3.3.2. Tree mensuration

Weight, volume and density

The results of disc analysis (section 3.3.1) were used in conjunction with harvested tree weight data (section 3.2.4) to derive estimates of the dry-weight, green and dry-density and volume of the timber and bark, stem and branchwood of harvested trees. Results are listed for individual trees of each species in Appendices XII and XIII. Tree mensuration data for dead trees are tabulated in Appendix XIV.

Species comparisons

Comparison of volume and weight of *E. caliginosa* and *E. laevopinea* in terms of CNVOL, HT and DBH revealed a similarity in tree form and timber and bark factors (Tables 3.7 - 3.9). Student's *t*-tests (Zar 1984, section 3.2.5) found no significant difference between any of the nine covariates. The data for both species were pooled into a common 'stringybark' class, the results of which were tested against those of yellow box.

With respect to independent variable HT, no significant variation was observed between stringybark and yellow box in tree volume or weight (Table 3.8). Conversely, the relationship between each of the dependent variables with DBH differed markedly between stringybark and yellow box (Table 3.9). The volume-CNVOL and green-weight-CNVOL functions also differed between species, and the species difference in the relationship between dry-weight and CNVOL was marginally significant ($0.05 < P < 0.1$) (Table 3.7).

Table 3.7. Between-species comparisons of volume and weight as a function of CNVOL.

	E. caliginosa vs. *E. laevopinea*			stringybark vs. *E. melliodora*	
Dependent variable	*t*	P	c	*t*	P
Volume	0.894	0.2 < P < 0.5	✓	3.200	0.002 < P < 0.005 **
Green-weight	0.335	P > 0.5	✓	2.487	0.01 < P < 0.02 *
Dry-weight	0.616	P > 0.5	✓	1.817	0.05 < P < 0.1

c = *E. caliginosa* and *E. laevopinea* data combined if P > 0.05 (✓)

Table 3.8. Between-species comparisons of volume and weight as expressed by HT.

	E. caliginosa vs. *E. laevopinea*			stringybark vs. *E. melliodora*	
Dependent variable	*t*	P	c	*t*	P
Volume	1.190	0.2 < P < 0.5	✓	0.272	P > 0.5
Green-weight	1.581	0.1 < P < 0.2	✓	0.434	P > 0.5
Dry-weight	1.402	0.1 < P < 0.2	✓	0.789	0.2 < P < 0.5

c = *E. caliginosa* and *E. laevopinea* data combined if P > 0.05 (✓)

Table 3.9. Between-species comparisons of volume and weight as expressed by DBH.

	E. caliginosa vs. *E. laevopinea*			stringybark vs. *E. melliodora*	
Dependent variable	*t*	P	c	*t*	P
Volume	1.012	0.2 < P < 0.5	✓	3.991	P < 0.001 ***
Green-weight	0.083	P > 0.5	✓	6.505	P < 0.001 ***
Dry-weight	0.056	P > 0.5	✓	7.568	P < 0.001 ***

c = *E. caliginosa* and *E. laevopinea* data combined if P > 0.05 (✓)

3.3.3. Single-variate regression

Derivation of functions

Regression analyses were undertaken on yellow box data and pooled stringybark data. DBH as the independent variable was the best predictor of fuelwood biomass variables in forest trees. At least 83.3% (r^2) of the variation in all biomass variables was explained by DBH and each expression was significant at the 0.001% level according to the *F*-statistic. Table 3.10 lists the weight and volume regression equations for stem and branch, timber and bark components of live-felled stringybark and yellow box, along with relevant statistical results.

As in other tree biomass studies (Feller 1980; Schönau and Boden 1982; Corbyn *et al.* 1988), branchwood was the least well predicted of all variables, especially in stringybark. The largest stringybark sampled (DBH = 80 cm) grew in a clearing and contained a disproportionately high quantity of branchwood and a smaller amount of stemwood than stringybarks in open forest. The individual stem and branch data for this tree were found to reduce substantially the predictive power of stem and branch models in stringybark, and were subsequently omitted from the derivation of respective functions listed in Table 3.10.

Figures 3.6, 3.7 and 3.8 present regression plots for stringybark and yellow box of green tree weight, air-dry tree weight and tree volume, respectively (scatterplots of relationships of DBH with individual tree components are provided separately in Appendix XV (i-ix)). The total weight of a yellow box tree is comparatively greater than the total weight of a stringybark tree for any value of DBH (Figures 3.6 and 3.7). This is explained by the higher timber density, higher timber : bark volume ratio, and the more prolific branching traits of yellow box, as explained further in the following sections.

Table 3.10. Least squares univariate regressions of weight and volume on DBH for stringybark and yellow box.

