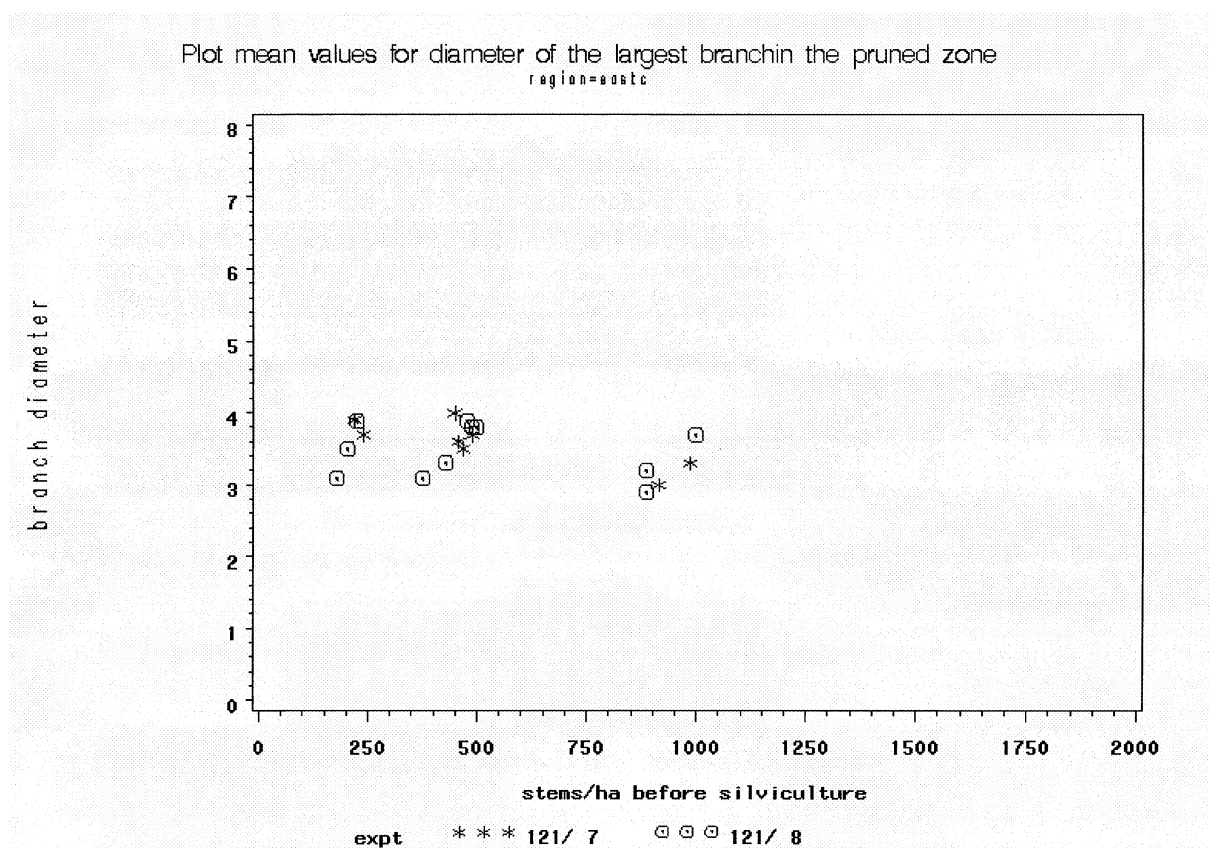


Figure 5. Data for the Hawkes Bay Growth Modelling Region.

