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Theme: Radiata Management

Task No:F10307 **Report No. FFR-R071**
Milestone Number:3.07.1

Comparison of Radiata pine Modelling Systems

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Research Provider:
SCION

Date:July 2012

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
INTRODUCTION 3
Study Objectives 4
Differences between the Systems 4
METHODOLOGY 7
Growth Modelling Systems 7
Forecaster versus Radiata Calculator 7
Site and Crop Data 7
Regimes 8
Function Sets 9
Log Product Definitions and Cutting Strategy 10
Data Analysis 10
Economic Analysis 11
Forecaster versus Forest Carbon Predictor 12
Site and Crop data 12
Regimes 13
Function Set 14
Data Analysis 15
RESULTS 16
Forecaster versus Radiata Calculator 16
Stand Estimates 16
Log Yield 21
Economic Analysis 23
Forecaster versus Forest Carbon Predictor 24
Stand Estimates 24
Carbon Sequestration 26
CONCLUSION 29
ACKNOWLEDGEMENTS 32
REFERENCES 33
APPENDICES 34
Appendix 1: Simulation Process in Forecaster 34
Appendix 2: Simulation Process in Calculator 35
Appendix 3: BIX Modelling in Forecaster 36
Appendix 4: BIX Modelling in the Calculator 37
Appendix 5: MTH Offset Created in Forecaster 38
Appendix 6: Log Product Definitions 39
Appendix 7: Cutting Strategy 40
Appendix 8: NPV Obtained from Discounted Cash Flow Analysis 41

EXECUTIVE SUMMARY

Growth and yield modelling systems are an essential component of forest management in New Zealand. FFR Forecaster and FFR Radiata Calculator are the most extensively used modelling systems in the New Zealand forest industry, and the Forest Carbon Predictor (FCP) is another modelling system that is of significance to forest owners.

The same models – 300 Index growth model (v1.05), C_Change carbon model (v3.0) and Beets Kimberley sheath density model (v2.0) - have been implemented in the latest versions of these three modelling systems, and because of this, new users expect these systems to give the same predictions. However, we know that there are differences in predictions of volume, log yield and carbon due to differences in the implementation of the underlying models. These differences in predictions, in particular log yield estimates, carry financial consequences; hence the need to understand, quantify and document these differences.

In this study we ran the three systems with the same set of inputs and compared the outputs to determine the key differences and the factors causing these differences between the three systems. Our results showed that while stand-level estimates for mean top height (MTH), basal area (BA) and stocking were very similar among Forecaster, the Calculator and FCP, there were differences in total standing volume estimates. These differences are attributed to the way volume is calculated among the systems – stem level modelling in Forecaster versus stand level modelling in the Calculator and FCP. The comparison of log yield estimates revealed that Forecaster gave higher estimates for framing (S grade) logs, and the reverse was observed with the Calculator, with the system predicting higher estimates for utility (L grade) logs. Different log yield estimates were expected due to different log bucking methodologies in the two systems. However, this study has also revealed that while the two systems have the same underlying Knowles Kimberley 1997 BIX model, the methodology through which BIX is modelled is different in each system. This further contributed to the differences in log yield estimates. The BIX model is implemented in Forecaster in the same manner as it was originally documented and implemented in STANDPAK. Further work needs to be done to determine if the STANDPAK approach could be implemented in the Calculator to align the two systems. It is anticipated that this modification to the BIX modelling process will be included in Calculator v4.0, which has an expected release date of July 2012.

For carbon sequestration, Forecaster and FCP total carbon predictions were within 5%, FCP predictions being higher. Calculator total carbon predictions on the other hand were within ±1% of FCP predictions. Since stand-level estimates for MTH, BA and stocking were very similar between the systems and Beets Kimberley sheath density model is implemented in the latest versions of the systems, we can conclude that the difference in carbon estimates is caused by the underlying volume functions (stem level modelling in Forecaster versus stand level modelling in FCP) and use of Soil C% and Soil N% (rather than adjusted soil C/N ratio), leading to slight sheath density differences between the FCP and the Calculator. To align the three systems, we recommend that the Calculator be modified to use adjusted soil C/N ratio.

Users of these modelling systems need to keep in mind these differences when selecting a particular system for growth and yield estimates. We recommend the following:

- use either Forecaster or the Calculator for stand level estimates;
- use either Forecaster or the FCP for carbon sequestration; and
- use Forecaster for log yield estimates, as predictions based on stem level measurements are more accurate.

This study, the first part of the set of four tech transfer papers under FFR Objective 3.07 Modify Virtual Forest System, has played a key part in highlighting the importance of maintaining the consistency of models, and documenting internal processes in these three systems. We recommend that Scion and FFR start discussions on implementing the systems in a single framework. This will reduce overheads/administrative costs, and ensure users have access to a single set of underlying models. We also suggest FFR facilitate an industry-led study on log yield reconciliation (predicted versus actual log yield) as requested by various FFR members at previous TST and FFR Members meetings.

INTRODUCTION

Growth and yield modelling systems are an essential component of forest management in New Zealand. FFR Forecaster and FFR Radiata Calculator are two of the most extensively used modelling systems in the forest industry.

Forecaster, developed by Scion, is a decision support system used to predict the growth and yield of stands, schedule silvicultural operations, and generate yield tables. It allows users to simulate impacts of site, silviculture, and genetics on tree growth and form, branching and wood properties[1]. Forecaster was recognised as a primary means of delivering science to the industry's end-users in a readily useable format, and this resulted in the transfer of Forecaster's ownership from Scion to FFR in 2010.Significant science outputs delivered to the industry through Forecaster include the individual stem level implementation of the 300 Index growth model[2] and C_Change carbon model[3], amongst other branching and wood properties models[1].

Radiata Calculator is a Microsoft Excel based growth and yield modelling system, with a stand-level implementation of the300 Index growth model, C_Change carbon model and other supporting functions embedded in the system. The Calculator, as it is commonly known, was developed as a joint undertaking between the NZ Farm Forestry Association (NZFFA) and the Plantation Management Cooperative (PMC), and is now owned and managed by FFR. The Calculator is more popular amongst less experienced users such as consultants and those in smaller forest companies[1].

Another modelling system of significance to forest owners is the Forest Carbon Predictor (FCP).The FCP, also a MS Excel implementation, was developed by Scion for the New Zealand Ministry for the Environment(MfE)for predicting carbon sequestration in plantations. The FCP is being used by MfE for the Land Use and Carbon Analysis System (LUCAS) project set up to measure and monitor carbon stocks at a national level for New Zealand's reporting requirements under the Kyoto Protocol[4]. As with the Calculator, the FCP has a stand-level implementation of the 300 Index growth model, C_Change carbon model and the Beets Kimberley sheath density model[5] embedded in the system. However, FCP does not predict log yield, unlike Forecaster and the Calculator. FCP is also currently being used by Scion as a reference spreadsheet model to develop a customised module for Ministry for Primary Industries (MPI) to calculate carbon yield tables from measured plot data. This module, called Forecaster-Carbon, is intended to be integrated with MPI's Climate Change Information System (CCIS) application as part of the rollout of the Field Measurement Approach (FMA) for the Emissions Trading Scheme (ETS) (S. Lewis, personal communication, April 17, 2012).

Because the same models have been implemented in the three modelling systems, users expect these systems to give the same predictions. However, results between the systems differ due to differences in model implementation and supporting assumptions. These differences in predictions, in particular log yield estimates, carry financial consequences; hence the need to understand, quantify and document these differences.

In this study we ran the three systems with the same set of inputs, and compared the outputs to determine the key differences and the factors causing these differences among the three systems. The intention of this study is to help users understand the implications of using each system and enable them to have more confidence in the results.

This study is the first part of the set of four tech transfer papers, under FFR Objective 3.07 Modify Virtual Forest System, planned for the 2011/12 and 2012/13 years:

1. Comparison of radiata pine growth modelling systems (this document)
2. Analysing silvicultural regimes using the 300 Index growth model in Forecaster
3. Modelling the influence of silviculture on wood quality and log-grade outturn
4. Modelling long rotations for carbon sequestration.

The aim of these tech transfer papers is to provide guidance on using modelling systems and to demonstrate the impacts of using various features within the systems on the final modelled outcomes.

Study Objectives

The objectives of this study are to:

- compare estimates mean top height (MTH), basal area (BA), stocking and total standing volume (TSV);
- compare projected log yield by grade;
- compare projected carbon sequestration;
- understand and describe the factors causing any differences among the predictions; and
- understand and describe the implications of using each system.

Differences among the Systems

Direct comparisons between Forecaster, the Calculator and FCP are not possible due to several key differences between the implementations. These differences arose from aligning each system to meet the needs of its users; for example Forecaster was intended as a means of modelling individual stems through a silvicultural regime, which enables the prediction of detailed properties such as branch habit, stem form and wood properties. This requirement limited Forecaster to using models designed at an individual stem level rather than at stand level. The Calculator and FCP, on the other hand, were originally designed for use by farm foresters and researchers respectively, in an easy to use interface. These two systems do not provide the ability to model stem level properties which Forecaster was designed for (G. West, personal communication, May 9, 2012).

The key differences among the systems and their implications on the methodology adopted and the resulting outputs are discussed below. Users wishing to compare the outputs from these systems need to understand these differences to ensure that valid comparisons can be made.

Calculation of stand volumes: Forecaster calculates stand volume by summing the volumes of each stem as predicted by the stem volume and taper function, whereas the Calculator and FCP use a stand level volume function. As a result, total stand volumes reported by the systems will differ.

Log bucking algorithms: Forecaster models the size and shape of individual stems, and cuts each stem into logs according to the log specifications. The Calculator generates diameter distribution classes and branch index (BIX) classes within each diameter class. A cutting simulation is then iterated for modelled trees in each diameter and BIX class[6]. This will result in different log yield estimates between the two systems. Appendices 1 and 2 show the high level simulation processes, including the harvesting process, in both systems.

Also, The Calculator does not include sweep in log making, unlike Forecaster. This difference can easily be addressed by removing sweep specifications from Forecaster log product definitions.

Implementation of the BIX model: Forecaster currently has two BIX models available for radiata pine – the Inglis Cleland 1981[7]and Knowles Kimberley 1997[6] BIX models. These models use different algorithms for converting BIX into maximum branch size. The Calculator contains only the Knowles Kimberley 1997 BIX model.

Appendices 3 and 4 show how BIX is modelled in the two systems (M. Kimberley and J.Gordon, personal communication, February 16, 2012). The figures illustrate that the implementation of BIX modelling is different in each system, and as a result the predicted BIX, the calculated maximum [redacted]

MTH derivation: Forecaster derives MTH from the modelled stem list using first principles, that is, by fitting a height/diameter regression, calculating the mean top diameter (MTD – mean diameter of the 100 largest diameter stems per hectare), and using these to find the height corresponding to MTD. This is consistent with the New Zealand definition of MTH. The Calculator uses a stand level function to derive MTH from mean height and stocking. This means that MTH following a thinning and the individual stem heights predicted by Forecaster may differ from the Calculator. To compare runs meaningfully between the two systems, silvicultural events need to be scheduled on age rather than MTH to remove this known difference and ensure the events take place at the same time.

MTH offset: If the site index specified for a crop predicts a different MTH from what is entered at the measurement age, Forecaster calculates the difference between the predicted and entered MTH values and adds this difference as an offset to all MTH predictions. As a result, the MTH at the measurement age is the same as the entered value, but the MTH at age 20 will be different from the entered site index (see Appendix 5 for an example of this). In the Calculator, the predicted MTH at age 20 will be the same as the specified site index. When comparing simulations between the two systems, the user needs to ensure that the Forecaster simulation uses the entered site index. This can be done by adjusting the crop's height to be "on-the-curve" so an offset is not created. The Calculator would not require this change as its simulations are seeded from the entered SI.

