Allometric relationships for estimating biomass in grey box (*Eucalyptus microcarpa*)

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Summary

A procedure is described for obtaining allometric relationships between stem diameter and aboveground biomass for grey box, *Eucalyptus microcarpa*, a commonly occurring tree in the Victorian and New South Wales Riverina. While usually having a single trunk, a significant proportion of grey box individuals have multiple stems from near the ground. This is an artifact of enhanced epicormic growth when juvenile, often resulting from stock grazing disturbance. The procedure treats each stem formed from below 30 cm above ground as a discrete tree that shares a proportion of the butt and other elements common to all stems. Significant allometric relationships, using both the commonly-applied log-transformed method, and a recently proposed additive error method, were developed between stem diameter at breast height and at 30 cm above ground, tree height and width, and the dry weights of each aboveground component. These relationships were similar to those previously obtained for single-stemmed trees in southern Australia.

Keywords: biomass; relationships; grey box; *Eucalyptus microcarpa*; Australia

Introduction

Grey box is a small to medium-sized woodland tree found on gentle slopes and plains in New South Wales, adjacent areas of Queensland, in central and northern Victoria, and in limited localities in South Australia (Brooker and Kleinig 1983; Boland *et al.* 1984). The species occurs as the dominant in woodland formation, but is regularly associated with other eucalypts including yellow box (*Eucalyptus melliodora*), Blakely's red gum (*E. blakelyi*), red box (*E. polyanthemos*), river red gum (*E. camaldulensis*), yellow gum (*E. leucoxylon*), red ironbark (*E. sideroxylon*) and mugga ironbark (*E. tricarpa*), in an association commonly referred to as box-ironbark woodland (Boland *et al.* 1984; Calder *et al.* 1994).

Grey box is commonly 15–25 m in height, up to 1 m diameter at breast height (dbh), and at its best is of good form, with a straight bole to about one half of tree height (Boland *et al.* 1984). There is a high proportion of stems from near ground level at sites where it has been impacted by stock grazing when juvenile, and where the vegetative response has been the formation of epicormic growth (Hamilton and O'Dwyer 2004).

Living organisms exhibit size-correlated variations in form, and this is referred to as allometry. Allometric relationships are used to relate the biomass of components to auxiliary variables that are easily measured, such as tree dimensions. Calibration data are obtained for biomass and tree dimensions from individual trees that cover a range of sizes, and are representative of the population (Keith *et al.* 2000). Allometric equations for estimating above-ground biomass of southern Australian eucalypts from the measurements of stem dbh or at some other stem height have been reported in a number of studies (e.g. Attiwill 1966; Ashton 1976; Hingston *et al.* 1979; Stewart *et al.* 1979; Feller 1980; Applegate 1982; Adams and Attiwill 1988; Bi *et al.* 2004). Most of these studies have been conducted on commercially significant single-trunked erect eucalypts in wetter forest types, such as *E. diversicolor*, *E. grandis*, *E. obliqua*, *E. pilularis* and *E. regnans* (Keith *et al.* 2000). Some of the more recent studies have focused on the estimation of both older and younger individuals with an emphasis on establishing the biomass of the tree from a carbon sequestration viewpoint (Keith *et al.* 2000). In all of these cases, robust allometric relationships between dry weight and stem diameter have been consistently established (Attiwill 1966; Ek 1979). This has reinforced the view that geometric relationships between tree dimensions and biomass describe the mechanistic dependency that underpins the usually strong statistical correlation (Keith *et al.* 2000).

There have been no allometric studies on southern woodland eucalypts, but some mallee and northern woodland species (Burrows 1976; Westman and Rogers 1977a,b; Burrows *et al.* 2000) have been evaluated. Only the study by Clough *et al.* (1997) on mangrove species has examined multi-stemmed species. Clough *et al.* (1997) noted that, in principle, it should be possible to obtain reliable allometric relationships for multi-stemmed (or branched) trees using either of two approaches. The first is to treat each stem as a separate tree and to partition the common biomass to each stem according to its relative diameter. The second is to combine the diameters of separate stems (or main branches) in a way that provides an estimate of the equivalent stem diameter of a tree with a single stem.

In this paper, we show that the first of these approaches, in which each stem is treated as an individual tree, and shared material is divided between the stems, can yield reliable allometric relationships in a species that is predominantly single-trunked, but will regularly form multiple trunks after disturbance when juvenile.

