SGMC Modelling Strategy Project 2006/2007

Collated by

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Report No. 140 ***February 2007***

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EXECUTIVE SUMMARY

At the July 2006 Stand Growth Modelling Cooperative meeting members considered that it was important for SGMC to invest in developing a comprehensive modelling strategy to put to Future Forest Research Ltd as the way forward for growth modelling in the future. To this end, the proposed project 2.4 was expanded in size and would, where necessary, include analysis of data from trial series to illustrate the benefits of alternative modelling approaches.

This document summarises the work carried out in this project up to February 2007. Phase 1 involved preparation of a document outlining different approaches to modelling and a questionnaire to stimulate discussion on the future strategy within the members. The results and comments were collated, summarised and presented at a Modelling Strategy Sub-committee meeting in August 2006. Phase 2 involved preparation of another document and series of questions to all members. These results and comments were also collated, summarised and presented at the SGM Technical Committee meeting in October 2006.

The questionnaire responses indicated that any new model developed should:

- Be empirical
- Include both individual tree-distance independent and stand level functionality
- Include recently collected data
- Be regionally based and/ or reactive to freely available site variables
- Cover ages 5-40 years in one model (provided the accuracy is not compromised at rotation end)

This project is to continue to hopefully guide modelling research through at least until the commencement of Future Forests Research Ltd (FFR).

SGMC Modelling Strategy Project 2006/2007

At the July 2006 Stand Growth Modelling Cooperative meeting members considered that it was important for SGMC to invest in developing a comprehensive modelling strategy to put to Future Forest Research Ltd as the way forward for growth modelling in the future. To this end, the proposed project 2.4 was expanded in size and would, where necessary, include analysis of data from trial series to illustrate the benefits of alternative modelling approaches. Consequently the 'Modelling Strategy' project for 2006 combined the original project proposal nos. 2.4, 1.3, 1.4 and 1.5 (Table 1) with a total Cooperative budget of $25,000. The project was to involve consultation with industry representatives and there was an expectation that there would be an initial report completed to present to the joint Cooperative meeting in October 2006.

Table 1.

Proposed Project No	**Task**	**Total Cost**	**SGMC Cost**
2.4	Develop a strategy for future model development	9,585	6,710
1.3	Analyse and document influence of site, seedlot and silviculture on tree growth in the 1987 series of trials	17,250	12,075
1.4	Analyse and document the influence of site, seedlot and silviculture on tree growth in the 1990/1991 (FR121) series of trials	17,250	12,075
1.5	Analyse and document the influence of site, seedlot and silviculture on tree growth in the 1992/1994 (FR172 and FR215) series of trials	17,250	12,075
Total		61,335	42,935
Accepted Project	**Future Modelling Strategy**		**25,000**

In August 2006, for phase 1 of the project, Jenny Grace prepared a word document (Appendix 1a) outlining different approaches to modelling and an excel spreadsheet questionnaire (Appendix 1b) to stimulate discussion on the future strategy within the members. An email forum to obtain the members' views was initiated early August and a group set up (Jenny Grace, Peter Oliver, Steve Dowman, Brian Rawley and Bob Shula) to discuss the results of the survey sent out to all members.

Jenny Grace received eight replies from member companies, to the document and questionnaire sent out early August; Carter Holt Harvey, City Forests, Crown Forestry, Ernslaw One, Hancock Forest Management, Matariki Forests, Silmetra and Wenita Forest Products. The results and comments were collated and summarised (Appendices 2a – 2f). The sub-group meeting was held on 23rd August (attended by Peter Oliver, Steve Dowman, Brian Rawley and Jenny Grace) to discuss the responses and decide on what future tasks were required.

Jenny compiled a document after the sub-group meeting - phase 2 of the modelling strategy (Appendix 3).

The Phase 2 document on the future modelling strategy was emailed to all members by Jenny Grace in September 2006 along with another series of questions. The questions that were put to members were:

- Will the 300 Index model, being developed within the Plantation Management Cooperative (PMC), satisfy your needs?
- Is it desirable to maintain separate models for different parts of the rotation?
- What age range should the new model cover?
- Do we need an individual tree model for the silvicultural years?
- Given the issues with length of projection period, would a new model dedicated to growing inventory data forward be worth developing?
- What site / environmental conditions do you have available for your forests that we could incorporate in any future models.
- Is further research needed to improve starting points for models?

A variety of responses were received to the second series of questions. These responses were collated and are attached in Appendix 4.

Jenny gave an overview of the results to the Technical meeting of the Cooperative in October 2006, in Palmerston North. She said that many companies were interested in 'new' empirical ITG/stand combo model/s. Any future strategy for long-term research needs to provide for future advances. The questionnaire responses indicated that any new model developed should:

- Be empirical
- Include both individual tree-distance independent and stand level functionality
- Include recently collected data
- Be regionally based and/ or reactive to freely available site variables
- Cover ages 5-40 years in one model (provided the accuracy is not compromised at rotation end)

At the joint Cooperative meeting held at the same time, SGMC made four presentations(by Bob Shula, Jenny Grace, Ian Jenkin and Brian Rawley) covering the history of the SGMC, past notable achievements, current and future research, industry uptake, usage and future needs.

There was some concern expressed by SGMC members at the PMC approach to modelling, with the perception that modelling priorities were weighted more towards the small consultants rather than the larger forestry companies. It was agreed though, that if PMC are looking at serious modelling, we should be working in conjunction with them. Peter wrote to the Chairman of the Plantation Management Coop in December 2006 formally requesting that a joint modelling steering group be set up to guide modelling research through at least until the commencement of FFR.

Appendix 1a

Background information for the development of a future modelling strategy - Phase 1

The objective of this report is to provide background information for the development of a future modelling strategy for the Stand Growth Modelling Cooperative. This strategy is being developed to provide the forest industry with the types of growth models etc that they will need in the foreseeable future, and will provide a summary of the SGMC aims for FFR.

