RADIATA PINE CROWN ARCHITECTURE:
Summary of SGMC Research and Future Opportunities

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NOTE : Confidential to participants of the Stand Growth Modelling Cooperative.
: This is an unpublished report and must not be cited as a literature reference.

EXECUTIVE SUMMARY

The Stand Growth Modelling Cooperative supported research into radiata pine crown architecture.

This report summarises the state of the research in 2007 when the Stand Growth Modelling Cooperative was terminated, and covers the following topics:

- Model structure
- Data sets collected for model development
- Data sets collected to examine model performance
- Comments on model performance
- Revisions to be implemented
- Industry Issues
- Potential improvements to TreeBLOSSIM algorithms

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INTRODUCTION

The Stand Growth Modelling Cooperative supported research into radiata pine crown architecture. The research fell into four areas:

- Initial literature review, and model formulation
- Data collection for model development
- Development of a radiata pine branch model. This model is a component of the individual tree growth and branching model, TreeBLOSSIM
- Collecting data to determine how the model performs for a wider range of sites, silvicultural treatments and improved seedlots

This report summarises the SGMC research and future opportunities.

MODEL STRUCTURE

The branching component of TreeBLOSSIM does not model the whole crown architecture; it models those components of branching that were considered important to the value of the tree at the end of the rotation. The specific aspects of branching considered are:

- The number of branch clusters formed in an annual shoot (annual height increment)
- The distribution (location) of these branch clusters within the annual shoot
- The number of branches and cones in each branch cluster
- The azimuthal distribution of these branches and cones
- The change in branch diameter through time (at a point adjacent to the stem but avoiding a nodal swelling)
- The angle of the branch from verticality and its pattern through time
- When each branch dies – becomes bark encased
- If bark is trapped above a live branch

This level of detail is more than sufficient to grow inventory data forward in time, but the advantage is that the detail is sufficient as input to a sawing simulator such as AUTOSAW (e.g. Todoroki, 1990).

DATA SETS COLLECTED FOR MODEL DEVELOPMENT

In developing any model, there are three main aspects that need to be considered:

- The variation with site conditions
- The variation due to silvicultural treatment
- The variation due to the material planted (genetic origin of the trees)

The number of possible combinations of these three variables for radiata pine in New Zealand is large.

Many more measurements are required from an individual tree in order to be able to model its crown development than are required to model changes in DBH and height through time. For example a mature radiata pine tree may have over 100 branch clusters and up to 15 branches and /or stem cones in a cluster. Consequently the number of trees available for developing TreeBLOSSIM is limited.

For the development of TreeBLOSSIM, individual trees were felled from stands that were generally over 20 years of age. These trees were intensively measured to provide data on crown development throughout the rotation.

The main focus has been to obtain datasets for "850" seedlots from each of the growth modelling regions (Table 1). These data have been used in the development of the current version (V3.1) of TreeBLOSSIM (see SGMC Report No. 125). In addition a few dataset have been collected from other seedlots (Table 2). Some of these were used in the development of the initial versions of TreeBLOSSIM (see SGMC Report No. 108).

Table 1. Branching datasets collected for 850 seedlots approx. GF14

Region	Trial Series	Trial Number	Number of trees sampled	Sampling Strategy	SGMC Report
Sands	Diallel	AK622/2	8	2 from each of 4 CP families	76
Clays	Permanent Sample Plot	FR58/1	5	From given percentage points in DBH distribution.	
Central North Island	Diallel	RO320/25	8	2 from each of 4 CP families	63 72
Central North Island	Final Crop Stocking	RO2098	3	1 tree from each of 3 different final crop stockings. All similar DBH at time of thinning	86
Hawkes Bay	Permanent Sample Plot	WN235/0	3	Trees that showed stem fluting	87
Hawkes Bay	Genetic Gain	WN377	6	Selected to cover DBH range in GF14 PSPs	147
Nelson	Permanent Sample Plot	NN469/0	3	Given percentage points in DBH distribution	88
Nelson	Final Crop Stocking	NN529/1	3	1 tree from each of 3 different final crop stockings. All similar DBH at time of thinning	
Nelson	Genetic Gain	NN530/2	8	Range of DBH and outerwood density in 1 GF14 PSP	132 146
Canter-bury	Final Crop Stocking	CY597	3	1 tree from each of 3 different final crop stockings. All similar DBH at time of thinning	
Southland	Diallel	SD413	8	2 from each of 4 CP families	72 76
West Coast	Diallel	WD174	8	2 from each of 4 CP families	

