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Carbon Calculators for Alternative Species

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EXECUTIVE SUMMARY

The aim of this report was to summarise the state of tools currently available for calculating carbon for a range of tree species in New Zealand. The species investigated are: Douglas-fir (*Pseudotsuga menziesii)*, the eucalypts, the cypresses, redwood (*Sequoia sempervirens*), totara (*Podocarpus totara*), and kauri (*Agathis australis*). The tools are available within Scion software, as calculators on the FFR website, or as look-up tables from MPI.

A literature review was conducted predominantly through use of Scion's reporting database (SIDNEY), through an abstract and citation database of peer-reviewed literature (Scopus), and through Google keyword searches. Authors of existing carbon calculators were also contacted for comment.

From the above searches, the most prevalent model for predicting carbon content is C_Change [1]. Although developed for radiata pine, it can be used in conjunction with other species with input of species-specific volume and growth models and density data. C_Change is implemented in the Forest Carbon Predictor (FCP), was implemented in the Douglas-fir calculator in 2008, and has linkages with the *E. fastigata* web tool. Greg Steward and Peter Beets, developed an Excel spreadsheet for predicting carbon for kauri[2]. This is not incorporated in the kauri calculator.

Look-up tables, published by MAF[3], have also been derived for various forest types (i.e. groupings of species) based on results derived from C_Change and averaged across the country and across management regimes.

Carbon calculators and look-up tables for non radiata pine tree species in New Zealand.

Species	Calculators	Look-up table (Forest type, thinning assumption)
Douglas-fir	C_Change, FCP, Douglas-fir calculator: Excel	Douglas-fir, common thinning regimes
Eucalypts	C_Change *E. fastigata* web tool (MAF) FFR EUFAS web calculator	Exotic hardwoods group, no thinning
Cypresses	*	Exotic softwoods group, as for *P. radiata*
Redwood	*	Exotic softwoods group, as for *P. radiata*
Totara	*	Indigenous forest group, no thinning
Kauri	Excel worksheet	Indigenous forest group, no thinning

*No information found, but use of C_Change possible with input of species-specific data.

Apart from Douglas-fir, carbon calculations for the other species are, at best, rough estimates, and cannot be used for accurate carbon estimates at the stand or regional levels.

In order to achieve improved accuracy in carbon estimates, greater geographical coverage of models is required. This will require additional sample plot measurements, and further planting and management of the species. The number of plots required depends on the current knowledge base and the accuracy required for the carbon estimates.

INTRODUCTION

The Emissions Trading Scheme (ETS) and the Permanent Forest Sink Initiative (PFSI) were created by the New Zealand Government as part of a package of climate change initiatives that will support New Zealand's ratification of the Kyoto Protocol. The ETS and PFSI provide investors and landowners with the ability to earn carbon units from eligible forests (which include planted exotic, planted and regenerating indigenous tree species).The government plans to allocate carbon units to eligible forests under 100ha in size by using a look-up table approach for key species.

Current look-up tables are based either on national or regional averages carbon estimates for radiata pine and may over-estimate carbon sequestration rates for forests planted on more marginal (high, dry, cold) land, or under-estimate carbon sequestration for forests planted in fertile land. Improvements are needed to ensure ETS tables more accurately reflect likely tree growth rates and thus carbon sequestration rates to ensure fair allocation of carbon units for investors, forest owners and the government.

Improvements in carbon estimation are also needed where the species is one other than radiata pine. This follows from the fact that the national and regional averages provided in look-up tables are based on aggregates of model runs based on radiata pine.

In this report, we summarise models and look-up tables for carbon sequestration for species other than radiata pine.

METHODS

A literature review was conducted predominantly through use of Scion's reporting database (SiDNEY), but also through use of an abstract and citation database of peer-reviewed literature (Scopus), and through Google search.

Authors of the carbon calculators identified through the literature review were provided with a draft of this document and asked to comment on it.

MODELS

C_Change

The software C_Change [1] is a stand-level modelling system that was developed for estimating carbon stocks in above and below ground biomass and in litter pools in managed radiata pine plantations. C_Change incorporates mortality and decay functions, and expansion factors. While built upon radiata pine growth models, C_Change can also be used with other species, provided that yield tables and density functions (or constant values) are also known.

The linkage between plot-based data and allometric functions that predict biomass to determine carbon content, and the alternative approach with tree volume functions and growth models to determine carbon inventories and projected carbon estimates is shown in Figure 1. Data availability will generally determine which approach is the more appropriate.