Dep. Var.	TC*	Spp.	N	Regression equation	r	Adj. r^2	SE(est)
Green Weight (kg)	S-t	SB	23	$= 0.605*(DBH-5)^2 - 58.938$	0.985	0.970	88.5
		YB	12	$= 0.731*(DBH-5)^2$	0.999	0.998	46.2
	S-b	SB	23	$= 0.127*(DBH-5)^2 - 7.289$	0.984	0.968	19.2
		YB	12	$= 0.074*(DBH-5)^2 + 30.859$	0.924	0.840	31.0
	B-t	SB	23	$= 0.243*(DBH-15)^2 + 18.799$	0.920	0.839	59.0
		YB	12	$= 0.445*(DBH-5)^2$	0.985	0.970	109.0
	B-b	SB	23	$= 0.084*(DBH-15)^2 + 6.294$	0.936	0.871	17.9
		YB	12	$= 0.093*(DBH-5)^2$	0.984	0.969	23.3
	S	SB	23	$= 0.732*(DBH-5)^2 - 66.227$	0.985	0.969	107.3
		YB	12	$= 0.800*(DBH-5)^2 + 39.728$	0.996	0.992	68.5
	B	SB	23	$= 0.326*(DBH-15)^2 + 25.092$	0.924	0.848	76.9
		YB	12	$= 0.538*(DBH-5)^2$	0.985	0.970	132.0
	t	SB	52	$= 0.830*(DBH-5)^2 - 103.446$	0.986	0.971	151.4
		YB	12	$= 1.175*(DBH-5)^2$	0.998	0.996	108.9
	b	SB	52	$= 0.181*(DBH-5)^2 - 8.796$	0.986	0.972	32.2
		YB	12	$= 0.169*(DBH-5)^2 + 27.051$	0.964	0.953	47.3
	TOT	SB	52	$= 1.011*(DBH-5)^2 - 112.242$	0.986	0.972	181.4
		YB	12	$= 1.359*(DBH-5)^2$	0.997	0.994	148.2
Air-dry Weight (kg)	S-t	SB	23	$= 0.422*(DBH-5)^2 - 43.038$	0.985	0.969	61.8
		YB	12	$= 0.568*(DBH-5)^2$	0.999	0.998	34.2
	S-b	SB	23	$= 0.092*(DBH-5)^2 - 6.836$	0.985	0.968	13.7
		YB	12	$= 0.043*(DBH-5)^2 + 16.609$	0.934	0.860	16.9
	B-t	SB	23	$= 0.163*(DBH-15)^2 + 12.755$	0.917	0.833	40.6
		YB	12	$= 0.344*(DBH-5)^2$	0.985	0.970	84.3
	B-b	SB	23	$= 0.052*(DBH-15)^2 + 3.919$	0.930	0.858	11.7
		YB	12	$= 0.052*(DBH-5)^2$	0.984	0.969	13.1
	S	SB	23	$= 0.513*(DBH-5)^2 - 49.874$	0.985	0.969	75.4
		YB	12	$= 0.608*(DBH-5)^2 + 24.359$	0.997	0.993	48.7
	B	SB	23	$= 0.215*(DBH-15)^2 + 16.674$	0.920	0.839	52.3
		YB	12	$= 0.397*(DBH-5)^2$	0.985	0.970	97.2
	t	SB	52	$= 0.606*(DBH-5)^2 - 83.458$	0.981	0.962	127.4
		YB	12	$= 0.932*(DBH-5)^2$	0.996	0.996	110.1
	b	SB	52	$= 0.128*(DBH-5)^2 - 7.012$	0.987	0.974	21.9
		YB	12	$= 0.097*(DBH-5)^2 + 14.439$	0.967	0.929	26.0
	TOT	SB	52	$= 0.733*(DBH-5)^2 - 90.469$	0.983	0.965	147.1
		YB	12	$= 1.036*(DBH-5)^2$	0.996	0.992	132.5
Volume (m^3)	S-t	SB	23	$= 0.000580*(DBH-5)^2 - 0.065499$	0.983	0.965	0.092
		YB	12	$= 0.000602*(DBH-5)^2$	0.999	0.998	0.036
	S-b	SB	23	$= 0.000221*(DBH-5)^2 - 0.015241$	0.982	0.962	0.036
		YB	12	$= 0.000077*(DBH-5)^2 + 0.030984$	0.934	0.859	0.030
	B-t	SB	23	$= 0.000248*(DBH-15)^2 + 0.014851$	0.941	0.880	0.051
		YB	12	$= 0.000375*(DBH-5)^2$	0.987	0.975	0.084
	B-b	SB	23	$= 0.000132*(DBH-15)^2 + 0.007838$	0.946	0.890	0.026
		YB	12	$= 0.000098*(DBH-5)^2$	0.987	0.975	0.023
	S	SB	23	$= 0.000801*(DBH-5)^2 - 0.080740$	0.983	0.964	0.127
		YB	12	$= 0.000676*(DBH-5)^2 + 0.036581$	0.997	0.992	0.058
	B	SB	23	$= 0.000380*(DBH-15)^2 + 0.022689$	0.943	0.884	0.077
		YB	12	$= 0.000473*(DBH-5)^2$	0.987	0.975	0.106
	t	SB	52	$= 0.000799*(DBH-5)^2 - 0.109227$	0.978	0.956	0.180
		YB	12	$= 0.000977*(DBH-5)^2$	0.999	0.997	0.073
	b	SB	52	$= 0.000304*(DBH-5)^2 - 0.011812$	0.981	0.961	0.065
		YB	12	$= 0.000176*(DBH-5)^2 + 0.027763$	0.970	0.935	0.045
	TOT	SB	52	$= 0.001103*(DBH-5)^2 - 0.121039$	0.980	0.960	0.237
		YB	12	$= 0.001192*(DBH-5)^2$	0.996	0.993	0.142

* TC = tree component (S = stem; B = branches; t = timber; b = bark)

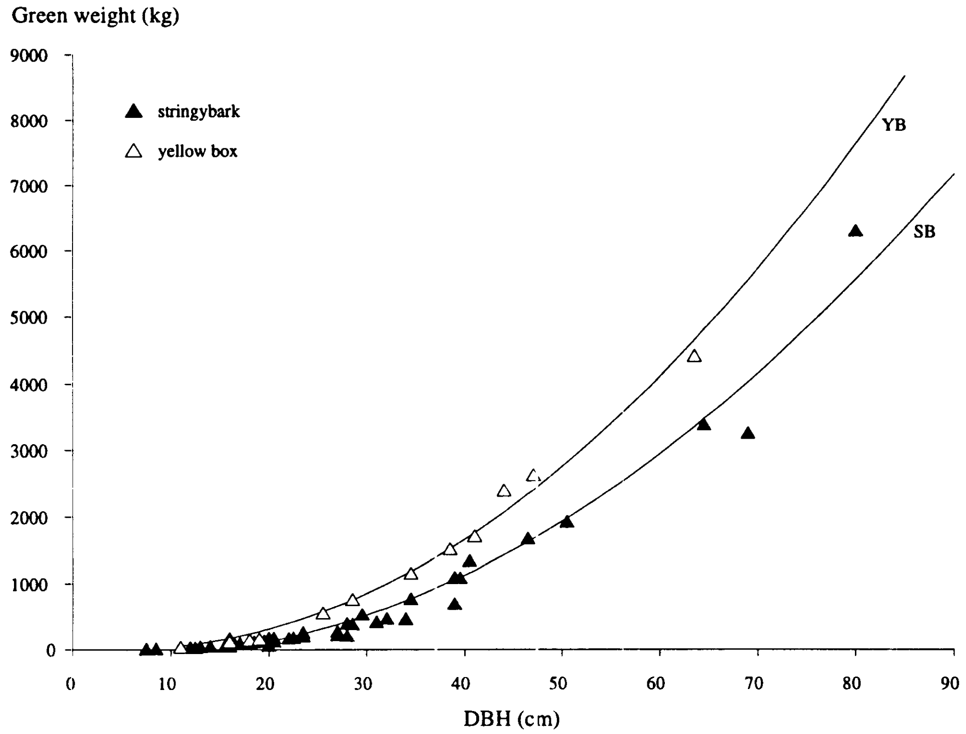


Figure 3.6. Relationship between green-weight of fuelwood biomass and tree DBH in stringybark and yellow box.