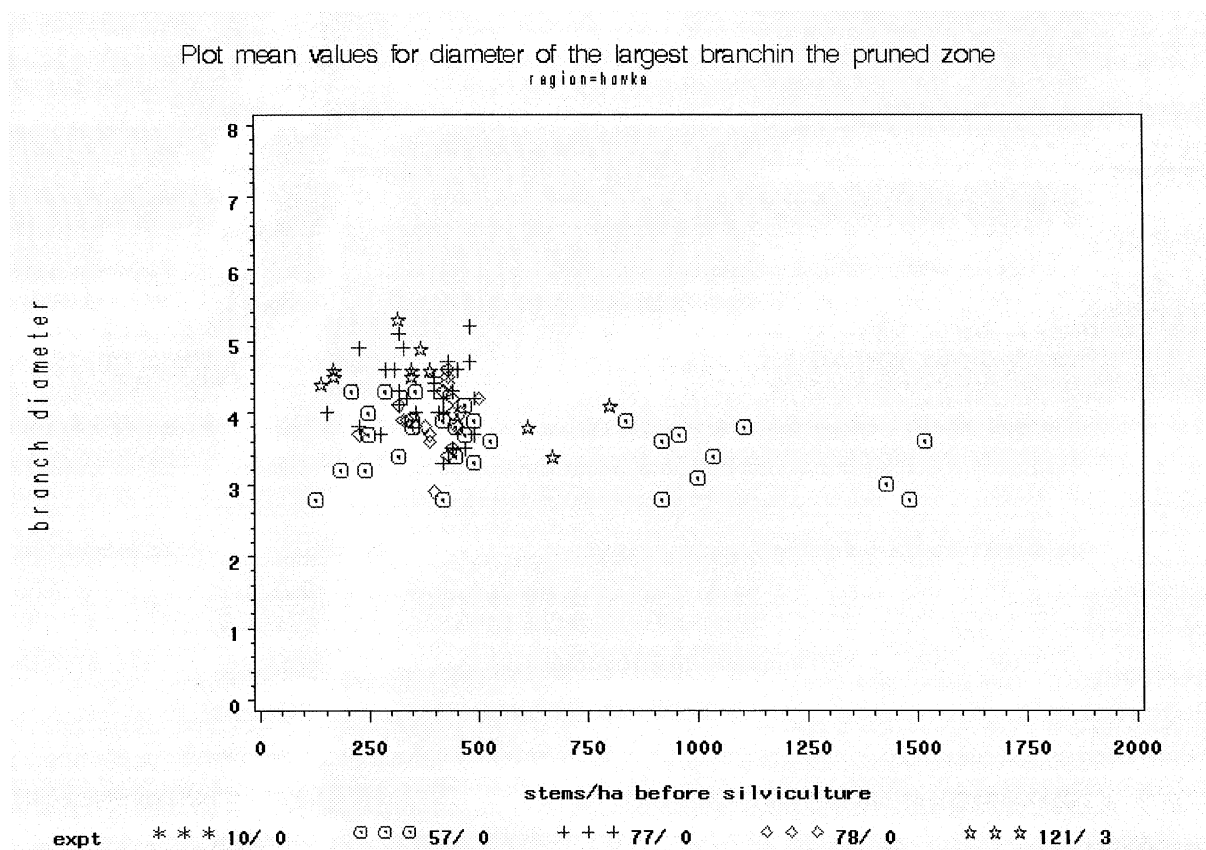


Figure 6. Data for the Nelson Growth Modelling Region.