This study also compares two methods used to calculate biomass in the components of trees and total tree biomass: the more commonly used log-transformed approach, and a more recent variant to produce a more reliable total tree biomass using additive error terms from component regressions (Bi *et al.* 2004). The stimulus for this research is to develop a method for the reliable estimation of overstorey biomass to assist in the determination of the biomass and nutrient levels in all components of a grey box woodland ecosystem.

Methods

Sampling sites

Trees were sampled from within the Dookie Bushland Reserve (DBR). This is an area of about 270 ha, located in the centre of the Dookie College campus of the University of Melbourne (Dookie 8025 1:100 000 AMG 382 5970). Dookie College is about 8 km south of the township of Dookie, some 35 km east of Shepparton and 35 km west of Benalla, in northern Victoria. The climate of the DBR is typically Mediterranean, with an average annual rainfall of 556 mm and 99 rain days, mostly in the winter months. The DBR and its biophysical features are fully detailed in Hamilton (1999) and Hamilton *et al.* (2002).

Sampling

A total of 18 trees was sampled across the range of tree sizes found within the DBR. Larger-diameter trees were opportunistically sampled (i.e. after the natural fall of a stem following a storm or from trees felled for power line or fence clearance) through the period July 1996 to June 1998, and smaller trees were deliberately felled in July 1996.

The diameter of the stem at 30 cm above the ground (D_{30}), dbh (1.3 m), the length and diameter of the main stem at its apex, the height of tree and the width of the canopy were measured. Trees were considered to be single stemmed if branching occurred at a height greater than dbh. Three of the trees sampled had two stems from near ground level (branching from below 30 cm), and thus all stems had a D_{30} and dbh recorded, even if they were from the same tree. In these individuals, the stemwood and stembark material below the point of branching was proportionally divided between the two stems, alleviating the need for separate calculations of shared biomass.

Data from individual stems were modelled using

$$\log_{10}(y_i) = b + cT_i + (a + dT_i)\log_{10}(x_i) + \varepsilon_i, \qquad (1)$$

where y_i represents the individual dependent variable data point, x_i represents the individual independent variable data point, ε_i is the residual error term, and T_i is a dummy variable such that when the tree is single-stemmed $T_i = 0$ and when the tree is multi-stemmed $T_i = 1$. The regression constants a, b, c and d are used for the multi-variable regression. The dummy variable T_i was included to better model the influence of the multi-stemmed status of the tree in the regression model.

No fewer than 6 discs of stemwood and stembark of 10 cm width were cut at equidistant spacing along each stem. These discs were separated into stemwood and stembark, and the fresh weight of each recorded on-site with a 50 kg spring scale. The separated components were then dried to constant weight at 80°C and weighed. Wood density values were obtained using increment corer samples derived from grey box trees (felled for the purposes of road widening), and by the water displacement method (Ilic *et al.* 2000). Twelve tree stems (all of over 25 cm dbh) were used for core sampling, with four cores being taken along the stem of each. The resulting density value of 837 kg m^{-3} (± 11 kg m^{-3} sd) compares favourably with, and has considerably less variance than, the only published values available: 835 kg m^{-3} (Bootle 1983) and 840 kg m^{-3} (Dadswell 1972). The fresh weight to dry weight ratio, volume and density of the stemwood discs, and the stem dimensions were used to determine the biomass of the main stem from this sub-sampling procedure.

All leaves, twigs and branches from a stem were separated, and the branchwood and branchbark were further separated into individual components. Live and dead branches were combined. The fresh weight of all samples over 20 kg in weight was determined using a weighbridge (± 0.5 kg), and the weight of samples under 20 kg was determined using a desktop electronic balance (± 10 g). Sub-samples of each of these components were taken randomly, then dried to constant weight at 80°C and weighed, and the dry weight to fresh weight ratio determined.

Regression equations relating the dry weight of individual tree components and total tree aboveground weight to diameter measurements were then developed. Total stem biomass was calculated by two methods:

- separate equations for tree components and total tree biomass using tree diameter as the variable using log-transformed data through least squares regression (after Keith *et al.* 2000);
- a series of additive biomass equations for components and total tree biomass using tree diameter as the variable which take into account the inherent correlation among biomass components (after Bi *et al.* 2004).