Tree growth may be influenced by a range of factors including: light availability, temperature, water availability, nutrient availability, and windiness of the site. The limiting factor is likely to change between sites. Regionally-based growth models implicitly incorporate this without recourse to measuring a lot of variables. Process-base models allow the exploration of how these factors interact, and potential uses include understanding within year variation in wood properties and the influence of wind on tree development.

The SGMC research strategy has the following themes:

- Data provision
- External stem modelling
- Crown modelling
- Internal stem modelling
- Integrated growth and quality models
- Maintenance of stand level models

A modelling system that predicted stem volume, branch position, stem shape and 3-d distributions of wood properties within the stem would be able to link with wood processing models being developed by other groups within Ensis and overseas; and thus create a modelling system for the whole value-chain.

The document contains a very brief overview of different aspects of modelling to give you an idea of what could be achieved and stimulate discussion. Please consider these different approaches and provide feedback as to the types of models you wish to see developed, and also any comments about currently available models. This information will help develop the future strategy.

Approaches to modelling tree growth and wood properties

Levels of aggregation

1. Stand level models
   These predict variables such as mean top height and basal area growth. Individual tree sizes are obtained from diameter-distribution functions. (Models developed using Oscar Garcia's methods fall into this category, as does the 300 Index model).

2. Individual tree distance independent models
   These models predict the growth of individual trees without reference to the location of their neighbours. (ITGM and SYM (silviculture years model) fall into this category of models)

3. Individual tree distance dependent models
   These models predict the growth of individual trees in relation to the location of neighbours. These models require the location of individual trees, and provide an understanding of how competition influences tree development. Such models maybe useful for understanding the growth of individual clones within single-tree-plot experiments.

Levels of coverage

1. Nationwide models
   The 300 Index model falls into this category. It is adjusted by site index and 300 Index, both variables estimated from measurements.

2. Regional models
   Current growth models developed by the SGMC fall into this category. Currently we have 7 growth modelling regions. The Land Environments of New Zealand (Ministry of Environment, 2003) classifies New Zealand into areas of similar climate and soils at various levels of similarity. At the top level (level 1) there are 20 environments, some of which have very little exotic forestry (Table 2). Should we develop new/ more regional growth models based on the Land Environment classification?

3. Forest models
   Is the resource so variable that we should develop models for individual forests?

Mathematical formulation

1. Empirical models
   Such models fit mathematical relationships to field measurements of the variables to be predicted. Models developed by the SGMC fall into this category. Issues include obtaining the best mathematical fit to the data, and having functional forms that are realistic from a biological perspective.

1a. Empirical models incorporating environmental variables / synthesising process-based models
   Some empirical models incorporate environmental variables. Such models would allow for variation in growth due to environmental conditions. Recently a process-based model has been synthesised to a set of equations that can be fitted empirically.

2. Process-based / functional-structural models
   Such models incorporate mathematical equations that predict underlying growth processes, and tree growth variables are a consequence of these equations. Such models are useful for exploring how tree growth processes and environment influence tree growth and wood properties. The model CABALA (developed by staff in Ensis in Australia) falls into this category. Elsewhere models have been developed to investigate the influence of wind on trees.

Outputs that could be predicted from models – will depend on model formulation

1. Mean top height
2. Individual tree height
3. Stand Basal area
4. Individual tree basal area
5. Individual tree branching patterns
6. Ring average wood properties (e.g. density, microfibril angle, modulus of elasticity, spiral grain)
7. Within ring variation in wood properties (will allow the influence of climate on wood properties to be explored)
8. 3-d stem shape
9. Circumferential variation in wood properties (e.g. will allow prediction of compression wood and resin pocket distributions)

Data Provision

Trials are necessary to provide data for understanding tree growth (i.e. the effects of site, silviculture and genetics) and the development of models. We already have a good general knowledge of how trees grow in New Zealand, but due to the continuing changing genetics/species, changes in silviculture and climate we will continually need data on tree characteristics for model development. Without new data, models would stagnate.

We need to determine a cost-effective method for obtaining the data required.

1. Very high-stocked mini-plots have been used to determine site productivity. Is this approach worth expanding?
2. Nelder trials are a compact way of investigating the influence of stocking on tree growth. These are probably best suited to developing individual tree models.
3. Traditional PSPs as trials covering a range of silviculture and genetics
4. Traditional PSPs within forests matching current silviculture and seedlots.

Other issues

An important issue is how we develop growth models for situations where there is currently little data available for model fitting. Issues that fall into this category include:

1. Continual improvement of planting stock quality through tree improvement. The issue here is how to predict rotation age tree sizes when we have no prior knowledge of how the genotype will perform at the end of the rotation.
2. Site specific planting of clones / tree species.
3. Continuous cover forestry

Model Acceptability

All models contain assumptions, and no model will be "perfect". Improvements in model predictions are likely to be made with better understanding of tree growth and more data (both plots and variables) for model development.

Ideas for potential sub-projects within the SGMC future strategy project

I would like to see a number of different modelling approaches investigated at a pilot study level to help formulate future modelling directions. The following list can be expanded with your ideas.

1. Determine Land Environment regions for SGMC trials and also forests within the current growth modelling regions. Examine whether there are any trends in model residuals due to land environment. (For example SGMC report 39 indicated that there were trends in residuals for some forests within the Canterbury Growth Modelling Region).
2. Analyse data from SGMC trial series to determine whether the relative impacts of site, silviculture and genetics on tree growth are related to the Land Environment classification, e.g. which Land environments show the most benefits from genetically improved seedlots.
3. Investigate how well the process-based model CABALA performs for different SGMC trial series.
4. Use data from SGMC trials series to obtain model coefficients for a recently published growth model (an empirical growth model where the equations have been developed from Valentine and Makela, 2005).
5. Use SGMC trials to investigate the performance of the integrated branch growth and wood property model for predicting radial growth. (This model, developed by D. Pont, is an enhancement to TreeBLOSSIM and being used within the Internal Stem Modelling Theme).
6. Investigate statistical methods for being able to extend currently available growth models to new genotypes/ clones.

