F.R.I. PROJECT RECORD

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METHODOLOGY FOR COLLECTING BRANCH GROWTH DATA

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EXECUTIVE SUMMARY

Two methods for measuring branch diameter growth were suggested:

measuring branch diameter at selected points along the branch,
measuring branch diameter adjacent to where the branch joins the stem.

Field tests (at Kaingaroa and Tikitere) indicated that the second method was more useful.

The data collected indicate that branch diameter increases to a maximum and then decreases slightly in size. At young ages there is a lot of interchange between branches when ranked according to diameter.

An equation was developed to predict branch diameter at any age from branch age and maximum branch diameter.

For any branch older than 6-years, given branch diameter and branch age, this equation can be used to predict branch diameter at any future age with reasonable accuracy.

METHODOLOGY FOR COLLECTING BRANCH GROWTH DATA

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INTRODUCTION

The position and size of branches affects the quality of timber obtained at the end of the rotation. Rawley and Hayward (1990) suggest that improved estimation of stand log outturn could be achieved by developing a methodology for growing quality variables forward in time from a mid-rotation inventory. However the mechanisms controlling branch development are poorly understood and there are no commonly-used techniques for measuring branch development.

In order to model crown development (for both currently formed and unformed whorls), Grace (1992) suggested that we would need to predict:

- Number whorls formed each year
- Position of whorls within the annual shoot
- If and how internode lengths change as the tree ages
- Number of branches per whorl
- Angle branches make with the stem
- Rate of branch length development
- Rate of branch diameter growth
- When branches stop growing
- When branches die

For growing quality variables forward in time, the last three questions are the most important. In particular we will need to predict how silviculture will influence these processes.

The first step towards developing a model of crown development is to determine the most appropriate techniques for measuring crown development and in particular branch diameter growth.

There are two major ways branch growth data could be collected:

- by retrospectively sampling branches after they have grown
- by measuring the branches annually as they grow

Restrospective sampling enables one to obtain several years of growth data at one time. However one cannot measure how competition from neighbouring trees has influenced growth, particularly if the neighbouring tree has disappeared or has changed its dominance.

With long-term monitoring of branch growth, it will take several years to obtain sufficient data to model branch growth. An advantage is that it would be feasible to monitor the influence of competition from surrounding trees.

The same data can be obtained using either of these two methods.

Branch diameter growth can be measured in two ways:

- by measuring branch diameter at selected points along the branch
- by measuring branch diameter close to where the branch joins the stem

These two methods provide slightly different data, so it is important to decide which technique will be the more useful.

When used with retrospective sampling, the first method is equivalent to stem analysis along the branch. The method may also provide data on branch length development from the number of branch growth rings at each point, and branch senescence (as Larson (1969) suggests branches die by forming incomplete growth rings along the length of the branch).

The second method has the advantage that one is measuring branch development on that part of the branch which will be within the stem at time of harvest. When this method is used with retrospective sampling, it is not feasible to measure branch length development over time. It should be feasible to estimate time of branch mortality from observing bark encasement (e.g. Fujimori and Kiyono (1986)).

OBJECTIVE

The objective of this study was to examine the feasibility of using retrospective sampling with the above two methods to provide data for modelling branch diameter growth.

BRANCH GROWTH AT SELECTED POINTS ALONG THE BRANCH

METHOD

Experiment RO905 (in Kaingaroa Forest) was planted in 1967 at an initial spacing of 1.8 m by 1.8 m. Plots 1-8 suffered from windthrow during 1982 and have been "abandoned" as sample plots though the trees are still standing. Three trees (with diameter at breast height (DBH) close to the plot mean, maximum and minimum) were felled from plot 8 which had been thinned to a nominal stocking of 500 stems/ha (SPH) at predominant mean height of 22m.

For each tree, the following were measured:

- tree height
- diameter at breast height (1.4 m)
- height to base of branch cluster
  - (below where branch cluster was unlikely to impact on the stem)
- height to top of branch cluster
  - (above top of highest branch in the branch cluster)
- diameter of each branch in the cluster (to the nearest cm)
  - (at end of branch collar and far enough out to avoid any swelling)

Many branches were broken when the trees were felled, limiting the choice of sample branches for obtaining data on branch development over time. Generally only one unbroken branch per cluster was sampled.

For each sample branch, the distance along branch to each cluster of 2nd-order branches was measured. The branch was then cut midway between each cluster of 2nd-order branches and the widths of the branch growth rings recorded. Ring width were measured in the field for the first tree (mean tree). For the other two trees, ring widths were measured in the office by "highlighting" the cuts with petrol (cf James and Tustin, 1970) and using a magnifying glass.

PROBLEMS

1. The branch rings were difficult to observe in the field and there were discrepancies between observers in the number of rings at a given point along a branch. Highlighting the cuts with petrol made it slightly easier to observe the rings.

2. Ring counts did not increase consistently towards the base of the branch for about 1/4 of the branches measured in the office. This was considered to be due to the difficulty in measuring branch ring widths rather than incomplete rings being formed due to branch senescence.

3. Branch age from noting the position of narrow parastiches (leaf scars) (see Bannister, 1962) tended to greater than branch age from counting the number of branch growth rings. This was considered to be due to some rings not being visible to the naked eye. When one sample was examined under a microscope, extra rings were observed close to the bark.

4. The difficulty in observing branch growth rings made the method unsuitable for observing incomplete growth rings due to branch growth slowing down.

