

Multi-species Carbon Calculator help file

Version 1.0 – 4 December 2023

Model summary

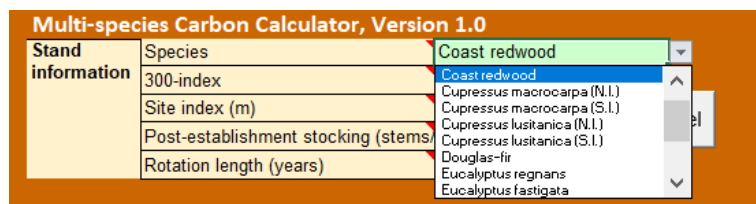
This calculator predicts growth metrics for even-aged, single-species, forest plantations for radiata pine and many of the alternative exotic tree species grown in New Zealand. The growth metrics predicted include tree height, basal area, stem volume, timber yield, and sequestered carbon. The growth models underpinning the calculator were developed using extensive growth data from permanent sample plots (PSP's) distributed across New Zealand. The effect of site is incorporated into the predictions using height and volume productivity indices – these values can be sourced from pre-defined local or regional values or through plot data. Once these productivity indices are set, the impacts of rotation length and different silviculture on timber yield, carbon and log grade out-turn can be explored.

The following explanation takes the user through typical usage of the model.

1. Inputs

1.1 Defining the species and site productivity

Step 1. Select the species from the dropdown menu on the first page (see below).



The screenshot shows the 'Stand information' section of the calculator. The 'Species' dropdown menu is open, displaying a list of species: Coast redwood (selected), Cupressus macrocarpa (N.I.), Cupressus macrocarpa (S.I.), Cupressus lusitanica (N.I.), Cupressus lusitanica (S.I.), Douglas-fir, Eucalyptus regnans, and Eucalyptus fastigata.

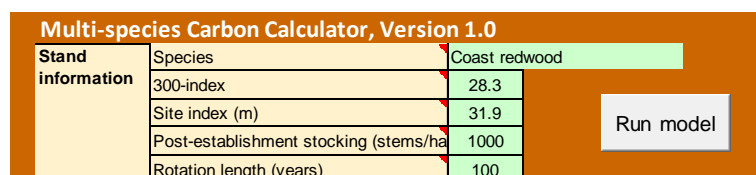
Stand information	Value
Species	Coast redwood
300-index	Coast redwood
Site index (m)	Coast redwood
Post-establishment stocking (stems/ha)	Coast redwood
Rotation length (years)	Coast redwood

The following 11 species are available within the calculator:

- Blackwood (*Acacia melanoxylon*)
- Coast redwood (*Sequoia sempervirens*)
- *Cupressus macrocarpa*
- *Cupressus lusitanica*
- Douglas-fir (*Pseudotsuga menziesii*)
- *Eucalyptus regnans*
- *Eucalyptus fastigata*
- *Eucalyptus nitens*
- *Eucalyptus delegatensis*
- *Eucalyptus saligna*
- Radiata pine

Three of the species (*C. macrocarpa*, *C. lusitanica*, *E. nitens*) have separate mortality models for the North Island (N.I.) and South Island (S.I.) as the mortality of these species varies significantly by Island.

Step 2. Input the 300 Index and site index in the top box (see below)



The screenshot shows the 'Stand information' section of the calculator. The input fields are filled with values: 300-index (28.3), Site index (m) (31.9), Post-establishment stocking (stems/ha) (1000), and Rotation length (years) (100). A 'Run model' button is visible to the right.

Stand information	Value
Species	Coast redwood
300-index	28.3
Site index (m)	31.9
Post-establishment stocking (stems/ha)	1000
Rotation length (years)	100

There are three options for specifying the 300 Index (volume productivity index) and site index (height productivity index). These depend on the situation being modelled and available data.

Option 1. If the calculator is being used to predict growth for a greenfields site (i.e., an area to be afforested) where no plot data are available values of both productivity indices from spatial surfaces or regional estimates can be used. In this case the user should select the top box under 'Site productivity index options' – see below.