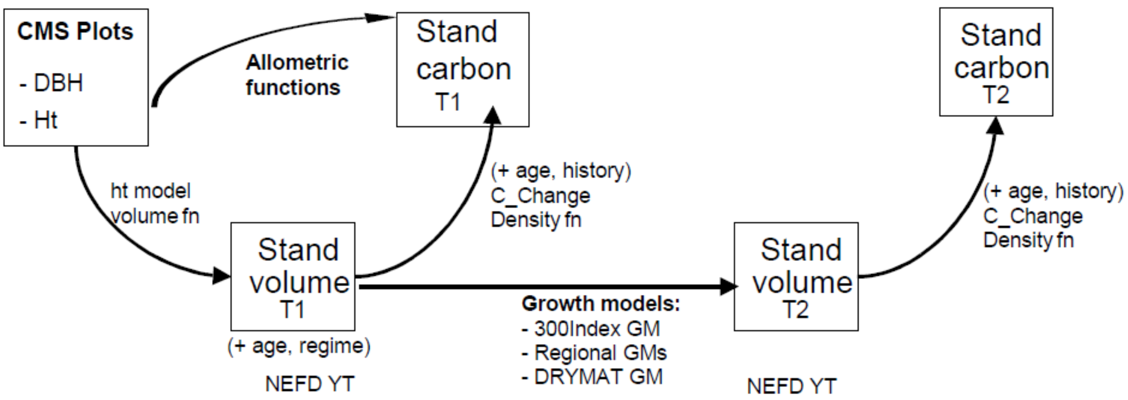


Figure 1: Plot-based carbon inventory and projections incorporating growth models (GM) over time (T & T2) for Carbon Monitoring System (CMS) plots. Yield tables (YT) form part of the National Exotic Forest Description (NEFD). Source: Beets et al[4]

For individual trees, the carbon content (usually measured in kg) can be found by multiplying tree biomass by 0.521 for hardwoods, and by 0.498 for softwoods. That is, the carbon content of live/recently harvested wood, regardless of species, is about 50% carbon (48% “stable” and 2% “volatile”) by dry weight. Tree biomass in turn can be determined either through destructive tree sampling, or non-destructively using allometric models requiring input of diameter and/or height measurements.

Allometric functions are typically of the form:

$$M=aD^b$$

where M= biomass, a and b, are species-related coefficients, and D (cm) is diameter at breast height. In addition to D, tree height may also be included as an explanatory variable.

Allometric functions for predicting biomass have been derived for Douglas-fir and the eucalypts by Moore et al.[5]. The Douglas-fir functions were based on a dataset of 72 trees while the eucalypts functions were based on a dataset of 168 mixed eucalyptus trees. A number of other biomass studies have been performed (Madgwick et al.[6] for *E. fastigata* and *E. nitens*; Frederick et al.([7]&[8]) for *E. regnans*). Frederick et al.[9] also analysed wood density of young *E. regnans* and McKinley et al.[10] analysed that of *E. fastigata*, *E. nitens*, *E. regnans*, and other species.

Volume functions (which when multiplied by wood density can be used to calculate biomass, and hence carbon content) have been developed for Douglas-fir, *E. fastigata*, *E. nitens*, *E. regnans*, *Cupressus macrocarpa*, redwood, kauri, and all are available within FFR Forecaster software.

C_Change for Douglas fir

To improve carbon predictions for Douglas-fir, C_Change has recently been upgraded to include:

- an improved Douglas-fir wood density model, which is integrated with the 500 Index model,
- a productivity index that combines site index and basal area 'level' (as represented by site basal area potential, SBAP).

The 500 Index is a growth model based on a productivity index that combines site index and basal area 'level' (as represented by site basal area potential, SBAP). The index has been standardised to a specific regime, involving thinning to waste by 15m MTH to 500 stems/ha, and then growing the stand to age 40 yrs. Hence it has been named the '500 Index'[11].

C_Change was also introduced into the Douglas-fir calculator (discussed later in this document)

C_Change for *E. fastigata*

C-Change has linkages to the *E.fastigata* carbon sequestration web tool (Figure 2). Details of the web tool are given on p10.

