PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: info@ffr.co.nz
Web: www.ffr.co.nz

## Theme: Diversified Species

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# Comparison of Douglas-fir Modelling Systems

**Authors:**
**P Narayan, J Snook, J Gordon,
M Kimberley, S Kennedy**

**Research Provider:**
**Scion**



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# EXECUTIVE SUMMARY


In this comparison study we ran the same set of site and crop inputs through FFR Forecaster and the Douglas-fir (Dfir) Calculator, and compared the outputs (such as volume, carbon and log grade distribution) to determine the key differences and the factors causing these differences.

While stand-level estimates for mean top height (MTH), basal area (BA) and stocking were very similar between the two systems, there were significant differences in total standing volume (TSV) estimates. This difference is attributed to the methods used to calculate volume in the two systems – stem level modelling in Forecaster versus stand level modelling in Dfir Calculator. The comparison of log yield estimates revealed that Forecaster gave higher yield estimates for higher value logs than Dfir Calculator. Differences in log yield estimates were expected, due to different log bucking methodologies in the two systems. For carbon sequestration, the Dfir Calculator typically over-predicted total carbon (compared to Forecaster) by 14-23% following thinning. This difference in total carbon estimates is caused by:

- the underlying volume functions (stem level modelling in Forecaster versus stand level modelling in Dfir Calculator);
- different versions of the C_Change carbon model (Forecaster has the most recent implementation with new carbon adjustment functions for Dfir and Dfir Calculator has an older version of C_Change which uses radiata pine biomass allocation and decay functions); and
- different wood density models (sheath density model in Forecaster and stem density model in Dfir Calculator).

This study has highlighted the need to maintain the consistency of models implemented in the two systems. A preferred and more viable solution in the long term would be to implement the two systems in a single framework. This would not only reduce overheads and administrative costs, but also ensure access to a single set of underlying models.

# INTRODUCTION

FFR Forecaster and the Douglas-fir (Dfir) Calculator are commonly-used growth and yield modelling systems for Douglas-fir in the New Zealand forest industry.

Forecaster, developed by Scion and owned by FFR, 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]. In addition to its use as an operational tool, Forecaster is also a means of delivering new science to the forestry industry. Such outputs provided through Forecaster include the individual stem level implementations of the 300 Index[2] and 500 Index[3] growth models and C_Change carbon model[4], amongst other branching and wood properties models[1].

Dfir Calculator is a Microsoft Excel-based growth and yield modelling system, with a stand-level implementation of the 500 Index growth model and other supporting functions embedded in the system. It was developed as a joint undertaking between the NZ Farm Forestry Association (NZFFA) and the NZ Douglas-fir Research Cooperative, and is now owned and managed by FFR. Dfir Calculator is popular amongst  consultants and smaller forestry companies[1].

Because both the Douglas-fir National 500 Index growth model (DFNat500Index) and the C_Change carbon sequestration model have been implemented in these two modelling systems, users expect both systems to give the same predictions. However we expect differences in volume and log yield predictions due to differences in the methods used to model the various processes. Prediction differences (in particular log yield estimates) carry financial consequences and hence the need to understand, quantify and document them.

# STUDY OBJECTIVES

The objectives of this study are to compare results between FFR Forecaster and Dfir Calculator for:

- stand estimates of mean top height (MTH), basal area (BA), stocking and total standing volume (TSV);
- projected log yield by grade;
- projected total carbon sequestration;

and additionally, to understand and describe the factors causing any differences between the predictions from the two systems.

# METHODOLOGY

## Site and Crop Data

Model runs were carried out using stand information from a Southland forest (Table 1).

**Table 1: Southland site characteristics**

| **Latitude** (dec °S) | **Longitude** (dec °E) | **Altitude** (m) | **MAT** (°C) | **Soil C/N ratio** |
|---|---|---|---|---|
| 45.849 | 169.123 | 300 | 9.6 | 20.72 |

A stem list was created from appropriate Douglas-fir PSP measurement data, and used as starting crop data in Forecaster. To ensure consistency, a stand-level crop was generated from this for use in Dfir Calculator (Table 2). Use of stand-level averages in Forecaster was deliberately avoided to prevent Forecaster from using any radiata pine assumptions when creating stem lists from whole stand data. Values were derived for 500 Index and site index from the stem list, and specified in Dfir Calculator.

**Table 2: Crop at whole stand level used in Dfir Calculator**

| | |
|---|---|
| Date planted | April 1984 |
| Initial stocking (stems/ha) | 1667 |
| Date measured | April 1994 |
| Whole stand stocking (stems/ha) | 1406 |
| Basal area/ha ($m^2$/ha) | 8.76 |
| Mean top height (m) | 6.37 |

## Regimes

Framing waste thin regimes, with various thinning timings and rotation ages, were used (Table 3).