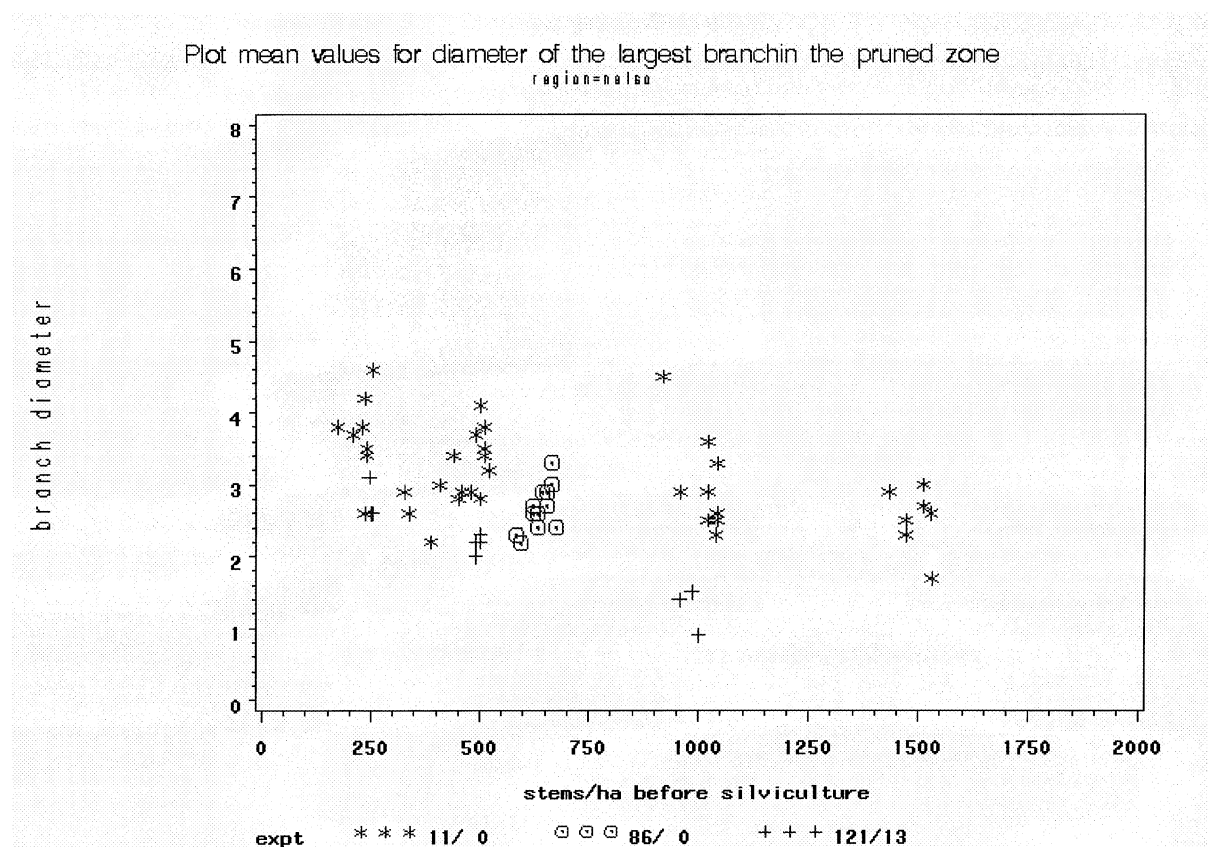


Figure 7. Data for the Canterbury Growth Modelling Region.