Monthly growth adjustment: Forecaster accounts for seasonal growth trends by applying the proportion of annual growth that has occurred by the end of each month. In the Calculator, the annual growth is merely attributed pro-rata within the year. When comparing simulations between the systems, only predictions at integer ages will be compared to remove the effect of growth adjustments.

Stem selection at time of thinning or pruning: Forecaster offers the ability to modify the stem selection criteria to allow a subset of stems to be selected for silvicultural events. The stem list is ordered according to the required stem ordering as well as the level of randomness which is applied to this ordering. The event is performed when sufficient stems meet the specified criteria. The intent of this control is to allow the user to simulate operational realities of stem selection such as spacing and malform[8].

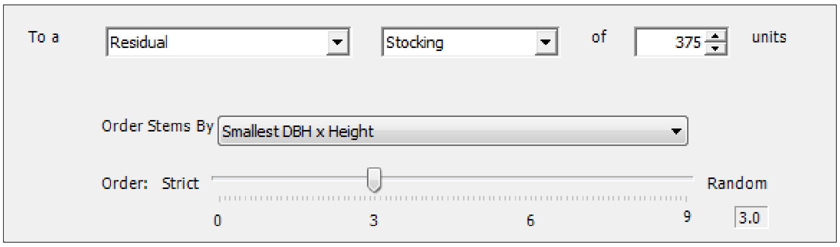

Figure 1: Stem selection criteria for a waste thin event in Forecaster

The Calculator uses a thinning criterion based on the concept of thinning coefficient. The thinning coefficient, defined as the proportion of basal area relative to stocking that remains following a thinning, indicates the size of trees thinned, that is, 1=row thinning, <1=thinning from below, and >1=thinning from above[9]. A default value of 0.78 is used in the Calculator if one isn't specified by the user. This value was obtained from the analysis of historical PSP data (M. Kimberley, personal communication, February 1, 2011). When comparing simulations between the systems, the consistency of this input needs to be maintained.

METHODOLOGY

Growth Modelling Systems

The versions of growth modelling systems used include:

- FFR Forecaster pre-release version 1.11.0.957;
- FFR Radiata Calculator pre-release version 4.0; and
- Forest Carbon Predictor version 4.07.

We chose the versions mentioned above to ensure that the systems contained the same version of the 300 Index growth model (v1.05), C_Change carbon model (v3.0) and Beets Kimberley P.RAD sheath density model (v2.0). This was necessary to rule out differences due to model inconsistencies.

Forecaster versus Radiata Calculator

Two broad silvicultural regimes (clearwood and framing) were modelled on two contrasting sites, Bay of Plenty (BOP) and Southland. These regimes consisted of a base simulation with variations corresponding to differences in factors such as final crop stocking, timing and intensity of thinning, and rotation age. CSV files for these runs have also been posted on the members' section of the FFR website.

Site and Crop Data

For each of the two sites (BOP and Southland), 300 Index and site index values for standard forest sites were obtained from the national look-up tables (Table 1).These lookups were derived in 2006 using data from 4,608 permanent sample plots (PSP) that were established from 1975 onwards (M. Kimberley, personal communication, February 1, 2011). These tables contain information on average site and productivity indices (site index and 300 Index), altitude and latitudes for each of sixteen growth modelling regions.

Table 1: Characteristics of standard forest sites in BOP and Southland

Name	**Latitude** (dec deg S)	**Longitude** (dec deg E)	**Altitude** (m)	**300Index** (m^3/ha/yr)	**Site index** (m)	**GF rating**
BOP Forest	38.2	176.6	260	27.2	32.5	GF7
Southland Forest	46.3	169.1	650	26.5	25.6	GF7

Forecaster allows a crop to be created from three different information levels – a stemlist, whole stand summary and stand subset. Use of whole stand summary was chosen to allow for comparison with the Calculator. The Calculator was used to generate an age 5 crop for each site using the information available in Table 1. Stocking, MTH and BA values obtained from the age 5 crop were then fed into a whole stand generator spreadsheet[10] to determine starting DBH and height distributions for a 3-year BOP crop and a 4.5-year Southland crop (Table 2).These particular ages were chosen to accommodate the earliest silvicultural operation, that is, the first prunings for each crop.

Table 2: Crop at whole stand information level

	BOP	Southland
Month/Year planted	Jul/2004	Jul/2004
Initial stocking (sph)	800	800
Month/Year measured	Jul/2007	Jan/2009
Whole stand stocking (sph)	759.43	758.99
Quadratic mean DBH (mm)	38	71
Basal area/ha (m^2/ha)	0.86	3.02
Stem basal area CV (%)	58.86	47.88
Mean top height (m)	3.54	4.05
Stem DBH max (mm)	75.27	109.73
Stem height CV (%)	17.23	17.09

To avoid an offset being added to MTH predictions in Forecaster, the MTH of the measured crop was adjusted to ensure that the predicted MTH at age 20 matched the site indices specified for each site.

Regimes

Base clearwood and framing regimes were run for each site. Timings of prunings and thinnings were based on recommended best practice, such as scheduling prunings on diameter over stubs (DOS) and thinnings on MTH (Table 3).Forecaster was used to determine the timings of the silvicultural events by simulating these regimes scheduled on DOS and MTH. The annual crop condition outputs were used to determine the dates at which the silvicultural events took place. The silvicultural events were then scheduled on these date-based triggers and re-simulated in Forecaster.

For the Calculator runs, stand information and regime inputs were specified as batch runs on the Multiple Runs worksheet. The silvicultural events were scheduled on the actual ages at which the events took place as predicted by Forecaster.

Age-based triggers were used instead of DOS- or MTH-based triggers to avoid the influence of monthly growth adjustments and MTH prediction differences between Forecaster and the Calculator.

The stem selection randomness criteria of the waste thinning events in Forecaster were determined by trial and error method to achieve a thinning coefficient as close as possible to the recommended coefficient for waste thinning 0.78. This was done to ensure that the simulated waste thinnings reflected realistic waste thinning conditions.

Variations to the final crop stocking, timing and intensity of thinning and rotation ages were also modelled.

Table 3: Description of base regimes and the variations to them

Clearwood base regime	Variations
Plant 800 sph	
Prune 375 sph to 2.4 m at DOS 16 cm (minimum green crown remaining 3.5 m, minimum lift length of 1.5 m)	
Thin to waste to 375 sph	
Prune 250 sph to 4.3 m at DOS 17 cm (minimum green crown remaining 3.5 m, minimum lift length of 1 m)	Prune 300 to 350 at 50 sph increments
Prune 250 sph to 6 m at DOS 17 cm (minimum green crown remaining 3.5 m, minimum lift length of 1 m)	Prune 300 to 350 at 50 sph increments
Thin to waste to 250 sph	Thin to waste to 300 to 350 at 50 sph increments
Clearfell at age 30 years	Clearfell at ages 25 to 35 years at 5 year increments

Framing base regime	Variations
Plant 800 sph	
Thin to waste to 400 sph at MTH 8	Thin to waste to 350 to 500 at 50 sph increment Thinning timing at MTH 10 to 14 at 2 m increments
Clearfell at age 30 years	Clearfell at ages 25 to 35 years at 5 year increments

Function Sets

When modelling the growth of these stands and their response to silvicultural treatments, the function sets given in Table 4 were used.

Table 4: Function sets used in Forecaster simulations

Model type	Models for growth modelling regions		Model properties
	BOP Forest	**Southland Forest**	
Growth model	300 Index	300 Index	Mortality addition, Mortality multiplier, Regional drift
Monthly adjustment	2 (Kaingaroa 1985)	7 (Otago Coast Tennent 1986)	-
Height/age table	112	112	-
DOS function	DOS1999	DOS1999	-
Sweep model	Generic	Generic	-
Forking model	Generic	Generic	-
Volume table	471 (All NZ)	471 (All NZ)	-
Taper table	237 (KANG Trans crop)	237 (KANG trans crop)	-
Breakage table	17 (KANG 1997)	1 (KANG 1976)	-
BIX model	Knowles Kimberley 1997	Knowles Kimberley 1997	

Additional inputs required by the 300 Index growth model include:

- Mortality addition to account for extra mortality not included in the model, for example windthrow – kept at the default value of 0.
- Mortality multiplier to adjust the predicted mortality to account for regions with above or below average mortality – kept at the default value of 0.
- Regional drift setting to allow a 300 Index drift correction function to be applied to adjust growth and account for subtle regional differences in growth trajectories. This was kept at the recommended settings: 0 for BOP and 0.35 for Southland[11].

Log Product Definitions and Cutting Strategy

Log product definitions with cutting strategies were based on MPI's generic domestic log grade specifications[12] and prices[13]. Sweep specifications were removed from the log product definitions to restrict Forecaster from including sweep in log making. These tables are given in Appendices 6 and 7.

Data Analysis

Simulation results in the form of annual crop condition and log yield tables and stand history results were exported to Excel for further analysis. Projected stand-level estimates (MTH, BA, stocking) and TSV throughout the rotation and log yields at clearfell were compared between the two systems. Factors causing differences between the predictions were determined.

Economic Analysis

Discounted cashflow analyses were carried out to quantify the impact of any differences between the two systems in monetary terms. A discount rate of 8% was adopted. The operational costs that were used are provided in Table 5.

Table 5: Operational costs used in the discounted cash flow analysis

Operation	Amount	Units	Year of operation
General costs			
Site preparation	80	$/ha	-1
Dothistroma spray	60	$/ha	4, 8
Annual costs			
Administration	5	$/ha	-1 to CF
Land rental	150	$/ha	-1 to CF
Property maintenance	10	$/ha	-1 to CF
Insurance	20	$/ha	-1 to CF
Rates	15	$/ha	-1 to CF
Management	30	$/ha	-1 to CF
Event costs			
Planting	0.15	$/stem	0
Planting stock	0.45	$/stem	0
Clearwood Prune 1	1.80	$/stem	
Clearwood Thin 1	0.90	$/stem	
Clearwood Prune 2	1.40	$/stem	
Clearwood Prune 3	1.40	$/stem	
Clearwood Thin 2	1.00	$/stem	
Framing Thin MTH 8	0.90	$/stem	
Framing Thin MTH 10	1.00	$/stem	
Framing Thin MTH 12	1.10	$/stem	
Framing Thin MTH 14	1.20	$/stem	
Harvesting costs			
Roading	2000	$/ha	1 year before CF
Harvesting ground-based	25	$/m^3	CF

Forecaster runs were analysed using the economic analysis module, and a discounted cashflow analysis spreadsheet was developed in-house using MS-Excel to analyse the Calculator runs. This was done to ensure that runs from both systems were analysed using the same fundamental assumptions, some of which are immediate and undiscounted first cashflows, end year discounting for the remaining cashflows and application of costs at truncated (integer) forms of the actual ages.

A key difference in the discounted cash flow analysis is the exclusion of log bucking waste when calculating harvesting costs for the Calculator runs. Because waste volumes reported by the Calculator do not differentiate between felling waste and log bucking waste, the waste component was not included in the calculation of harvesting costs for the Calculator runs. We have assumed that this exclusion will have a minimal effect on the Net Present Value (NPV).

Forecaster versus Forest Carbon Predictor

Three broad silvicultural regimes (clearwood, framing and carbon) were modelled on two contrasting sites (BOP and Southland). These regimes consisted of a base simulation with variations corresponding to differences in initial stocking and rotation age. CSV files for these runs have also been posted on the members' section of the FFR website.

Site and Crop Data

Table 6 shows the site characteristics for BOP and Southland.