New variables to be measured within PSPs

Different modelling approaches require different and varying amounts of information about the site and forest resource. In particular process-based models a substantial number of additional variables. Should we be measuring more variables within PSPs to help with the development of new models using alternative approaches?

Some variables that could be considered include:

- revision of crown height definition to record both lowest live branch and lowest live branch cluster - I consider the current approach to be too subjective
- crown width – needed for process-based models
- leaf area – needed in process-based models
- soil measurements – needed in process-based models
- meteorological data – needed in process-based models
- heights of stem defects – would help improve branching models
- wood properties at fixed ages – would be useful in the development of wood property models
- PhotoMARVL at fixed mean top height – would help improve branching models, and development of stem shape models

Other questions to consider and provide comments

I would appreciate your views on the following questions as well as your responses to the attached questionnaire.

- What are perceived problems with current models?
- What questions do you want models to answer?
- How important will it be to be able to model the following both now and in the future?
    - stem volume
    - stem shape including characteristics such as sweep, nodal swelling, butt flare, fluting
    - branching characteristics
    - 3-d distributions of wood properties

Would you be prepared to collect more variables if they led to improvement in model performance?

Table 2.

The 20 Level 1 Land Environments for New Zealand (from Land environments of New Zealand, Ministry of Environment, 2003)

Level 1 Environments	Description	Land Area (000 ha)	% exotic forestry
A	Northern Lowlands	1860	5.8
B	Central Dry Lowlands	693	7.4
C	Western and Southern North Island Lowlands	639	1.3
D	Northern Hill Country	2104	12.1
E	Central Dry Foothills	1327	7.4
F	Central Hill Country and Volcanic Plateau	5253	12.5
G	Northern Recent Soils	344	16.2
H	Central Sandy Recent Soils	137	13.0
I	Central Poorly-drained Recent Soils	123	0.6
J	Central Well-drained Recent Soils	297	7.9
K	Central Upland Recent Soils	163	4.3
L	Southern Lowlands	312	2.0
M	Western South Island Recent Soils	229	0.2
N	Eastern South Island Plains	2052	2.1
O	Western South Island Foothills and Stewart Island	1423	2.5
P	Central Mountains	3252	2.4
Q	Southeastern Hill Country and Mountains	3276	4.1
R	Southern Alps	1931	0.0
S	Ultramafic Soils	34	1.2
T	Permanent Snow and Ice	159	0.0

Appendix 1b.

Questionnaire on Future modelling strategy

Answer all questions with a rank between 1 and 5; 1 definitely not to 5 definitely yes
Levels of model aggregation
What types of growth models would you like to see developed?
Stand - level models
Individual tree - distance independent models
Individual tree - distance dependent models
Levels of coverage
What level of coverage would you like to see for growth models?
Nationwide models
Regional models
Forest Models
Other options (please list in comments column)
Mathematical formulation
What types of models would you like to see developed?
Empirical models
Empirical models incorporating environmental variables/ synthesis of process-based models
Process-based models
What variables would you like models to output?
Mean top height
individual tree height
stand basal area
individual tree basal area
individual tree branching patterns
ring average wood properties
within variation in wood properties
3-d stem shape
Circumferential variation in wood properties (resin defects and compression wood
Other variables (please list in comments column)
Potential sub-projects within future strategy
Investigate models errors within respect to land environments
Relative impact of site silviculture and genetics with respect to Land Environment
Performance of CABALA
Fitting empirical/ process-based model to SGMC trials
Investigate performance of inegrated branch growth and wood property model
Statistical techniques for modelling genotypes/ clones
Other ideas (please list in comments column)
New variables to be measured in PSPs
revision of crown height definition
crown width
leaf area
soil measurements at fixed times during the rotation
remotely sensed weather stations in important trials
measurement of height of any stem defects
measurements of wood properties at fixed times during rotation
PhotoMARVL of selected sample trees at a fixed mean top height
Other variables (please list in comments column)

Appendix 2a.

Levels of model aggregation		
What types of growth mdoels would you like to see developed?		
Stand - level models	1	
Individual tree - distance independent models	5	I understand this approach is best for Crown modelling
Individual tree - distance dependent models	3	As you say, this may be more appropriate for clonal models.
Stand - level models	5	
Individual tree - distance independent models	5	
Individual tree - distance dependent models	1	
Stand - level models	3	
Individual tree - distance independent models	3	Pure individual tree models are unlikely to be satisfactory.
Combined stand/tree models – distance independent	5	Need estimates at tree level but may need to forecast stand parameters to get them
Individual tree - distance dependent models	1	No point basing models on variables that won't be collected in inventory
Stand - level models		that provide a prediction given various inputs of site, silviculture, and genetics. (In this case could use
Individual tree - distance independent models		measures to validate predictions)
Individual tree - distance dependent models		
Tree population level		Tree population level may be from individual trees or from tree population means and variation.
Stand - level models	5	Original SGMC models are OK, though need to be continuously updated/improved as new data is available
Individual tree - distance independent models	1	To date have not had any success with them - not sure how they can work effectively without distance dependence in terms of modeling effects of different stocking/thinning?
Individual tree - distance dependent models	1	These would be the ultimate given that they would probably help model the effects of thinning & stocking on growth, but the amount of information required to input into them to make them work would be beyond standard inventory cost/time budgets.
Stand - level models	3	
Individual tree - distance independent models	3	
Individual tree - distance dependent models	1	
Hybrid stand / individual tree level models	5	
Stand - level models	4	constrained individual tree to stand parameters better
Individual tree - distance independent models	4	
Individual tree - distance dependent models	1	
Stand - level models	5	V. impt, need to develop a process for continual updating so that they are relevant to the current harvest crop
Individual tree - distance independent models	5	"
Individual tree - distance dependent models	3	Could prove to be useful for research, for understanding and developing distance independent models and interpreting other trials. Not for production situation however, because of burden of data collection

Appendix 2b.

