

**WHAT IS AN APPROPRIATE LEVEL TO
MODEL BRANCH DEVELOPMENT FOR FOREST MANAGEMENT?**

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EXECUTIVE SUMMARY

The locations and dimensions of branches encased within a tree-stem influence the appearance, strength and ultimately the end use of timber. The New Zealand forest industry requires a model to predict branch development through time. This would enable better estimates of log and timber grades to be predicted at time of harvest from inventory information collected at any time during the rotation.

Choosing the appropriate level to model branch development for forest management requires a compromise between understanding growth processes, data collection costs, model accuracy and precision, and suitability for use by forest management .

The approach chosen was to model the occurrence of branch clusters within annual shoots, and to model the diameter growth of branches at the point of attachment to the tree stem. This approach has several major advantages. It is based on an understanding of branch morphology and basic growth processes. It allows the utilisation of existing models of annual height development, stem taper and growth which are based on extensive field measurements. We believe that the model structure is cost-efficient in terms of the data requirements. The increased data collection costs to develop a more detailed model of the full extent of the crown would not be matched by a similar increase in worth to the forest industry.

INTRODUCTION

The ability to accurately predict tree growth and the development of stem quality in response to differences in tree-breed, site and silvicultural practice over the length of a rotation is necessary for the effective management of a forest resource. When a growth and quality prediction model of individual trees is integrated with a sawing-simulator, detailed predictions of timber quality and hence value can be made. This paper describes research carried out to predict branch development for the *Pinus radiata* D. Don plantations of New Zealand as a component of such an integrated modelling system.

A model to predict branch development should operate on inventory information collected at any time during the rotation, from a small set of average stand parameters early in life, through to detailed measurements obtained close to harvest. Choosing the appropriate level to model branch development requires a compromise between understanding growth processes, data collection costs, model accuracy and precision, and suitability for use by forest management.

New Zealand Environment

New Zealand consists of two main islands, located in the South Pacific Ocean between latitudes 34° and 48° and longitudes 166° and 180°. The climate has been divided into 17 groups (New Zealand Meteorological Service, 1983). The north of the North Island has warm humid summers and mild winters with a rainfall between 1000 and 2500 mm/year. The south of the South Island has warm summers and cool winters with rainfall between 900 and 1300 mm/year. The east of the country is drier than the west due to the prevailing winds, and the approximate north-south axis of the mountain ranges.

Soils are of recent origin and are varied. They have been ranked as “satisfactory”, “marginal” or “deficient” in several nutrients (nitrogen, phosphorus, potassium, magnesium and boron) with regard to the growth of radiata pine (Hunter *et al* 1991). Combining climate with soil results in a large number site types which influence the growth and morphology of the trees. Separate stand growth models of radiata pine have been developed for major biogeoclimatic regions in order to account for differences in growth characteristics (Goulding 1994).

Planted Radiata Pine Resource

It is estimated that there are 1.7 million hectares of radiata pine plantations in New Zealand (April 1997), within a total land area of 27 million hectares (Ministry of Agriculture and Forestry 1998). Over the last five planting seasons, afforestation has occurred at an average annual rate of 76,000 hectares. The plantations are intensively managed, often with several thinnings to waste early in the rotation, sometimes with one or more production thinnings and sometimes with several pruning operations to remove live, green branches. The main objective of management is usually profitability. Rotations are moderately short, between 25 and 35 years, and total merchantable volume mean annual increment (MAI) for the stands currently being harvested average 18 m³ ha⁻¹ year⁻¹ (including the volume removed by production thinning). The combination of a tree breeding programme (Shelbourne *et al* 1986), a recent trend to higher final crop stockings and the tendency of new planting to be on better sites, promises to lift MAI to perhaps over 25 m³ ha⁻¹ year⁻¹.

Radiata pine has considerable site tolerance (Burdon, in press), and has been planted over a large number of site types. In the North Island, on very good sites with appropriate silviculture, MAI's can be above $45 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$. Conversely, there are plantations growing on sites that are marginal for survival and growth. Branching characteristics vary visually, for example, large branches and poor form when grown at wide spacing on ex-pasture sites; many moderately large branches with a tendency to form swept stems in the Central North Island; and fine branching habit on former sand-dune sites. The tree improvement programme (Shelbourne et al 1986) has deliberately produced different "breeds" of radiata, with genetically inherited differences in branching habit - multinodal with more clusters and smaller branches versus long internodes, with less clusters and relatively larger branches. Branch growth clearly responds to silviculture, with wider spacing promoting larger branches (Tomblason et al 1990), but the ability of radiata pine branches to respond to increased spacing following thinning is not well understood.