Table 6: Characteristics of standard forest sites in BOP and Southland

Name	Latitude (dec deg S)	Longitude (dec deg E)	Altitude (m)	300Index (m^3/ha/yr)
BOP Forest	38.2	176.6	260	27.2
Southland Forest	46.3	169.1	650	26.5

FCP runs were simulated from age 0 without providing any measurement data. Stocking, MTH and BA values for an age 4 crop were obtained from the FCP runs and used as starting crops in Forecaster (Tables 7 and 8).

Table 7: BOP starting crops for Forecaster simulations

Site_Initial stocking	BOP_800	BOP_1000	BOP_1200	BOP_1400
Month/Year planted	Jul/2004	Jul/2004	Jul/2004	Jul/2004
Month/Year measured	Jul/2008	Jul/2008	Jul/2008	Jul/2008
Whole stand stocking (sph)	799.08	998.85	1198.62	1398.4
Quadratic mean DBH (mm)	68	67	67	66
Basal area/ha (m^2/ha)	2.89	3.54	4.17	4.75
Stem basal area CV (%)	39.08	39.08	39.08	39.08
Mean top height (m)	5.49	5.49	5.49	5.49
Stem DBH max (mm)	102	100.5	100.5	99
Stem height CV (%)	15.49	15.49	15.49	15.49

Table 8: Southland starting crops for Forecaster simulations

Site_Initial stocking	STH_800	STH_1000	STH_1200	STH_1400
Month/Year planted	Jul/2004	Jul/2004	Jul/2004	Jul/2004
Month/Year measured	Jul/2008	Jul/2008	Jul/2008	Jul/2008
Whole stand stocking (sph)	799.39	999.27	1199.11	1399
Quadratic mean DBH (mm)	26	25	25	24
Basal area/ha (m^2/ha)	0.41	0.49	0.57	0.64
Stem basal area CV (%)	39.08	39.08	39.08	39.08
Mean top height (m)	3.16	3.16	3.16	3.16
Stem DBH max (mm)	39	37.5	37.5	36
Stem height CV (%)	15.49	15.49	15.49	15.49

Regimes

Base clearwood, framing and carbon regimes were run for each site. Variations to initial stocking and rotation ages were also modelled (Table 9).

Table 9: Description of base regimes and the variations to them

Clearwood base regime	**Variations**
Plant 800 sph	
Prune 375 sph to 2.4 m at DOS 16 cm (minimum green crown remaining 3.5 m, minimum lift length of 1.5 m)	
Thin to waste to 375 sph	
Prune 250 sph to 4.3 m at DOS 17 cm (minimum green crown remaining 3.5 m, minimum lift length of 1 m)	
Prune 250 sph to 6 m at DOS 17 cm (minimum green crown remaining 3.5 m, minimum lift length of 1 m)	
Thin to waste to 250 sph	
Clearfell at age 30 years	Clearfell at ages 25 to 35 years at 5-year increments

Framing base regime	**Variations**
Plant 800 sph	
Thin to waste to 400 sph at MTH 8	
Clearfell at age 30 years	Clearfell at ages 25 to 35 years at 5-year increments

Carbon base regime	**Variations**
Plant 800 sph	Initial stocking of 1000 to 1400 sph at intervals of 200
Clearfell at age 50 years	

Function Set

When modelling the carbon yield of these crops, the function sets given in Table 10 were used.

Table 10: Function sets used in Forecaster simulations

Model type	Models for growth modelling regions		Model properties
	BOP Forest	**Southland Forest**	
Growth model	300 Index	300 Index	Mortality addition Mortality multiplier Regional drift
Monthly adjustment	2 (Kaingaroa 1985)	7 (Otago Coast Tennent 1986)	-
Height/age table	112	112	-
DOS function	DOS1999	DOS1999	-
Sweep model	Generic	Generic	-
Forking model	Generic	Generic	-
Carbon model	C_Change	C_Change	Clearfell Percent Needle Retention Score Production Thin Percent Mean Annual Air Temperature
Volume table	471 (All NZ)	471 (All NZ)	-
Taper table	237 (KANG Trans crop)	237 (KANG trans crop)	-
Breakage table	17 (KANG 1997)	1 (KANG 1976)	-
BIX model	Knowles Kimberley 1997	Knowles Kimberley 1997	

Model properties for the 300 Index growth model include:

- Mortality addition – kept at default value of 0.
- Mortality multiplier – kept at default value of 0.
- Regional drift setting – kept at the recommended settings 0 for BOP and 0.35 for Southland[11].

Model properties for C_Change carbon model include:

- Clearfell percent is the amount of clearfelled stem volume removed from the site – kept at default of 85%.
- Needle retention score refers to the mean number of years that needles are retained – kept at default of 2.1 years.
- Production thin percent is the amount of thinned stem volume removed from the site. This value was not required, as production thinning was not simulated.
- Mean annual air temperature was kept at 12.1 for BOP and 9.1 for Southland (obtained from LENZ 2010 mean annual air temperature surface). A note to Forecaster users: the released version of Forecaster v1.11.0 utilises MAT values derived from the underlying NIWA 2012 spatial surface for carbon modelling. NIWA 2012 spatial surface had not been implemented when this study was carried out, and hence the workaround was to use values derived from the LENZ 2010 spatial surface instead.

In Forecaster and FCP, C_Change is hardwired to a sheath density model which requires an adjusted soil carbon/nitrogen ratio (C%/(N%-0.014)) to calibrate the model to a particular site. Values derived from Forecaster's spatial surface for adjusted soil C/N ratio, 18.8 and 20.7, were used as inputs for BOP and Southland respectively.

The same runs were also simulated in the Calculator. Calculator v4.0 uses Soil C% and Soil N% (rather than adjusted soil C/N ratio) as inputs to calibrate the sheath density model to a site. The following values were used (an adjustment of 0.014 is applied internally):
BOP: Soil C%=4.0 and Soil N%=0.2268
Southland: Soil C%=4.0 and N%=0.2072
The Calculator reports only total carbon estimates, so we limited the comparison to this output.

Data Analysis

Simulation results in the form of stand history and carbon by pool outputs were saved for further analysis in MS Excel.

Projected estimates (MTH, BA, stocking and TSV) were compared among the three systems. Factors causing differences between the predicted values were discussed. Stand carbon content in various pools – total, above ground live, below ground live, dead woody litter and fine litter – predicted by Forecaster and FCP were compared across two rotations. Factors causing differences between the predictions were determined.

RESULTS

The following section is divided into two parts:

1) Forecaster versus Radiata Calculator:
    i. Stand estimates
    ii. Log yield
    iii. Economic analysis

2) Forecaster versus Forest Carbon Predictor
    i. Stand estimates
    ii. Carbon sequestration

Forecaster versus Radiata Calculator

Stand Estimates

Figures 2 to 4 show the projected stand-level estimates from Forecaster and the Calculator for the clearwood base regime in BOP. Calculator runs were carried out with survival percentage input of 100%, that is, 100% of the planted stocking survived up to ages 2 to 3 years. Forecaster on the other hand models mortality from age zero. This explains the difference in stocking levels at ages 0 to 5 years in Figure 2. This input, however, had minimal effect on stand estimates and log yield at later ages. Forecaster also reports stand estimates for pre and post waste thinning, as reflected by the sharp drop in stand estimates at ages 5 and 7 years. The Calculator, on the other hand, reports only stand estimates at consecutive integer ages, and hence stand estimates straight after a thin are not exposed to the user.

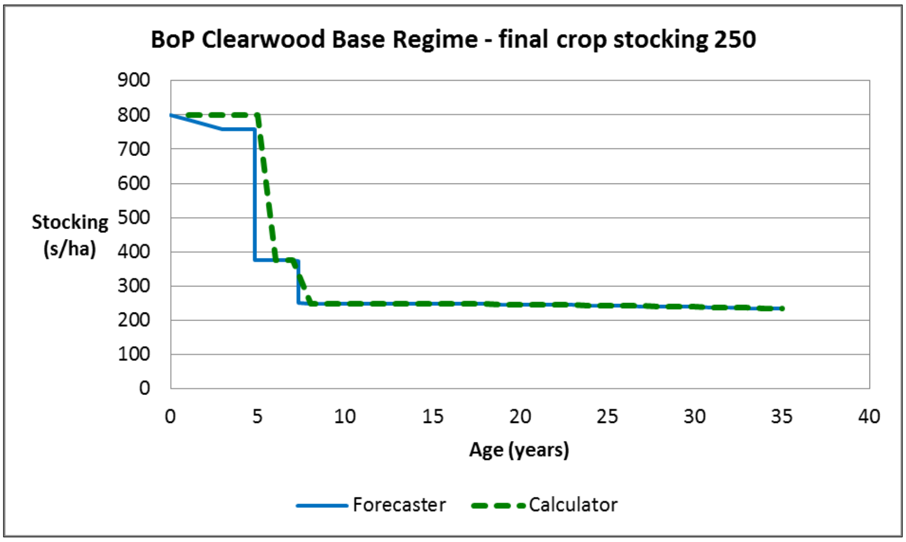

Figure 2: Stocking estimates by Forecaster and the Calculator for BOP clearwood base regime.

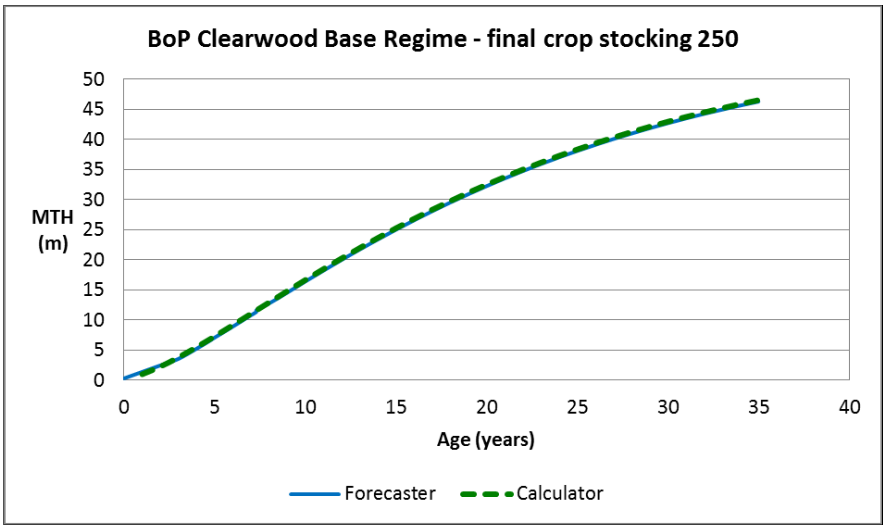

Figure 3: MTH estimates by Forecaster and the Calculator for BOP clearwood base regime.

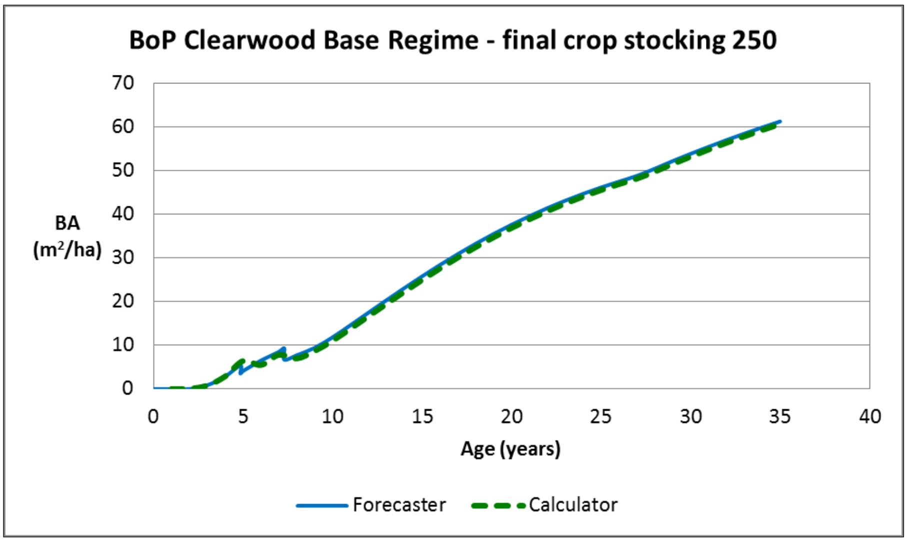

Figure 4: BA estimates by Forecaster and the Calculator for BOP clearwood base regime.