Site productivity index options:

Use indices specified in cells D3 and D4

Estimate indices from stand metrics

Estimate indices from Starting tree list

Option 1a. Spatial predictions of 300 Index and site index have been produced for radiata pine, coast redwood, *Cupressus lusitanica* and *Cupressus macrocarpa*. These surfaces are freely available on <https://koordinates.com/>. The user will need to sign up to koordinates, then should type in the name of the species of interest to locate the national surfaces of 300 Index (also known as volume productivity) and site index (also known as height productivity). These surfaces can then be downloaded to a GIS platform and the 300 Index and site index can be extracted for a point or area of interest. There are plans to complete surfaces of 300 Index and site index for blackwood and all five *Eucalyptus* spp. that are used in the calculator before March 2024.

Option 1b. Alternatively, regional estimates of 300 Index and site index, by species, are available for many New Zealand regions within Table 1 (see Appendix) in this document. The productivity indices for blackwood and *Eucalyptus* spp. do not include estimates for many regions as they are based on simple averages of plot data, rather than averages taken from modelled surfaces. Greater coverage will likely be available once spatial surfaces for blackwood and *Eucalyptus* spp. have been developed.

Please note that the 300 Index and site index estimates described above are for fully stocked permanent sample plots (PSPs). Consequently, any predictions of volume or carbon using these productivity indices **should be reduced by 15%** to account for gaps that occur within most forest stands.

Option 2. The user is interested in modelling growth for an existing stand and has stand metrics estimated from plot data. This form of data can be used to predict 300 Index and site index.

If the user has stand metrics from plot data, they should select the second option under 'Site Productivity index options', as shown below.

Site productivity index options:

Use indices specified in cells D3 and D4

Estimate indices from stand metrics

Estimate indices from Starting tree list

The user must then enter four metrics to estimate the two productivity indices as shown below. More details around the metrics can be viewed by hovering over the red triangle in each of the yellow cells. To produce reliable results the measurements should be taken from stands that are at least seven years of age.

Metrics used to estimate indices	Age (years)		12.1
	Stocking (stems/ha)		800.0
	Height (m) <input checked="" type="radio"/> MTH <input type="radio"/> Mean height		15.0
	BA (m ² /ha) or DBH (cm) <input type="radio"/> BA <input checked="" type="radio"/> DBH		20.0

There are a number of additional parameters that can be specified to refine the model predictions – these are listed under 'Other parameters' – see below.

Other parameters	Annual attritional mortality (%)	
	CV of DBH distribution	0.27
	Log length at harvest (m)	6.0
	Minimum log SED (mm)	150
	Stem break height (%)	65.0
	Volume losses at harvest (%)	4.0
	Wood density adjustment ($\pm\%$)	
	AG dead wood decay half life (years)	
	BG dead wood decay half life (years)	
	Latitude ($^{\circ}$ S)	
	Elevation (m)	
	Soil C%	
	Soil N%	
	Mean annual temperature ($^{\circ}$ C)	
	Drift factor	

Many of these parameters are specific to particular species, such as redwood, radiata pine and Douglas-fir. These parameters influence the rate of tree mortality, stand structure, log grade out-turn, and carbon. Details around each of these parameters are available through hovering over the top right triangles and default values are used when the cells are left blank.

For the redwood model, the calculator is able to accommodate an early measurement of height (usually <10 years) to refine the measurement of height entered above under 'Metrics used to estimate indices'. If this is available, the estimate can be entered into the cells shown below.

Early MTH measurement	Age (years)	
	MTH (m)	

Option 3. If plot data is available (i.e., a list of tree DBH and height measurements), these can be entered into the sheet entitled 'Starting tree list'. A sample of such data is shown below. In this case the third option under 'Site productivity index options' should be selected.