**Table 3: Description of framing waste thin regime and its variations**

| **Base regime** | **Variations** |
|---|---|
| Plant 1667 stems/ha | |
| Thin to waste to 550 stems/ha at MTH 15 m | Thinning at MTH 10 and 20 m |
| Clearfell at age 45 years | Clearfell at ages 40 and 50 years |

Initial simulations using Forecaster determined the ages corresponding to the target MTH for each regime. Integer ages were used to avoid the influence of monthly growth adjustments and also the MTH prediction differences between the two systems.

The stem selection randomness criteria of the waste thinning events in Forecaster were determined by trial and error to achieve a thinning coefficient as close as possible to the recommended thinning coefficient of 0.705 (default used in Dfir Calculator).

## Models

The models used in Forecaster analyses are described in Table 4.

The C_Change carbon model in Forecaster is hardwired to a Douglas-fir sheath density model which requires an adjusted soil carbon/nitrogen ratio to calibrate the model to a particular site. These values were derived from Forecaster's spatial surface for adjusted soil C/N ratio[5].

Dfir Calculator, on the other hand, uses the outerwood breast height density and the age at which this measurement is taken to calibrate the density model to a site. This value, 415 kg/m$^3$ at age 30, was obtained from Forest Carbon Predictor v4.10 using the mean annual temperature and soil C/N ratio values in Table 1.

**Table 4: Models used in Forecaster**

| Model type | Model name | Model properties |
|---|---|---|
| Growth model | 500 Index | Mortality adjustment=0<br>Survival percentage=100 |
| Height/age table | 189 | - |
| Monthly adjustment | 10 (DFEARLYNZ McInnes 1997) | (Note: seasonal growth effect was removed by modelling integer ages) |
| DOS function | Standard | - |
| Sweep model | Generic | - |
| Forking model | Generic | - |
| Carbon model | C_Change | Clearfell Percent=85<br>Needle Retention Score=2.1<br>Production Thin Percent=75% |
| Volume table | 136 (All NZ) | - |
| Taper table | 136 (All NZ) | - |
| Breakage table | 4 | - |
| Branch Index model | KnowlesMcInnes1997 | - |

## Log Product Definitions

The log specifications used in the analyses are described in Table 5.

**Table 5: Log product definitions used in the analyses**

| Name | Min length (m) | Max length (m) | Min SED (mm) | Max branch (mm) |
|---|---|---|---|---|
| D1 | 8 | 12 | 320 | 40 |
| DG | 4 | 12 | 320 | 70 |
| CF+ | 4 | 12 | 320 | 150 |
| DC | 8 | 12 | 220 | 40 |
| CF- | 4 | 6 | 220 | 150 |
| Pulp | 3 | 20 | 100 | 300 |

# RESULTS

## Stand Estimates

Forecaster and Dfir Calculator predict similar levels of stand growth for post thin ages as illustrated in Figures 1 to 3.

The differences in stocking levels from age 0 to 20 are explained as follows. Forecaster reports stocking estimates from age 0, starting with the initial stocking and passing through the specified measured crop stocking, while Dfir Calculator reports stocking estimates from a start age around 7-10 years old, and assumes normal mortality from the initial stocking defined by the user. The simulations do not pass through the specified measured crop stocking. The measured crop data in Dfir Calculator are used only to calibrate the stand for 500 index and site index values.

Forecaster also reports pre- and post-waste thinning stand estimates, as reflected by the sharp drop in stocking and BA estimates at age 20. The Calculator, on the other hand, reports only stand estimates at consecutive integer ages, and hence estimates straight after a thin are not exposed to the user.

Percentage differences between Forecaster and Dfir Calculator (ignoring the differences prior to thinning):

- Stocking: 0%
- MTH: 0%
- BA: 0 to 5% (absolute difference of 0 to 1 $m^2$/ha).