Table 11 shows that estimates for MTH, BA and stocking at age 30 were similar, with percentage differences of 0 to 3% between Forecaster and the Calculator estimates. This trend was consistent across the two sites and the range of clearwood and framing regimes, and confirms that Forecaster is predicting similar levels of stand growth to the Calculator at later ages.

Table 11: Stand estimates at age 30 for selected regimes

Site	Regime	Variable	Forecaster	Calculator	% diff
BOP	Clearwood base	MTH	42.7	43.0	+1%
		BA	53.8	53.2	-1%
		Stocking	237	239	0%
BOP	Framing base	MTH	42.7	43.0	+1%
		BA	65.2	64.7	-1%
		Stocking	360	360	0%
Southland	Clearwood base	MTH	38.7	38.7	0%
		BA	58.7	56.9	-3%
		Stocking	244	244	0%
Southland	Framing base	MTH	38.7	38.7	0%
		BA	75.4	744	-1%
		Stocking	379	379	0%

Table 12 shows differences in key stand-level variables between Forecaster and the Calculator throughout the rotation (0 to 35 years). Because of the different approaches to early mortality and reporting of pre- and post-thin estimates illustrated in Figure 2, differences prior to the first thinning event were ignored. A discrepancy has been noticed in the Calculator – runs using the 300 Index growth model carry out thinning at the specified ages, but runs using C_Change (estimates for which are reported on the Stand History worksheet of the Calculator) require thinning and pruning ages to be rounded to the nearest whole (integer) ages. For example Forecaster carried out a thinning at 4.8 years, and reported pre and post thin estimates at this age. The Stand History worksheet, however, reported that thinning was carried out at age 5 and post thin estimates were reported the following year at age 6. We recommend that the Stand History worksheet be corrected to show estimates from the 300 Index growth model runs rather than estimates from the C_Change carbon model runs.

Table 12: Minimum, mean and maximum differences in stand-level variables between Forecaster and the Calculator throughout the rotation (0 to 35 years)

Site	Regime	Variable	Mean	Min	Max
BOP	Clearwood variations	MTH	1%	1%	3%
		BA	-4%	-19 *(1 m²/ha)	-1%
		Stocking	0%	0%	0%
BOP	Framing variations	MTH	1%	1%	2%
		BA	-1%	-7%	0%
		Stocking	0%	0%	0%
Southland	Clearwood variations	MTH	0%	-1%	0%
		BA	-11%	-64% *(1.8 m²/ha)	-2%
		Stocking	0%	0%	7%
Southland	Framing variations	MTH	0%	-1%	0%
		BA	-3%	-14% *(1.3 m²/ha)	-1%
		Stocking	0%	0%	0%

* Absolute differences between Forecaster and the Calculator estimates

There were minor differences in TSV estimates, but these differences were too small to be obvious in the chart (Figure 5). Looking at TSV estimates for the BOP clearwood base regime at rotation 30 years, Forecaster predicts 744 m^3/ha and the Calculator predicts 752 m^3/ha – a difference of 1%. Looking across the range of clearwood regimes and rotation ages, the Calculator predicts 1 to 3% more volume at age 30 in BOP than Forecaster, and Forecaster predicts 0 to 1% more volume at age 30 in Southland than the Calculator.

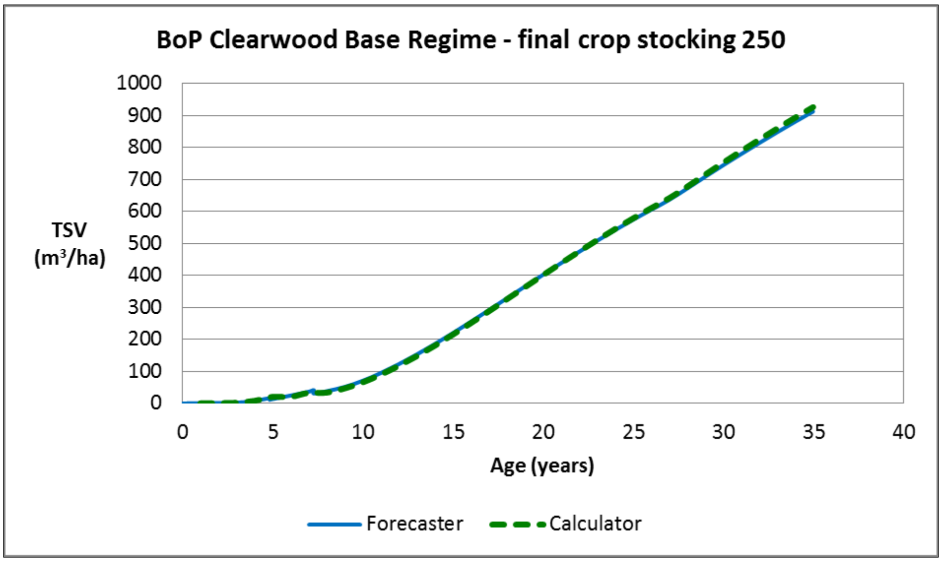

Figure 5: TSV estimates by Forecaster and the Calculator for BOP clearwood base regime.

The same trend is illustrated in Figure 6, which shows TSV estimates for a BOP framing base regime. Forecaster predicts 881m^3/ha, and the Calculator predicts 916m^3/ha at age 30 – a difference of 4%. Looking across the range of framing regimes and rotation ages, the Calculator predicts 3 to 4% and 1 to 2% more volume at age 30 for BOP and Southland respectively than Forecaster.

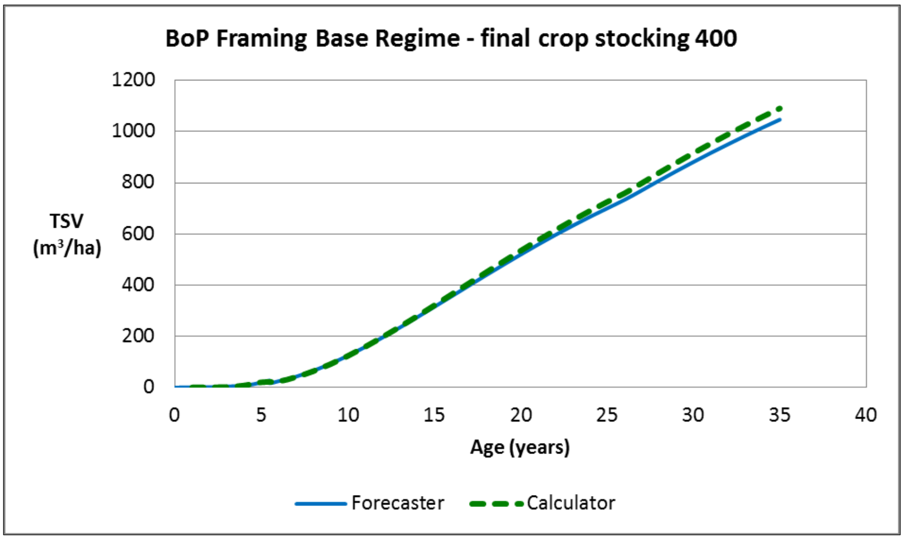

Figure 6: TSV estimates by Forecaster and the Calculator for BOP framing base regime.

These differences in TSV estimates can be attributed to the way stand volume is calculated between the two systems. Forecaster calculates stand volume by summing the volumes of each stem as predicted by the stem level volume and taper functions, whereas the Calculator uses a stand level volume function.

Forecaster also provides the ability to specify a different volume function to suit a specific site. We chose tree volume 471[14] to be used in these runs, as this particular function is a stem level implementation of the national stand volume function that is implemented in the Calculator. Forecaster. Users need to be aware that the choice of volume function can also contribute to volume differences among the systems.

Log Yield

When comparing log yields between the two systems, we removed the waste component from the comparison. This was due to the makeup of waste reported by the systems – Forecaster reports waste generated at the log bucking stage, whereas the Calculator reports waste generated at both felling and log bucking stages.

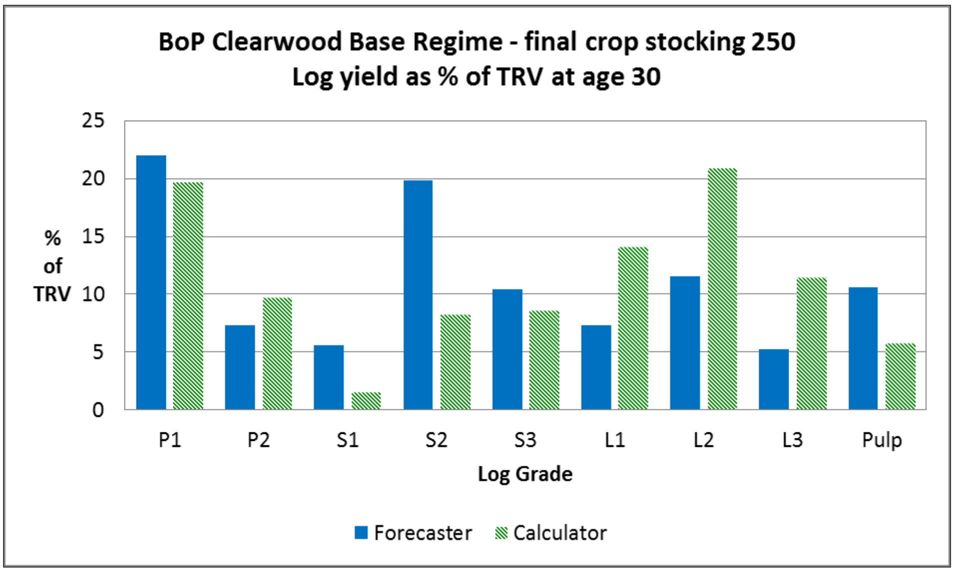

Figure 7: Log yield by grade expressed as a percentage of TRV at age 30 as predicted by Forecaster and the Calculator

Figure 7 shows that Forecaster predicts a higher yield for P1 (15% higher) and a lower yield for P2 (21% lower) than the Calculator. This difference could be attributed to differences in pruned height. Because Forecaster is modelling individual stems, there can be a distribution of pruned heights based on tree heights and pruning constraints (such as green crown requirements, minimum lift length, etc.), whereas the Calculator merely assumes a uniform pruned height across the modelled stand.

The differences observed in the prediction of aggregated S and L grades, on the other hand, were of higher concern. For the BOP clearwood base regime, Forecaster predicts twice as much structural grade volume than the Calculator. This trend is consistent across the two sites and clearwood regime variations, with Forecaster predicting between 26% and 115% more S grade volume than Calculator at age 30 for the BOP site, and between 122% and 415% more for Southland (it should be noted that the structural volume predicted by the Calculator in Southland was very low – only 5% of TRV in the most extreme case).