Levels of coverage		
What level of coverage would you like to see for growth models?		
Nationwide models	1	
Regional models	5	There are growth differences between regions, so this is the best approach. The Land Environments could be used, but some of them look similar to the existing growth modelling regions.
Forest Models	3	Only the largest forests have enough PSP's, and the large forests represent growth modelling regions or land environments anyway.
Nationwide models	2	
Regional models	4	
Forest Models	1	
Nationwide models	2	
Regional models	5	Regional definition that is environmental rather than political would be good
Forest Models	1	
Nationwide models	3	
Regional models	5	
Forest Models	1	
Nationwide models		
Regional models		
Forest Models		
Other options		Models with site, silviculture, and genetics inputs. Distinction between national, regional, and forest
Nationwide models	1	
Regional models	3	If anything, regional models probably best approach - reasonable balance in terms of cost & accuracy between site specific & national average models. - but would like to know why the old 7 regions need replacing? Are these new environmental regions a finetuning of the older regions? Don't want to see a whole new suite of regional models developed when they overlap existing regions.
Forest Models	1	
Other options	5	Would like to see the current 'regional' models re-calibrated/updated/improved before trying to develop a whole suite of new national/regional/forest models
Nationwide models	3	
Regional models	5	
Forest Models	1	
Nationwide models	3	Regional variation impt. to account for - 'averages' not really that useful except for broad planning/valuation exercises. 'Regions' must be based on forest growing distinct environments, not general environments. May need sub-regions.
Regional models	5	
Forest Models		
Other options	3	See above

Mathematical formulation		
What types of models would you like to see developed?		
Empirical models	5	Would like growth models, and associated taper/volume models, that work well, and that are regularly updated to keep in touch with forest resource - empirical models to date appear to have been most successful
Empirical models incorporating environmental variables/ synthesis of process-based models	2	This has some merit, but the existing empirical models often already encompass this by the fact that they have been developed for an area with a particular environmental limiting factor (e.g. hills vs. plains in Canterbury)
Process-based models	1	These would be the ideal, but to date have always found the level of information required to make them work well (e.g. soil depth, soil fertility, clay content, min/max temp., min/max rianfall, etc, etc) at the stand level is well-beyond that available at reasonable collection costs. Forest inventory on the other hand, along with stand growth models, is still preferred and needs support. Have seen where process-models are Ok for broad growth modeling (e.g. relates to data availability), and may be good for high level carbon-credit modeling but our primary aim is to target stand growth for harvest prediction & valuations
Empirical models		Whatever works. Empirical models are very dependant on the data they are derived from. Our problem
Empirical models incorporating environmental variables/ synthesis of process-based models		is our current data set does not cover the range of sites they are required to be used for. Perhaps
Process-based models		model development needs to include an element of extrapolation analysis (behavioural analysis) that enables their use outside the bounds of the base data. (Do not necessarily need to use PSP data - could include other measurement data at the extremes in order to "anchor" the model
Empirical models	4	
Empirical models incorporating environmental variables/ synthesis of process-based models	5	
Process-based models	2	
Empirical models	4	
Empirical models incorporating environmental variables/ synthesis of process-based models	5	
Process-based models	1	
Empirical models	3	
Empirical models incorporating environmental variables/ synthesis of process-based models	5	
Process-based models	1	
Empirical models	5	Proven technology
Empirical models incorporating environmental variables/ synthesis of process-based models	4	If environmentalvariables can be incorporated successfully, this would be a better approach.
Process-based models	2	
Empirical models	4	
Empirical models incorporating environmental variables/ synthesis of process-based models	5	
Process-based models	2	
Empirical models	4	
Empirical models incorporating environmental variables/ syn	5	Would like to see some testing of synthesis models to see whether gains can be made that result in practical (in terms of data collection) models
Process-based models	2	

What variables would you like models to output?		
Mean top height	5	
individual tree height	5	
stand basal area	5	
individual tree basal area	5	Would like the variables that grow TRV as no.1 priority, especially over longer periods, as volume is a large driver in estimating value
individual tree branching patterns	1	
ring average wood properties	1	Although the benefit of being able to grow all these characteristics through time is obvious for determining marketable log products, there is still so much work to be done on growing the standard tree/stand variables to simply obtain an accurate TRV over time (especially longer time periods), that I think the time & effort should be spent there as higher priority - some of these wood quality variables are probably best covered by WQI funding? Would like to avoid overlap if possible.
within variation in wood properties	1	
3-d stem shape	2	
Circumferential var in wood properties	1	
Other variables	5	Possibly need a less complex model (or update of existing) of branch growth/mortality for growing younger inventory data forward to harvest age. Inventory can pick up branch size & distribution up the stem, 'just' need to grow forward those measured branches and estimate when mortality occurs. For standard inventory procedures, don't need a model to predict where and what the branches look like - get the basics right first.
Mean top height		Key output from empirical models is volume by grade.
individual tree height		This tends to be derived from quantitative variables -
stand basal area		stems per hectares, tree diameter, tree height,
individual tree basal area		and qualitative variables - (qualitative in that they are assessed subjectively)
individual tree branching patterns		branch size, sweep, and stem defect
ring average wood properties		Other variables that may be used to classify a population of trees include -
within variation in wood properties		density, MOE/stiffness, compression wood, resin defects, and internal checking
3-d stem shape		Other models/functions are used for tree volume, taper, breakage, DBH distribute, height relationships, etc
Circumferential var in wood properties		Model output variables need to be consistent with measurement and assessment variables that are used
Other variables		for volume by grade estimation.
Mean top height	4	
individual tree height	4	
stand basal area	4	
individual tree basal area	4	
individual tree branching patterns	3	
ring average wood properties	2	
within variation in wood properties	2	
3-d stem shape	3	
Circumferential var in wood properties	2	
Other variables		important to keep stand sph and stem mortality probability functions
Mean top height	4	
individual tree height	5	
stand basal area	4	
individual tree basal area	5	
individual tree branching patterns	3	
ring average wood properties	1	
within variation in wood properties	1	
3-d stem shape	1	I guess that empirical models of tree shape (taper/volume functions) with inputs that reflect how a tree has grown (e.g. final dbh & height) will be more satisfactory than trying to grow a 3D shape for a long time to come.
Circumferential var in wood properties	1	
Other variables		Stand stocking (stems/ha) (4), individual tree survival (5)