Starting tree list		
Plot area (ha)	0.170	
Age (years)	12.0	
Stem number	DBH (cm)	Height (m)
1	25.6	
2	24.7	14.0
3	23.5	
4	26.8	16.2
5	22.4	
6	25.8	
7	19.2	11.0
8	22.4	

Details around the data requirements of this sheet are available through hovering over the top right triangles.

1.2. Defining the initial stocking, thinning schedule, pruning schedule and rotation length

Initial stocking and rotation length are defined within the lower two cells in the top box, illustrated below,

Multi-species Carbon Calculator, Version 1.0					
Stand information	Species	Coast redwood			
	300-index	28.3			
	Site index (m)	31.9			
	Post-establishment stocking (stems/ha)	1000			
	Rotation length (years)	100			
<input type="button" value="Run model"/>					
Thinning schedule		Thin 1	Thin 2	Thin 3	Thin 4
	Waste/production thin	<input checked="" type="radio"/> Waste <input type="radio"/> Prod.	<input checked="" type="radio"/> Waste <input type="radio"/> Prod.	<input checked="" type="radio"/> Waste <input type="radio"/> Prod.	<input checked="" type="radio"/> Waste <input type="radio"/> Prod.
	Age at thinning (years)	9			
	Stocking after thinning (stems/ha)	500			
	Thinning coefficient				
Pruning schedule		Lift 1	Lift 2	Lift 3	Lift 4
	Age at pruning (years)				
	Number of stems pruned (stems/ha)				
	Pruned height (m)				

Up to four thinnings can be specified within the thinning schedule box. These can be either thinnings to waste or production thinnings (check the appropriate box). There is an option for using a thinning coefficient, which controls the proportion of basal area that remains in relation to the stocking. More details on this option are available through hovering over the box and a default value will be used if no value is entered.

Four pruning lifts can be scheduled within the pruning schedule box. The pruning schedule box should be left blank for an unpruned stand. Only the radiata pine growth model currently modifies tree growth in response to pruning.

1.3. DBH distribution options

Although the growth models in the calculator are primarily intended for predicting stand-level metrics such as per hectare stem volume and carbon, they also predict the distribution of individual stems and logs for thinnings and at the end of the rotation. To do this they require a DBH distribution.

The following two options are available to define the DBH distribution:

1. DBHs are generated from a Weibull distribution with the coefficient of variation specified in cell E30.
2. Scaled values of the DBHs in the "Starting tree list" worksheet are used (i.e., for Option 3 when 300 Index and site index are defined by the plot data).

These are selected through the box below.

DBH distribution options:	
<input checked="" type="radio"/>	Weibull distribution
<input type="radio"/>	Scaled tree list

1.4. Running the model

Once all the above options have been selected the model is ready to run. To do this press the 'Run model' button, illustrated below:

<input type="button" value="Run model"/>
--

2. Outputs

2.1. Growth model outputs (on first sheet)

The growth model predicts annual values of various stand metrics and sequestered carbon with the latter predicted for 1st and 2nd rotations. A sample of typical outputs is shown below:

Age (years)	Stocking (stem/ha)	Growth model predictions								Carbon 1st rotation (tCO ₂ /ha)					Carbon 2nd rotation (tCO ₂ /ha)				
		BA (m ² /ha)	DBH (cm)	Stem Vol. (m ³ /ha)	Harvest vol. (m ³ /ha)	MTH (m)	Mean height (m)	Wood dens. (kg/m ³)	Green crown height (m)	Total	Above ground	Below ground	Dead wood	Litter	Total	Above ground	Below ground	Dead wood	Litter
0	1000	0.0	0.0	0	0	0.3	0.3	339.0	0.0	0	0	0	0	0	1656	0	0	1472	185
1	998	0.0	0.0	0	0	0.4	0.3	339.0	0.0	0	0	0	0	0	1179	0	0	1046	133
2	997	0.0	0.0	0	0	0.8	0.7	339.0	0.0	1	1	0	0	0	848	1	0	750	97
3	995	0.0	0.0	1	0	1.7	1.4	339.0	0.0	2	2	1	0	0	617	2	1	543	71
4	993	0.1	1.3	2	0	2.8	2.4	339.0	0.0	5	4	1	0	0	454	4	1	397	52
5	992	1.6	4.5	3	0	4.0	3.5	339.0	0.0	8	7	1	0	0	340	7	1	292	39
6	990	5.3	8.2	13	0	5.4	4.6	339.0	0.0	29	22	7	0	0	275	22	7	217	29
7	988	11.1	12.0	30	0	6.7	5.8	339.0	0.0	59	50	11	0	-3	243	50	11	163	20
8	987	18.6	15.5	55	0	8.1	7.0	339.0	0.0	102	88	19	0	-5	241	88	19	123	12
9	500	16.2	20.3	53	0	9.5	8.3	339.0	0.0	152	77	16	33	27	258	77	16	126	40
10	499	21.6	23.5	77	0	10.9	9.5	339.0	0.0	171	103	21	25	22	251	103	21	96	31
11	498	27.5	26.5	107	0	12.2	10.6	339.0	0.0	197	132	26	19	19	259	132	26	74	27
12	497	33.5	29.3	140	0	13.5	11.8	339.0	0.3	230	164	33	15	18	278	164	33	57	24
13	497	39.6	31.9	177	0	14.8	12.9	339.0	1.2	268	199	40	12	18	305	199	40	44	22
14	496	45.8	34.3	218	0	16.0	14.0	339.0	2.0	309	235	47	9	17	338	235	47	35	21
15	495	52.0	36.6	261	0	17.2	15.0	339.0	2.8	353	274	55	7	17	375	274	55	27	20
16	494	58.1	38.7	308	0	18.4	16.1	339.0	3.6	399	313	63	6	17	417	313	63	21	19
17	493	64.1	40.7	356	0	19.5	17.1	339.0	4.4	447	354	71	5	17	460	354	71	17	19
18	492	70.0	42.5	407	0	20.6	18.0	339.0	5.2	495	395	80	4	17	506	395	80	14	18
19	491	75.7	44.3	459	0	21.7	19.0	339.0	5.9	545	436	88	4	17	553	436	88	11	18
20	490	81.4	46.0	513	0	22.8	19.9	339.0	6.6	595	478	97	3	17	602	478	97	9	18

Growth model predictions, include the following:

- stocking
- basal area
- diameter at breast height
- total stem volume under bark
- volume under bark for the harvested logs
- mean top height (MTH)
- mean height
- basic wood density of the stem
- mean height to the base of the green crown

Carbon predictions over the 1st and 2nd rotation are also shown on this sheet. The carbon sequestration by the 1st rotation stand does not take into account carbon from previous vegetation. It only estimates carbon in the stem, branches, foliage and roots of the trees, but includes carbon in dead wood and litter from tree mortality and thinning and pruning slash. Soil carbon is not estimated. For the 2nd rotation predictions, carbon in logging slash and roots from the 1st rotation is included in the initial dead wood pool.

Values for both the 1st and 2nd rotation are expressed in tonnes of CO₂ per hectare removed from the atmosphere.

2.2. Harvest summary (on third sheet)

Outputs from this sheet provide a summary of the under-bark log volumes by height class and small-end-diameter (SED) at clearfelling and for each specified production thinning.

Example output for a North Island radiata pine stand, that is clearfelled at age 28 is given below.

Summary of volume of harvested logs by SED and height class (m ³ /ha)												
Age	Height class	Minimum SED (mm)										Total
		100	200	300	400	500	600	700	800	900	1000	
28	Butt log	6.1	36.2	78.6	61.0	10.9	0.0	0.0	0.0	0.0	0.0	192.8
	2nd log	4.7	22.6	31.8	13.2	1.1	0.0	0.0	0.0	0.0	0.0	73.4
	Upper logs	101.8	296.2	117.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	515.1
	Total	112.7	354.9	227.6	74.2	12.0	0.0	0.0	0.0	0.0	0.0	781.3

The height class is defined by Cell E31 on the “Growth model” tab, i.e., “Log length at harvest”. The lowest log is the Butt log, the next log is the 2nd log and then logs above this are aggregated into the “Upper logs”. Additional cells on the ‘Growth model’ tab that control the log output include ‘Minimum log SED’, ‘Stem break height’ and ‘Volume losses at harvest’. Details around each of these variables can be found through hovering over the red triangle in the cell corner.