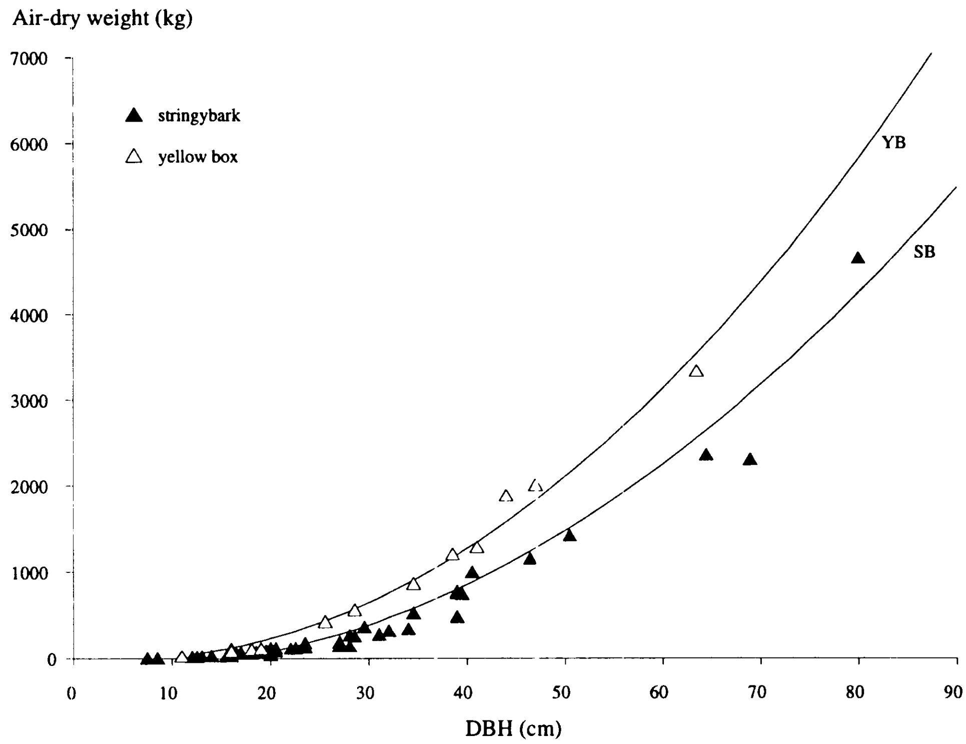


Figure 3.7. Relationship between dry-weight of fuelwood biomass and DBH in stringybark and yellow box.

Volume (m3)

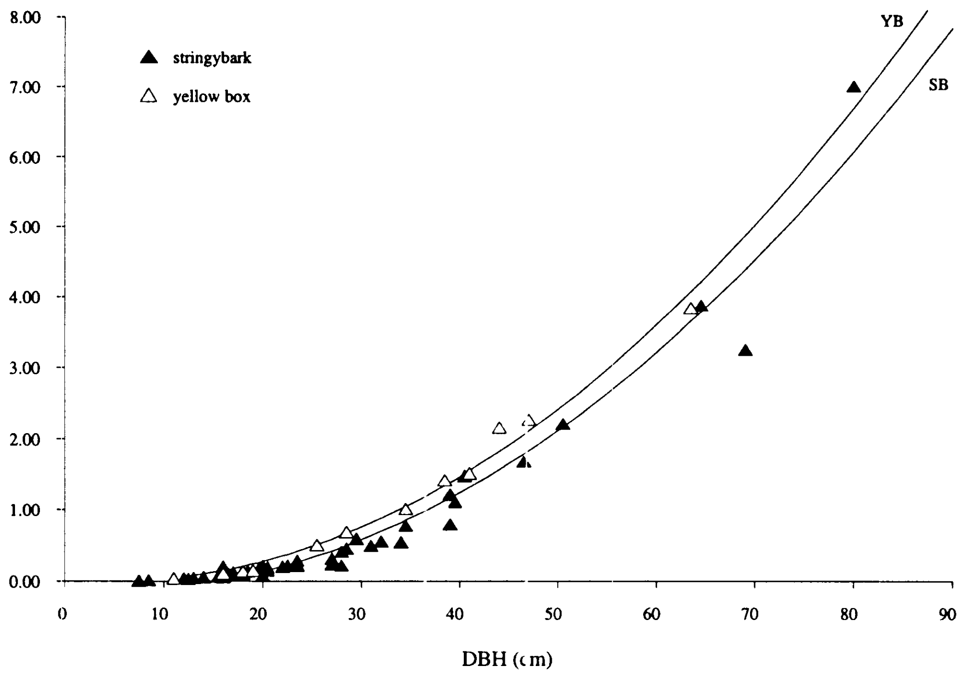


Figure 3.8. Relationship between volume of fuelwood biomass and tree DBH in stringybark and yellow box.

Stem and branch functions

Each of the stem and branch functions for dry-weight listed in Table 3.10 was used to compare the branch : stem ratios of stringybark and yellow box. Figure 3.9 shows the contribution of stem and branchwood to standing dry-weight and Figure 3.10 compares the branch : stem ratios of each.

It is evident from Figure 3.9 that branchwood contributes significantly more to total tree weight in yellow box than in stringybark for a given DBH. The branchwood of a tree with a 50 cm DBH, for example, comprises about 38% of the total dry-weight of fuelwood biomass in yellow box, compared with about 20% in stringybark. It is evident from Figure 3.10 that the proportion of branch to stemwood increases to a critical tree DBH in both species, after which it decreases with increasing DBH. The maximum ratio of branches to stems in yellow box is 0.72 at 52 cm DBH compared with 0.38 at 46 cm DBH for stringybark. The higher ratio in yellow box probably reflects the greater volume and branch weight of its canopy because of its association with open forest and woodland of lower stand density than stringybark. The results contrast with a similar stem-branch analysis undertaken by Corbyn *et al.* (1988) for oak and beech in the UK, in which the proportion of branch to stemwood was found to increase indefinitely with DBH. The comparison provides evidence of the propensity of eucalypts to shed more branches with increasing age, which appears from Figure 3.10 to accelerate as trees increase in size from about 50 cm DBH. Branch shedding is well documented in eucalypts, and has a passive role to play in stands managed specifically for fuelwood production (section 8.2.5).

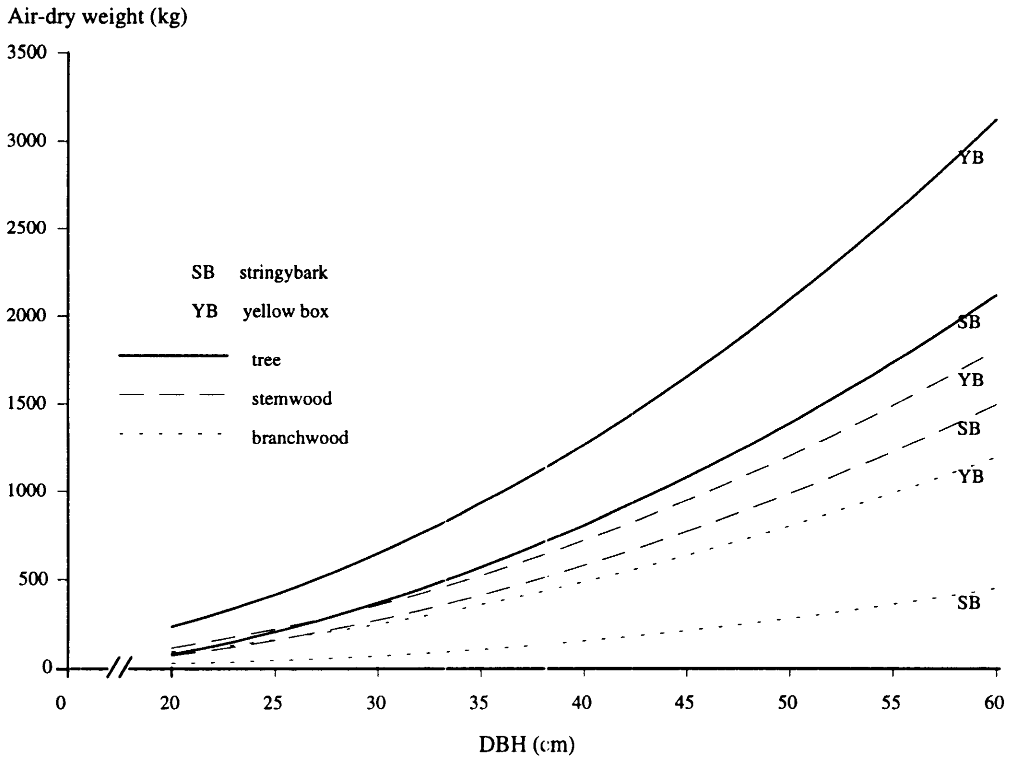


Figure 3.9. Distribution of dry-weight in the stem and branches of stringybark and yellow box.