ISSUES AFFECTING CHOICE OF MODELLING TECHNIQUE FOR FOREST MANAGEMENT

A "valid" simulation model is one about which there is:

"an acceptable level of confidence that an inference about a simulated process is a correct or valid inference about the actual process" (Van Horn 1969, Goulding 1979).

Models for management tend to be used to derive inferences about the effects of exogenous variables on the system, rather than to derive inferences about the underlying processes of the system.

We consider that there is no one modelling approach that is appropriate for all situations. For forest management, the technique needs to be chosen carefully, taking into account the requirements of the end-use of the model, the practicality and economics of collecting data to run it, and the development costs. Models for use by management should be based on measured data and on experimental evidence, and every effort is required to ensure that predictions are unbiased, as values predicted by the model may be directly used in practice. Regardless of the level of detail in the model, it is important that the functions developed are logically sound, based on our knowledge of tree growth, rather than merely attempting to obtain the "best-fit" to datasets, where there is a danger that latent variables with statistically non-significant regression coefficients may be the main factors affecting predictions.

Process-based models have been promoted as being useful to forest managers on the basis that if the growth processes were understood and could be modelled, then the model could be used to simulate alternative management regimes. Research was carried out to develop a process-model for radiata pine in New Zealand during the 1980's (see Goulding 1994). However the results did not reach the stage of being useful for forest managers. There were several reasons for this: not all the growth processes were understood; there was limited data for estimating the model functions which had to apply across a wide range of sites; and the resource had been intensively monitored which enabled more accurate empirical models to be developed in a much shorter time frame.

The dimensions, frequency and location of branches encased within a tree-stem are major factors in the appearance, strength and end-use of timber and influence the value of the tree at harvest-time. Currently, many forest managers predict branch size and the effect of branches on the quality of logs using empirical relationships within the STANDPAK suite of programmes (Whiteside 1990). Whiteside (1982) measured 124 logs from unimproved radiata pine trees in the Central North Island and found that the highest correlation between a variety of external branch variables and framing timber grade outturn was obtained using the mean of the 3 largest branches per quadrant on the log. The correlation using the mean of the largest branch per quadrant, Branch Index (Inglis and Cleland 1982), was only slightly lower. Branch Index is now predicted from 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, dominant height at the time of the last thinning. It is considered that DBH at age 20 years adequately accounts for the effects of site fertility and stocking¹. This model is not dynamic, in that it does not predict branch growth given actual inventory assessments of branches in a stand. The empirical nature of its construction implies that new sawing processes may produce different correlations between Branch Index and timber grade yield. More importantly, it does not predict branching characteristics in sufficient detail to provide input data to new log sawing simulation models being developed, such as AUTOSAW (Todoroki 1991, 1996).

It was therefore decided to use a process based modelling approach to formulate a branch model combined with empirical estimation of the functions within the model. The model was restricted to the location and dimensions of branches encased within the stem. No attempt was made to predict the complete external branch morphology or crown structure. This approach has concentrated the research effort to manageable proportions. Very detailed measurements obtained by destructive sampling a few tree-stems have been necessary to formulate the model (Grace and Pont 1998). Once the forms of the functions are determined, it is expected that it may be possible to estimate some of the coefficients by re-analysing data collected across the wide range of sites and silvicultural treatments to construct the existing empirical Branch Index functions.

BRANCH MODEL FOR RADIATA PINE

Several components are required to develop a practical system:

1. a realistic description of the location and diameter of branches for individual trees at any age,
2. the prediction of branch diameter increment, particularly the response to management practices,
3. the enhancement of typical inventory data to provide a more detailed description of a tree's branches.

To date research has concentrated on the first component.

¹ 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

The model is based on a series of functions chosen after reviewing previous literature (Grace and Pont 1997). These functions predict the number and location of each branch cluster within each annual shoot; the number, orientation and size of branches within each cluster; the change in branch diameters over time; and other features such as branch mortality and stem cone occurrence. Modelling at this level of detail has provided a framework that is easily adapted to include functions which predict basic wood density, spiral grain, the occurrence and severity of sweep, compression wood, and from these characteristics the strength and other properties of timber products.