CONCLUSION

Measuring branch diameter growth at selected points along the branch using retrospective sampling is not satisfactory for obtaining data on branch diameter growth.

BRANCH GROWTH ON PART OF BRANCH ENCASED WITHIN THE STEM

METHOD

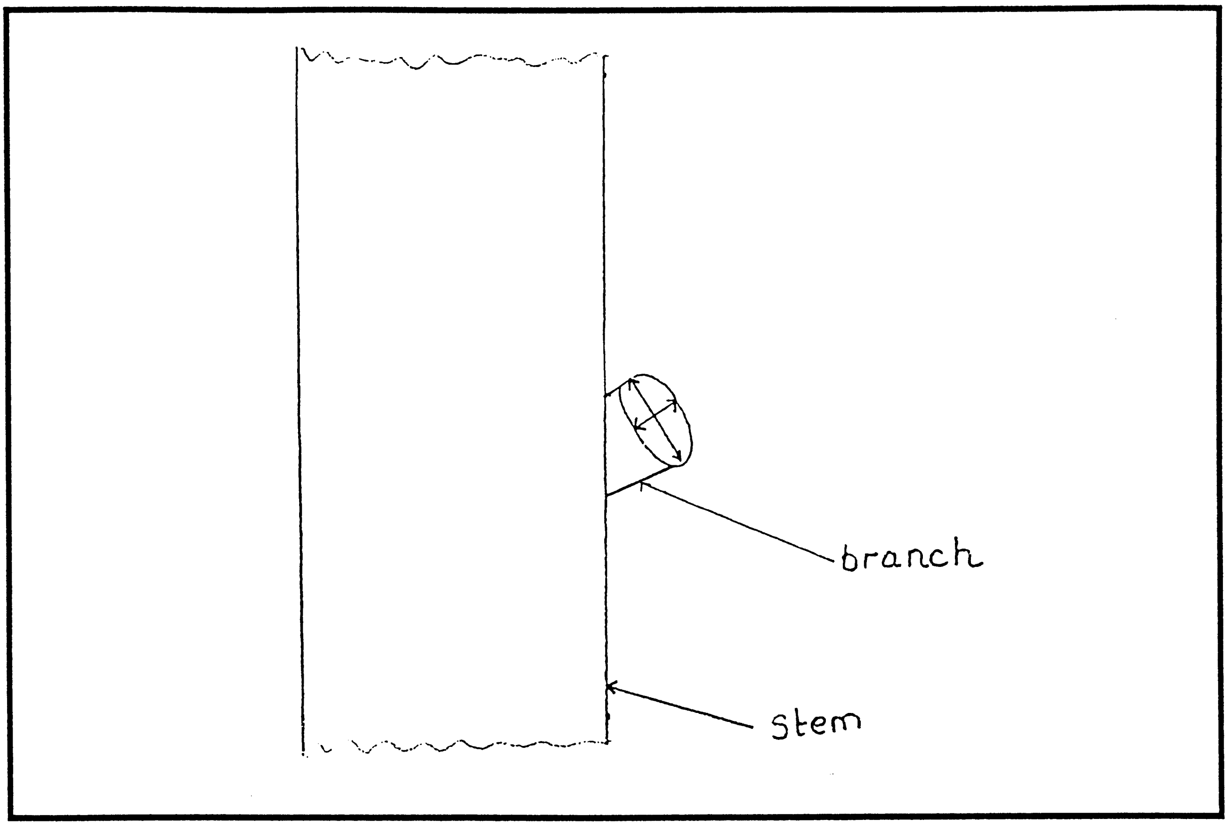
Two further trees with DBH close to the plot mean were felled from plots with different stockings to provide a range of tree size. One tree (DBH : 40.2 cm) came from plot 8 of experiment RO905.
The other tree (DBH 68.3 cm) came from a plot within the agroforesty trial at Tikitere (planted in 1973 using "850" seed) which had an initial stocking of 500 SPH and a final stocking of 100 SPH).

Once the trees were felled the following were measured:
- tree height
- height to base of each branch cluster
  - (below where branch cluster was unlikely to impact on the stem)
- height to top of branch cluster
  - (above top of highest branch in the cluster)

The branch clusters were numbered starting from the top of the tree.

For each unbroken branch, branch length and diameter in two planes at right angles (see Fig. 1) were measured. Two branch diameters were measured to allow the relationship between the two measurements to be estimated. This was necessary as final branch diameter (in other studies) has been measured in the horizontal plane, while branch diameter within the stem has been measured at right angles (see later).

Figure 1. Diagram showing how the two branch diameters were measured.



A line was drawn on the stem so that the angular distribution of branches could be reconstructed.

The tree was then cut into sections so that each branch cluster was contained within a section. These sections were then bought back to the workshop at FRI.