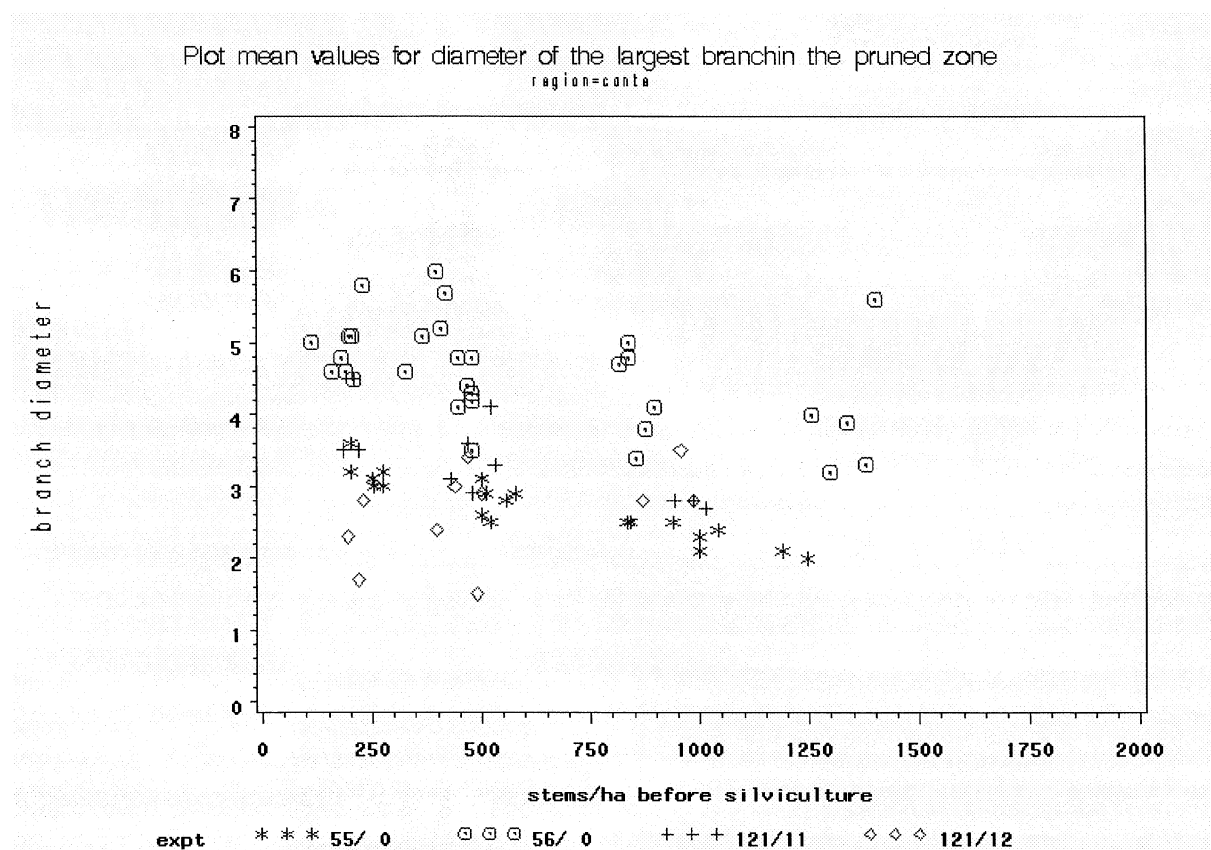


Figure 8. Data for the Southland Growth Modelling Region.

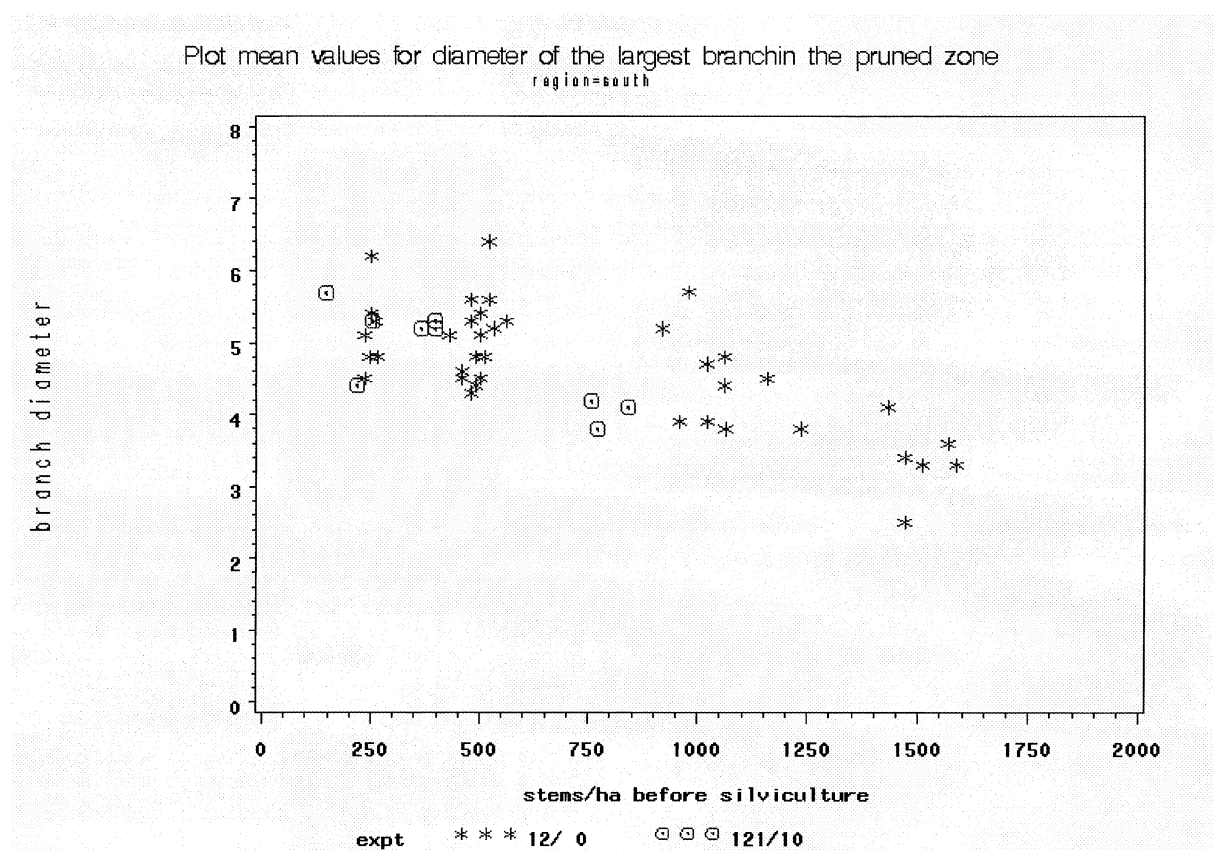


Figure 9. Predicted relationship between plot mean values for diameter of the largest branch in the pruned zone and stems/ha.