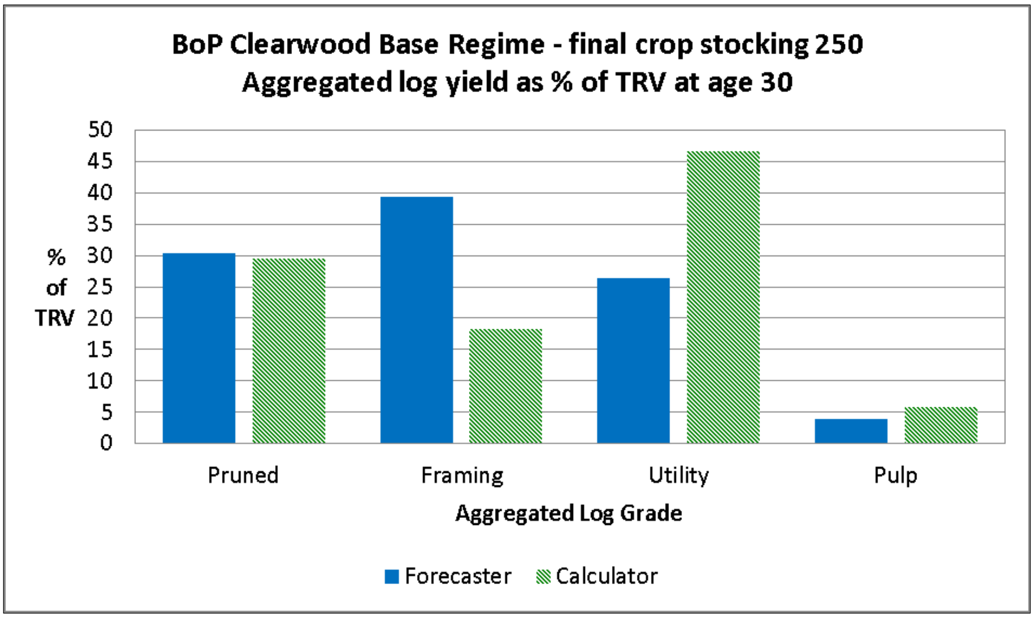

Figure 8: Aggregated log yield by grade expressed as a percentage of TRV at age 30 as predicted by Forecaster and the Calculator

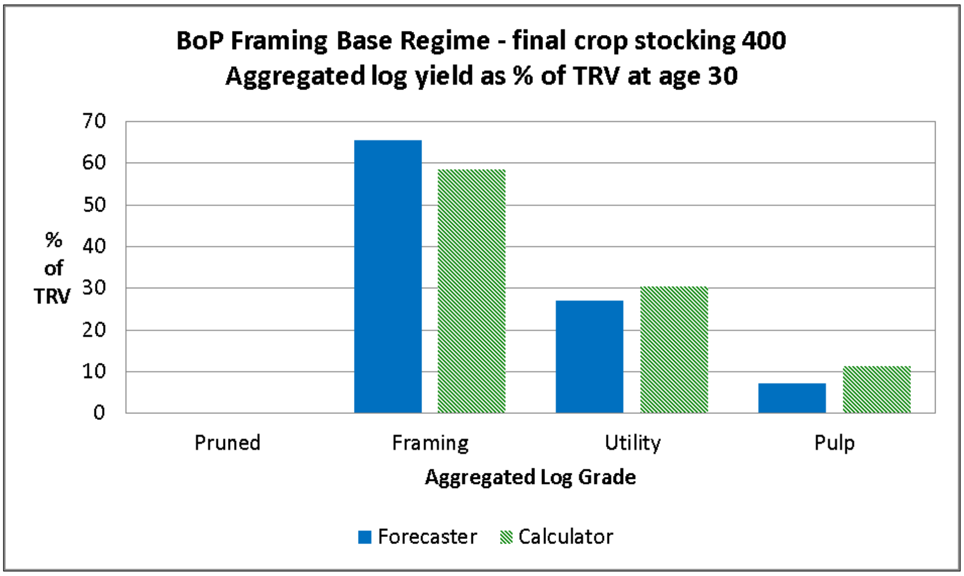

Figure 9: Aggregated log yield by grade expressed as a percentage of TRV at age 30 as predicted by Forecaster and the Calculator

For the BOP framing base regime (Figure 9), Forecaster predicted 12% more framing (aggregated S grade) volume than Calculator. Looking across the two sites and the range of framing regime variations, Forecaster predicted between 9% and 168% more S grade volume at age 30 than the Calculator.

Users should note that differences in log yields are expected due to differences in log bucking methodology between the two systems. An inspection at code level also revealed differences in the way the BIX model is implemented in the two systems (Appendices 3 and 4), which also affected log yield estimates. Despite these known differences between the systems, we decided to further investigate the allocation of logs to S or L grade in Forecaster.

BIX is defined as the mean diameter of the largest branches in each of the four quadrants per 5.5 m of stem length[15]. This value is used to determine the maximum branch size which subsequently determines the grade that the log is allocated to[6]. We took the BOP framing base regime as our test regime to investigate the BIX values predicted by both systems.

Forecaster reports BIX at log level, so we determined the volume weighted mean BIX from Forecaster's Log Trace output. For the BOP framing base regime, the volume weighted mean BIX calculated by Forecaster was 4.4 cm, compared to the Calculator's mean BIX of 4.6 cm. We then looked at Forecaster mean, minimum and maximum BIX values by log grade (Table 13).

Table 13: Forecaster mean BIX at log grade levelfor BOP framing base regime

Log grade	**Volume weighted mean BIX**(cm)	**Mean BIX** (cm)	**Minimum BIX**(cm)	**Maximum BIX**(cm)
All grades (including waste)	4.4	4.0	0.1	11.1
S grade	3.8	3.8	1.3	5.0
L grade	6.0	5.9	5.0	9.6

The following formula is used to calculate Maximum Branch Size for the Knowles Kimberley BIX model in Forecaster:
MaxBr = (BIX – 0.30469)/0.78125
(this formula mathematically converts to MaxBr=(BIX × 1.28)-0.39)

We applied this formula to the individual log BIX values provided in the LogTrace output, and found that the maximum branch size was less than 5.9 cm for S grade logs, and 11.9 cm for L grade logs. Keeping in mind that the maximum branch size constraint for S and L grades is 6 cm and 14 cm (Appendix 4), the conversion of BIX to maximum branch size and the consequent allocation of log grades in Forecaster appears to be correct.

Investigations carried out in the Calculator showed the use of the following BIX to MaxBr conversion:
MaxBr= (BIX × 1.28) – 0.29
The intercept is 1 mm smaller than what is implemented in Forecaster, but this difference would not have a major effect on the calculated branch size (M. Kimberley, personal communication, June 22, 2012).

This study has also revealed that the Knowles Kimberley BIX model is implemented in Forecaster in the same manner as it was originally documented and implemented in STANDPAK. Further work needs to be done to determine if the STANDPAK approach could be implemented in the Calculator to align the two systems (M. Kimberley, personal communication, June 22, 2012).

Economic Analysis

Appendix 8 lists the NPVs obtained for each regime from the discounted cash flow analysis. The main aim of this exercise was to quantify the impact of log estimates differences between the two systems in monetary terms.

The results showed that differences in log yield estimates had an impact on NPV estimates as expected. Forecaster, in at least 93% of the regimes run, predicted a higher NPV return than the Calculator. This was expected as Forecaster estimated a higher proportion of S grade logs for most runs.

The optimum regimes which returned the highest NPVsfor each site are summarised in Table 14.

Table 14: Optimum regimes for BOP and Southland based on NPV estimates

Site	Regime	Rotation age	NPV from Forecaster ($/ha)	NPV from Calculator ($/ha)	Difference in NPV ($/ha)
BOP	Clearwood – FCS 300	25	170	-364	534
BOP	Framing – FCS 500 MTH 8	25	1000	523	477
BOP	Framing – FCS 400 MTH 12	25	754	349	405
Southland	Clearwood – FCS 350	30	28	-504	532
Southland	Framing – FCS 500 MTH 8	30	778	277	501
Southland	Framing – FCS 400 MTH 14	30	427	107	320

Despite differences in log yield estimates, both Forecaster and the Calculator recommended the same regimes for the particular sites based on the NPVs obtained from the economic analyses.

Both systems recommended the following regimes for the BOP site:
- Clearwood regime with a final crop stocking of 300 s/ha at a 25-year rotation
- Framing runs with thinnings carried out at MTH 8 with a final crop stocking of 500 s/ha at a 25-year rotation

For Southland, the following regimes were recommended by both systems:
- Clearwood regime with a final crop stocking of 300 s/ha at a 30-year rotation
- Framing runs with thinnings carried out at MTH 8 with a final crop stocking of 500 s/ha at a 30-year rotation

Forecaster versus Forest Carbon Predictor

Stand Estimates

Tables 15 to 17 show that the stand level estimates – stocking, MTH and BA – were the same among Forecaster, the Calculator and FCP. This proved that the three systems were predicting the same level of stand growth.

Table 15: Stocking estimates for selected regimes

Site	**Regime**	**Age**(years)	**Forecaster** (s/ha)	**Calculator** (s/ha)	**FCP** (s/ha)
BOP	Plant & Leave 800	50	403	403	403
BOP	Clearwood FCS 250	30	239	239	239
BOP	Framing FCS 400 MTH 8	30	361	361	361
Southland	Plant & Leave 800	50	467	467	467
Southland	Clearwood FCS 250	30	244	244	244
Southland	Framing FCS 400 MTH 8	30	379	379	379

Table 16: MTH estimates for selected regimes

Site	**Regime**	**Age** (years)	**Forecaster** (m)	**Calculator** (m)	**FCP** (m)
BOP	Plant & Leave 800	50	53	53	53
BOP	Clearwood FCS 250	30	43	43	43
BOP	Framing FCS 400 MTH 8	30	43	43	43
Southland	Plant & Leave 800	50	57	58	58
Southland	Clearwood FCS 250	30	39	39	39
Southland	Framing FCS 400 MTH 8	30	39	39	39

Table 17: BA estimates for selected regimes

Site	**Regime**	**Age** (years)	**Forecaster** (m^2/ha)	**Calculator** (m^2/ha)	**FCP** (m^2/ha)
BOP	Plant & Leave 800	50	93	93	93
BOP	Clearwood FCS 250	30	53	53	53
BOP	Framing FCS 400 MTH 8	30	65	65	65
Southland	Plant & Leave 800	50	118	118	118
Southland	Clearwood FCS 250	30	58	58	58
Southland	Framing FCS 400 MTH 8	30	74	74	74

Table 18 illustrates that Calculator and FCP estimates for TSV were at the same level. Forecaster estimates, on the other hand, were lower, with percentage differences of 0 to 4%. This difference in TSV estimates is expected as Forecaster utilises a stem level volume function whereas the other two systems utilise a stand level volume function.

Table 18: TSV estimates for selected regimes

Site	**Regime**	**Age** (years)	**Forecaster** (m^3/ha)	**Calculator** (m^3/ha)	**FCP** (m^3/ha)	**% difference (Forecaster vs FCP)**
BOP	Plant & Leave 800	50	1552	1617	1617	4
BOP	Clearwood FCS 250	30	743	752	752	1
BOP	Framing FCS 400 MTH 8	30	893	916	916	2
Southland	Plant & Leave 800	50	2119	2212	2212	4
Southland	Clearwood FCS 250	30	735	737	737	0.2
Southland	Framing FCS 400 MTH 8	30	945	954	954	1

Carbon Sequestration

Kimberley *et al*.[16] summarised the process through which carbon estimates are obtained in FCP. The 300 Index growth model provides annual stand estimates such as BA, MTH, DBH, stocking and TSV, and the Beets Kimberley sheath density model predicts wood density for the incremental stem wood produced in each growth year. This information – the yield table and wood density predictions – is used by the C_Changecarbon model. C_Change models the annual development of several biomass pools (such as stem, foliage, branches, roots etc.), and converts these estimates into annual carbon pools (above ground live, below ground live, dead woody litter, fine litter).Forecaster uses the same models to get projections for carbon sequestration.