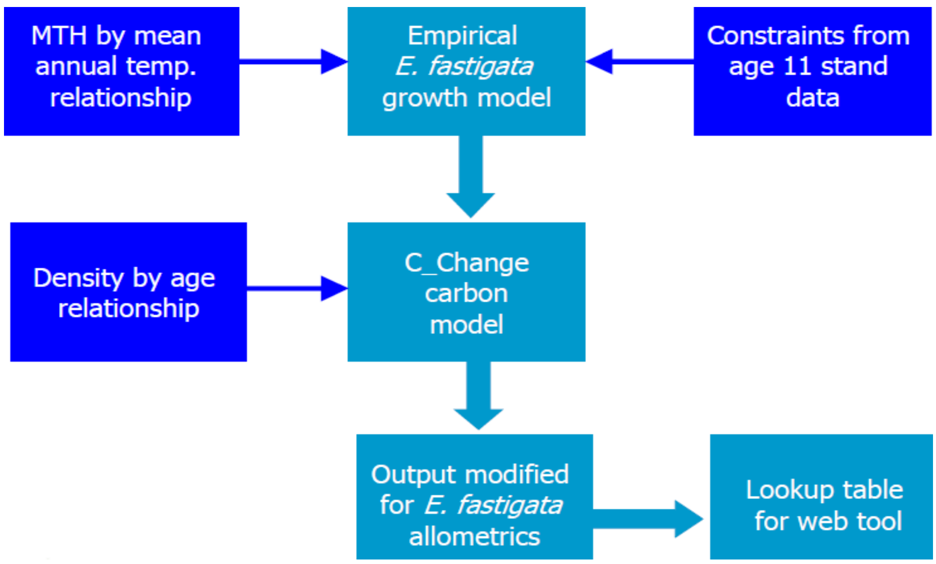


Figure 2: Relationship between C-Change and the *E. fastigata* web-based tool. Source: Meason[12]

The Forest Carbon Predictor, FCP

The Forest Carbon Predictor (FCP) is a VBA Microsoft Excel implementation of models used to predict carbon sequestration in planted forests. The FCP calculator, with the C_Change model embedded within it, was developed to predict carbon stocks in radiata pine stands, and was based on comprehensive biomass data from a range of tree ages, sites, and silvicultural regimes.

Adjustment functions are used to extend FCP to applications with species other than radiata pine Douglas-fir adjustment functions (based on the 300 Index model growth model[13]) include other improvements to FCP (implemented in FCP version 3) such as breast height pith-to-bark density functions for estimating growth ring density[14]. Within FCP version 4.10, there is now also a Douglas-fir adjustment function, based on growth from the 500 Index and on density from the Douglas-fir density model (as opposed to use of the radiate pine assumptions).

FCP is used to predict carbon stocks in the LUCAS Carbon Reporting Application (CRA, http://www.mfe.govt.nz/issues/climate/lucas/) for a network of sample plots covering post-1989 forests in New Zealand. Carbon estimates obtained from running FCP V2.2 (based on *P. radiata* growth, volume and wood density models) have been compared with those estimated for Douglas-fir, eucalypt species, and cypresses using the C_Change model in conjunction with species-specific growth models, stem volume functions and wood densities. Overall, carbon stocks were under-predicted by FCP2.2 for Douglas-fir and eucalypts, while those for cypresses were over-predicted[15].

FCP (Version 3) was used to develop carbon yield tables for Post-1989 LUCAS inventory plots of Douglas-fir, the eucalypts, and other species including cypresses[16].

ETS Look-up Tables

The ETS look-up tables published by MAF[3] are a series of pre-calculated values of forest carbon stocks, by age, for a given forest type. The forest carbon stock values in the tables include all carbon in all components of a forest: the stem, branches, leaves and roots, and in the coarse woody debris and fine litter on the forest floor. For post-1989 forest land, a separate set of tables provide the emissions from decay over time of the coarse woody debris, stumps, roots and other woody residues that remain after thinning or harvest.

The five forest types defined in the look-up tables are: radiata pine, Douglas-fir, exotic softwoods, exotic hardwoods, and indigenous forests.

Cypresses and redwoods are represented by the exotic softwoods group, eucalypts by the exotic hardwoods group, and kauri and totara by the indigenous forest group.

Look-up table values for forest types other than radiata pine reflect growth rates for typical forests in nationally averaged environments, under average forest thinning regimes. Carbon values for Douglas-fir were compiled from growth models assuming commonly used thinning regimes and model outputs averaged according to the proportion of existing exotic forest area under the different thinning regimes. The thinning regime assumed for exotic softwoods other than radiata pine and Douglas-fir, was the same as the nationally averaged regime for radiata pine.

For exotic hardwoods, it is assumed no thinning occurs, for the underlying growth model (*E. nitens*[17]). The national average carbon sequestration values for indigenous forest assume there is no thinning. The values implicitly account for both the enhanced natural mortality that is generally present in naturally regenerated stands, and for the decay of the resultant dead wood. Forest types and the underlying assumptions of the look-up table values are summarised in Table 1. Figure 3 shows plots of all values obtained from the look-up tables for pre-1990 forests (upper plot), and post-1989 forests (lower plots).