What variables would you like models to output?		
Mean top height	5	
individual tree height	5	
stand basal area	5	
individual tree basal area	5	
individual tree branching patterns	3	
ring average wood properties	2	
within variation in wood properties	1	
3-d stem shape	1	
Circumferential var in wood properties	1	
Other variables		stand stocking
Mean top height	5	
individual tree height	3	
stand basal area	5	
individual tree basal area	2	
individual tree branching patterns	5	
ring average wood properties	4	
within variation in wood properties	4	
3-d stem shape	5	
Circumferential var in wood properties	4	
Other variables		
Mean top height	4	
individual tree height	5	
stand basal area	4	
individual tree basal area	5	
individual tree branching patterns	3	
ring average wood properties	2	
within variation in wood properties	2	
3-d stem shape	2	not necessarily part of a growth model
Circumferential var in wood properties	1	
Other variables	5	stocking (4) / tree frequency (5)
Mean top height	5	
individual tree height	3	
stand basal area	5	
individual tree basal area	5	
individual tree branching patterns	3	
ring average wood properties	2	Need to be careful of overlap with WQI and relative importance of prediction vs. direct measurement of wood properties. This may be a question for FR to address in diresct conversation with WQI
within variation in wood properties	2	
3-d stem shape	4	
Circumferential variation in wood prope	2	
Other variables (please list in commer	5	Mortality v. impt to model for variety of environments

Appendix 2e.

Potential sub-projects within future strategy		
Investigate models errors within respect to land environments	3	This may have some merit if it showed up growing environments (containing PRAD) that need further modeling not covered by the current 7 regions, or it it could be used to fine-tune the current regional models (e.g. enhanced site specificity), but would hate to see the old models replaced without there being some major improvement out the other end
Relative impact of site silviculture and genetics wrt Land Environment	1	
Performance of CABALA	1	
Fitting empirical/ process-based model to SGMC trials	1	
Investigate performance of inegrated branch growth and wood property model	1	
Statistical techniques for modelling genotypes/ clones	1	
Other ideas (please list in comments column)	5	new options outside of the STAND growth modeling coop's main scope - get the basics right first
Investigate models errors within respect to land environments		Investigate model behaviour wrt site characteristics - altitude, aspect, exposure, soils, climate, etc
Relative impact of site silviculture and genetics wrt Land Environment		Investigate model behaviour with respect to site x silviculture x genetics interactions
Performance of CABALA		Investigate model behaviour outside the bounds of base data, and within the bounds of reality
Fitting empirical/ process-based model to SGMC trials		Reengineer models to reflect findings of investigation
Investigate performance of integrated branch growth and wood property model		Develop models that reflect the site x silviculture x genetics interactions (if required)
Statistical techniques for modelling genotypes/ clones		
Investigate models errors within respect to land environments	3	
Relative impact of site silviculture and genetics with respect to Land Environment	3	
Performance of CABALA	2	
Fitting empirical/ process-based model to SGMC trials	2	
Investigate performance of inegrated branch growth and wood property model	3	
Statistical techniques for modelling genotypes/ clones	2	
Investigate models errors within respect to land environments	3	
Relative impact of site silviculture and genetics wrt Land Environment	3	
Performance of CABALA	1	
Fitting empirical/ process-based model to SGMC trials	1	
Investigate performance of inegrated branch growth and wood property model	1	
Statistical techniques for modelling genotypes/ clones	1	
Other ideas (see below)		
Build new empirical, distance independent stand/tree models	5	
Investigate sources of low-cost environmental information that can be used as inputs during model development and use.	5	The feasibility of routinely using GIS to assign a climatic, soil or topographical variables to PSPs and to forest inventory, from national databases, is sufficiently high that these variables should be considered as model inputs.

Potential sub-projects within future strategy		
Investigate models errors within respect to land environments	3	
Relative impact of site silviculture and genetics wrt Land Environment	3	
Performance of CABALA	2	
Fitting empirical/ process-based model to SGMC trials	2	
Investigate performance of inegrated branch growth and wood property model	2	
Statistical techniques for modelling genotypes/ clones	3	
Investigate models errors within respect to land environments	4	
Relative impact of site silviculture and genetics wrt Land Environment	4	
Performance of CABALA	3	
Fitting empirical/ process-based model to SGMC trials	4	
Investigate performance of inegrated branch growth and wood property model	3	
Statistical techniques for modelling genotypes/ clones	3	
Investigate models errors within respect to land environments	4	growth that are best dealt with by regional subdivision, preferably based on readily available environmental data
Relative impact of site silviculture and genetics wrt Land Environment	3	
Performance of CABALA	1	
Fitting empirical/ process-based model to SGMC trials	2	
Investigate performance of inegrated branch growth and wood property model	2	
Statistical techniques for modelling genotypes/ clones	2	
Investigate models errors within respect to land environments	4	
Relative impact of site silviculture and genetics wrt Land Environment	3	
Performance of CABALA	3	
Fitting empirical/ process-based model to SGMC trials	2	
Investigate performance of inegrated branch growth and wood property model	2	
Statistical techniques for modelling genotypes/ clones	2	
Other ideas (please list in comments column)	5	Establish process for new model development (ie. Stand and tree based distant-independent empirical models)

Appendix 2f.