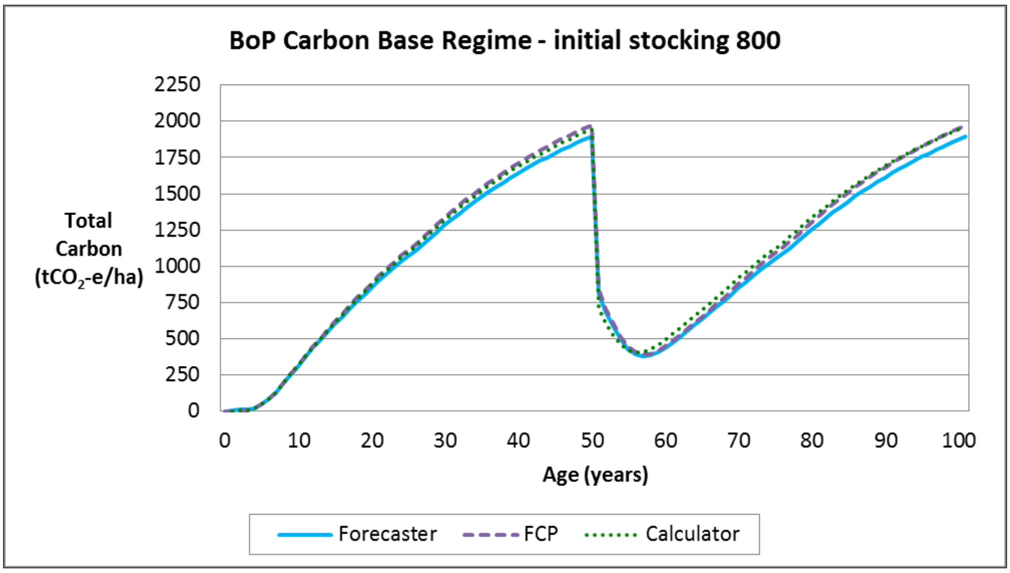

Figure 10: Total carbon estimates from the modelling systems for a BOP carbon base regime.

Figure 10 shows a comparison of total carbon estimates among Forecaster, the Calculator and the FCP for a carbon regime in BOP. Differences between Forecaster and FCP estimates were within 5%, FCP predictions being higher. The Calculator predictions, on the other hand, were within ±1% of FCP predictions. These trends were consistent across both BOP and Southland sites, and range of plant and leave regimes. Table 19 shows the differences in total carbon estimates for selected regimes.

Table 19: Total carbon estimates for selected carbon regimes

Site_Regime	**Age**	**Forecaster** (tCO_2-e/ha)	**FCP** (tCO_2-e/ha)	**Calculator** (tCO_2-e/ha)	**% difference (Forecaster vs FCP)**	**% ifference (Calculator vs FCP)**
BOP Plant & Leave 800	50	1895	1972	1943	4%	1%
BOP Clearwood FCS 250	30	869	879	867	1%	1%
BOP Framing FCS 400 MTH 8	30	1056	1083	1068	2%	1%
Southland Plant & Leave 800	50	2356	2459	2489	4%	-1%
Southland Clearwood FCS 250	30	792	793	802	0.1%	-1%
Southland Framing FCS 400 MTH 8	30	1027	1037	1049	1%	-1%

Volume and sheath density are the key driving factors of carbon sequestration. Sheath density is reported as an output in FCP and the Calculator, but not in Forecaster. For this reason, we were unable to compare this particular variable. We do know that Beets Kimberley sheath density model has been implemented in the three systems, and hence the differences in carbon estimates are caused by differences in underlying volume functions in Forecaster and use of soil C% and soil N% (rather than adjusted soil C/N ratio), which leads to sheath density differences in the Calculator.

Figures 11 to 14 below show carbon by pool estimates from Forecaster and FCP.

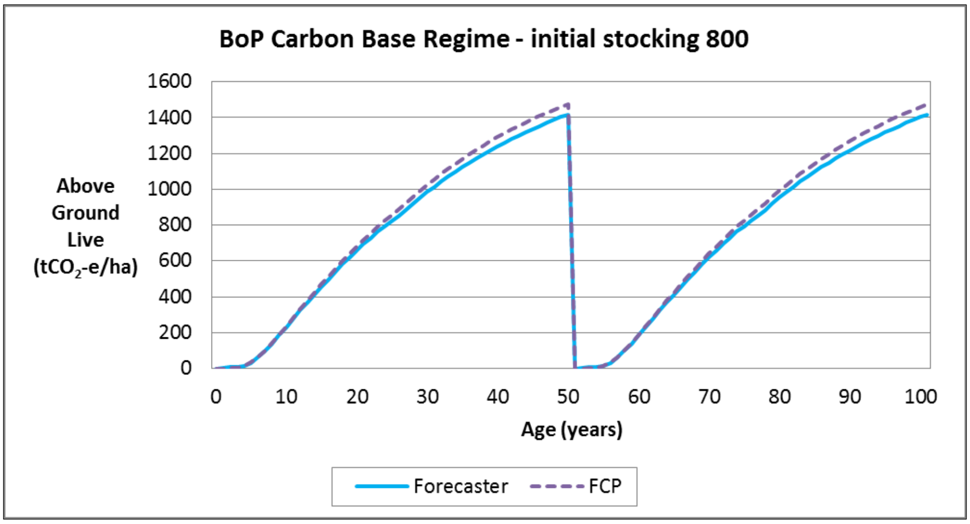

Figure 11: Carbon estimates in above ground live pool as predicted by Forecaster and FCP for BOP carbon base regime.

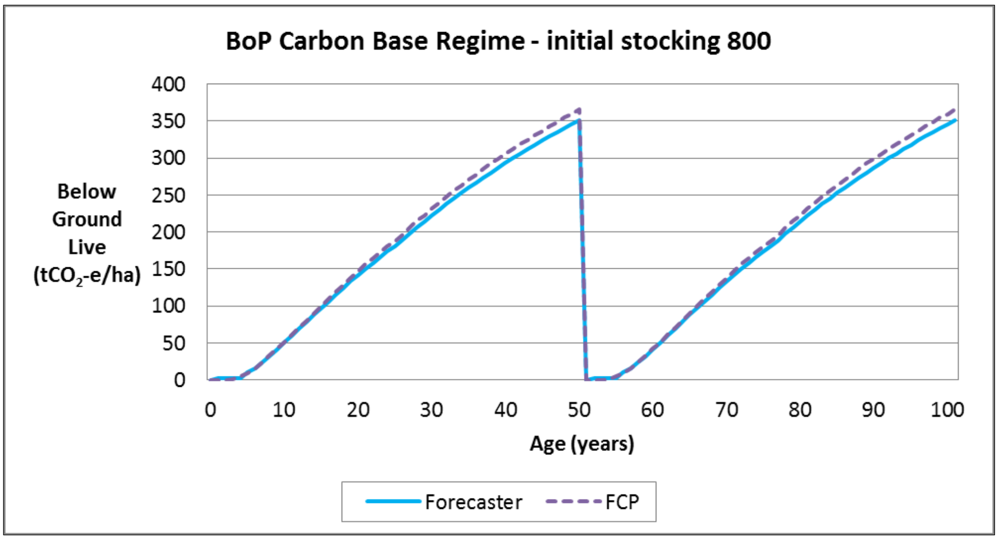

Figure 12: Carbon estimates in below ground live pool as predicted by Forecaster and FCP for BOP carbon base regime.

Figures 11 and 12 show carbon estimates in above and below ground live pools. There was an increase in carbon until age 50. At this age, carbon decreased to zero because of removal of stem material from the harvesting site and the switching of carbon to dead woody and fine litter pools. Carbon in both pools increased steadily in the second rotation (51 to 100 years) due to growth of the second rotation crop.

Figures 13 and 14 show that both Forecaster and FCP predicted similar levels of carbon in dead [redacted] from above and below ground live pools to dead woody and fine litter pools due to harvesting waste left behind at the site.

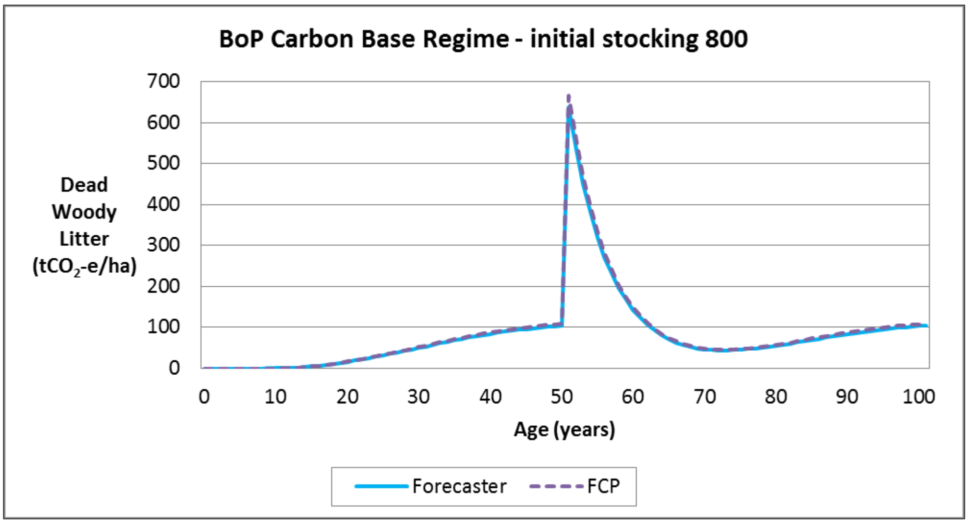

Figure 13: Carbon estimates in deadwoody litter pool as predicted by Forecaster and FCP for BOP carbon base regime.

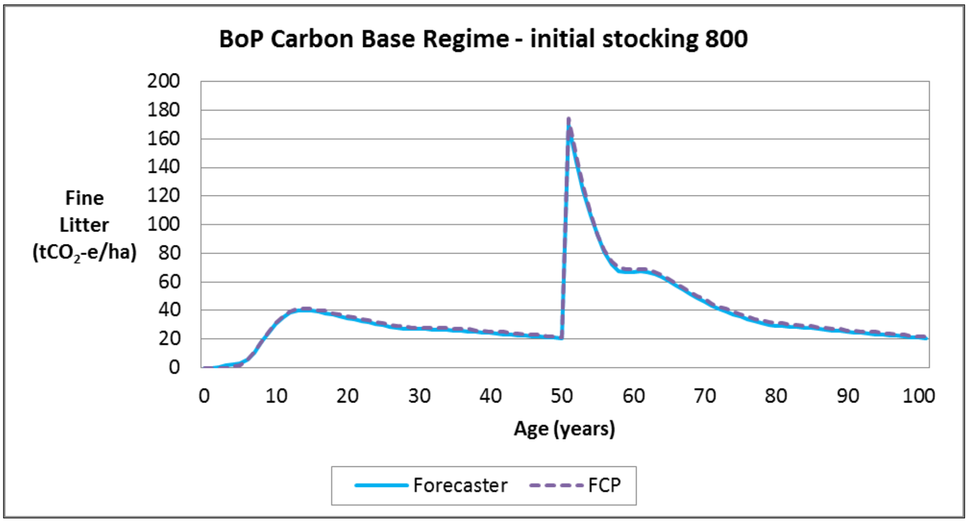

Figure 14: Carbon estimates in fine litter as predicted by Forecaster and FCP for BOP carbon base regime.