Data Collection

Over the last 4 years we have destructively sampled 49 trees in total from 5 separate experiments to obtain data for deriving the model functions. The detailed sampling required has limited the number of trees sampled but the trees have been carefully selected to cover the variability in the experiments.

Further data collection covering a wider range of tree-breed, site/environment and stand management practices is likely to be necessary to improve our understanding of branch development and the model functions.

Model Functions, Rationale and Results of Data Analysis

The approach taken with the data analysis has been to build up our understanding of a particular relationship by analysing the data first at an individual tree level, then at a site level and then combining data across sites. This approach provides a better understanding of the data and underlying growth processes compared with fitting one overall equation. The current form of the model functions are described below.

Position in the stem where branch clusters are initiated

Function 1 Number of branch clusters within the annual shoot.

From a mensurational perspective, the end of one annual shoot is assumed to occur in mid-winter when height increment is at a minimum. Using this definition allows annual shoot extension to be predicted by current height growth models which were developed using extensive measurements of height growth. However, from a morphological perspective, the end of an annual shoot is marked by a zone of compressed parastichies above a branch cluster. This zone of compressed parastichies is considered to be formed in summer. Autumn elongation is essentially a "head start" on the spring flush (Burdon 1994). Any consistent patterns in branching related to the annual morphological shoot could be obscured using the mensurational definition.

Previous research, indicates that radiata pine forms up to six branch clusters in an annual morphological shoot (Bannister 1962). The numbers of branch clusters in an annual shoot is influenced by many factors including: genetics (Fielding 1960), tree age (Bannister 1962), annual shoot length (Bannister 1962), and site/environment (Bollmann and Sweet 1976).

To link with current height growth models, we have chosen to use the mensurational definition of an annual shoot and assumed that an annual shoot terminates at a branch cluster. The number of branch clusters in an annual shoot varied between 1 and 6 (7 for two datasets).

However the frequency distribution varied between datasets. The number of branch clusters tended to increase with increasing shoot length and tree age. The prototype function developed is:

$$NC = a_1 \times A^{a_2} \times L^{a_3}$$

where:

NC is the number of branch clusters in an annual shoot

A is the age of the tree when the annual shoot was formed

L is the length of the annual shoot

a_1, a_2, a_3 are model coefficients

In the model, NC is rounded to the nearest integer. Analysis indicates that the model coefficients will vary with site and tree-breed.

Function 2 The relative position of the branch clusters within the annual shoot.

The relative position of clusters within the annual shoot will depend on the number of clusters and on the length of each growth unit within the annual shoot. Bannister (1962) suggested that the relative positions of clusters may be influenced by environmental conditions. Bannister's (1962) and our data indicates that there is generally a preferred position for each cluster. There was some evidence to suggest that the relative position of clusters may vary slightly according to the multinodality of the tree. At this stage we have implemented a look-up table for the relative position of each cluster using observed means.

Number of branches and stem cones within each cluster.

Function 3 The number of branches in each cluster

The number of branches in a cluster appears to be influenced by genetics; but not by tree age. In some instances, site/environmental factors may influence the number of branches in a cluster (Fielding 1960; Fielding 1967). Analysis indicated that the number of branches per cluster was independent of the number of clusters in an annual shoot, the position of the cluster within the annual shoot, and the number of stems per hectare. Uninodal trees tended to have more branches per cluster compared with the multinodal trees. The number of branches per cluster was similar for both sites with multinodal trees.

The number of branches in a cluster is predicted as a random observation from a Neyman type A distribution.

Function 4 The probability that the tree has reached reproductive maturity (produced stem cones)

In radiata pine, female cones can be borne on the main stem. They typically remain attached for several years and leave a significant defect in the stem wood. Prior to reproductive maturity, clusters contain only branches. After reproductive maturity, a cluster contains branches and/or stem cones. The age of reproductive maturity is quite variable. Bannister (1962) found cones on the fifth annual shoot and found 26 year-old trees with no obvious cones.

The percentage of trees which have reached reproductive maturity by a given age varied little between the data sets and it appears that one function could be used for all sites. The probability a tree has reached maturity is predicted by:

$$p(m) = \frac{1}{(1 + \exp(b_1 - b_2 \times A))}$$

where:

A is the tree age

$p(m)$ is the probability a tree is mature at age A

b_1 and b_2 are model coefficients

Function 5 The number of stem cones in each cluster once the tree has reached reproductive maturity.