This spreadsheet is compiled from the “Harvested logs” tab which lists all logs produced during harvest and production thinning by their stem number and height position. Within this tab the under-bark SED and large-end-diameter (LED) for each log are also specified. This tab includes more detail around the log attributes, and, for instance, can be used to disaggregate “Upper logs” into their position within the stem. Please note that if data from this tab is used to compile the harvest summary, then values need to be multiplied by the “Weighting” in column B to scale estimates to a per hectare basis.

The “Felled stems” tab provides a list of felled stems in thinnings and at the end of the rotation.

3. Notes and limitations

3.1. Site productivity

All the models use site index and a volume productivity index (300 or 500 Index) to characterise the site. Site index is defined as the mean height of the 100 largest diameter trees per hectare (mean top height) at a reference age. The models use a reference age for site index of 30 years for all species except radiata which uses 20 years and Douglas-fir which uses 40 years.

The volume productivity index is defined as the mean annual increment at a reference age and reference stand density under a defined silvicultural regime. For all species, apart from Douglas-fir, the 300 Index is used, which has a reference age of 30 years and a reference stand density of 300 stems/ha. The Douglas-fir model uses the 500 Index which uses a reference stocking of 500 stems/ha at age 40 years.

3.2. Wood density

Existing wood density functions were used for each species. Predictions of wood density for radiata and Douglas-fir are based on published models that account for temperature, soil C/N ratio and tree age. The cypress and redwood models use a constant wood density which is not affected by age or environment. Although there will be environmental effects on their wood density these are currently unknown. Most of the *Eucalyptus* spp. show strong pith to bark trends in wood density and published models were used to characterise these changes.

3.3. Carbon predictions

Predictions of carbon are undertaken through a number of steps. First, the model uses the stand-level volume x wood density to predict stem wood biomass. The C-Change model is then used to predict biomass of other components using appropriate ratios for all species groups. C-Change also tracks carbon in dead wood, litter, etc, keeping track of thinning and pruning events, and using decay functions to decay dead wood and litter. Redwood does not use the C-Change model to track carbon, but applies published ratios for components and tracks carbon using a similar process to C-Change.

4. Mean regional estimates of productivity indices

Mean values of 300 Index and site index, by region, are documented in Table 1 of the Appendix. These values were determined as regional means from productivity surfaces for radiata pine, redwood, *Cupressus lusitanica* and *Cupressus macrocarpa*. As productivity surfaces of 300 Index and site index are not available for the remaining species, the mean regional values were determined directly from the permanent sample plot data (PSP's). For many species there are regions without values as PSP data does not cover all regions for all species, as shown in Figure 1, within the Appendix. To ensure that mean regional values were relatively robust, means are only provided when there are 10 or more PSP's in each region. Clustered PSP's with more than one plot at the same location were averaged before estimating the regional mean to ensure spatial coverage was less biased. Similarly, at the island level, at least 10 plots were required before mean values of site index and 300 Index were displayed. As there are far more PSPs in the North than South Island (Figure 1, Appendix), the model output presented below uses mean North Island values.

5. Model output

Using mean estimates of 300 Index and site index for the North Island, predictions of volume, basic density and carbon for all species over a 100 year rotation are shown in Figure 2 in the Appendix. These predictions assumed a starting stand density of 1,000 stems/ha and a single thinning at age 9 to 500 stems/ha. The values of volume and carbon were reduced by 15% to account for stand gaps.