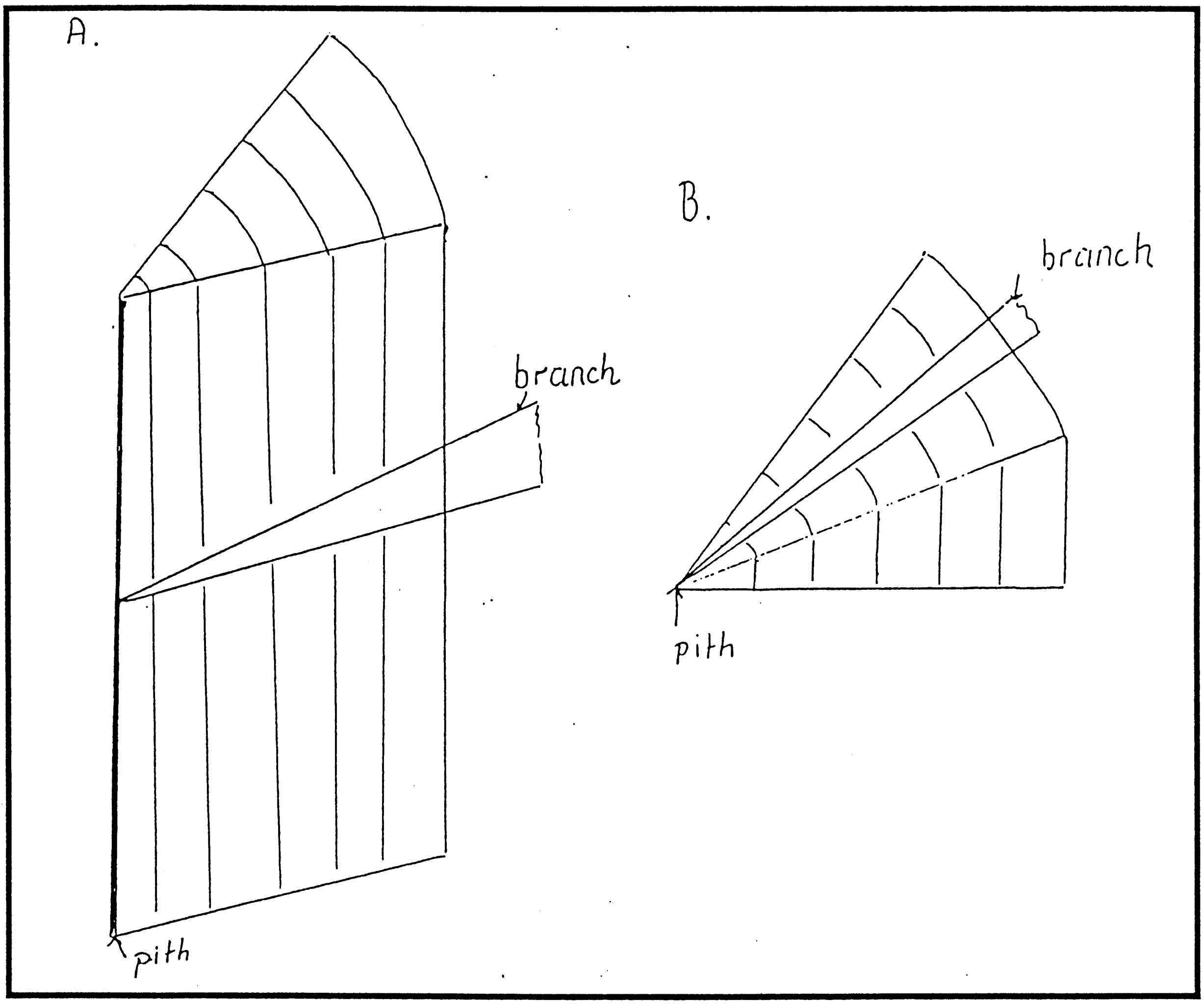
For each branch cluster:
 the number of branches were counted

For each branch within the cluster:
 branch diameter in two planes (see Fig. 1) was measured
 the bearing, from the marked line, was measured.

For both trees, the circumference was measured at the base of each stem section and the average radius calculated. The width of the stem rings was measured along a random radius of length equal to the average radius.

There were two possible ways of cutting the section to expose the centre of the branch:
- to cut vertically down the section (see Fig.2A)
- to cut into the section at an angle (see Fig.2B)

Figure 2. Diagram showing the two methods of cutting a branch to expose the pith



The disadvantage with the second method is that the angle the branch makes with the stem is known to change over time due to branches bending outwards under their own weight (Jacobs, 1938), and thus one is likely to be cutting on a curve. This proved to be the case on a preliminary sample. The first method was therefore used for this study.

The stem sections were generally cut using a band-saw and the number of branches for which the pith was exposed varied between one on small sections to about three on larger sections. The larger sections from Tikitere first needed to be cut by a sawmill and it was only feasible to expose the pith of one or two branches.

For the smaller branches, it was difficult to identify individual branch growth rings so the outline of the branch was marked and the diameter of the branch (perpendicular to the pith from the top surface of the branch) was measured for each year that the stem section had grown (at the end of the growth ring). By subtraction, the annual branch growth is obtained. For the larger branches, the individual branch growth rings were identified until they became too close together to distinguish, when an outline was drawn as above. The branch diameter was measured (perpendicular to the pith from the top surface of the branch) for each year that the stem section had grown (at the end of the growth ring).