Data analysis involved the calculation of the slope, intercept, correlation coefficient (r^2), standard error of slope and standard error of intercept for the linear regression between the logarithm to base ten of either D_{30} or dbh and the various tree growth parameters. The significance of all regressions was tested using analysis of variance.

Results and discussion

The properties and characteristics of the eighteen stems evaluated from the fifteen sample trees are shown in Table 1. Stems ranged from 6 to 101 cm in dbh, 6.3 to 19.8 m in height, 0.9 to 15.6 m in width, and from 15.6 to 7410 kg in total biomass (Table 1). Clearly, stemwood and stembark are the major contributors to stem biomass (Table 1). The total biomass of the largest grey box individuals is similar to estimates for same diameter individuals of sclerophyll forest species, such as *E. obliqua*, *E. pilularis* and *Corymbia intermedia* (Keith *et al.* 2000). However, all of these species typically have taller individuals and maintain a more erect growth habitat, and generally occur in greater density (Boland *et al.* 1984), so comparisons are difficult to make.

Table 1. Properties of the 18 stems of grey box measured ranked according to increasing dbh. Stems with the same number were from the same individual tree. All weight values are dry weights. Total biomass has been calculated by summing all components.

Stem	No. of stems on tree	dbh (cm)	D_{30} (cm)	Height (m)	Width (m)	Stem-wood (kg)	Stem-bark (kg)	Leaves (kg)	Branch-wood (kg)	Branch-bark (kg)	Twigs (kg)	Total biomass (kg)
1	1	6.0	8.5	6.3	0.9	10.2	3.5	0.3	5.0	1.2	1.7	22.0
2a	2	9.0	11.0	9.1	3.2	10.0	3.0	0.2	1.4	0.5	0.5	15.6
2b	2	19.0	25.0	10.5	5.9	73.6	15.4	2.9	15.9	2.6	10.0	120.5
3	1	10.5	14.0	8.7	3.4	12.5	3.0	0.4	3.7	0.9	2.9	23.3
4	1	13.0	16.0	8.5	3.8	47.1	10.9	1.6	5.0	1.1	1.7	67.5
5	1	17.0	21.0	11.1	6.2	74.5	19.0	2.7	8.9	1.6	2.1	108.9
6a	2	22.0	28.5	12.1	7.5	147.7	34.9	4.9	22.8	3.8	6.1	220.2
6b	2	29.0	36.0	14.3	9.4	210.9	39.8	10.2	52.5	9.7	10.6	333.7
7	1	32.0	40.5	13.8	9.3	287.7	65.7	18.9	50.1	6.5	11.1	440.0
8a	2	38.0	46.5	14.0	10.1	476.5	94.7	23.7	101.7	21.0	29.4	747.0
8b	2	52.0	58.5	16.4	12.0	1209.3	222.3	42.3	304.8	67.7	40.3	1886.5
9	1	40.5	47.5	15.2	10.7	502.3	97.2	21.3	156.8	27.3	23.0	827.9
10	1	42.5	49.0	16.8	13.2	594.8	115.1	24.0	176.5	30.7	18.4	959.6
11	1	43.0	51.5	14.9	10.8	575.7	106.7	18.6	233.7	25.4	40.9	1001.0
12	1	63.0	71.0	18.0	14.2	1789.5	298.3	59.0	403.7	74.6	55.7	2680.8
13	1	77.0	87.0	18.4	14.0	3243.6	444.7	70.1	582.5	105.6	70.2	4516.8
14	1	80.0	89.0	18.3	15.6	2874.3	418.3	60.3	622.6	98.6	65.5	4139.6
15	1	101.0	114.0	19.8	15.5	5504.1	645.7	79.4	956.2	142.3	82.3	7410.1

Table 2. Log–log regressions for biomass components in grey box. Individual stem details are given in Table 1. All regressions are for allometric relationships between tree components and tree diameter in the form $\log_{10}(\text{component}) = a \log_{10}(\text{dbh}) + b$, where dbh is diameter at breast height (1.3 m). rsd is the residual standard deviation.