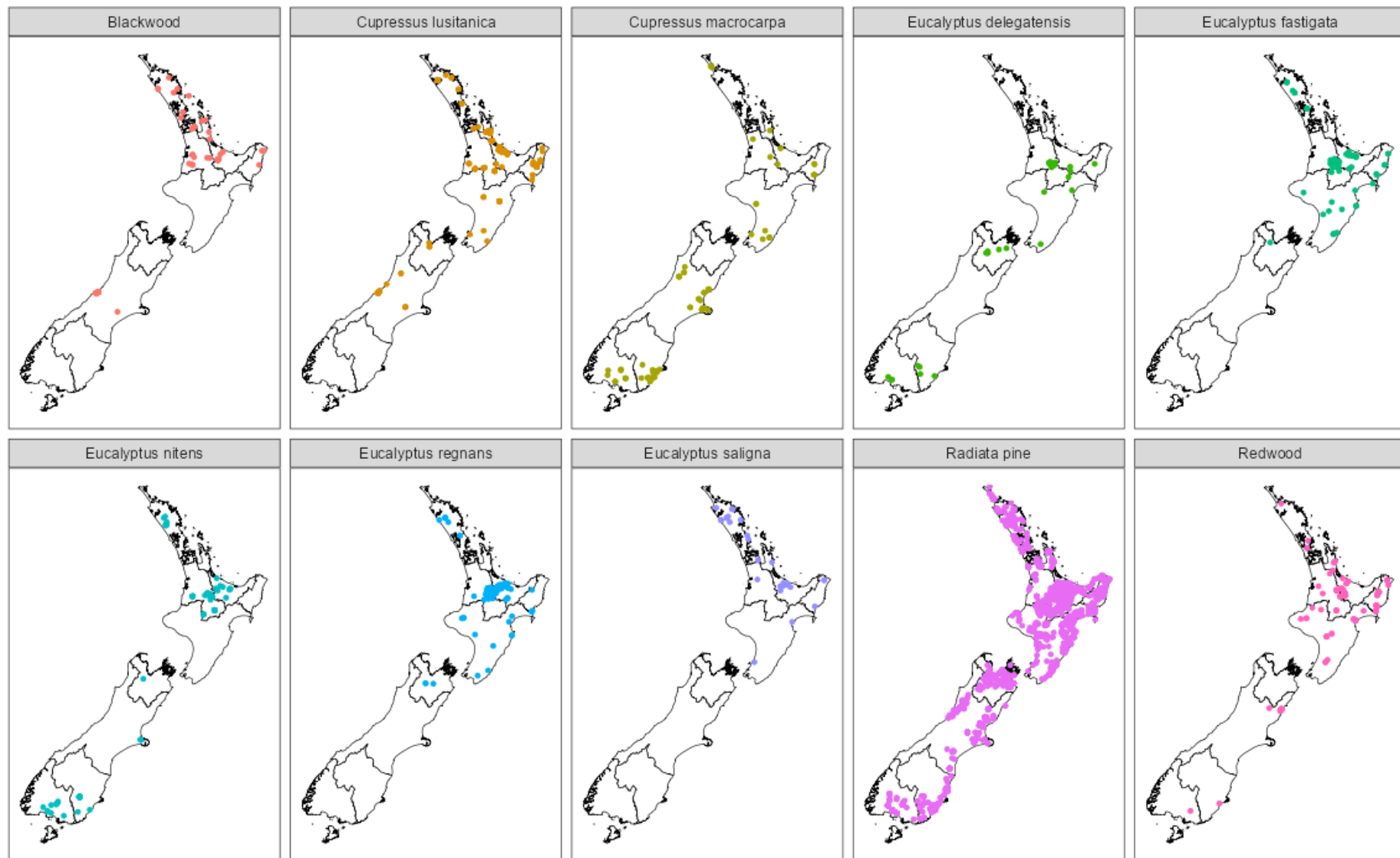
6. Further likely improvements

Additional improvements that are likely to take place include the following:

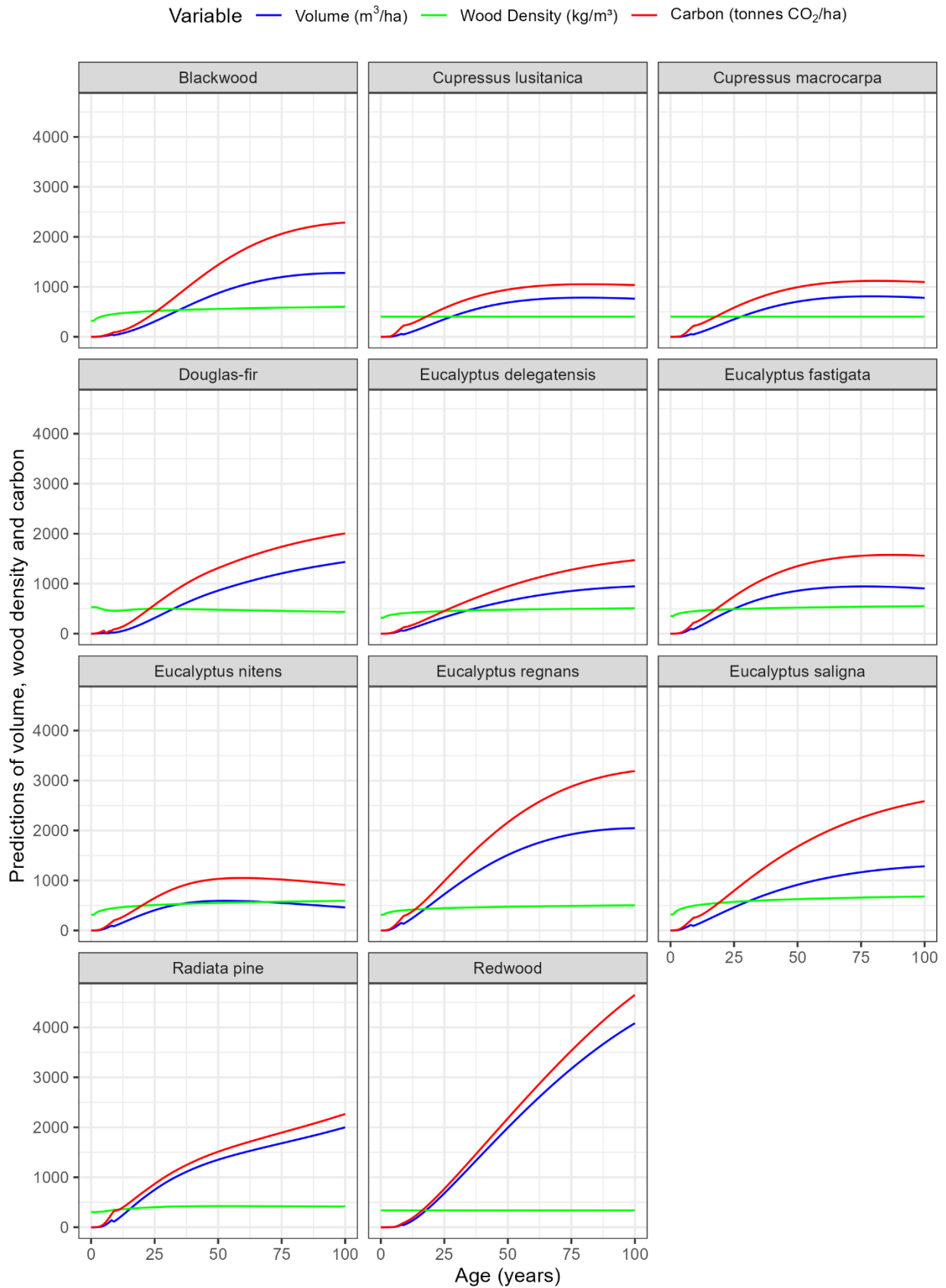
- A video will be constructed to help users
- Spatial surfaces will be developed for blackwood and all *Eucalyptus* spp.
- Taper functions for *Eucalyptus* and *Cupressus* spp. will be included in the log making routine
- Implement the radiata pine and Douglas-fir branch diameter models and incorporate branch size into the log grading routine
- Update models with additional PSP data as it becomes available