Both systems also predicted carbon sequestration in shrub understorey, but this component was excluded from this study because of its minor contribution to the total carbon pool.

CONCLUSION

This comparison study on commonly used growth modelling systems in the NZ forest industry has shown that estimates differ between the three systems due to differences in the implementation of underlying models.

While stand-level estimates for MTH, BA and stocking were very similar among Forecaster, the Calculator and FCP, there were differences in TSV estimates. This difference is attributed to the way volume is calculated between the systems – stem level modelling in Forecaster versus stand level modelling in the Calculator and FCP. This study revealed a discrepancy in the reporting of stand estimates on the Stand History worksheet in the Calculator. We recommend that this worksheet be corrected to show stand estimates from the 300 Index growth model runs rather than those from the C_Change carbon model runs.

The comparison of log yield estimates revealed that Forecaster gave higher estimates for framing (S grade) logs than the Calculator. The reverse was observed with the Calculator predicting higher estimates for utility (L grade) logs. Users need to keep in mind that the two systems have different log bucking and BIX modelling methodologies. Due to these differences, differences in log yield estimates are expected. Investigations confirmed that the conversion of maximum branch size and the consequent log grade allocation is implemented correctly in Forecaster. This study has also revealed that the Knowles Kimberley 1997 BIX model is implemented in Forecaster in the same manner as it was originally documented and implemented in STANDPAK. Further work needs to be done to determine if the STANDPAK approach could be implemented in the Calculator to align the two systems. Economic analysis reflected that the differences in log yield estimates had an impact on NPV estimates as expected. Forecaster, in at least 93% of the regime runs, predicted a higher NPV return than the Calculator. However, despite differences in log yield estimates, both Forecaster and the Calculator recommended the same regimes for the particular sites based on the NPVs obtained from the economic analysis.

For carbon sequestration, Forecaster and the FCP showed up to 5% differences in the estimates for total carbon, FCP predictions being higher. Calculator total carbon predictions were within ±1% of FCP predictions. Since stand-level estimates for MTH, BA and stocking were very similar among the systems and the Beets Kimberley sheath density model is implemented in the latest versions of the systems, we can conclude that the differences in carbon estimates are caused by the underlying volume functions (stem level implementation in Forecaster versus stand level implementation in FCP), and use of Soil C% and Soil N% (rather than adjusted soil C/N ratio) leading to sheath density differences between the Calculator and FCP. To align the three systems, we recommend that the Calculator be modified to utilise user-specified adjusted soil C/N ratio.

Table 20 below summarises the key differences among the systems that users need to keep in mind when deciding on selecting a particular system for growth and yield estimates. We recommend the following:

- use either Forecaster or the Calculator for stand level estimates;
- use either Forecaster or the FCP for carbon sequestration; and
- use Forecaster for log yield estimates, as predictions based on stem level measurements are more accurate.

Table 20: Key differences between the radiata pine modelling systems

Operation	Forecaster	Calculator	FCP	Comment
Growth model	300 Index v1.05 – stem level implementation	300 Index v1.05 – stand level implementation	300 Index v1.05 – stand level implementation	
Volume model	Table 471 – stem level implementation of the national volume function	National stand volume function	National stand volume function	
P.RAD sheath density model	Utilises adjusted soil C/N ratio derived from spatial surface	Utilises adjusted soil C/N ratio calculated from Soil C and Soil N values entered by user	Utilises adjusted soil C/N ratio entered by user	
BIX model	Knowles Kimberley 1997	Knowles Kimberley 1997	n/a	Same model but different BIX modelling methodologies
Log bucking	Modelled stem are cut into logs	Bucking simulation is applied to modelled trees in diameter and branch size distributions	n/a	Different log bucking methodologies

Forecaster runs for this study were done on v1.11.0.957. The version that will be released mid-July 2012 (v1.11.0.990) will contain several small changes to the 300 Index growth model. These changes include:

- The profile of volume through time will be smoothed (there was a slight kink in the previous version).
- Regional drift will be applied only to below age 30.
- Minor corrections will be made so the calculation of the 300 index and growth predictions will be closer to those from the spreadsheet implementation of the growth model.

These 300 index growth model changes will also be implemented in version 4.0 of the Radiata Pine Calculator. This version is expected to be released around July 2012 (M. Kimberley, personal communication, June 28, 2012). It is anticipated that v4.0 will also include modifications to the BIX modelling process to align it with STANDPAK's approach. We also recommend that the adjusted Soil C/N ratio be implemented in this version to ensure Calculator uses the same set of inputs for carbon modelling as Forecaster and FCP.

Both FFR and Scion should note that maintaining three separate systems is costly and time consuming. We recommend that both parties move towards implementing the three systems in a single framework. Apart from reducing overheads and administrative costs, this will ensure users have access to a single set of underlying models[17]. In the meantime, consistency of the models among the three systems should be maintained.

We stress the importance of documenting internal processes in the systems, in particular the log bucking methodologies in the systems. Users should also be able to identify details such as the underlying models and their version numbers easily. This information is available in Forecaster, whereas in the Calculator and FCP, these details are embedded in the VBA code and are not accessible by the user.

We also suggest that FFR facilitates an industry-led study on log yield reconciliation (predicted versus actual log yield) as requested by various FFR members at previous TST and FFR Members’ meetings.

ACKNOWLEDGEMENTS

We wish to thank the following people for providing help and guidance throughout the project: Andrew Gordon, Brian Clement, Graham West, Joel Gordon, John Moore, Mark Kimberley, Mark Self, Mike Baker, Paul Charteris, Peter Beets, Peter Hall, Philip Elworthy, Sarah Orton.

We also wish to acknowledge the FFR Radiata Management theme members that have supported this project by supplying data.

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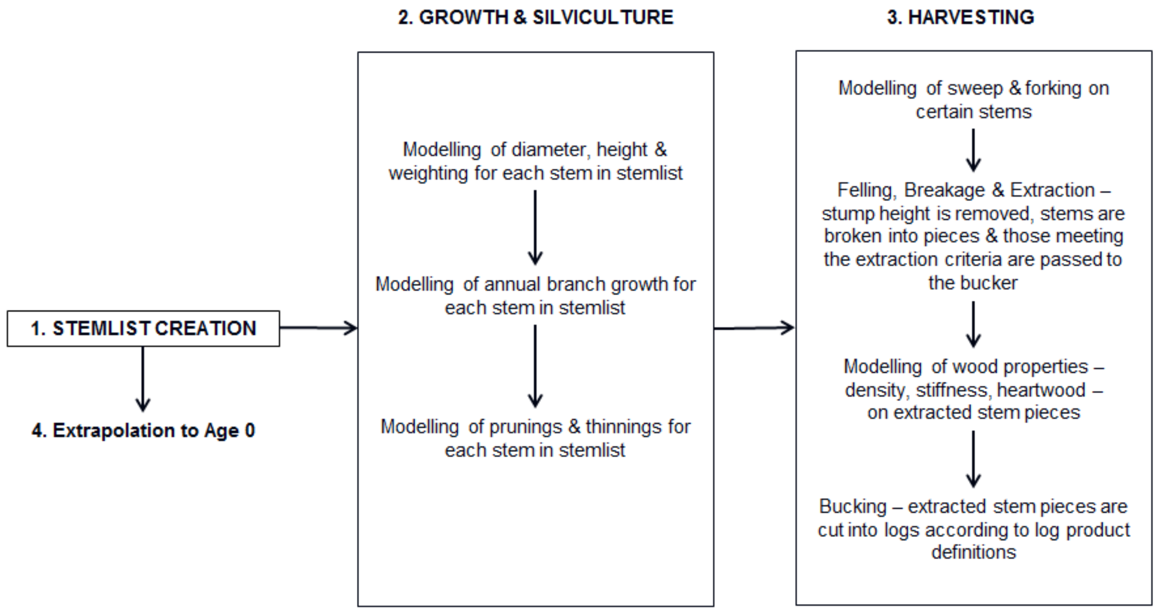
APPENDICES

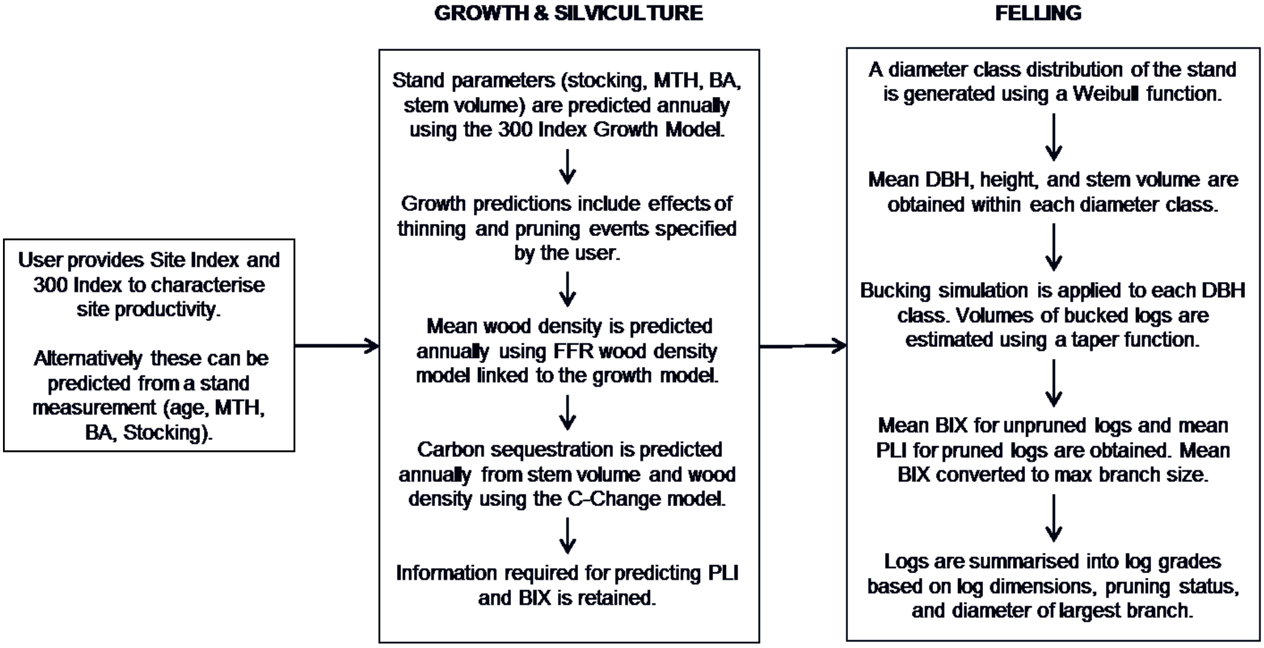
Appendix 1: Simulation Process in Forecaster

The flow chart below gives a high level view of the processes and the order in which they occur in a Forecaster simulation. The simulation begins with the creation of a list of stems. This list is then grown through silvicultural events until harvest. Harvesting involves a number of sub-processes. Some processes such as carbon modelling require stand level values from age 0 (i.e. planting) to measurement age. This is done in the final stage at the end of the simulation.