New variables to be measured in PSPs		
revision of crown height definition	1	
crown width	1	
leaf area	1	
soil measurements at fixed times during the rotation	1	
remotely sensed weather stations in important trials	1	
measurement of height of any stem defects	1	
measurements of wood properties at fixed times during rotation	3	Internal wood qualities are becoming more important - would WQI have access to this data?
PhotoMARVL of selected sample trees at a fixed MTH	1	
revision of crown height definition		All variables assessed/measured must relate to end use, e.g., model development
crown width		
leaf area		
soil measurements at fixed times during the rotation		
remotely sensed weather stations in important trials		
measurement of height of any stem defects		
measurements of wood properties at fixed times during rotation		
PhotoMARVL of selected sample trees at a fixed MTH		
revision of crown height definition	2	
crown width	2	
leaf area	2	
soil measurements at fixed times during the rotation	2	
remotely sensed weather stations in important trials	3	
measurement of height of any stem defects	3	
measurements of wood properties at fixed times during rotation	3	
PhotoMARVL of selected sample trees at a fixed MTH	3	
revision of crown height definition	1	
crown width	1	
leaf area	1	Tell me how to get this in inventory and my interest will increase
soil measurements at fixed times during the rotation	3	However, there is a danger in having perfect knowledge when model is built but imperfect knowledge when it is used.
remotely sensed weather stations in important trials	3	However, there is a danger in having perfect knowledge when model is built but imperfect knowledge when it is used.
measurement of height of any stem defects	1	
measurements of wood properties at fixed times during rotation	1	
PhotoMARVL of selected sample trees at a fixed MTH	1	
Any soil, climate, geographic variables for which national continuous databases exist	5	This is the information that is most likely to be used as input when the models are used so it should be considered when they are built.

New variables to be measured in PSPs		
revision of crown height definition	2	
crown width	2	
leaf area	2	
soil measurements at fixed times during the rotation	3	
remotely sensed weather stations in important trials	3	
measurement of height of any stem defects	2	
measurements of wood properties at fixed times during rotation	2	
PhotoMARVL of selected sample trees at a fixed MTH	2	
revision of crown height definition	5	
crown width	2	
leaf area	2	
soil measurements at fixed times during the rotation	5	
remotely sensed weather stations in important trials	2	
measurement of height of any stem defects	5	
measurements of wood properties at fixed times during rotation	5	
PhotoMARVL of selected sample trees at a fixed MTH	4	
revision of crown height definition	2	
crown width	2	
leaf area	1	
soil measurements at fixed times during the rotation	3	
remotely sensed weather stations in important trials	3	
measurement of height of any stem defects	4	
measurements of wood properties at fixed times during rotation	1	
PhotoMARVL of selected sample trees at a fixed MTH	1	
revision of crown height definition	5	
crown width	2	
leaf area	1	
soil measurements at fixed times during the rotation	3	
remotely sensed weather stations in important trials	3	
measurement of height of any stem defects	4	Worth establishing branches for deformation rates, pairing with stem events etc.
measurements of wood properties at fixed times during rotation	2	
PhotoMARVL of selected sample trees at a fixed mean top height	3	

Appendix 3.

Report on development of a future modelling strategy - Phase 2

This future strategy will cover all aspects of the current SGMC research strategy, which has 6 themes (see below). So far more emphasis has been given to the external stem modelling theme. The current SGMC Research Strategy has 6 themes:

- Data Provision
- External Stem Modelling
- Crown Modelling
- Internal Stem Modelling
- Integrated Growth and Quality Models
- Maintenance of Stand-level Models

General Summary

Any future research strategy should include short, intermediate and long-term needs of the forest industry. Modelling of tree growth and development is considered to be a never-ending task for a variety of reasons:

- New data collected
- New sites planted
- New genotype / species being planted
- New modelling approaches being developed
- Availability of new measurement technology

From the responses to the questionnaire, there appears to be an immediate need is to develop new integrated stand and tree level models for projecting inventory data, for the forest industry, that incorporate recently collected data. For forest management, models serve two distinct uses:

- Prediction of yield from forest inventory data
- To evaluate regimes and make silvicultural decisions

Separate models have previously been developed for both aspects but the link between early and late growth models is often disjointed. A model that covered the whole rotation would overcome this problem, BUT the performance of current models is affected by the length of the projection period, generally, the longer the projection period, the poorer the performance.

As FFR will merge all current cooperatives together, one question that is bound to come up is:

"Won't the 300 Index model, being developed within the Plantation Management Cooperative satisfy your needs?"

The 300 Index model is a stand level model that covers the whole rotation. There is a current project (within the Plantation Management Cooperative) to develop an individual tree level model that links with the 300 Index model. The 300 Index model is currently incorporated in Atlas Forecaster but not Atlas Cruiser.

Your answer to this question will be an important part of the strategy.

Possible structure for a new "external stem model" for industry

Assuming that a new model is to be developed, the model structure would need to be designed from scratch. There is no routine methodology.

From the questionnaire, the structure of a new model would be as follows:

- Empirical
- Individual tree – distance independent and stand level functionality
- Individual tree model constrained by the stand level model
- Regionally based and / or reactive to site variables/ environmental conditions
- Use site/ environmental variables that are readily and cheaply available (e.g. via GIS)
- Most importantly, predict variables required for the estimation of volume
- Data set used to include recently collected data

One aspect that needs further thought is the age-range that would be covered by any new model. Currently we have different models for different age ranges within a rotation.