Table 1: Forest types identified in the Emissions Trading Scheme

Forest type	Underlying growth model assumptions	Species in this study
Pinus radiata	Common thinning regimes, by region	
Douglas-fir	Common thinning regimes	Douglas-fir
Exotic softwoods	Nationally averaged *Pinus radiata* thinning regimes	Cypresses, Redwoods
Exotic hardwoods	No thinning – based on growth model for *E. nitens*	Eucalypts
Indigenous forest	No thinning	Kauri Totara

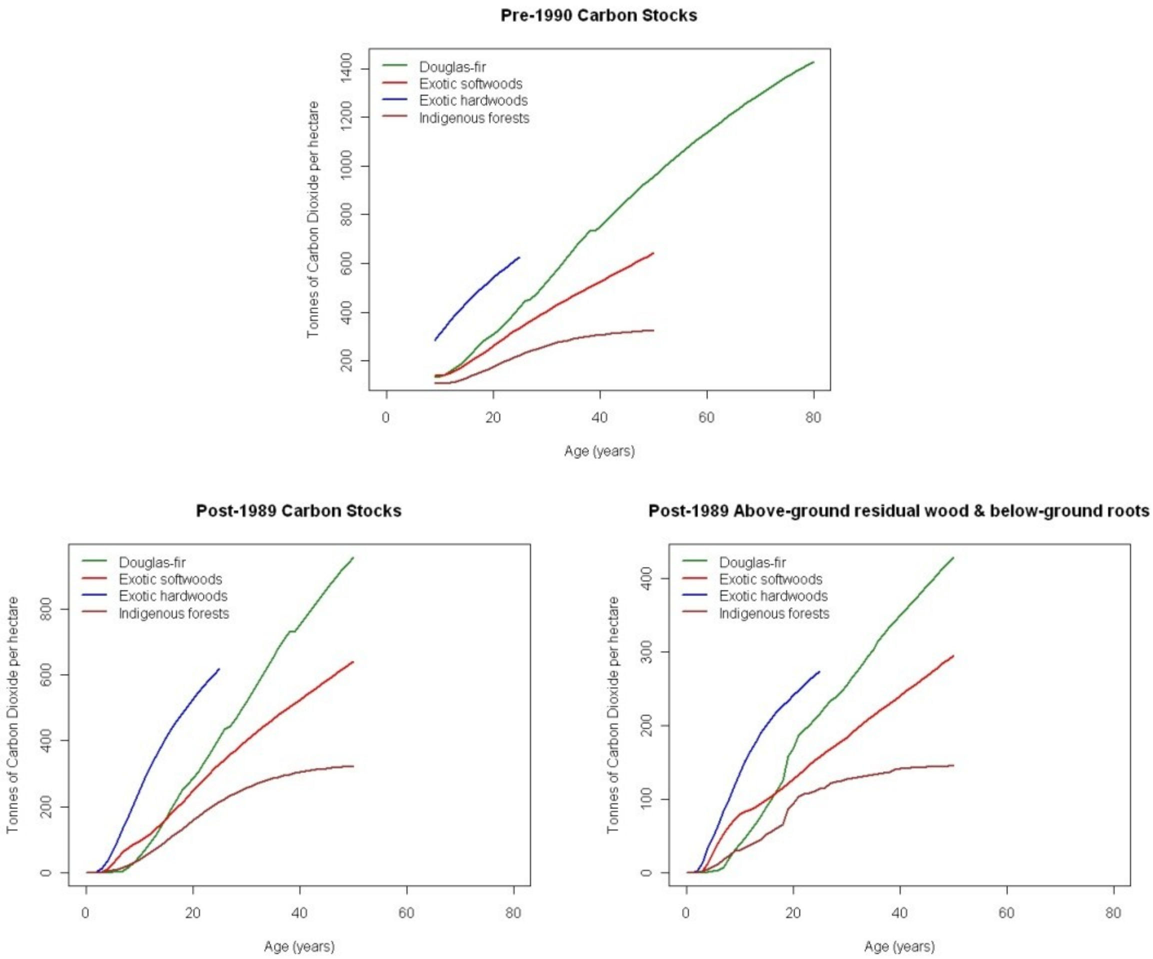


Figure 3: Carbon estimates obtained from the look-up tables for pre-1990 forests (upper plot), and post-1989 forests (lower plots). Source: MAF[3]

Note that the plots of carbon estimates shown above represent averages and do not show the large degree of variation that exists about the average, nor carbon estimates for specific plots. Variation, can however be observed in the carbon yield plots produced by Paul and Beets[16] and reproduced in Figure 4.