DATA ANALYSIS - BRANCH DIAMETER GROWTH

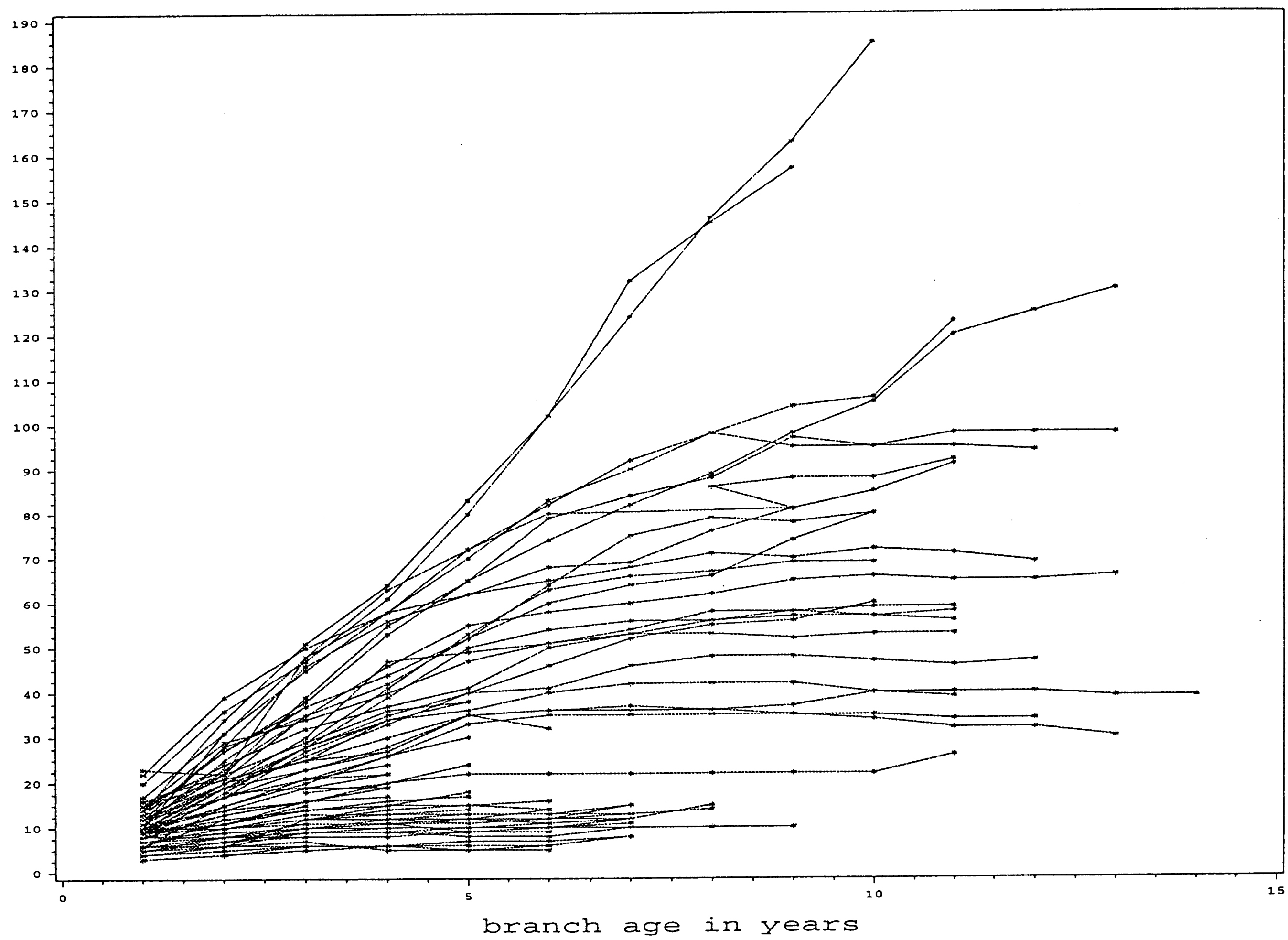
For both trees, branch diameter increases to a maximum and then decreases slightly in size (Fig. 3). The decrease in size is considered to be due to the stem growth encasing the tapering branch. At young ages there is a lot of interchange of branches in terms of ranking by diameter.