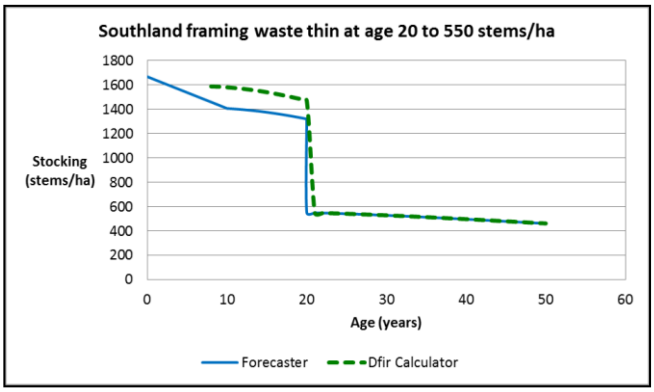


**Figure 1: Stocking estimates by Forecaster and Dfir Calculator**

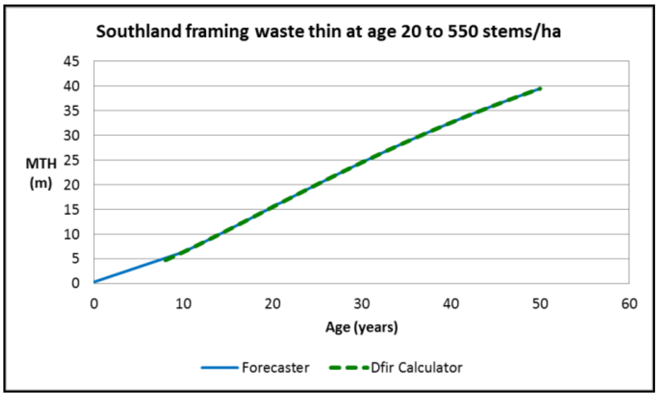


**Figure 2: Mean top height estimates by Forecaster and Dfir Calculator**

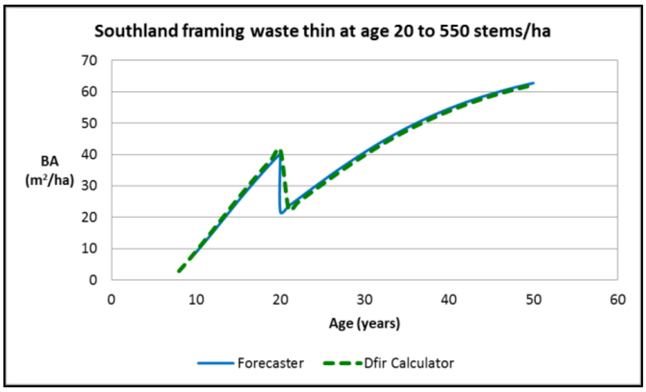


**Figure 3: Basal area estimates by Forecaster and Dfir Calculator**

Percentage differences between Forecaster and Dfir Calculator TSV estimates (post-thinning) ranged from 3 to 9% (absolute differences of between 2 and 62 $m^3$/ha). These differences can be attributed to the way stand volume is calculated between the two systems. Forecaster calculates stand volume by summing the volume of each stem as predicted by stem-level volume and taper functions, whereas Dfir Calculator uses a stand-level volume function.

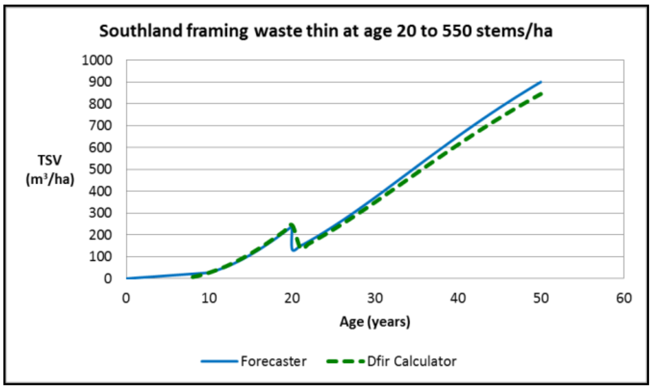


**Figure 4: Total standing volumes estimates by Forecaster and Dfir Calculator**

## Log Yield

Forecaster predicts a larger proportion of higher value logs (50% more of D1+DG grades and 85% more of CF- grade), and a lower proportion of DC (-12%) and Pulp (-44%) logs (Figure 5). Differences in log yield estimates are to be expected due to different log bucking methodologies in the two systems.

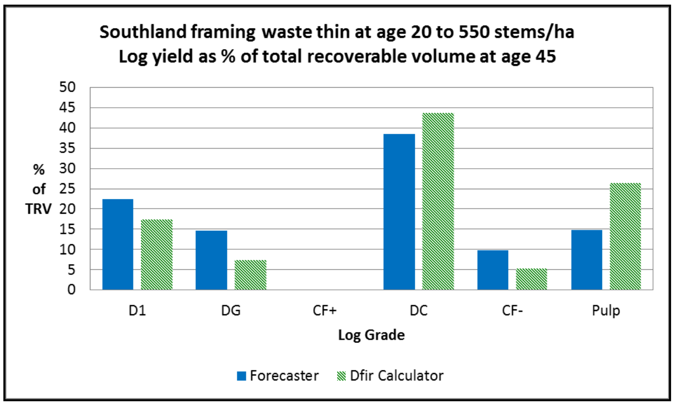


**Figure 5: Log yield by grade expressed as a percentage of TRV at age 45**

## Carbon Sequestration

The Dfir Calculator under-predicts total carbon compared to Forecaster, by between 14% and 100% throughout the rotation (high percentages occur during very early years where the total carbon predicted by the Dfir Calculator remains very low, as shown in Figure 6). Typically the Dfir Calculator under-predicted Forecaster by 14-23% following thinning.