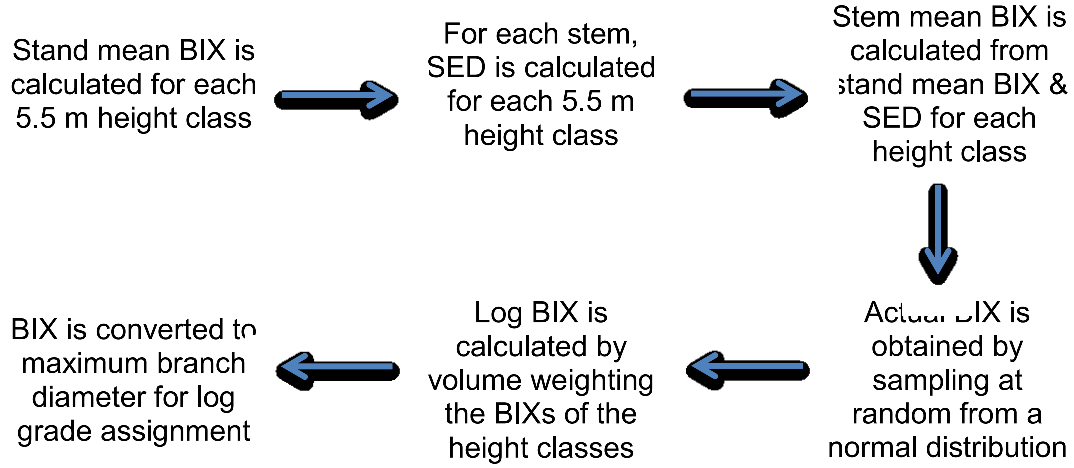


Appendix 2: Simulation Process in Calculator

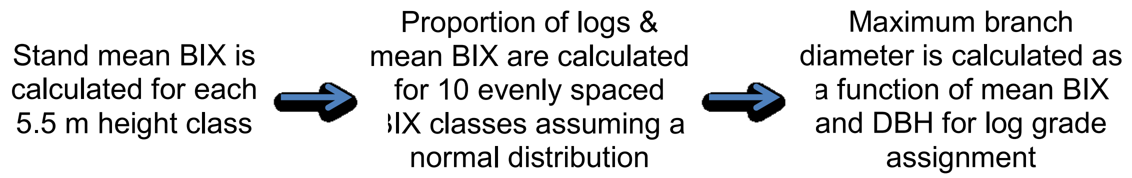
The flow chart below gives a high level view of the processes and the order in which they occur in a Calculator simulation. A key difference between Forecaster and the Calculator is the sub-processes involved in harvesting/felling. In Forecaster, distributions of stems or logs are not created at time of harvest as is the case with the Calculator. The distribution of various log level attributes is assumed to be embodied in the stem list provided to Forecaster.



Appendix 3: BIX Modelling in Forecaster



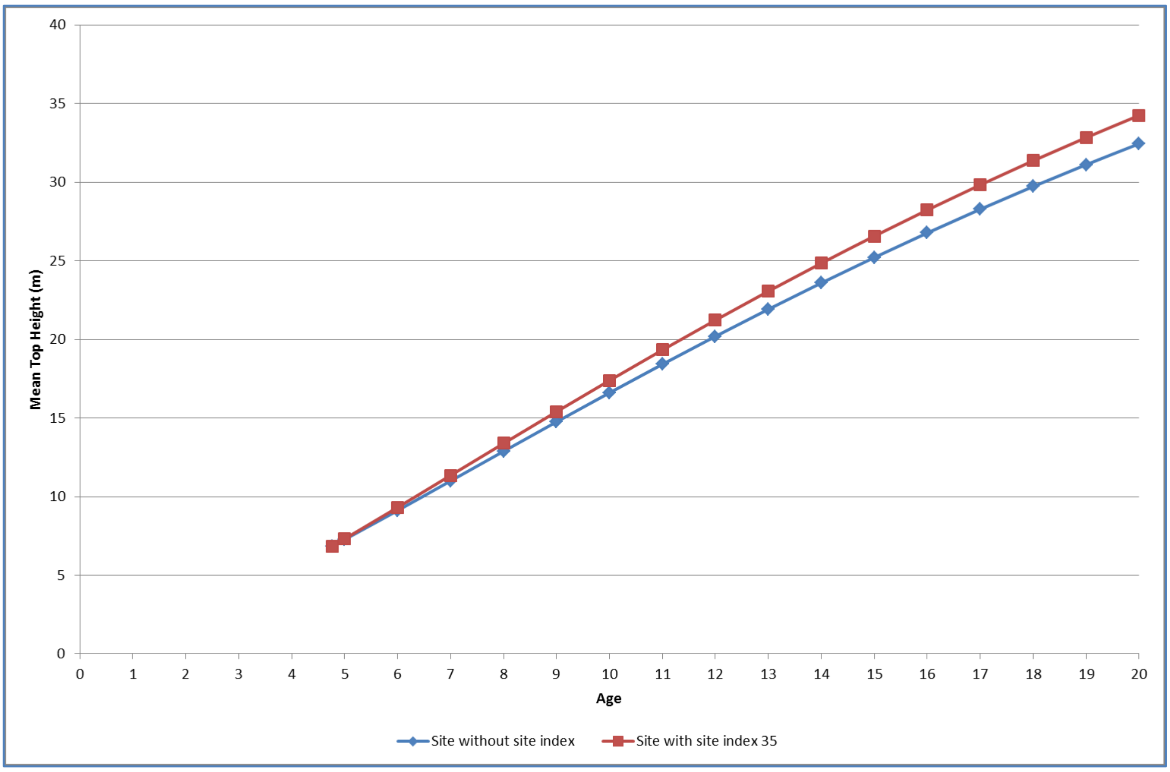
Appendix 4: BIX Modelling in the Calculator



Appendix 5: MTH Offset Created in Forecaster

If the site index specified for a crop predicts a different MTH to what is entered at the measurement age, Forecaster calculates the difference between the predicted and entered MTH values and adds this difference as an offset to all MTH predictions. As a result, the MTH at the measurement age will be the same as the entered value, but the MTH at age 20 (i.e. the modelled site index) will be different from the entered site index.

The graph below shows the MTH offset for such an example. The predicted MTH at the measurement age is the same as the entered value, but the MTH at age 20 is different from the site index entered because of the offset.



Appendix 6: Log Product Definitions

Name	Description	Log price ($/m^3)	Min length (m)	Max length (m)	Min SED (mm)	Max SED (mm)	Max LED (mm)	Max live branch absolute (mm)	Max dead branch absolute (mm)
P1	Domestic large pruned	132	3.7	6.2	400	999	999	0	0
P2	Domestic small pruned	107	3.7	6.2	300	399	999	0	0
S1	Large, small-branched sawlog	92	3.7	6.2	400	999	999	60	60
S2	Med, small-branched sawlog	86	3.7	6.2	300	399	999	60	60
S3	Small, small-branched sawlog	73	3.7	6.2	200	299	999	60	60
L1	Large, large-branched sawlog	77	3.7	8.1	400	999	999	140	140
L2	Medium, large branched sawlog	77	3.7	8.1	300	399	999	140	140
L3	Small, large branched sawlog	73	3.7	8.1	200	299	999	140	140
Pulp	Pulplog	50	3.7	8.1	100	999	999	0	0

Source: MPI (2011)

Appendix 7: Cutting Strategy

Name	Description	Log Price $/m^3$	Priority	Max/stem
P1	Domestic large pruned	132	1	9
P2	Domestic small pruned	107	2	9
S1	Large, small-branched sawlog	92	3	9
S2	Med, small-branched sawlog	86	4	9
S3	Small, small-branched sawlog	73	5	9
L1	Large, large-branched sawlog	77	6	9
L2	Medium, large branched sawlog	77	7	9
L3	Small, large branched sawlog	73	8	9
Pulp	Pulplog	50	9	99

Appendix 8: NPV Obtained from Discounted CashFlow Analysis

Regime	Rotation Age (years)	NPV from Forecaster ($/ha)	NPV from Calculator ($/ha)	Difference in NPV ($/ha)
BoP Clearwood Base Regime - FCS 250	25	-85	-556	472
BoP Clearwood Base Regime - FCS 250	30	-540	-1028	488
BoP Clearwood Base Regime - FCS 250	35	-1193	-1619	426
BoP Clearwood - FCS 300	25	45	-448	493
BoP Clearwood - FCS 300	30	-451	-948	496
BoP Clearwood - FCS 300	35	-1151	-1547	396
BoP Clearwood - FCS 350	25	170	-364	534
BoP Clearwood - FCS 350	30	-390	-882	492
BoP Clearwood - FCS 350	35	-1104	-1543	439
BoP Framing Base Regime - FCS 400 MTH 8	25	713	313	399
BoP Framing Base Regime - FCS 400 MTH 8	30	136	-185	321
BoP Framing Base Regime - FCS 400 MTH 8	35	-562	-852	290
BoP Framing - FCS 350 MTH 8	25	547	153	393
BoP Framing - FCS 350 MTH 8	30	14	-340	354
BoP Framing - FCS 350 MTH 8	35	-678	-959	281
BoP Framing - FCS 450 MTH 8	25	876	431	445
BoP Framing - FCS 450 MTH 8	30	303	-88	392
BoP Framing - FCS 450 MTH 8	35	-426	-765	339
BoP Framing - FCS 500 MTH 8	25	1000	523	477
BoP Framing - FCS 500 MTH 8	30	363	-25	388
BoP Framing - FCS 500 MTH 8	35	-373	-693	320
BoP Framing - FCS 400 MTH 10	25	720	332	388
BoP Framing - FCS 400 MTH 10	30	181	-187	368
BoP Framing - FCS 400 MTH 10	35	-520	-833	313
BoP Framing - FCS 400 MTH 12	25	754	349	405
BoP Framing - FCS 400 MTH 12	30	199	-156	355
BoP Framing - FCS 400 MTH 12	35	-505	-815	310
BoP Framing - FCS 400 MTH 14	25	738	349	389
BoP Framing - FCS 400 MTH 14	30	222	-151	374
BoP Framing - FCS 400 MTH 14	35	-487	-800	312
Southland Clearwood Base Regime - FCS 250	25	-725	-1073	348
Southland Clearwood Base Regime - FCS 250	30	-381	-859	478
Southland Clearwood Base Regime - FCS 250	35	-697	-1138	440
Southland Clearwood - FCS 300	25	-475	-857	381
Southland Clearwood - FCS 300	30	-151	-681	531
Southland Clearwood - FCS 300	35	-469	-952	483
Southland Clearwood - FCS 350	25	-322	-718	396
Southland Clearwood - FCS 350	30	28	-504	532
Southland Clearwood - FCS 350	35	-302	-853	550
Southland Framing Base Regime - FCS 400 MTH 8	25	237	-97	334

[redacted]

Regime	Rotation Age (years)	NPV from Forecaster ($/ha)	NPV from Calculator ($/ha)	Difference in NPV ($/ha)
MTH 8				
Southland Framing Base Regime - FCS 400 MTH 8	35	-513	-386	127
Southland Framing - FCS 350 MTH 8	25	8	-306	314
Southland Framing - FCS 350 MTH 8	30	218	-229	447
Southland Framing - FCS 350 MTH 8	35	-772	-557	215
Southland Framing - FCS 450 MTH 8	25	429	75	354
Southland Framing - FCS 450 MTH 8	30	608	153	455
Southland Framing - FCS 450 MTH 8	35	-325	-227	98
Southland Framing - FCS 500 MTH 8	25	618	217	401
Southland Framing - FCS 500 MTH 8	30	778	277	501
Southland Framing - FCS 500 MTH 8	35	-171	-123	48
Southland Framing - FCS 400 MTH 10	25	238	-64	302
Southland Framing - FCS 400 MTH 10	30	394	15	378
Southland Framing - FCS 400 MTH 10	35	34	-337	372
Southland Framing - FCS 400 MTH 12	25	261	-27	288
Southland Framing - FCS 400 MTH 12	30	426	66	360
Southland Framing - FCS 400 MTH 12	35	62	-290	352
Southland Framing - FCS 400 MTH 14	25	242	-5	247
Southland Framing - FCS 400 MTH 14	30	427	107	320
Southland Framing - FCS 400 MTH 14	35	97	-232	329