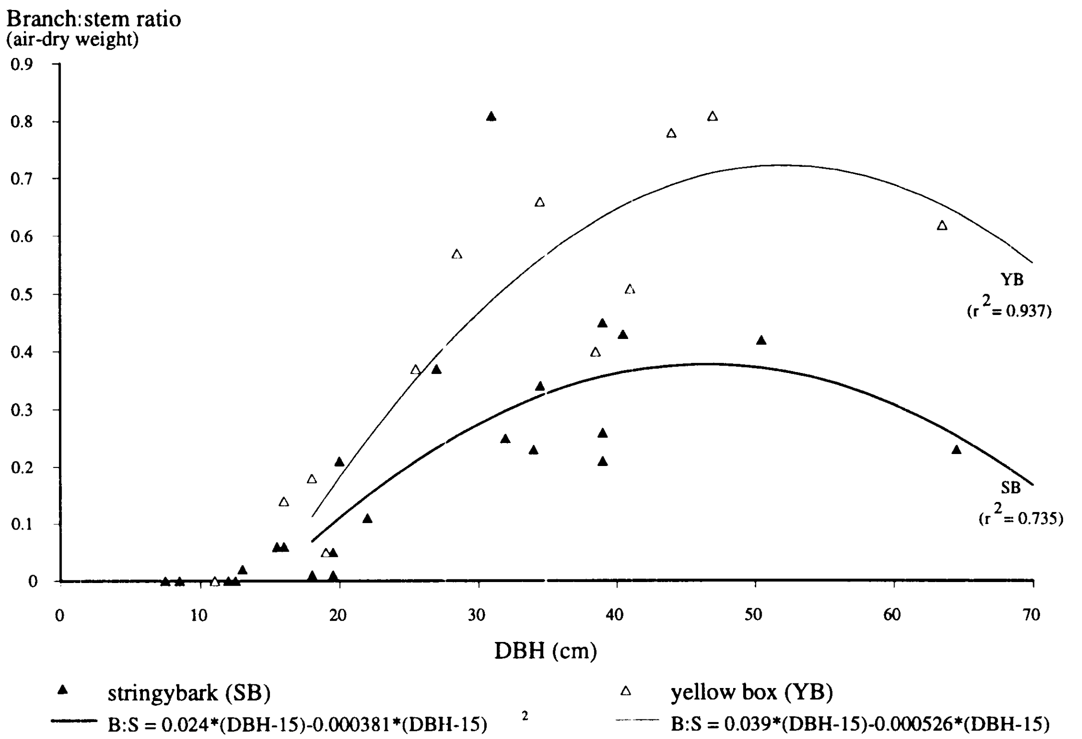


Figure 3.10. Dry-weight of branchwood expressed as a ratio of the dry-weight of stemwood for stringybark and yellow box over a range of tree sizes.

Timber and bark functions

The timber and bark functions for dry-weight listed in Table 3.10 were used to compare timber : bark weight ratios of stringybark and yellow box. Figure 3.11 shows the contribution of timber and bark to total dry-weight and Figure 3.12 compares their ratios. Bark contributes more to total weight in stringybark than yellow box. For a tree of 50 cm DBH, bark contributes about 18% of the total 1 400 kg in stringybark, compared to 10% of the total 2 100 kg in yellow box.

The timber : bark weight ratio in both species increases with DBH (Figure 3.12), indicating that the rate of formation of wood increases with respect to the rate of formation of bark as trees increase in size. This is supported by other studies of eucalypt biomass allocation (Frederick *et al.* 1985a,b; Madgwick *et al.* 1991; Ranasinghe and Mayhead 1991). Using respective bark-volume equations in Table 3.10, stringybark contains more bark than yellow box in trees of DBH 31.3 cm and over despite the former's comparatively low proportion of branchwood and subsequent surface area. This indicates a large species difference in bark depth or thickness. Feller (1980) found similar results when comparing the stem bark biomass of *E. obliqua* with that of mountain ash *E. regnans* and broad-leaved peppermint *E. dives*.

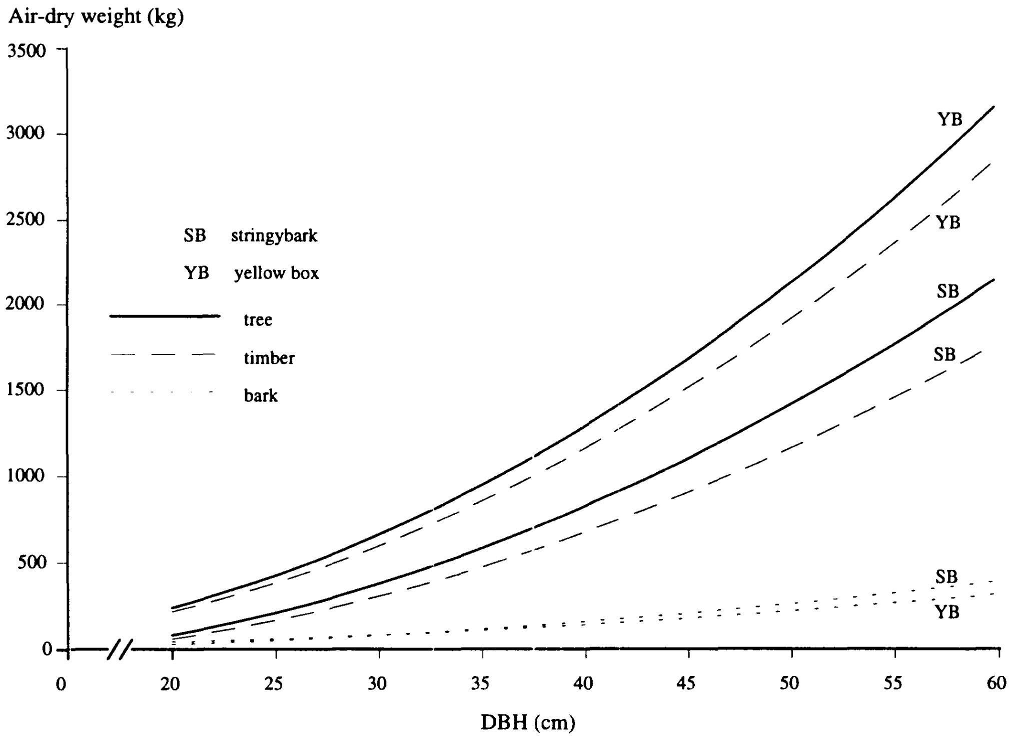


Figure 3.11. Distribution of dry-weight in the timber and bark of stringybark and yellow box.