Appendix Table 1. Regional values of 300 Index and site index. Values for radiata pine, redwood and the two *Cupressus* species were derived from productivity surfaces. As there are currently no productivity surfaces for blackwood, Douglas-fir and the five *Eucalyptus* spp. these values were extracted from the permanent sample plot (PSP) data. Average values are only displayed when there are 10 or more spatially separate PSP locations for the region or island. Spatially clustered values of both productivity indices derived from PSP data were averaged, by location, before undertaking this final averaging by region and island.

	Auckland	Waikato/ Taranaki	Bay of Plenty	Gisborne	Hawkes Bay/Southern NI	Nelson/ Marlborough	Canterbury/ Westland	Otago	Southland		North Island	South Island
300 Index (m³/ha/yr)												
Blackwood	12.7	16.7					3.4				13.5	3.4
<i>Cupressus lusitanica</i>	17.8	14.2	14.6	15.3	13.3	7.6	4.8	4.0	4.3		14.6	5.0
<i>Cupressus macrocarpa</i>	12.5	16.3	17.4	20.6	15.9	14.0	10.2	9.1	10.5		15.8	10.7
Douglas-fir (500 Index)		22.4	18.3	18.3	14.6	18.9	19.5	19.7	21.8		17.6	19.1
<i>Eucalyptus delegatensis</i>		10.5									13.5	20.4
<i>Eucalyptus fastigata</i>	15.0	22.1	21.4		21.5						20.8	
<i>Eucalyptus nitens</i>	20.3	17.4	22.2					19.0	25.5		18.8	20.5
<i>Eucalyptus regnans</i>		30.7	40.1		25.5						32.5	
<i>Eucalyptus saligna</i>	19.7		18.1								19.0	
Radiata pine	26.9	29.6	29.9	31.0	30.1	24.0	20.3	19.2	23.6		29.4	21.3
Redwood	28.3	29.2	30.0	25.2	28.0	14.7	11.7	5.6	13.5		28.3	11.3
Site index (m, base age 30)												
Blackwood	26.3	27.5					17.7				26.9	17.7
<i>Cupressus lusitanica</i>	27.3	25.1	25.5	26.1	23.8	21.7	13.3	8.1	13.3		25.1	13.8
<i>Cupressus macrocarpa</i>	25.0	27.5	27.5	29.5	27.1	25.6	21.9	19.8	23.8		27.0	22.5
Douglas-fir (base age 40)		32.8	32.8	32.8	28.2	32.7	31.5	30.6	30.9		31.0	31.7
<i>Eucalyptus delegatensis</i>		35.6									36.1	34.4
<i>Eucalyptus fastigata</i>	34.2	44.3	44.2		39.8						41.7	
<i>Eucalyptus nitens</i>	39.9	41.2	45.7					39.9	40.7		41.5	40.1
<i>Eucalyptus regnans</i>		51.2	48.2		43.4						49.5	
<i>Eucalyptus saligna</i>	40.7		39.6								39.9	
Radiata pine (base age 20)	30.0	31.1	31.9	30.6	29.5	26.9	25.5	21.2	22.7		30.3	24.2
Redwood	34.5	30.9	33.8	30.5	30.9	23.2	18.8	15.5	21.5		31.9	19.3



Appendix Figure 1. Location of permanent sample plots (PSP's), by species. Plots are overlaid on regional boundaries.



Appendix Figure 2. Predictions of total volume (blue line), wood density (green line) and total carbon (red line) against age, by species. Model predictions were extracted from the calculator using the North Island productivity indices shown in Table 1 (Appendix). All runs had a starting stand density of 1,000 stems/ha and were thinned at age 9 to 500 stems/ha. The values of volume and carbon were reduced by 15% to account for stand gaps.