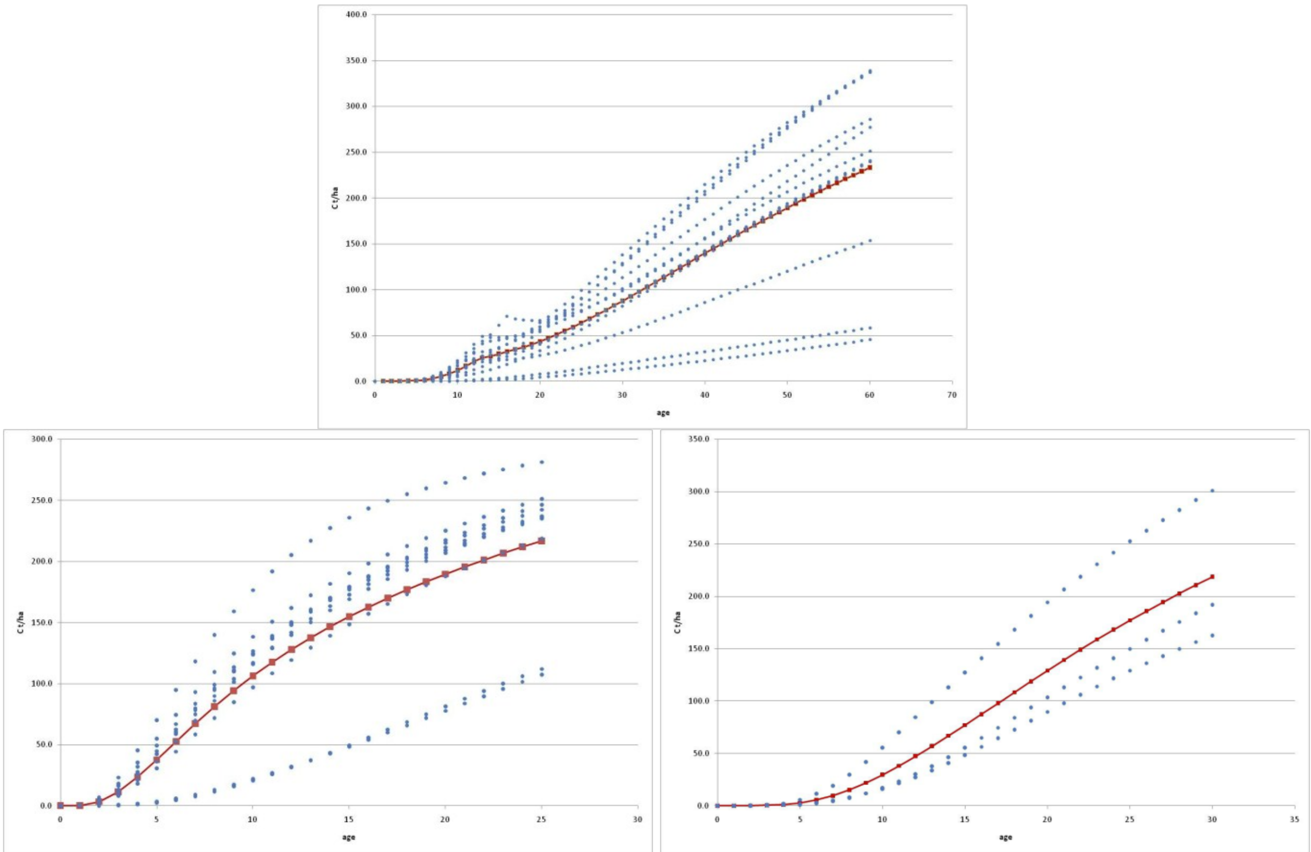


Figure 4: Carbon yield estimates for Douglas-fir (top), eucalypts (lower left), and other species (lower right) for individual (points) and the averaged yield (red). Source: Paul and Beets[16].

Douglas-fir Calculator

The Douglas-fir calculator[18],[19] is written using Visual Basic for Applications (VBA) code and implemented in Excel. It is available from Future Forest Research Ltd. and can be used to:

- analyse growth and log quality,
- determine the average BA increment for a fully stocked stand to age 40, and
- estimate biomass and carbon stocks in Douglas-fir stands growing in New Zealand.

A summary of growth models and other functions used within the calculator is provided in Knowles et al.[19], an overview of the carbon calculations in Kimberley and Beets[20], and a screen dump of an early version of the calculator is in Figure 5.

Carbon estimates are made using the national Douglas-fir growth model (DFNAT)), also referred to as the 500 Index growth model, with a series of stand-level functions[21], and developed through algebraic manipulation of the equations presented by Ponette et al.[22] and Ranger and Gelhaye[23].