Figure 3. Diagram showing branch diameter development

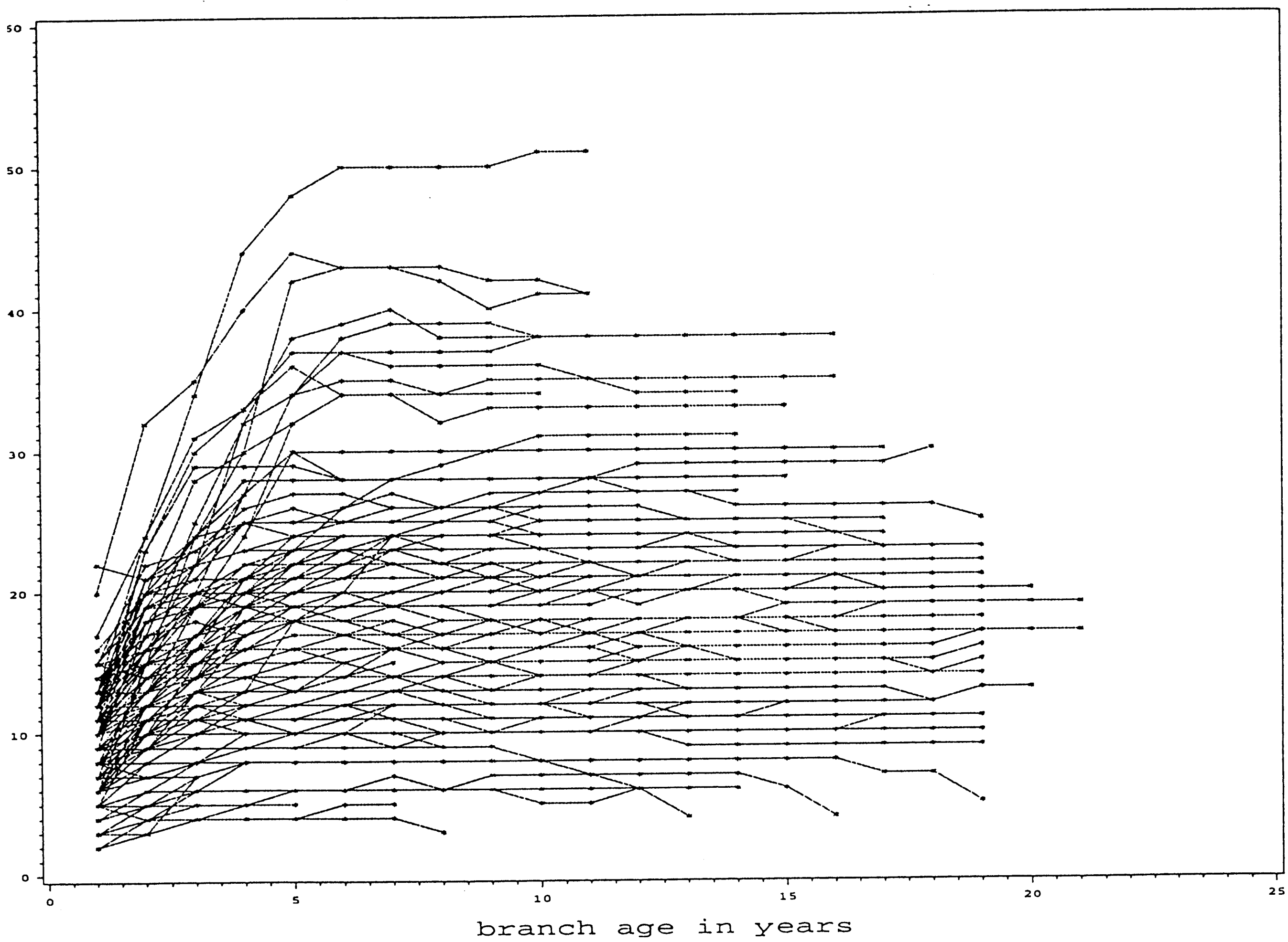
a. Tree from Tikitere

b. Tree from Kaingaroa

a. Tree from Tikitere

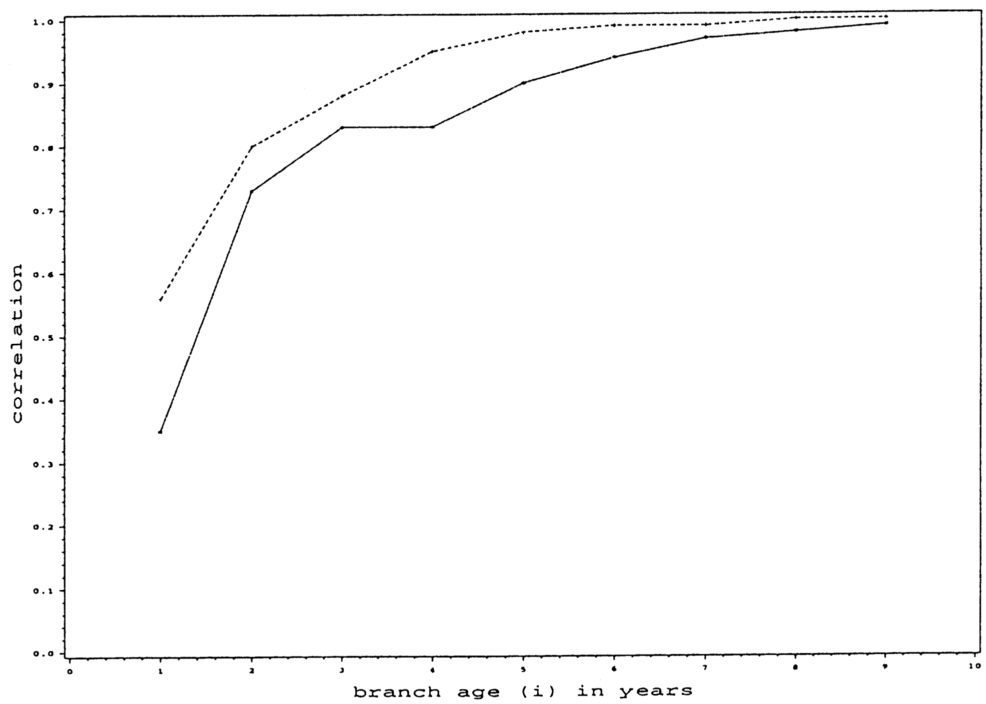


b. Tree from Kaingaroa



The correlation coefficient between branch diameter at age i years (i=1,9) and branch diameter at age 10 years was calculated (Fig. 4). For both trees the correlation between diameter at age 6 years and the diameter at age 10 years was close to or greater than 0.95. This implies that if the branch diameter when the branch is 6 years old is known, future diameters can be predicted with reasonable accuracy.

Figure 4. Correlation between branch diameter at age i and age 10 years
- - - - : Tree from Kaingaroa
____ : Tree from Tikitere



In order to derive a set of compatible growth curves for each tree, only branches with six or more growth rings were considered. Eqn. 1 was fitted to each branch independently.

$$D = A / (a + b * A^2) \tag{1}$$

where:

D is the branch diameter
A is the age of the branch
a, b are model parameters

Using this equation allows the branch diameter to grow to a maximum and then decline.