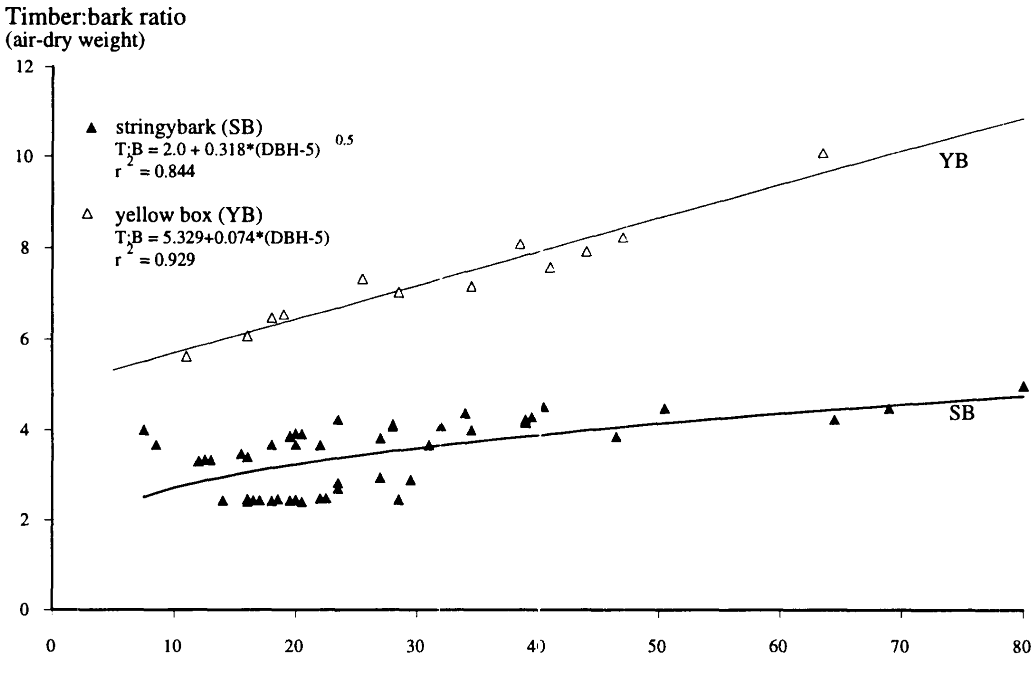


Figure 3.12. Dry-weight of timber expressed as a ratio of the dry-weight of bark for stringybark and yellow box over a range of tree sizes.

Dead trees

Dead trees play a prominent role in fuelwood supply systems in temperate Australia (Morse 1985b; FTS and UT 1989; Wall and Reid 1993). The harvesting and weighing of 13 dead trees (Appendix XIV) revealed two important factors. First, standing dead trees had a moisture content in excess of the norm for air-dry timber (~ 12%). The average moisture content in dead stringybark and yellow box was 18.1% and 15.7% respectively (not including the largest felled yellow box which had probably died within 5 years and retained most of its bark). This suggests that dead standing trees are somewhat limited in their capacity to air-dry fully for wood combustion. Natural branch abscission and formation of hollows, and subsequent interception and gravitational flow of water inside the stem during rainfall events, may impede moisture loss and enhance the decomposition process in dead standing trees, particularly in the heartwood. Second, a comparison of the weight-DBH points obtained for dead trees against the air-dry timber weight plots for stringybark and yellow box (Figure 3.13) illustrates that dead stringybark trees weigh more than would be predicted by the air-dry function in Figure 3.7 while dead yellow box trees weigh less. Coincidentally, dead yellow box fits the trend of air-dry stringybark timber almost perfectly. Although a very small sample of trees was used, the low yellow box weights are possibly explained by loss of branchwood in dead trees. The high weights recorded for dead stringybark could result from moisture retention.

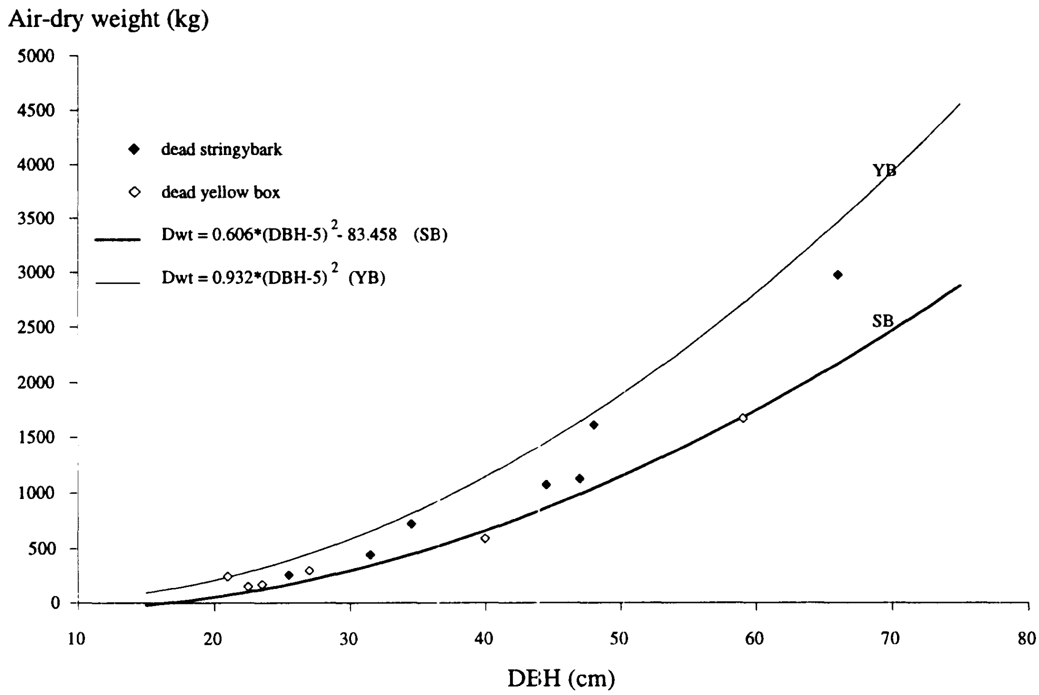


Figure 3.13. Overlay of weight-DBH points for dead trees (Appendix XIV) on timber dry-weight curves (Figure 3.7) for stringybark and yellow box.

3.3.4. Multi-variate regression expressions

Table 3.11 lists the multi-variate weight and volume expressions for stringybark and yellow box. The variables HTB (height to first branch), CNHT and CNAREA did not affect the least-squares fit for any expression and were excluded from analysis.

3.3.5. Effect of site quality on species height and form

Within-species HT-DBH comparisons

Site quality was found to influence the relationship between HT and DBH in stringybark (i.e. the slope of HT-DBH curves varied significantly between site quality classes), but not in yellow box, grey box, ironbark and red gum (Tables 3.12 and 3.13). To determine which site quality classes contributed to HT-DBH differences in stringybark, the multiple comparison Tukey technique using the q-statistic (Zar 1984; section 3.2.6) was employed to compare each pair of slopes using transformed data (eq. 3.27). Results are listed in Table 3.14.

Table 3.11. Least square multiple regression equations for weight and volume variables of stringybark and yellow box.