Cones do not occur in every cluster once a tree has reached reproductive maturity. They rarely occur in the last cluster of the morphological annual shoot, they occasionally occur in the second to last cluster and are generally present in all other clusters (Bannister 1962).

Using the mensurational definition of an annual shoot, cones have been found to occur in the last cluster of an annual shoot. The probability of finding cones in this cluster appears to be slightly lower compared with other clusters.

We have implemented a look-up table for the probability that cones occur in a given cluster in an annual shoot. The number of cones in a cluster is predicted using the observed frequency distribution.

Azimuthal location of branches

The azimuthal location of branches is important for determining what parts of the log can be used for different products. There are two issues which need to be addressed. Firstly, are azimuthal angles such that there are sectors of the stem without branches. Secondly, do the larger branches occur in the same azimuthal sector of the stem or are they distributed more evenly round the stem.

Function 6 Arrangement of branches in each cluster.

Examination of clusters from the top few annual shoots of both uninodal and multinodal trees in the Central North Island has indicated that radiata pine has spiral phyllotaxy. For most clusters, successive branches in the ontogenetic sequence are separated by an angle of approximately 137.5°.

Branch diameter also tended to increase with position in the ontogenetic sequence from the base to the top of the cluster. Within a cluster, we have ranked branches in order of diameter, with successive branches being separated by 137.5 degrees. This assumption leads to the larger branches being distributed around the stem.

Function 7 Azimuth angle of the largest branch in a cluster.

In order to be able to predict the correct distribution of branches for the whole tree, we need some method to create a link between clusters. We have chosen to do this by comparing the azimuth angles of the largest branch in each cluster.

The azimuth angle for the largest branch in each cluster has been examined on 25 trees from the Central North Island and 5 trees from the South Island. The azimuth angle of the largest branch was typically very variable. However, for 67 percent of the trees there was a preferred azimuth angle for the largest branch in each cluster using the Rayleigh test of uniformity (Mardia 1972). There was no trend in the azimuth angle with increasing height of the cluster.

Recent studies indicate that crowns tend to be asymmetrical to the south in the Northern hemisphere (Rouvinen and Kuuluvainen 1997; Skatter and Kucera 1998). For our sample of trees in the southern hemisphere, the preferred azimuth tended to be on the northern side of the tree. It is unclear how much this angle has been influenced by the path of the sun and how much it has been influenced by the position of the sample tree within the stand. In a shelterbelt, the diameter of branches is influenced by orientation (Tomblinson and Inglis 1988). Field observation indicates that edge trees have larger branches towards open space regardless of orientation.

At present we have assumed that the azimuth angle of the largest branch in a cluster can be predicted by a random number from a circular uniform distribution which is valid for some but not all of the trees. When we have sufficient information to confidently assign mean angle and circular variance to individual trees, we can implement a preferred azimuth direction by selecting random numbers from an appropriate circular distribution.

Branch diameter

Input data for the branch model may come from measurements taken during an inventory, when a few of the largest branch diameters will be estimated; or from stand parameters at a young age, when little information on branching will be available.

To be able to generate all the branches on a tree, the distribution of the largest branch diameter in a cluster, and the distribution of branch diameters in a cluster relative to the largest branch are predicted.

Function 8 The diameter of the largest branch within the cluster

Several components are needed to predict the maximum diameter attainable by the largest branch in a cluster. Within tree variability and trends with cluster height need to be predicted. Trends with cluster height will be influenced by silviculture. Within a stand, between tree variability needs to be predicted. This is likely to be a function of relative spacing. Finally the between stand variability needs to be predicted as a function of site characteristics.

Clusters where the branches had stopped growing were used to determine the variability in the diameter of the largest branch per cluster. Where trees had grown at a constant nominal stocking, there was no trend in the diameter of the largest branch per cluster with cluster height. Analyses to date have not revealed any patterns based on cluster position within an

annual shoot. The observed distribution was approximately normal, and at present, a normal distribution has been used to predict the diameter of the largest branch in a cluster.

Between trees, the mean of the maximum branch diameter in a cluster is positively correlated with tree DBH. However tree DBH is not a satisfactory variable for predicting between tree variability as DBH changes with tree age. A “growing space index” based on the relative tree size and stand stocking was found to be approximately constant with tree age for a given stocking in the naturally regenerated stand.