The maximum branch diameter (D_m) was estimated for each branch. The two parameters of Eqn 1 were then estimated as functions of D_m. An appropriate equation including D_m is:

$$D = A / (x1\, D_m^{\ y1} + x2\ D_m^{\ y2} A^2) \tag{2}$$

where:

D is the branch diameter
A is the branch age
D_m is the maximum branch diameter for the branch
x1, x2, y1, y2 are model parameters

For each tree, Eqn 2. was then fitted to the data set consisting of branches with 6 or more growth rings by weighted regression with each observation being weighted by 1/n where n is the number of measurements of diameter for that branch.

The parameter values are shown in Table 1.

TABLE 1.
Estimated regression coefficients from fitting Eqn 2 to data from two trees separately

	Kaingaroa Tree		Tikitere Tree	
	estimated value	SE	estimated value	SE
x1	1.92	0.18	0.85	0.10
y1	-0.80	0.03	-0.56	0.03
x2	0.13	0.01	0.30	0.07
y2	-1.20	0.03	-1.43	0.05

The residuals from fitting Eqn. 2 were plotted against whorl number. Branch diameters were generally predicted to within 10 mm. However branch growth was poorly predicted for one branch on tree T.

Eqn 2. was then fitted by weighted regression analysis to the combined dataset to see if one equation was realistic. The weights were as above. The parameter estimates are given in Table 2.

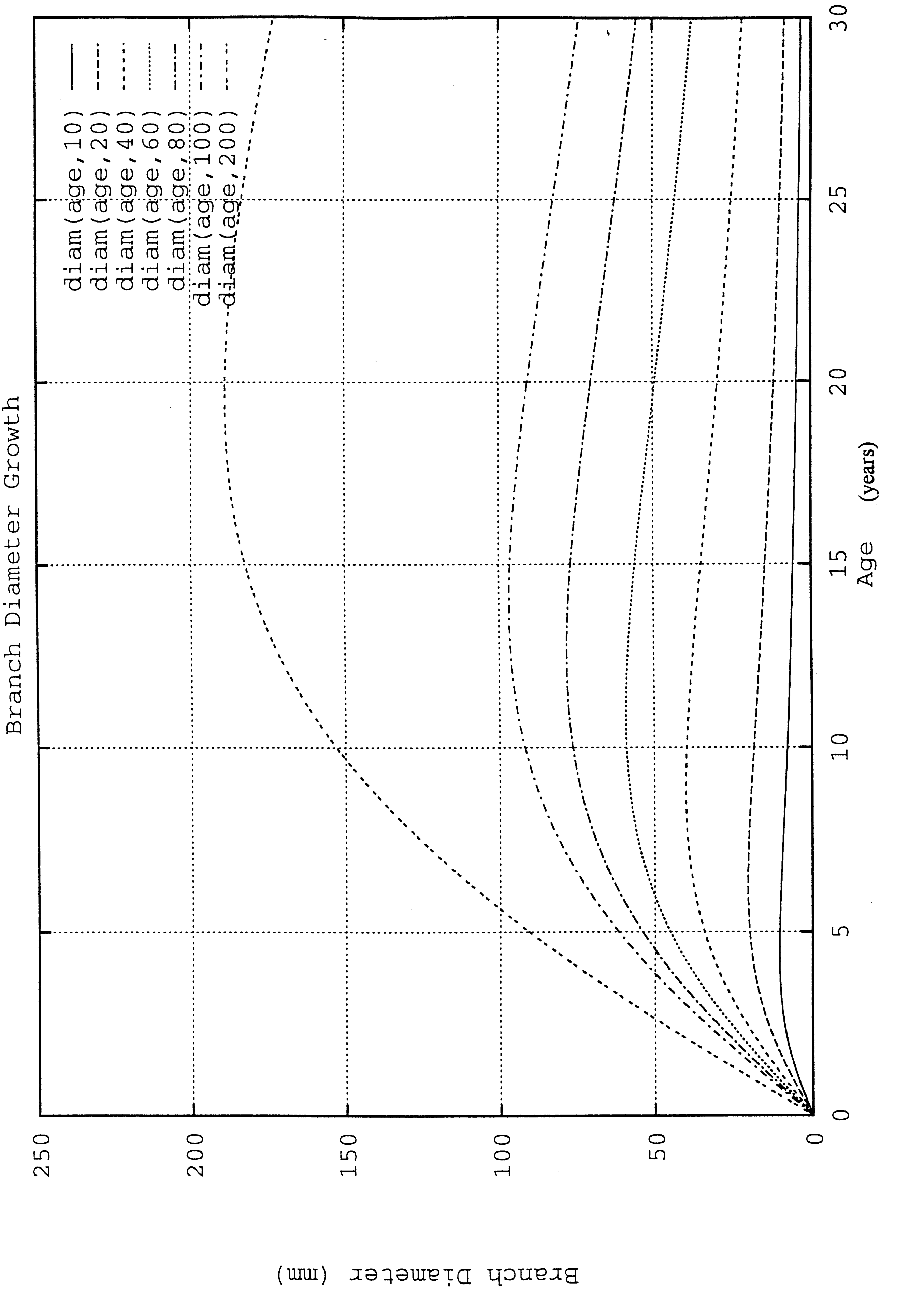
TABLE 2.
Estimated regression coefficients from fitting Eqn 2 to data from both trees.

	estimated value	SE
x1	0.625	0.027
y1	-0.471	0.010
x2	0.309	0.019
y2	-1.46	0.017

The single and combined equations were compared in several ways:

- by plotting residuals against predicted values
- by plotting residuals against whorl number
- by examining the frequency distribution of residuals
- by examining the mean residual by branch

It was concluded that a combined equation is realistic for these two trees. One equation may well be suitable for predicting branch diameter growth for branches older than 6 years within the Central North Island. However further data collection will be needed to confirm this. The shape of Eqn. 2 (using the predicted coefficients for the combined data set) for various maximum branch diameters is shown in Fig. 5.