Dep. Var.	TC*	Spp.	Multiple regression equation
Green Weight (kg)	S-t	SB	= 2.702*(HT*(DBH-5)^2)/100 + 0.439*(HT-5)^2
		YB	= 2.425*(HT*(DBH-5)^2)/100 + 1.495*(HT-5)^2
	S-b	SB	= 0.533*(HT*(DBH-5)^2)/100 + 0.187*(HT-5)^2
		YB	= 0.020*(DBH-5)^2 + 0.532*(HT-5)^2
	B-t	SB	= 5.174*(DBH-15) + 0.146*CNVOL
		YB	= 1.391*(HT*(DBH-5)^2)/100 + 0.191*CNVOL
	B-b	SB	= 1.649*(DBH-15) + 0.054*CNVOL
		YB	= 0.277*(HT*(DBH-5)^2)/100 + 0.044*CNVOL
	S	SB	= 3.235*(HT*(DBH-5)^2)/100 + 0.627*(HT-5)^2
		YB	= 2.471*(HT*(DBH-5)^2)/100 + 2.100*(HT-5)^2
	B	SB	= 6.823*(DBH-15) + 0.200*CNVOL
		YB	= 1.669*(DBH-5)^2)/100 + 0.235*CNVOL
	t	SB	= 1.954*(HT*(DBH-5)^2)/100 + 0.777*CNVOL
		YB	= 3.807*(HT*(DBH-5)^2)/100 + 1.029*(HT-5)^2 + 0.279*CNVOL
	b	SB	= 0.303*(HT*(DBH-5)^2)/100 + 0.169*(HT-5)^2 + 0.206*CNVOL
		YB	= 0.296*(HT*(DBH-5)^2)/100 + 0.540*(HT-5)^2 + 0.065*CNVOL
	TOT	SB	= 2.305*(HT*(DBH-5)^2)/100 + 0.990*CNVOL
		YB	= 4.103*(HT*(DBH-5)^2)/100 + 1.569*(HT-5)^2 + 0.344*CNVOL
Air-dry Weight (kg)	S-t	SB	= 1.904*(HT*(DBH-5)^2)/100 + 0.254*(HT-5)^2
		YB	= 1.875*(HT*(DBH-5)^2)/100 + 1.182*(HT-5)^2
	S-b	SB	= 0.399*(HT*(DBH-5)^2)/100 + 0.101*(HT-5)^2
		YB	= 0.015*(DBH-5)^2 + 0.288*(HT-5)^2
	B-t	SB	= 3.537*(DBH-15) + 0.096*CNVOL
		YB	= 1.080*(HT*(DBH-5)^2)/100 + 0.147*CNVOL
	B-b	SB	= 1.058*(DBH-15) + 0.033*CNVOL
		YB	= 0.155*(HT*(DBH-5)^2)/100 + 0.025*CNVOL
	S	SB	= 2.302*(HT*(DBH-5)^2)/100 + 0.355*(HT-5)^2
		YB	= 1.912*(HT*(DBH-5)^2)/100 + 1.516*(HT-5)^2
	B	SB	= 4.595*(DBH-15) + 0.129*CNVOL
		YB	= 1.236*(HT*(DBH-5)^2)/100 + 0.172*CNVOL
	t	SB	= 1.314*(HT*(DBH-5)^2)/100 + 0.612*CNVOL
		YB	= 2.884*(HT*(DBH-5)^2)/100 + 1.029*(HT-5)^2 + 0.223*CNVOL
	b	SB	= 0.256*(HT*(DBH-5)^2)/100 + 0.112*(HT-5)^2 + 0.127*CNVOL
		YB	= 0.178*(HT*(DBH-5)^2)/100 + 0.295*(HT-5)^2 + 0.037*CNVOL
	TOT	SB	= 1.602*(HT*(DBH-5)^2)/100 + 0.744*CNVOL
		YB	= 3.061*(HT*(DBH-5)^2)/100 + 1.324*(HT-5)^2 + 0.260*CNVOL
Volume (m^3)	S-t	SB	= 2.778*(HT*(DBH-5)^2)/100
		YB	= 2.038*(HT*(DBH-5)^2)/100 + 1.167*(HT-5)^2
	S-b	SB	= 0.971*(HT*(DBH-5)^2)/100 + 0.233*(HT-5)^2
		YB	= 0.023*(DBH-5)^2 + 0.536*(HT-5)^2
	B-t	SB	= 4.245*(DBH-15) + 0.178*CNVOL
		YB	= 1.193*(HT*(DBH-5)^2)/100 + 0.155*CNVOL
	B-b	SB	= 2.190*(DBH-15) + 0.097*CNVOL
		YB	= 0.294*(HT*(DBH-5)^2)/100 + 0.045*CNVOL
	S	SB	= 3.708*(HT*(DBH-5)^2)/100 + 0.136*(HT-5)^2
		YB	= 2.098*(HT*(DBH-5)^2)/100 + 1.776*(HT-5)^2
	B	SB	= 6.435*(DBH-15) + 0.276*CNVOL
		YB	= 1.487*(HT*(DBH-5)^2)/100 + 0.200*CNVOL
	t	SB	= 1.315*(HT*(DBH-5)^2)/100 + 1.000*CNVOL
		YB	= 3.223*(HT*(DBH-5)^2)/100 + 0.920*(HT-5)^2 + 0.203*CNVOL
	b	SB	= 0.374*(HT*(DBH-5)^2)/100 + 0.311*(HT-5)^2 + 0.407*CNVOL
		YB	= 0.325*(HT*(DBH-5)^2)/100 + 0.574*(HT-5)^2 + 0.061*CNVOL
	TOT	SB	= 1.776*(HT*(DBH-5)^2)/100 + 1.420*CNVOL
		YB	= 3.476*(HT*(DBH-5)^2)/100 + 1.736*(HT-5)^2 + 0.273*CNVOL

* TC = tree component (S = stem; B = branch; t = timber; b = bark)

Table 3.12. Analysis of the effect of site quality on the HT-DBH relationship of ironbark and grey box using *t*-tests (2 site quality classes).

Tree	SQ test	Resid. MS	SE	n	*t*	P
GB	6 v 7	8.271	0.184	56	1.529	0.1 < P < 0.2
IB	6 v 7	16.074	0.123	214	-0.869	P > 0.5

Table 3.13. Analysis of the effect of site quality on the HT-DBH relationship of red gum, stringybark and yellow box using analyses of covariance (3 or more site quality classes).

Tree	SQ test	DF	n	*F*	P
RG	5 v 6 v 7	3	272	1.766	0.1 < P < 0.25
SB	1 v 2 v 3 v 4 v 5 v 6 v 7	7	662	11.528	P < 0.001 ***
YB	3 v 5 v 6 v 7	3	265	2.043	0.1 < P < 0.25

Table 3.14. Multiple comparison of site quality differences in HT-DBH for stringybark (based on *q*-distribution).