When trees are thinned, the larger and younger branches on the larger trees were found to respond to the increased growing space though increased diameter growth. For these larger trees, a slight increase in the diameter of the largest branch in a cluster with cluster height was observed. The “growing space index” defined to predict between tree variability will change when a thinning occurs thus allowing trees with increased growing space to have bigger branches.

The Branch Index database should be useful for determining between site variability.

Function 9 The relative diameter of the other branches from the diameter of the largest branch.

Within a cluster, branch diameter varies considerably. When branches within a cluster are ranked in order of decreasing diameter, each successive branch has a mean diameter approximately 12% smaller than the previous branch (Madgwick 1994).

Our data indicates that there is considerable variability between clusters on a given tree, however we have had limited success in understanding what is controlling this variability. The relative diameter of branches in a cluster is predicted using the following function:

$$\frac{D_n}{D_{\max}} = \left(-c_1 \times (n-1)^{c_2} \right)$$

where:

n is the rank (position) of the branch in the cluster when ranked from largest to smallest in terms of diameter.

D_n is the diameter of the n^{th} branch in the cluster (overbark)

D_{\max} is the maximum branch diameter in the cluster (overbark)

c_1, c_2 are model coefficients

We have investigated whether the age of the tree when the cluster was formed, the number of branches in a cluster and the maximum branch diameter in the cluster influence the predicted values of c_1 and c_2 . However the results were inconclusive. There are statistical, but not practical differences between the shape of this curve for different datasets.

We plan to investigate whether we can develop a more accurate model using actual diameters rather than relative diameters.

Branch development over time.

Function 10 Branch diameter at any age

Branch diameter, adjacent to the stem, increases rapidly for the first few years and then remains approximately constant in diameter (Brown 1962).

Initial attempts to develop a function to predict branch diameter increment from current branch diameter and branch age were unsuccessful. We therefore developed a function that predicted branch diameter, adjacent to the stem, as a function of age and the maximum diameter attained. Branch diameter decreases slightly after the maximum has been reached due to the stem growing over a tapering branch. The form of the model equation incorporates this phenomenon.

$$UD = d_1 \times UD_{\max}^{d_2} + d_3 \times UD_{\max}^{-1} \times A_b + d_4 \times UD_{\max}^{d_5} \times A_b^{0.5}$$

where:

A_b is the age of the branch in years

UD is the branch diameter (underbark) at age A_b

UD_{\max} is the maximum diameter attained by the branch (underbark).

d_1 - d_5 are model coefficients

There appears to be little practical difference in the shape of the curve due to tree-breed, site, or tree size.

Predicting branch diameter as a function of age is not a satisfactory approach in the long-term. An increment equation is needed to be able to simulate the response to silvicultural treatment. We propose to develop an increment function during the coming year. In the previous attempt, residuals were correlated with the maximum diameter attained by the branch. It is thought that each branch in a cluster needs "potential" based on its position in the ontogenetic sequence in the cluster to model the observed variability.

Function 11 The vertical distance between the point of intersection of the branch pith with the stem pith and the position of the branch pith at the stem surface

Within a cluster, at a given age, the angle between the stem and the upper side of the branch tends to decrease with increasing branch diameter. Observations on sample branches, which have been planed to expose the branch pith indicate that the angle between the stem and the upper side of a branch is initially small but tends to increase with age. Jacobs (1938) suggests this is due to increasing branch weight. A better understanding of the process is necessary as it is proving difficult to develop a realistic function.

The function currently implemented is:

$$y = (e_1 \times UD_{\max}^{e_2} \times (1 - e_3 \times A_b))$$

where:

y is the vertical component of the distance between the join of the stem and branch piths and the current position of the branch pith

A_b is the age of the branch

UD_{\max} is the maximum diameter attained by the branch (underbark)

e_1 - e_3 are model coefficients

Function 12 The occurrence of bark encasement due to branch mortality

Branches increase rapidly in diameter for a number of years. This phase of rapid growth is followed by a phase where the branch is alive but diameter remains constant. Bark-encasement occurs after the branch dies.