Branch Diameter Growth
Branch Diameter (mm)
Age (years)
0
50
100
150
200
250
0
5
10
15
20
25
30
diam(age,10)
diam(age,20)
diam(age,40)
diam(age,60)
diam(age,80)
diam(age,100)
diam(age,200)

POTENTIAL USE OF EQN 2 FOR PREDICTING MAXIMUM BRANCH SIZE

Eqn. 2 has the potential to provide an estimate of the maximum size for branches measured during an inventory.

If we know the tree diameter, height and site index we could estimate tree height for each year of growth and hence the age at which the branch was formed and the current age of the branch. Eqn. 2 could then be solved to give D_m, the maximum size of the branch.

This method is unlikely to give reliable estimates for branches under six years old at the time of inventory due to the variablilty in growth at young ages (see Fig. 3).

PROBLEMS

Measuring branch diameter within the stem by retrospective sampling provides good quality data for estimating branch diameter growth. There were however several problems.

The tree from Kaingaroa was about 100m into the forest. Sections (containing a cluster of branches) near the base of the tree (which provide the longer sequences of branch growth) had to be carried out singly and some had to be cut in half. It was just feasible to cut these sections on the bandsaw in the FRI workshop.

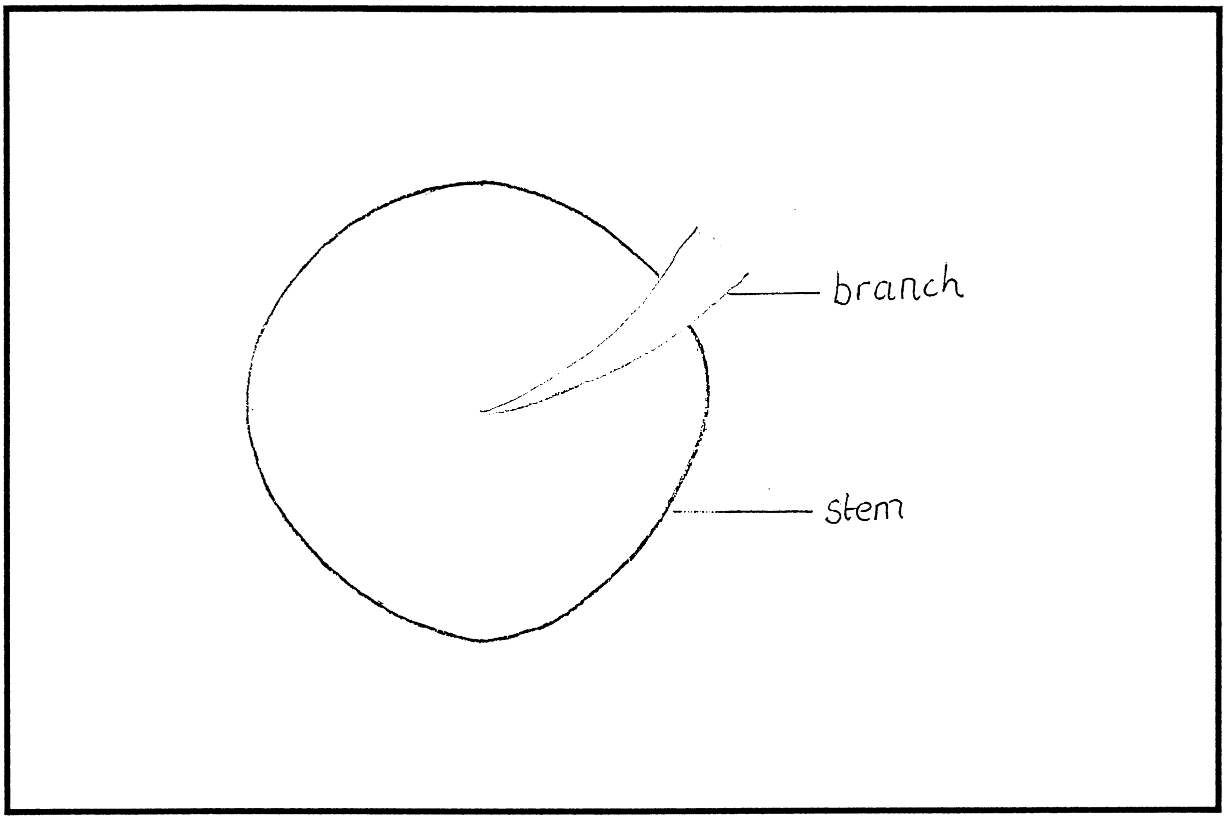
The lower sections of the tree from Tikitere were considerably bigger and it required two people to move them. Also these sections were too big to fit on the bandsaw and had to be cut into smaller segments at the Timber Industry Training Centre. These smaller segments were then tidied up on the bandsaw.

The size of the tree is thus critical for this methodology to be a practical way of obtaining a large data set on branch growth. The tree at Tikitere is the extreme in that some branches were essentially open-grown.

It would also be advantageous to be able to develop a methodology to cut segments out of the discs in the field in order to reduce the amount of timber to be brought back to FRI.

A more serious problem was that several branches were curved within the stem segment - see Fig. 6. That the branches could be curved within the horizontal plane had not been considered when designing the methodology and this curvature made it difficult to expose the centre of the branch. Branches which appeared to be straight tended to be chosen in preference to branches which appeared to be curved. It appeared that the larger branches were more likely to be curved. A possible reason for the curvature is that branches grow into gaps in the canopy.