Table 2. Branching datasets for other seedlots

Region	Trial Series	Trial Number	Seedlots	Number of trees sampled	Sampling Strategy	Reports
Central North Island	Spacing trial	RO696	Regen	12	Small, medium and large DBH tree from plots at final crop stocking of 200, 400, 600 and 800 stems/ha	50 51
Central North Island	Thinning trial	RO905	GF3	13	1-2 trees of varying DBH from a range of thinning treatments	52
Central North Island	Uninodal progeny	RO320/16	LI	8	2 trees from each of 4 OP families	63
Central North Island	Special Purpose Breed	RO172/3	various	12	1-3 trees from each of 5 seedlots	126 127 131
Canterbury	Silvicultural breeds	FR121/11	GF25 and LI	20	2 trees of average DBH from a range of thinning treatments	139

DATA SETS COLLECTED TO EXAMINE MODEL PERFORMANCE

Due to the limited number of trees sampled for the development of TreeBLOSSIM, it was considered essential to determine TreeBLOSSIM performance for a far wider range of sites, silvicultural treatments and seedlots. To this end, TreeD, a non-destructive photogrammetric technique, has been used. The datasets available at the end of June 2007 are shown in Table 3. In total, measurements are available for:

- 259 trees from 54 PSPs with a GF rating of 14,
- 193 trees from 35 PSPs with a GF rating between 21 and 25,
- 134 trees from 25 PSPs containing long internode seedlots with a long internode rating between 19 and 28.

In each PSP, sample trees were selected in the office to span the range of tree DBH within the plot and avoid trees where stem damage had been noted. Later examination of the images indicated that some of these trees showed evidence of previous stem damage.

For the analyses (SGMC Report No. 145) all TreeD data were compared with predictions from TreeBLOSSIM V3.1. The version of TreeBLOSSIM used in the initial comparisons has varied (see Table 4).

Table 3. TreeD datasets collected (to September 2007) to determine the performance of TreeBLOSSIM

Region	Regional Dataset	Low site Index	Medium site index	High Site Index	High Basal Area
Clays			Tungrove (1990 SB) stocking + seedlot	Tairua (1990 SB) stocking + seedlot	Mamaranui (1988 SB) stocking + seedlot
Sands		Aupouri (1978GG) only seedlot	Woodhill (1975 FCS) only stocking		
CNI			Kaingaroa (1975 FCS) only stocking Tahorakuri (1987 SB) stocking + seedlot Kinleith (1990 SB) stocking + seedlot	Kaingaroa (1978 GG) only seedlot	Kawerau (1989 SB) stocking + seedlot
East Coast					Huanui (1990 SB) stocking + seedlot
Hawkes Bay	Yes	Gwavas (1990 SB) stocking + seedlot			Mohaka (1978 GG) only seedlot Glengarry (1987 SB) stocking + seedlot
Nelson		Golden Downs (1975 FCS) only stocking	Golden Downs (1978 GG) only seedlot	Golden Downs (1991 SB) stocking +seedlot	
Canterbury		Eyrewell (1975 FCS) only stocking	Waimate (1978 GG) only seedlot		
Southland	Yes		Dean, SD (1980 GG) only seedlot		Longwood (1978 GG) only seedlot
Westland	Yes				

Table 4. Version of TreeBLOSSIM used in original comparisons of TreeD data with TreeBLOSSIM predictions.

Dataset	Version of TreeBLOSSIM	SGMC Report
1975 FCS (Kaingaroa)	June 2001	99, 110
1975 FCS (Woodhill, Golden Downs)	1.2 (12.4.2002)	112, 116
1975 FCS (Eyrewell)	2.0x (23.5.2003)	104, 117
1978 GG (Aupouri, Kaingaroa, Mohaka, Golden Downs, Waimate, Longwood)	2.0x (23.5.2003)	119, 120
1987-9 SB (Tahorakuri, Glengarry, Mamaranui, Kawerau)	3.1 (February 2006)	133
1990-1991 SB (Tairua)	3.0 (February 2005)	135
1990-1991 SB (Huanui, Tungrove, Gwavas, Golden Downs, Kinleith)	3.1 (February 2006)	135, 142, 148
Regional – Hawkes Bay	3.0 (February 2005) and 3.1 (February 2006)	134
Regional – Westland	3.1 (February 2006)	136
Regional - Southland	3.1 (February 2006)	137

Note: All TreeD (excluding Kinleith) were compared with TreeBLOSSIM 3.1 predictions in SGMC Report No. 145

COMMENTS ON MODEL PERFORMANCE

The performance of TreeBLOSSIM for GF14 seedlots across the far wider range of site and silvicultural conditions was considered to be very promising, given the very limited dataset used to develop the model (see SGMC Report No. 145).