- Is it desirable to maintain separate models for different parts of the rotation?
- What age range should the new model cover?
- Do we need an individual tree model for the silvicultural years?
- Given the issues with length of projection period, would a new model dedicated to growing inventory data forward be worth developing?

If we aim to develop a model structure that is reactive to site conditions then we need to know what variables are cheaply available, e.g. from field collection or available data-bases.

It would be good if each member could provide a list of site / environmental conditions that they have access to that we could incorporate in any future models.
It was suggested that if models incorporate such variables, then there should be look-up tables of default values.

Summary of questionnaire topics

Levels of Aggregation

From a forest management perspective, both stand level and individual tree level models are required. The individual tree models should be distance-independent and constrained by the stand-level models.

There needs to be a well-defined process for continually updating such models as new data becomes available to ensure that they are relevant for the current crop.
Individual-tree distance-dependent models have a role as a research tool, for example to understand the influence of thinning and local-stocking on tree growth, and understand the growth of clones. Such models are unlikely to be used for practical forest management because it would be cost-prohibitive to routinely collect such data in forest inventories.

Levels of Coverage

A regional approach to growth modelling is considered to be the most appropriate given that there are differences in growth between the current regions. The regions used should be based on environmental conditions (forest-growing environments rather than 'general' environments).

Mathematical Formulation

Process-based modelling is the least favoured approach for harvest prediction and valuation. One reason is that the inputs required cannot be collected at reasonable cost.
Empirical models are the favoured approach, but it is suggested that an important part of the model development is "extrapolation analysis" to determine their behaviour outside the range of data available. Incorporation of environmental variables in empirical models is considered worth investigating. It is worth investigating whether a recently developed approached based on a synthesis of process-based models can result in practical models (in terms of data collection).

What variables would you like models to output

The most important variables for models to predict are those that are required for the estimation of volume as it is a large driver in estimating value.

Branching characteristics are next in importance and it was questioned whether a less complex approach could be developed. The current approach was taken because we had very little knowledge of branch growth mechanisms, and because the inventory assessment classes were too broad to grow forward directly.

Stem shape and wood properties were considered the least important, and it was questioned where was the most logical place for such research (within WQI or within FFR) as overlap should be avoided. An advantage of understanding and modelling wood properties is that they can be included as an estimator of value.

Potential sub-projects within future strategy

Whilst not explicitly stated, the potential sub-projects listed would contribute towards the development of new models for forest management.

The most highly ranked projects were investigating the errors in current models with respect to Land Environments; and investigating the relative impacts of site, silviculture and genetics within the different Land Environments. The rest of the projects had a lower but similar weighting.

New variables to be measured within PSPs

Several possibilities for new variables to be measured in PSPs were presented. These variables were ones that have an impact on tree growth and are listed below in order of most favoured to least favoured.

- Soil measurements
- Measurement of heights of stem defects
- Revised definition for crown height
- Automatic weather stations in important trials
- Wood properties
- Imaging trees using PhotoMARVL or TreeD
- Crown width
- Leaf area

An issue is that if we find that certain variables are appropriate to be included in models, will those same variables be available when the model is applied. In this respect, variables that are readily available in GIS systems are more likely to be of use for model development than having good knowledge of some variables in PSPs that are unlikely to be available when models are used. (The current issue with crown length is one such example.)

Data Provision

There needs to be a rationalisation of data provision (trials, PSPs etc) within FRR.
We should provide a brief summary of SGMC trials to FFR.

Other modelling themes

Crown and internal stem modelling themes are still important to the SGMC, but are currently less important that having updated models for the prediction of volume.

General

- Volume, taper, and breakage functions also need to be continually updated
- Having good starting points is important when projecting data forward in time. Is further research needed to improve starting points?
- Determine the main drivers for DBH and height?

Long-term needs

Long-term research is needed to provide for future advances.

- Internal stem modelling should be continued as part of the long-term strategy
- Process-based models like CABALA may be useful for long-term research.
- Individual-tree distance-dependent models have a role as a research tool, for example to understand the influence of thinning and local-stocking on tree growth.

What next?

There are 3 immediate next steps:

1. For industry members to provide answers to questions in the above document and listed below
2. To develop an SGMC presentation for the FFR meeting in October
3. To reach consensus on the research component of this project for the rest of the financial year.

Will the 300 Index model, being developed within the Plantation Management Cooperative satisfy your needs?

- No
- I think it is yet to be proven whether the 300 index model is working well for older stands. At this stage it appears to be primarily useful as a silvicultural decision making and regime analysis tool. Therefore, at this stage there is still a need for updated models for mid-rotation onwards.
- We don't have access to this model so I can't really answer this. We would like to stay on the ITGM path though.
- No - want ITGM for inventory projection
- No
- Not 100% sure, but don't think that one model will function accurately across the whole of NZ and under various site/silvicultural regimes. Need more experience/testing with 300 Index model to confirm – has SGMC done any testing to date on this?
- Don't know

Is it desirable to maintain separate models for different parts of the rotation?

- Not a priority. Only when justified by data fitting.
- In my view this is purely a pragmatic decision. Ideally one model would do all, but what gives the best result, and can the result be reasonably used by end users?
- Not if a combined model is just as realistic with predictions and there is no transition bump.
- The main requirement is accurate estimation - if that can be satisfied by a single model then good but if not it is preferable to have two rather than compromise the quality of the yield estimates.
- No.
- Would be preferable to have one model that could function throughout the full rotation to ensure that silvicultural regimes will provide a suitable outcome at harvest. However, if we still needed 2 models to maintain accuracy, it would be good to research ways into making them link up better.
- No. It is not desirable at all. The main reason is that the separate models are unlikely to combine neatly to allow projection across multiple age ranges. The symptoms of this will be Non-path-invariance. Yield at age 30 from a projection from age 5 to age 30 will be dependent on the point at which the switch is made between models. This is a bad symptom for most companies with discontinuities at the point of transfer.
- It might be desirable to use different functions at different parts of the rotation to explain growth of, for example DBH or basal area, but only if the multiple functions are combined into a single seamless model.
- There is no acceptable reason for dividing the rotation into separate parts for attention by different research providers or different factions within the same research provider.