Analysis of the Central North Island data indicated that the number of years of rapid diameter growth can be predicted as a function of the maximum diameter attained by the branch. Differentiating function 10 yields:

$$yr = f_1 \times UD_{\max}^{f_2}.$$

where:

yr is number of years of rapid diameter growth

UD_{\max} is the maximum diameter attained by the branch (underbark)

f_1, f_2 are predicted coefficients

The number of years that a branch remains alive while diameter remains approximately constant is also predicted as a function of the maximum diameter attained by the branch:

$$ya = g_1 \times UD_{\max}^{g_2}$$

where:

ya is the number of years that the branch remains alive while its diameter remains approximately constant

UD_{\max} is the maximum diameter attained by the branch (underbark)

g_1, g_2 are predicted coefficients

The age at which bark encasement, due to mortality, occurs is:

$$yb = yr + ya$$

where:

yr is number of years of rapid diameter growth

ya is the number of years that the branch remains alive while its diameter remains approximately constant

yb is the number of years until a branch becomes bark encased due to branch mortality

Function 13 The occurrence of bark inclusions above the branch which are not due to mortality

Sometimes bark becomes trapped above some live branches. The amount of bark trapped varies from small patches to a continuous layer along the top surface of the branch and is a common defect in radiata pine.

Personal observations of the planed sample branches indicate that bark inclusion occurs on any large and steeper-angled branch.

As the steepness of a branch (function 11) is predicted as a function of UD_{max} , it was logical to predict bark inclusion from only UD_{max} . Analysis indicated that, for a given branch diameter, bark inclusion was unlikely to be influenced by site, stocking, or genotype.

A probability table has been implemented to predict bark inclusion as a function of UD_{max} .

MANAGER'S PERSPECTIVE

Two anticipated forest industry applications for the described branch models are:

- the attachment of virtual branch whorls to virtual stems for input to bucking optimisers.
- the inclusion of virtual branches in virtual logs for input to log processing models, such as sawing simulators.

In both cases the decision support context could be any one of market planning, stand valuation, mill design or silvicultural policy determination. Every context places different weights on the accuracy of, and the necessity for, each of the various components of the model.

Every context provides different opportunities to collect input data to upgrade, re-parameterise or replace each model component. Internode length is very important in the context of supply to a sawmill producing clear components. In this context, there is likely to be the opportunity to substitute measured whorl positions for functions 1 and 2. In another example, mean largest branch might be determined via a double sampling scheme in the context of a specific pre-harvest inventory, or predicted from a separate national model when hypothetical silvicultural regimes are being compared.

The branch modelling project has generated independent, empirically derived functional components which work from readily available inputs. They integrate well with existing stand measurement and growth modelling approaches and are relatively easy to incorporate into different software frameworks. They are individually upgradeable, replaceable and ultimately disposable. For forest managers, their appeal is not in their biological elegance but in their immediate utility.

CONCLUSION

The model forms a logical framework to incorporate our understanding of branch development. It has the potential to be a powerful tool for forest managers. Models of other wood properties can easily be included and data files for sawing simulators can be generated.

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Table 1 Characteristics of data sets

Location	Genetic Material	Treatments	Trees Sampled
Central North Island	Naturally regenerated	Regeneration thinned to establish plots at 200, 400, 600, and 800 stems/ha	12 in total, a tree with small, medium and large DBH at each stocking
Central North Island	Unimproved seed, planted	Stand planted at 3086 stems/ha. Thinning carried out at different predominant mean heights to leave 200, 300, 400 or 500 stems/ha. Pruned to about 2 m	13 trees sampled to cover range of tree sizes for different thinning heights
Central North Island	Uninodal families	Planted at 4 m × 2 m (1250 stems/ha). Thinned at age 6 years to 600 stems/ha. Pruned to about 2 m.	8 trees sampled, two from each of 4 families covering range of branch cluster frequency breeding values. (see Note 1).
Central North Island	Multinodal families	Improved trees planted at 5 m × 5 m (400 stems/ha). Filler trees planted between rows in one direction, but removed at a very young age. Pruned to 6 m in three lifts	8 trees sampled, two from each of 4 families covering range of branch cluster frequency breeding values. (see Note 1).
Southland, South Island	Multinodal families	Improved trees planted at 5 m × 5 m (400 stems/ha). Filler trees planted between rows in one direction but removed at a very young age. Pruned to about 4 m.	8 trees sampled, two from each of 4 families covering range of branch cluster frequency breeding values (see Note 1).

Note 1:

The two trees from each family were chosen to be approximately ± 1 standard deviation from the mean of 10 randomly selected crop trees in terms of both diameter at breast height (DBH) and mean internode length (MIL); and in accordance with observed, but generally non-significant trend between DBH and MIL.