Figure 6. Diagram showing how a branch is curved within the stem



CONCLUSION

Measuring branch diameter adjacent to the stem is the better method for obtaining data on branch diameter growth.

RETROSPECTIVE SAMPLING VERSUS LONG-TERM MONITORING

Table 3 summaries how retrospective sampling and long-term monitoring will enable us to answer other questions related to branch growth. It can be seen that long-term monitoring provides a better understanding of the factors influencing branch development. However it will take several years to obtain the data necessary for a branch growth model.

It is therefore considered worthwhile to develop a strategy for using retrospective sampling within a stand in order to provide data for prototype branch growth models.

TABLE 3. Comparison of long-term monitoring and retrospective sampling for measuring crown development.

QUESTION	LONG-TERM MONITORING	RETROSPECTIVE SAMPLING
How many whorls are formed each year?	With small branches,only feasible to measure base of crown. May be feasible to obtain by photographing trees each year.	Can be obtained by ageing stem at each whorl.
What variables control the number of whorls formed each year?	Have the ability to see if the number changes with the size of the tree relative to its neighbours and with stocking	Time consuming to examine several complete trees in a stand. Also may not have data on its size with respect to neighbours over time.
What variables control whorl depth?	Can examine influence of neighbouring trees	Can only examine influence of sample tree and stand variables.
Does whorl depth change with age?	Can be answered by measuring whorl depth in successive years	Cannot be answered by retrospective sampling
What variables control the length of internodes?	Can examine influence of neighbouring trees	Can only examine influence of sample tree and stand variables
Does the length of a particular internode change as the tree ages?	Can be answered by measuring internode length in successive years	Cannot be answered by retrospective sampling
What controls the number of branches per whorl?	Can examine influence of neighbouring trees	Can only examine influence of sample tree and stand variables
What angles do branches make with the stem and how does this angle change with time?	Can be answered by measuring branch angle over time	Can measure changes in branch angle on exposed section of the branch.
What is the rate of branch length development?	Can approximately measure changes in branch length if the branch is assumed to be linear. May be more appropriate to measure crown spread. This determines canopy closure.	Easier to measure actual branch length. However it was difficult to precisely age branches. Not feasible to estimate length for each year that branch grows

QUESTION	LONG-TERM MONITORING	RETROSPECTIVE SAMPLING
What variables control the rate of branch length development?	Have the ability to investigate the influence of surrounding trees on branch length development	Can only be defined as a function of the individual tree and stand variables
What is the rate of branch diameter growth?	Can be estimated through long-term monitoring	Can be estimated through retrospective sampling
What variables control the rate of branch diameter growth?	Have the ability to determine influence of surrounding trees	Not feasible to determine influence of surrounding trees
When do branches stop growing?	Can observe/ measure when branches stop growing and see if it could be a function of stand development	Can be determined by lack of branch diameter increment, but reasons cannot be determined.
When do branches die?	Can observe when branches have lost all their foliage	Can be determined by bark encasement in the stem, but reason for death cannot be determined
How do branches respond to increased space/light following a thinning?	Can be observed if suitable stands are chosen	May be feasible to pick up from changes in rates of branch diameter growth, but will not necessarily be certain that response is due to increased space.
If a branch has stopped growing will it respond to a thinning?	Can be observed if suitable stands are chosen	As above

FUTURE WORK

Future research will concentrate on obtaining answers to the following questions.

A. Can we observe any changes in branch growth rate due to silviculture treatment using retrospective sampling?

This will be achieved by "matching" time of silviculture to growth rings on individual branches.

B. What is an appropriate retrospective sampling strategy for measuring branch growth within a stand?

Sensitivity analysis (using the data collected for this study) will be used to detemine:
- whether we could just sample branches from one "face" of the stem
- what length of stem needs to be sampled

The method will then be applied on a stand basis.

C. What effect do neighbouring trees have on branch growth rates?

This question will be answered by setting up a longer-term experiment to measuring branch development over time on a group of trees with a range of distances between trees. The silviculture/ breed trial would be appropriate.
This would complement research in A.

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REFERENCES

Bannister, M.H. 1962. Some variation in the growth pattern of *Pinus radiata* in New Zealand. New Zealand Journal of Science 5:342-70.

Fujimori, T and Kiyono, Y. 1986. Dynamics of crown structure and effects of crown control on tree growth in *Cryptomeria japonica*. pp 192-189 In: Fujimori, T. and Whitehead, D. (eds) Crown and Canopy structure in relation to productivity. Forestry and Forest Products Research Institute, Ibaraki, Japan.

Grace, J.C. 1992. Branch Dynamics in Radiata Pine: Literature Review. Stand Growth Modelling Co-operative Report No. 28.

Jacobs, M.R. 1938. Notes on pruning *Pinus radiata.* Part 1. Observations on the features which influence pruning. Commonwealth Forestry Bureau, Canberra, Bulletin No 23.

James, R.N. and Tustin, J.R. 1970. Diameter response of branches after thinning in radiata pine. FRI Production Forestry Report No. 27 (unpublished).

Larson, P. R. 1969. Wood formation and the concept of wood quality. Yale University, School of Forestry, Bulletin No. 74.

Rawley, B. and Hayward, W. 1990. A new paradigm for growth models - discussion paper. Stand Growth Modelling Co-operative (unpublished).