	n	Slope (*a*)	Intercept (*b*)	r^2	Standard error (slope)	Standard error (intercept)	rsd
Height (m)	18	0.39	0.54	0.96	0.02	0.03	0.03
Width (m)	18	0.86	–0.38	0.88	0.08	0.12	0.11
Stemwood (kg)	18	2.43	–1.16	0.98	0.08	0.12	0.11
Stembark (kg)	18	2.12	–1.40	0.97	0.09	0.13	0.13
Branchwood (kg)	18	2.43	–1.82	0.94	0.15	0.22	0.21
Branchbark (kg)	18	2.23	–2.26	0.93	0.15	0.23	0.22
Twigs (kg)	18	1.80	–1.56	0.90	0.15	0.23	0.22
Leaves (kg)	18	2.32	–2.47	0.96	0.13	0.19	0.18
Total biomass (kg)	18	2.35	–0.84	0.98	0.08	0.13	0.12
Height (m)	18	0.39	0.54	0.96	0.02	0.03	0.03
Width (m)	18	0.86	–0.38	0.88	0.08	0.12	0.11
Stemwood (kg)	18	2.43	–1.16	0.98	0.08	0.12	0.11
Stembark (kg)	18	2.12	–1.40	0.97	0.09	0.13	0.13
Branchwood (kg)	18	2.43	–1.82	0.94	0.15	0.22	0.21
Branchbark (kg)	18	2.23	–2.26	0.93	0.15	0.23	0.22
Twigs (kg)	18	1.80	–1.56	0.90	0.15	0.23	0.22
Leaves (kg)	18	2.32	–2.47	0.96	0.13	0.19	0.18
Total biomass (kg)	18	2.35	–0.84	0.98	0.08	0.13	0.12

For the three trees that branched near ground level, when the model (1) was applied, in all cases the probability that *c* and *d* were equal to zero was far greater than 0.05. Therefore it was concluded that there was no significant difference between the stems from either single-stemmed and multi-stemmed trees in this investigation. However, given the small number of branched stems sampled, it would be inappropriate to suggest that there was no difference in canopy dimensions and biomass, and further evaluation is required.

Log-transformed approach

Table 2 shows the log–log relationships between dbh and the various tree growth parameters and components, while Table 3 shows the same for D_{30}. There was no statistical difference in the use of one diameter measurement over the other ($P < 0.05$) in terms of the estimated biomass for either individual components and total stem, and so we suggest dbh be used for convenience in field measurement.

Table 3. Log–log regressions for biomass components in grey box. Individual stem details are given in Table 1. All regressions are for allometric relationships between tree components and tree diameter in the form $\log_{10}(\text{component}) = a \log_{10}(D_{30}) + b$, where D_{30} is diameter of the stem at 30 cm in height. rsd is the residual standard deviation.

	n	Slope (a)	Intercept (b)	r^2	Standard error (slope)	Standard error (intercept)	rsd
Height (m)	18	0.42	0.46	0.95	0.02	0.04	0.03
Width (m)	18	0.92	–0.55	0.88	0.09	0.14	0.12
Stemwood (kg)	18	2.62	–1.66	0.98	0.09	0.14	0.12
Stembark (kg)	18	2.28	–1.83	0.97	0.10	0.16	0.13
Branchwood (kg)	18	2.62	–2.33	0.95	0.15	0.24	0.20
Branchbark (kg)	18	2.40	–2.71	0.93	0.16	0.26	0.22
Twigs (kg)	18	1.96	–1.96	0.92	0.15	0.24	0.20
Leaves (kg)	18	2.50	–2.95	0.96	0.13	0.20	0.17
Total biomass (kg)	18	2.53	–1.32	0.98	0.09	0.14	0.12

Table 4. Biomass estimates for various live components of grey box (n = 18), independent of component contributions for hypothetical individuals. Upper and lower limits (P = 0.05) are calculated assuming variable slope and intercept.

dbh (cm)	Stemwood (kg)	Stembark (kg)	Branchwood (kg)	Branchbark (kg)	Twigs (kg)	Leaves (kg)	Total biomass (kg)			
							Sum of components	Calculated		
								Allometric	Upper limit	Lower limit
20	101	23	22	4	6	4	160	164	216	125
40	544	100	118	21	21	18	822	836	1130	618
60	1459	236	317	51	43	45	2152	2164	2978	1573
80	2938	435	638	97	73	88	4268	4252	5922	3053
100	5055	699	1097	160	108	147	7266	7178	10092	5105