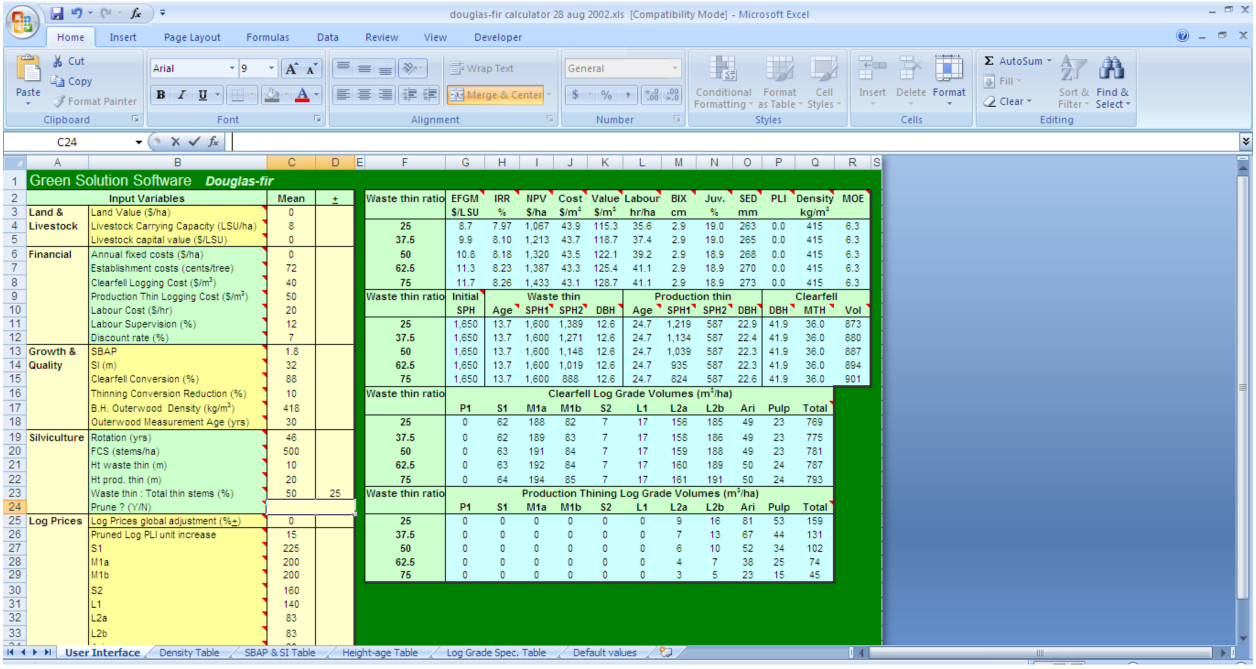
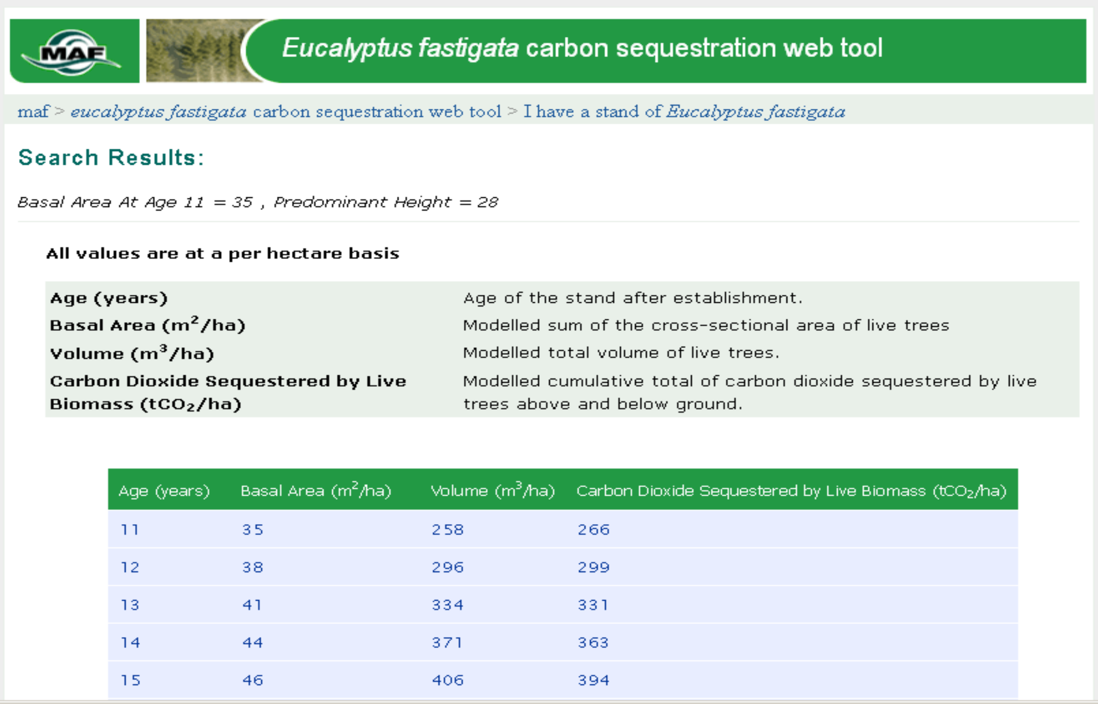


Figure 5: Illustration of one of the worksheets of the Douglas-fir calculator.