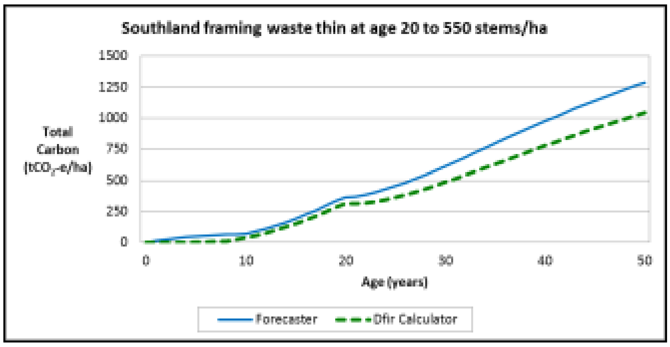


**Figure 6: Total carbon estimates by Forecaster and Dfir Calculator**

Forecaster and Dfir Calculator follow a similar process to get projections for carbon sequestration. The 500 Index growth model provides annual stand estimates such as BA, MTH, DBH, stocking and TSV, and the sheath density model (wood density model in Dfir Calculator's case) predicts density for the incremental stem wood produced in each growth year. This information – the yield table and density predictions – is then used by the C_Change carbon model to model the annual development of several biomass pools (such as stem, foliage, branches, roots etc.). These estimates are then converted into annual carbon pools (above ground live, below ground live, dead woody litter, fine litter).

From the modelling process described above, volume and density are the key driving factors of carbon sequestration. Forecaster utilises stem level volume functions and the latest version of C_Change, including a sheath density model and biomass allocation functions[6] specific to Douglas-fir for carbon estimates. On the other hand, Dfir Calculator uses stand level volume function, an older version of C_Change model (which uses radiata pine biomass allocation and decay functions) and wood density model for this process. This explains the differences in total carbon estimates between the two systems.

# DISCUSSION

Differences in the modelling frameworks of Forecaster and Dfir Calculator (Table 6) 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[7]. This means Forecaster grows a distribution of stems through time, whereas Dfir Calculator generates a distribution of stems at clearfell. These differences are further described in a white paper available on the FFR website.

**Table 6: Models in the Douglas-fir modelling systems**

| | **FFR Forecaster** | **Dfir Calculator** | **Comments** |
|---|---|---|---|
| **Latest released version** | 1.12.0.1082 | 4.0 | |
| **Date of release** | Dec 2012 | Sept 2010 | |
| **Growth model** | DFNat 500 index v2.0 - stem level implementation | DFNat 500 index v2.0 - stand level implementation | |
| **Volume model** | Various stem level implementations (120 Ashy, 136 All NZ, 228 Longwood, 273 G.Downs, 274 Southland, 275 Canterbury, 438 Kaingaroa) | Stand level implementation - Beekhuiz | Forecaster calculates stand volume by summing the volume of each stem as predicted by the stem volume & taper function, whereas Dfir Calculator uses a stand level volume function. |
| **Carbon model** | C_Change v3.0 | C_Change v2.0 | |
| **Density model** | Dfir sheath density | Kimberley Dfir 2002 | |
| **Branch Index model** | KnowlesMcInnes 1997[8] | KnowlesMcInnes 1997 | |
| **Log bucking** | Models the size & shape of individual stems & cuts each stem into logs according to the log specs. | Bucking simulation is applied to modelled trees in diameter & branch size distributions | |

# IMPLICATIONS

We recommend the following:

- Use either Forecaster or Dfir Calculator for stand level estimates of basal area, mean top height and stocking.
- Use Forecaster for carbon estimates as it contains the most recent C_Change carbon model, upgraded adjustment functions and sheath density model for Douglas-fir. This more closely aligns the modelling methodology used within Forecaster with that used and validated by New Zealand's Ministry for the Environment. Note that there are still carbon differences due to the different approach to volume modelling, and it is recommended that the stand-level volume function be hard-wired into Forecaster in the future to resolve this.
- Use Forecaster for log yield estimates, as predictions of yields based on stem level measurements are likely to be more accurate than predictions based on crudely modelled log size class distributions.

The following issues were raised when a similar comparison study was carried out between Forecaster and Radiata Calculator[7], and are just as valid for this study.

- Both FFR and Scion should be aware that maintaining separate systems is costly and time consuming. We recommend that both parties move towards implementing the various 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[9]. In the meantime, consistency of the models between the various systems should be maintained.We stress the importance of documenting underlying models and processes in the systems. Users should also be able to identify details easily, such as the underlying models and their version numbers. This information is available in Forecaster, whereas in Dfir Calculator, these details are embedded in the VBA code and are not accessible to the user.

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