All allometric regressions displayed in Tables 2 and 3 were highly significant ($P < 0.001$). The strong level of significance between both dbh and D_{30} of stems, total biomass and the various components conforms with the generally high level of significance observed across the many allometric equations developed with Australian tree species reviewed by Keith *et al.* (2000). As has been the case in most species for which allometric equations have been formed (Keith *et al.* 2000), the strength of the statistical relationships derived in this study, as indicated by the values for rsd for each component, are in the order stemwood > total > stembark > leaves > branchwood/branchbark/twigs (Tables 2 and 3). This is in part due to the greater variability between individuals in the biomass of components such as twigs and branches (and probably the vagaries of the sub-sampling of these components and the extrapolation of these results, as well as the proportion of dead material included), compared with the relative ease of mathematically determining the stemwood and stembark biomass.

Keith *et al.* (2000) evaluated this difference in total biomass value derivation in a case study, and found that summing resulted in a slightly lower total biomass per stem than a total derived from one allometric equation. They considered the summing of component biomass and the associated variances would be an overestimate, and that calculation of an accurate error term for the total biomass derived by the summing of components was a research question requiring further analysis. A hypothetical evaluation of stems with a dbh of 20, 40, 60, 80 and 100 cm using the developed allometric equations for grey box reveals that the difference between summed total biomass and a total biomass calculated by one allometric equation was very small, and both totals fell within the 95% confidence limits of the variability of the intercept attributed to the calculated total biomass (Table 4). The 95% confidence limits at each diameter class indicate a high level of variance about the predicted total biomass (Table 4).

Additive equation approach

Table 5 shows the additive equation relationships between dbh and the various tree growth parameters and components. These relationships are based on the equations of Bi *et al.* (2004) (models 6 and 7 from that paper) that resulted in separate equations for stemwood, stembark, branch and leaves, and an additive equation based on additive error for total stem biomass. The use of these equations has required combining branchwood and branchbark and twigs into one value.

All relationships displayed between dbh and component biomass in Table 5 were highly significant ($P < 0.001$). The strength of the statistical relationships derived using the additive equation approach are in the order total > stembark > branch > leaves > stemwood (Table 5), a somewhat different order to that noted for the log-transformed regressions (Tables 2 and 3). The reduced error of the total stem biomass using this method compared to the log-transformed approach is to be expected given the basis for the derivation of these relationships using additive error terms based on the correlation of component regressions to the total biomass.

Table 5. Estimated coefficients of the system equations (ß) and fit indices (r^2) for grey box stems (n = 18). All regressions are for allometric relationships between tree components in the form $Y = e_{i0}^{\beta} \mathrm{D}_{i1}^{\beta} \varepsilon_i$ where Y is the biomass (kg), D is diameter of the stem at breast height (1.3 m), β_{i0} and β_{i1} are the coefficients of the regression for the ith stem/parameter combination, e is the exponential function, and ε_i is the error term for the ith stem/parameter combination.

Component	Parameter	Parameter value	MS error ratio	Fit index ratio
Stemwood	ß$_{10}$	–2.67	5.35	1.00
	ß$_{11}$	2.43		
	r^2	0.98		
Stembark	ß$_{20}$	–3.22	5.15	1.00
	ß$_{21}$	2.12		
	r^2	0.97		
Branch	ß$_{30}$	–3.37	5.20	1.00
	ß$_{31}$	2.29		
	r^2	0.94		
Leaves	ß$_{40}$	–5.68	5.29	1.00
	ß$_{41}$	2.31		
	r^2	0.96		
Total	r^2	0.99	5.12	1.01

Table 6. Biomass estimates for various live components of grey box (n = 18), based on the additive equation approach of Bi *et al.* (2004). Upper and lower limits (P = 0.05) are calculated assuming constant slope but variable intercept.

dbh (cm)	Stemwood (kg)	Stembark (kg)	Branchwood (kg)	Leaves (kg)	Total biomass (kg)			
					Sum of components	Calculated		
						Allometric	Upper limit	Lower limit
20	100	23	33	4	160	161	178	144
40	541	100	160	17	818	825	909	739
60	1450	235	406	44	2135	2155	2369	1930
80	2917	433	784	85	4219	4263	4678	3818
100	5017	694	1310	142	7161	7240	7936	6484

A hypothetical evaluation of stems with a dbh of 20, 40, 60, 80 and 100 cm using the developed additive equations for grey box reveals that the summed total biomass and a total biomass calculated by the one allometric equation were the same, and both totals fell within the 95% confidence limits of the variability of the intercept attributed to the calculated total biomass (Table 6). The 95% confidence limits at each diameter class indicate a very low level of variance about the predicted total biomass (Table 6).