What age range should the new model cover?

- Needs to cover ages 5 to 35, though realise that stands have not necessarily 'settled down' at age 5, so this may be ambitious. Perhaps ages 10 to 35 more realistic, as inventory at age 10 would be more likely to reflect future growth - though of course this would miss the silvicultural treatments, one of the main points of being able to model at young ages!
- Ages 5 – 40 years
- The most urgent need is for a mid-rotation age onwards model
- Priority for us is updated stand growth model and ITGM for age 15 and above.
- There is a definite requirement for a single model to cover the full range (up to at least 40 years) suitable for regime analysis etc. But it may be necessary to have one or more models which provide a higher level of accuracy for early growth (tending scheduling) and post about age 15 (suitable for inventory projection)
- Ages 4-40 years

- Ideally age 5 to 60 for P. radiata. Greater range might compromise a model's predictive ability or behaviour. If this is the case then we should consider narrowing the range. Assuming that much before age 5 the compromises will warrant increasing the start age to at

Do we need an individual tree model for the silvicultural years?

- Unsure. Don't know enough about how individual tree models would improve the process to comment at this stage.
- Yes. We need models that will grow trees from inventory data to produce yield tables. Some of that inventory data is currently collected in the silvicultural years.
- An early model should be able to make full use of, and not require more than inventory and/or qc and/or pre-assessment data commonly collected.
- It should also integrate seamlessly with a late model. The late model will be an individual tree / stand level model. How this is best achieved is up to the modeller.
- No. At the silvicultural decision making stage, stand averages are sufficient.
- This is a nice to have for us.
- Yes, if there data is available to support development
- We need a single model that is responsive to silviculture, site and genetics, and can project volume and quality in sufficient detail through to rotation end to allow for simulated bucking into log grades which recognise size, branching, and wood quality features. Individual tree models are best suited for this.

Given the issues with length of projection period, would a new model dedicated to growing inventory data forward be worth developing?

- We certainly focus a lot of our attention on growing inventory data forwards through time, for pre-harvest planning (say 3-5 years growth), for strategic modelling (say 20 to 5 years growth) and for yield table development, so yes, this could be worthwhile focusing on.
- That is a terrible question for three reasons:
- It implies that projection period and using inventory data as an input are somehow related. The fact is that people collect inventory data at all points in the rotation and they use that inventory for building yield tables. They tend to collect more later in the rotation and they tend to use the data collected earlier for other things as well as yield table generation but that does not remove the need to grow inventory collected early in the rotation for the purposes of estimating yield.
- It implies that a model that covers a full rotation will automatically be less capable when projecting from late-rotation inventory than it would have been if the model had not covered the whole rotation. I do not accept this. It may be less capable at projecting from early-rotation inventory than from late-rotation inventory but that does not mean that it will be inherently inferior to a model dedicated to projecting from late-rotation. It sounds like the beginnings of an excuse to partition growth modelling activity between different research factions.
- Not a priority. Only when justified by data fitting. The current models were developed from data limited to certain ages, so it is not all that surprising they perform poorly when used over ages outside the input range. Whether you use one or two models to grow from age 5 to age 40 doesn't change the overall projection period.
- In my view this is purely a pragmatic decision. Ideally one model would do all, but what gives the best result, and can the result be reasonably used by end users?
- We would like to see the stand growth model and ITGM for age 15 and above updated if it is possible to improve the accuracy by having a separate model for this purpose then definitely yes
- Absolutely. What else would you base a starting point on? Maybe I'm missing something in the question, but it seems logical to me that an individual tree model should start with a list of individual trees.

What site / environmental conditions do you have available for your forests that we could incorporate in any future models?

- GIS datasets such as Elevation (10m contours); Slope (generated from 10m contours converted to TIN); Aspect (generated from 10m contours converted to TIN); Latitude/Longitude; Land Resource Information (LRI) Data (e.g. 1: 63 000 scale Land-use capability, Rock Types, Soil Units, Erosion Form & degree, Soil characteristics); Land Environments NZ (LENZ) Data
- As a general principle, model inputs should be generally available rather than to a specific forest owner. It is likely that non forest owners who specialise in environmental variables will have access to such data. e.g. NIWA or Landcare.
- The main datasets consistent for the whole estate are LENZ & NZLRI, and altitude.
- Altitude, average and seasonal variations in rainfall, average and seasonal variations in temperature, relative humidity data, forest nutrition data (built up from many years of foliage sampling and analysis), soil types, aspect, exposure level, wind speeds (averages and ranges), sunshine hours.
- Soil type, aspect, slope, altitude, distance from sea, predominant wind and speed, ave. rainfall, ave. sunshine hours? and ave. temperature at the block/forest level.
- Reasonably accurate estimates of altitude. More generlaised weather records (eg rainfall and temperature) and soil type
- Nothing (beyond site index). If any site or environmental factors were to be included in any future model, we would hope that these would be freely available, e.g. Metservice weather station records, altitude etc.

Is further research needed to improve starting points for models?

- Yes, but not necessarily by the SGMC. Growth modelers should be aware of potential advances in forest measurement but don't need to become distracted by them. There is enough inventory data collected using existing methods to justify improving growth models and this pool of measurement data won't disappear or even stop growing if measurement methods change.
- Yes – well worth exploring.
- No
- Probably
- My interpretation of "starting point" must be different than yours. To me, a starting point is an inventory, or list of tree measurements. Not sure how you would improve on this....it already represents current reality, at least as far as statistically possible from the sampling.