	SQ1	SQ2	SQ3	SQ4	SQ5	SQ6
SQ2	*ns*					
SQ3	*ns*	*ns*				
SQ4	***	*ns*	*ns*			
SQ5	***	***	***	**		
SQ6	***	*ns*	*ns*	*ns*	*ns*	
SQ7	***	***	***	**	*ns*	*ns*

ns not significant (P > 0.05)
* 0.01< P < 0.05
** 0.001 < P < 0.01
*** P < 0.001

Three distinct site quality groups were obtained for stringybark: SQ1-2-3; SQ4; and SQ5-6-7, between which the HT-DBH relationship varied significantly and within which it was similar. HT-DBH regression equations are listed in Table 3.15 and illustrated in Figure 3.14 ; scatterplots are shown in Appendix XVI.

Table 3.15. Least squares regression equations derived from HT-DBH ordinates of fuelwood species in southern New England.

Tree	SQ	Regression equation	n	r	Adj. r^2	SE
GB	6-7	$HT = (DBH)^2 / (1.965 + 0.184*(DBH))^2 + 1.3$	60	0.992	0.984	0.539
IB	6-7	$HT = (DBH)^2 / (2.47 + 0.18*(DBH))^2 + 1.3$	218	0.986	0.973	0.738
RG	5-6-7	$HT = (DBH)^2 / (2.389 + 0.217*(DBH))^2 + 1.3$	278	0.972	0.945	1.082
SB	1-2-3	$HT = (DBH)^2 / (2.195 + 0.151*(DBH))^2 + 1.3$	79	0.977	0.955	0.849
	4	$HT = (DBH)^2 / (2.03 + 0.17*(DBH))^2 + 1.3$	74	0.982	0.964	0.561
	5-6-7	$HT = (DBH)^2 / (2.153 + 0.191*(DBH))^2 + 1.3$	525	0.979	0.959	0.779
YB	3-5-6-7	$HT = (DBH)^2 / (2.267 + 0.130*(DBH))^2 + 1.3$	273	0.967	0.927	1.125

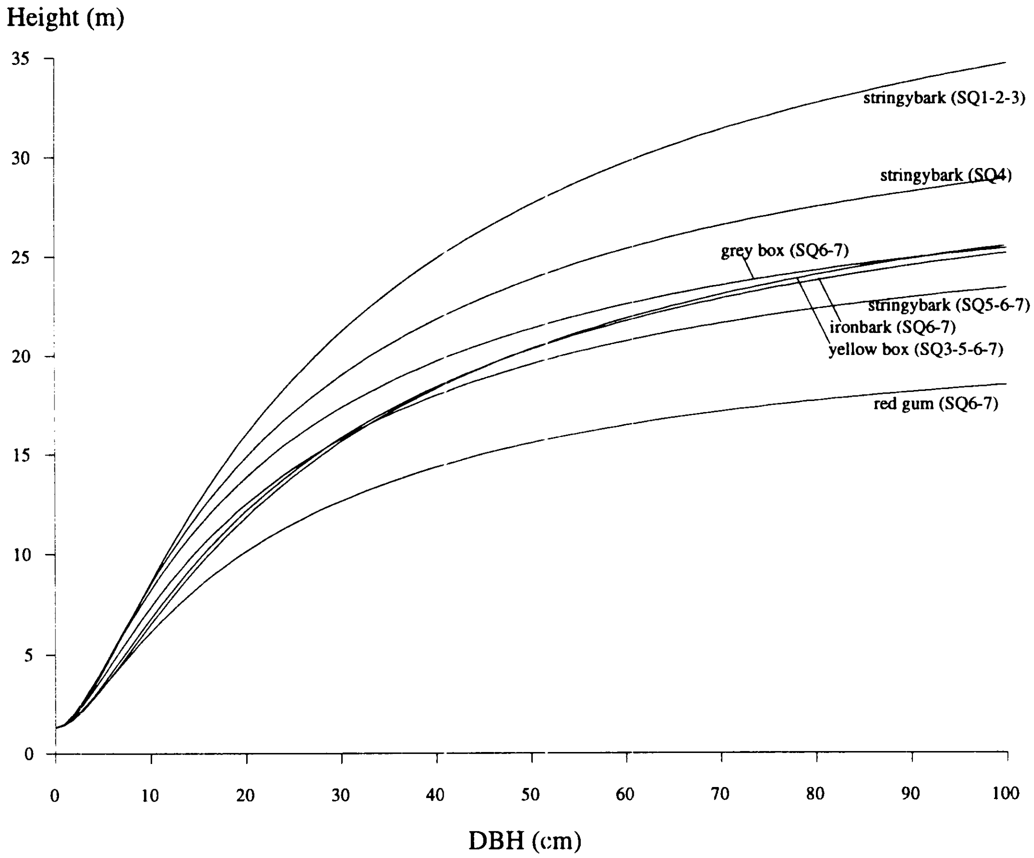


Figure 3.14. Height curves for fuelwood species in southern New England.

Between-species HT-DBH comparisons

Analysis of covariance was used to determine whether species differed in HT-DBH relationships (Table 3.16). Five significantly different HT-DBH groups were extracted from the table:

- grey box, ironbark, yellow box (nb. similar curves in Figure 3.14);
- red gum;
- stringybark (SQ1-2-3);
- stringybark (SQ4); and
- stringybark (SQ5-6-7).

Within-species CNVOL-DBH comparisons

CNVOL-DBH regression comparisons were carried out on four species using transformed values of DBH. Grey box was omitted due to lack of crown data. Site quality had no effect on CNVOL in ironbark, red gum (Table 3.17) or stringybark (Table 3.18), while CNVOL varied with site quality in yellow box (Table 3.18). According to q values obtained using a multiple comparison among slopes and Tukey's test (Zar 1984; section 3.2.6), the CNVOL-DBH relationship in yellow box was different for trees in the SQ7 class.

Table 3.16. Multiple comparison of species-site quality differences in HT-DBH for five species (based on *q*-distribution).

	GB6	GB7	IB6	IB7	RG5	RG6	RG7	SB1	SB2	SB3	SB4	SB5	SB6	SB7	YB3	YB5	YB6
GB7	*ns*																
IB6	*ns*	*ns*															
IB7	*ns*	*ns*	*ns*														
RG5	*ns*	*ns*	*ns*	*ns*													
RG6	*ns*	*ns*	*ns*	*ns*	*ns*												
RG7	*ns*	*ns*	***	**	*ns*	*ns*											
SB1	***	***	***	***	*	***	***										
SB2	*ns*	***	*ns*	*ns*	*ns*	*ns*	***	*ns*									
SB3	*ns*	***	*ns*	*ns*	*ns*	*ns*	***	*ns*	*ns*								
SB4	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***	***	*ns*	*ns*							
SB5	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***	***	***	**						
SB6	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***	***	*ns*	*ns*	*ns*	*ns*					
SB7	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*	***	***	***	**	*ns*	*ns*				
YB3	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***	*	*	*	*ns*	*ns*	*ns*			
YB5	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*	***	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*		
YB6	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	***	***	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	
YB7	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	**	*ns*	*ns*	*ns*	*ns*	**	*ns*	*	*ns*	*ns*	*ns*

ns not significant (P > 0.05)
* 0.01< P < 0.05
** 0.001 < P < 0.01
*** P < 0.001

Table 3.17. Analysis of the effect of site quality on the CNVOL-DBH relationships of ironbark and red gum using *t*-tests (2 site quality classes).