One area requiring further investigation was the prediction of the number of branch clusters in an annual shoot in the Sands growth modelling region. TreeBLOSSIM tended to predict more clusters than observed.

Two issues, not currently included in TreeBLOSSIM, were identified when examining trees where TreeBLOSSIM underpredicted branch diameters. One issue was stem damage, where the following scenario appears to occur. If a tree loses it leader / top, then branches compete to become the new leader, resulting in large-diameter steeply angled branches. The diameter of such branches was under-predicted by TreeBLOSSIM. The second issue was that branch diameters were under-predicted where there was a large gap on one or more sides of the tree. This indicates that branch diameter growth is influenced by the available space in the direction the branch is growing. Distance-dependent models, not distance-independent models, are the appropriate framework for modelling such an effect.

The performance of TreeBLOSSIM for the GF20+ seedlots was only slightly poorer than for the GF14 seedlots, but was noticeably poorer for the long-internode seedlots. Further research is required to develop versions of TreeBLOSSIM for other seedlots, in particular long-internode seedlots.

REVISIONS TO BE IMPLEMENTED

A simulation study, linking TreeBLOSSIM to AUTOSAW indicated that the number of branch clusters in an annual shoot and number of branches were the most important branching variables influencing value when boards are visually graded (Pont *et al*., 1999). Given that TreeBLOSSIM was designed to be linked with inventory data, and the limited number of datasets used in developing TreeBLOSSIM, research has been carried out to determine whether a field count of number of branch clusters during inventory could be used to adjust the function predicting the number of branch clusters in an annual shoot. It is considered that this approach would provide better predictions of the number of branch clusters for specific sites. Generic regional values would still be available for situations where cluster counts were not available.

Current Situation

The number of branch clusters in an annual shoot has been calculated from counting the number of stem growth rings below each branch cluster on felled trees. Analysis of these data indicated that the number of clusters increased as shoot length increased. Tree age when the annual shoot was formed had a small influence on the relationship.

This relationship forms part of the branch model within TreeBLOSSIM, which is an integrated stem and branch growth model. The stem growth model is used to predict the annual shoot length. The branch growth model then calculates the number of clusters in that shoot.

In the field data, annual shoot length, and consequently number of clusters in an annual shoot was quite variable, presumably a result of climatic variation between years. However, current height growth models only predict average trends in height growth, not year to year variation.

Alternative approach

An alternative approach, if we continue to use the current height growth models is to ignore the relationship between annual shoot length and clusters per year and just consider how numbers of clusters per year varies with tree age when the annual shoot was formed.

Trends in clusters per year with tree age

Data on the number of branch clusters in an annual shoot from 10 sites planted with GF14 seedlots have been included in the analysis below. All trees were pruned. The position of branch clusters in the pruning zone was recorded for only 1 of the 10 sites.

One feature of tree growth, that is likely to have an influence on number of clusters per year, is changes in leader. Leader changes can often be identified in standing or felled trees, but they are often not easy to pick up because of the trees ability to correct for any deviations from straightness. Annual shoots that have been recorded as containing a leader change were therefore excluded from the analysis below.

In total, data were available for 54 trees. The correlation between number of clusters in an annual shoot and tree age was calculated for each tree. The correlation was significant for only 1 of these 54 trees.

For each site, the mean number of clusters was calculated for each age, and the correlation calculated. Again the correlation was not significant.

A reasonable assumption, from these data, for a revised version of TreeBLOSSIM would be that:

- The number of branch clusters in an annual shoot is independent of tree age.

Botanically this assumption is probably not correct. The number of clusters should increase slightly with increasing age, and then decrease in old age (D. Bathelemy pers comm.). Two published studies have shown an increase in the number of branch clusters with increasing tree age (Bannister, 1962; Fernádez et al, 2007).
Radiata pine in New Zealand is currently felled around 30 years, and this is probably too soon for the decrease in clusters per year with old age to be visible.
Therefore the above assumption may hold for pruned radiata pine that is harvested before 30 years (the age of the "850" trees sampled varied between 21 and 29 years).

Further data is required to determine whether or not the assumption holds in unpruned stands, and stands harvested at a later age.

The mean number of clusters in an annual shoot was calculated for each tree, and the correlation with current tree DBH calculated for each site. Again the correlation was not significant, but the number of trees on each site was very low.

A reasonable assumption, from these data, for a revised version of TreeBLOSSIM would be that:

- The number of branch clusters in an annual shoot is independent of tree size.

Given the genetic variation in seedlots this is a reasonable assumption. It would be interesting to check the assumption using clonal material.