Comparison of approaches

It is reported that many of the allometric relationships derived for biomass, i.e. the log-transformed approach, generate separate estimates for components without taking into account the inherent correlation among biomass components measured on the same trees, and the logical constraint between the predicted biomass for tree components and the prediction for the total tree (Bi *et al.* 2004). Thus, it is suggested, these log-transformed equations are not estimated efficiently, leading to lack of additivity of equations in the calculation of a total stem biomass (Kozak 1970; Parresol 1999). The additive error approach is a more recent variant designed to produce a more reliable total tree biomass using additive error terms from component regressions (Bi *et al.* 2004).

Use of both approaches to calculate stem biomass in this paper has indicated little difference between modelled biomass estimates for either component or total tree (stem) biomass at hypothetical dbh values of 20, 40, 60, 80 and 100 cm: estimates of components and total biomass for either estimate at all diameter classes fitted well within the calculated upper and lower limits determined for either approach (P = 0.05, Tables 4 and 6). There was a much reduced variance about the predicted total biomass with the additive approach, as indicated by the 95% confidence interval about the intercept, leading to a higher level of confidence in the estimate provided.

Estimates for total biomass using the additive error approach also were similar to the total biomass values obtained with the log-transformed approach by the summing of component values derived by separate equations, particularly in the lower diameter classes (Tables 4 and 6).

It appears, therefore, that either approach provides estimates of component biomass of similar reliability. However, statistical appraisal indicates that the total tree (stem) biomass estimate derived by an individual equation, or indeed by adding component equations using the additive error approach, is a significantly better predictor than the log-transformed approach based on confidence intervals at $P = 0.05$.

Conclusion

Significant allometric relationships between stem diameter at 30 cm and breast height, total biomass and the biomass of tree components were established for grey box. Given the propensity of the species to develop multiple trunks from near ground level, this study indicated that the stems in such individuals were not significantly different in height, width or biomass compared to the stems of trees with only the primary stem. When trees with multiple stems branching near the ground were measured in this study, the portion of stem below the branching point was equally divided between the stems, and this biomass was included in the measurements for stemwood and stembark for the stem. The high level of significance of the relationships developed suggests that this method has attributed the biomass of this unbranched section of the trunk appropriately, but further specific studies on this aspect are required to assert this view with confidence.

Evaluation of the summed and calculated total biomass for grey box using the log-transformed approach resulted in no significant difference between the estimates. However, the likely greater error associated with the summed value (Keith *et al.* 2000) suggests that the calculated method is better. Comparison of the log-transformed and additive error approaches (Bi *et al.* 2004) revealed no significant differences in the determination of either stem components or stem total biomass; however, the total stem biomass is much more reliably calculated by the additive error approach, as indicated by reduced variance.

The developed relationships will be used to determine the total overstorey biomass (or biomass density value) of grey box woodland areas. This is essentially an up-scaling process, where the dbh of every stem in the defined area will be measured, and biomass of the components and of total tree biomass predicted using the derived allometric equations. The derived biomass density value is estimated without error in the summation process, and is independent of the number of trees or stems measured or the size of the plot (Keith *et al.* 2000).

Grey box will often occur in mixed species stands with yellow, black and white box, and river red gum, and clearly, the derivation of a total biomass density value for such areas would require extrapolation of the allometric relationships here to another species. Some studies have suggested that woody biomass allometry does not necessarily differ significantly within the same genus (Hingston *et al.* 1979; Senelwa and Sims 1998; Burrows *et al.* 2000), and Burrows *et al.* (2000) believes that it may not be necessary to determine individual biomass allometric relationships for all eucalypt species to obtain reliable biomass estimates in mixed communities. However, it is clear that this conclusion requires further testing in natural stands over a wide age class range. Nevertheless, it is likely that the relationships derived in this study could be applied with some confidence to species that share similar habitats and exhibit similar growth habits, such as yellow and white box. Differences in aspects such as wood density would need to be considered (e.g. published estimates for yellow box and white box are 899 kg m^{-3} and 900–915 kg m^{-3} respectively; Ilic *et al.* 2000).

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