A recent upgrade to the calculator (Version 4.0[24]) has removed bias in the growth model which caused under-prediction of carbon following thinning. Furthermore, validation exercises have indicated that overall, carbon results are unbiased[25].

E. fastigata Web Tool

Two web tools have been developed for *E. fastigata*, one for MAF, the other for FFR. The first is a simple web-based tool for estimating potential carbon sequestration of *E. fastigata* from age 11 to 30 years. Development of the tool is described in Meason et al.[12]. The tool can be used in conjunction with either new or existing stands. For existing stands, the tool requires two inputs: stand basal area per hectare at 11 years of age, and average height of the tallest 20% of trees in the stand, also at age 11. An example output is shown in Figure 6.

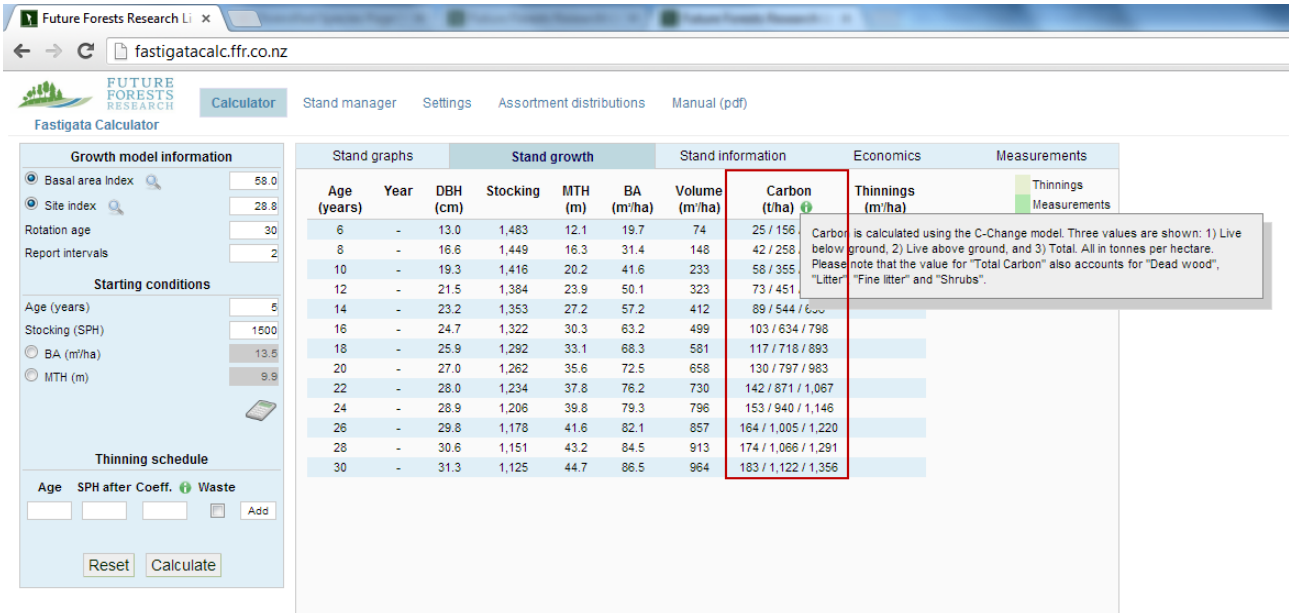


Age (years)	Age of the stand after establishment.
Basal Area (m^2/ha)	Modelled sum of the cross-sectional area of live trees
Volume (m^3/ha)	Modelled total volume of live trees.
Carbon Dioxide Sequestered by Live Biomass (tCO_2/ha)	Modelled cumulative total of carbon dioxide sequestered by live trees above and below ground.

Age (years)	Basal Area (m^2/ha)	Volume (m^3/ha)	Carbon Dioxide Sequestered by Live Biomass (tCO_2/ha)
11	35	258	266
12	38	296	299
13	41	334	331
14	44	371	363
15	46	406	394

Figure 6: Example of *E. fastigata* web tool output for an existing stand.
Source: http://ludt.scionresearch.com/FastigataCarbonTool/CarbonLookUp/CarbonTable-Search

The second tool, the FFR EUFAS web calculator, calculates carbon using the C_change model . A screenshot of FFR EUFAS is shown in Figure 7.