Possible implementation of cluster counts within TreeBLOSSIM

Cluster counts between two heights are currently being carried out within Cruiser Inventories. These cluster counts are being used to position clusters between these two heights. TreeBLOSSIM is then used to position clusters on the remainder of the stem. This may lead to the situation where clusters are widely spaced in the lower stem and much more tightly spaced in the upper stem. Such a result is undesirable, and it would be advantageous to use the cluster count as input to modify TreeBLOSSIM predictions for the whole stem.

The following is suggested as a potential way of incorporating a cluster count (n) into TreeBLOSSIM.

- Calculate the tree age for the lower cluster (a1)
- Calculate the tree age for the upper cluster (a2)
- Estimate the actual number of cluster per year as (n-1)/(a2-a1)
- Round number up to give upper limit for number of clusters per year for the tree
- Round number down to give lower limit for number of clusters per year for tree
- Assign clusters per year in measured part of stem to give actual number of clusters per year, with younger ages having lower cluster number and older ages having the upper cluster number.
- Apply upper cluster number to rest of tree.

To apply model to trees where there are no cluster counts

- Take trees with cluster counts
- Estimate upper limit for clusters per year
- Plot against tree DBH to determine whether there is a significant trend.
- Assign observed range of upper limits to other trees, randomly if no trend, or with respect to DBH if there is a trend.

Comments on approach

- It would be useful to expand the dataset of cluster per annual shoot. This could be achieved by measuring young trees in thinning operations, particularly thinning to waste.
- More research needs to be done to incorporate stem damage within the model. From the trees sampled at Mohaka it appears that longer than average internodes are observed at some point above stem damage. Often when trees lose their leader a branch will take over, and branches have been observed to have some long internodes.
- If it is important to be able to identify long internodes within a tree, then they should probably be measured within the inventory.

INDUSTRY ISSUES

One of the SGMC projects for July-September was to survey members for their comments on TreeBLOSSIM and its future. Only 6 members provided comments, 2 via a phone and 4 via email.

The following is a summary of the responses:

- There is support for the science to continue (see also SGMC Report No. 141)
- An issue with prototype software, such as TreeBLOSSIM, is that it is not in a form that is easily used by industry in their routine planning. There is insufficient time to "investigate" or learn to use prototype software that does not deliver an answer to a current task.
- Algorithms are best delivered in routinely used software, and that is where their usefulness will be assessed. This is true for both the algorithms in TreeBLOSSIM and the 300 Index Model.
- There are currently two commercial implementations of TreeBLOSSIM. From the responses received, one implementation of TreeBLOSSIM is routinely being used, and the other implementation has been investigated.
- The comments indicate that TreeBLOSSIM has not been widely tested. Within at least 1 company there are conflicting views as to its usefulness.
- Potential uses for "TreeBLOSSIM" implementations include:
    - Yield table production at clearfell from data collected at various times during the rotation, e.g. pruning QC, mid-rotation inventory and late-rotation (pre-harvest) inventory
    - To investigate the effects of alternative silviculture
    - To estimate branching patterns for stands where no branching information is available
    - To estimate the proportion of logs suitable for "internode grades"
    - Carbon accounting for young forests
- Some concerns with the model itself:
    - The small sample size used in generating the algorithms
    - The inability to predict larger branches caused by stem damage (random effects) which would make it difficult to use operationally
    - The generation of cluster positions is not sufficiently random
    - Whether the majority of branches on the valuable section of the stem are already dead at the time of pre-harvest and mid-rotation inventory.

One critical issue raised, that needs to be addressed as the Cooperatives merge into FFR, is how algorithms are delivered to industry. Some comments discussed:

- FFR should not be beholden to any one "software provider" for delivery of models.
- There is a role for in-house prototype models for testing ideas / concepts but that they should be passed onto "software companies" at more frequent intervals for incorporation into commercially available tools.
- It would probably be better for the prototype models to be developed by the scientists. The alternative of giving the development to say Atlas may disadvantage end-users of alternative software, but could work if this approach was primarily aimed at delivering prototype software for researchers and growth modellers to use in developing their models. Otherwise FFR should focus on producing the IP and leave the software deployment to whichever software providers the industry supports (probably more than one).

POTENTIAL IMPROVEMENTS to TreeBLOSSIM ALGORITHMS

- Concerns over the small dataset used to generate the algorithms in TreeBLOSSIM may easily be overcome by further data collection, but funding needs to be available.
- Further research is recommended to allow TreeBLOSSIM to be used with confidence to predict internodal material.
    - The algorithm predicting the relative position of branch clusters within an annual shoot needs to be modified.
    - The influence of stem damage on internode length needs to be further investigated.

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