Age (years)	Year	DBH (cm)	Stocking	MTH (m)	BA (m^2/ha)	Volume (m^3/ha)	Carbon (t/ha)	Thinnings (m^3/ha)
6	-	13.0	1,483	12.1	19.7	74	25 / 156	
8	-	16.6	1,449	16.3	31.4	148	42 / 258	
10	-	19.3	1,416	20.2	41.6	233	58 / 355	
12	-	21.5	1,384	23.9	50.1	323	73 / 451	
14	-	23.2	1,353	27.2	57.2	412	89 / 544	
16	-	24.7	1,322	30.3	63.2	499	103 / 634 / 798	
18	-	25.9	1,292	33.1	68.3	581	117 / 718 / 893	
20	-	27.0	1,262	35.6	72.5	658	130 / 797 / 983	
22	-	28.0	1,234	37.8	76.2	730	142 / 871 / 1,067	
24	-	28.9	1,206	39.8	79.3	796	153 / 940 / 1,146	
26	-	29.8	1,178	41.6	82.1	857	164 / 1,005 / 1,220	
28	-	30.6	1,151	43.2	84.5	913	174 / 1,066 / 1,291	
30	-	31.3	1,125	44.7	86.5	964	183 / 1,122 / 1,356	

Figure 7: Example of the FFR EUFAS web calculator.

Kauri Carbon Estimator

Estimates of carbon content in kauri can be obtaining using a simple Excel-based spreadsheet calculation[2]. Figure 8 shows calculations assuming a constant density of 435 kg/m^3. A revised figure of 450 kg/m^3 has been suggested by Greg Steward which, if entered at column C, would shift the curve shown in the figure upwards. The graph presented below follows the medium volume prediction from the growth model of Steward[2]. The estimate for carbon includes estimates for total tree biomass (below and above ground) provided by Peter Beets.

Age	Vol	stem carb	t C/ha	C/ha/yr	CO2/ha/yı	t CO_2/ha
0	0	0	0	0	0	0
5	0.01481	0.003221	0.004026	0.000805	0.00298	0.014898
10	1.053894	0.229222	0.286527	0.028653	0.106015	1.060152
15	9.520552	2.07072	2.5884	0.17256	0.638472	9.57708
20	35.74652	7.774869	9.718586	0.485929	1.797938	35.95877
25	85.72688	18.6456	23.307	0.93228	3.449435	86.23588
30	158.0901	34.38459	42.98073	1.432691	5.300957	159.0287
35	246.5107	53.61608	67.0201	1.91486	7.084981	247.9744
40	343.2041	74.64689	93.30862	2.332715	8.631047	345.2419
45	441.2749	95.97729	119.9716	2.666036	9.864333	443.895
50	535.6856	116.5116	145.6395	2.912791	10.77732	538.8662
55	623.3203	135.5722	169.4652	3.081185	11.40039	627.0212
60	702.6326	152.8226	191.0282	3.183804	11.78007	706.8045
65	773.191	168.169	210.2113	3.23402	11.96587	777.7818
70	835.2697	181.6712	227.0889	3.244128	12.00327	840.2291
75	889.5371	193.4743	241.8429	3.224572	11.93092	894.8188
80	936.8409	203.7629	254.7036	3.183795	11.78004	942.4034
85	978.0713	212.7305	265.9131	3.12839	11.57504	983.8786
90	1014.082	220.5629	275.7036	3.063374	11.33448	1020.103
95	1045.651	227.4291	284.2864	2.992488	11.07221	1051.86
100	1073.461	233.4777	291.8471	2.918471	10.79834	1079.834

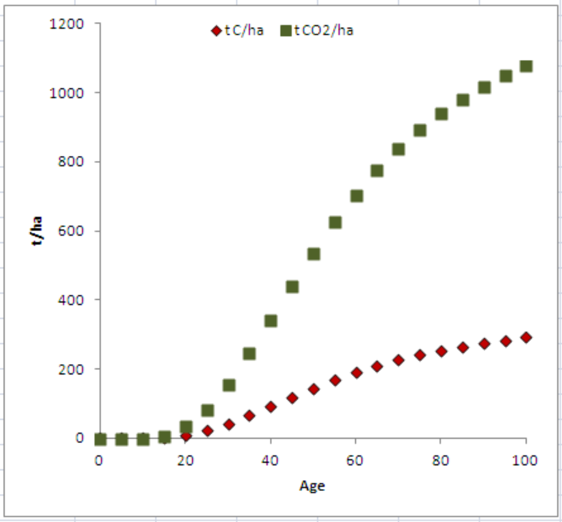


Figure 8: Carbon estimates of kauri based on assumptions of a volume function and constant density.

CONCLUSION

A variety of tools, techniques, and look-up tables, are available for estimating carbon sequestration for species other than radiata pine. Of these species, Douglas-fir is the most researched and, as such, several models currently exist for determining its carbon content.

For the other species investigated here (eucalypts, cypresses, redwood, totara, and kauri), carbon calculations are rough estimates and cannot be used to accurately represent differences at the stand or regional levels. In order to achieve improved accuracy, greater geographical coverage of growth and density models is required. This in turn will necessitate additional sample plot measurements, further planting throughout the country, and management of the species.

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