Tree	SQ Test	Resid. MS	SE	n	*t*	P
IB	6 v 7	933355	0.001	205	0.169	P > 0.5
RG	6 v 7	33142	0.005	96	0.239	P > 0.5

Table 3.18. Analysis of the effect of site quality on the CNVOL-DBH relationships of stringybark and yellow box using analyses of covariance (3 or more site quality classes).

Tree	SQ Test	DF	n	*F*	P
SB	1 v 2 v 3 v 4 v 5 v 6 v 7	7	527	0.893	P > 0.25
YB	5 v 6 v 7	2	123	20.848	P < 0.001 ***

Between-species CNVOL-DBH comparisons

Analysis of covariance was undertaken to determine species differences in CNVOL. Results are presented in Table 3.19. Four separate CNVOL-DBH groups were distinguished. Table 3.20 lists the respective regression functions and Figure 3.15 illustrates the respective composite crown curves. Individual crown curves are plotted in Appendix XVII.

Table 3.19. Multiple comparison of species-site quality differences in CNVOL-DBH for five species (based on *q*-distribution).

	IB6	IB7	RG6	RG7	SB1	SB2	SB3	SB4	SB5	SB6	SB7	YB5	YB6
IB7	*ns*												
RG6	***	***											
RG7	**	**	*ns*										
SB1	*ns*	*	**	*ns*									
SB2	*ns*	*ns*	*	*ns*	*ns*								
SB3	*ns*	*ns*	**	*ns*	*ns*	*ns*							
SB4	*ns*	*	***	*	*ns*	*ns*	*ns*						
SB5	*ns*	*ns*	***	***	*ns*	*ns*	*ns*	*ns*					
SB6	*ns*	*	**	**	*ns*	*ns*	*ns*	*ns*	*ns*				
SB7	*ns*	*ns*	***	**	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*			
YB5	*ns*	*ns*	*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*		
YB6	*ns*	**	**	*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	
YB7	*	*	***	***	***	***	**	***	***	***	***	***	***

ns not significant ($P > 0.05$)
* $0.01 < P < 0.05$
** $0.001 < P < 0.01$
*** $P < 0.001$

Table 3.20. Least squares regression equations derived from CNVOL-DBH ordinates of fuelwood species in southern New England.

Tree Groups	Regression equation	n	r	Adj. r^2	SE
SB, YB(5,6)	$CNVOL = 0.419*(DBH)^2$	657	0.825	0.679	628.7
YB(7)	$CNVOL = 0.886*(DBH)^2$	18	0.933	0.813	787.4
IB	$CNVOL = 0.525*(DBH)^2$	209	0.863	0.740	962.6
RG	$CNVOL = 0.214*(DBH)^2$	100	0.899	0.797	180.1

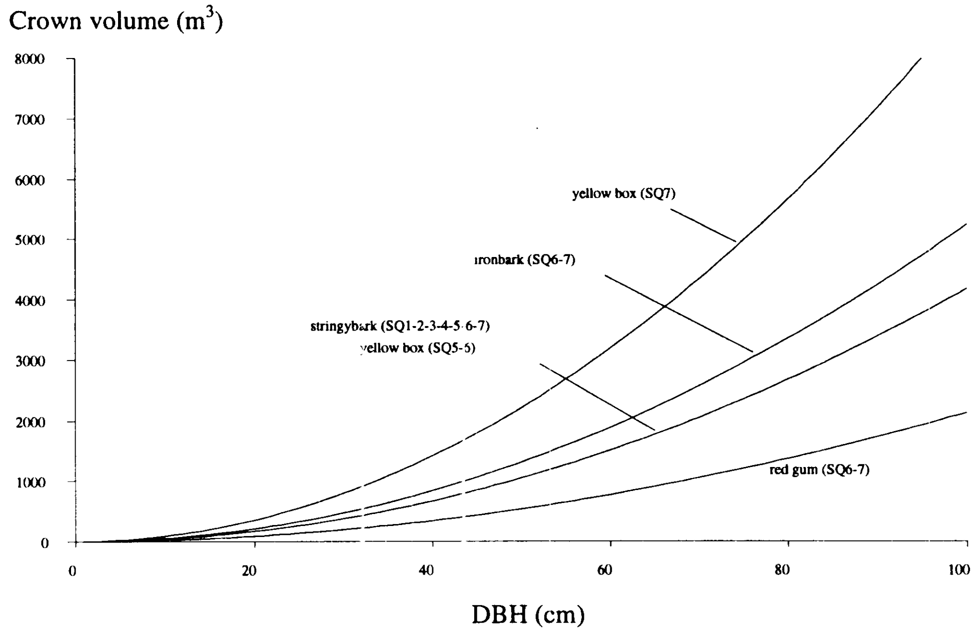


Figure 3.15. Composite crown volume curves for sampled fuelwood species.

Since tree form is dependent on HT and CNVOL, stringybark form varies between SQ1-2-3, SQ4 and SQ5-6-7 and yellow box form varies between SQ5-6 and SQ7. Therefore the timber weight and volume of each species is likely to vary for a given DBH between areas of different site quality in the study region.

3.3.6. Site dependent single-variate expressions for stringybark and yellow box

Allometric tree data for each of the stringybark groups SQ1-2-3, SQ4, SQ5 and SQ6-7 and yellow box groups SQ5, SQ6 and SQ7 were applied to the multi-variate equations derived from reference trees (harvested at site A, Newholme; SQ5) (Table 3.11) to obtain a set of biomass-DBH data-points specific to each group. The following example, using 'total green-weight' in stringybark SQ1-2-3 illustrates the approach. The respective single and multiple regression functions obtained from harvested trees are :

$GWt. = 1.011*(DBH-5)^2 - 112.242$ (from Table 3.10) 3.29

$GWt. = 0.02305*HT*(DBH-5)^2 + 0.990*CNVOL$ (from Table 3.11) 3.30

Allometric measurements of DBH, HT and CNVOL in stringybark SQ1-2-3 were applied to the multi-variate regression equation (eq. 3.30) to generate a set of site-specific GWt-DBH ordinates. These were plotted, and an 'adjusted' single-variate curve fitted by regressing GWt values onto corresponding DBH values (eq. 3.31 and Figure 3.16). In this case, stringybark SQ1-2-3 contains approximately 25% more green-weight than harvested trees at SQ-5 over all values of DBH (Figure 3.16).

$Gwt. = 1.202*(DBH-5)^2$ ($r^2 = 0.974$; SE = 805 7) 3.31

The adjusted biomass-DBH covariates obtained for each site quality group of stringybark and yellow box were subsequently compared between site quality groups (Table 3.21). The weight and volume of woody biomass in the stemwood of stringybarks differed significantly between all site quality groups due to differences in tree height. The branch biomass of stringybarks, in contrast, was similar between SQ1-2-3 and SQ6-7, which contained more fuelwood than those of SQ4 and SQ5. With respect to the whole tree (stem + branch), fuelwood biomass in stringybark varied between three site quality groups: SQ1-2-3; SQ4-6-7; and SQ-5, the latter containing least fuelwood. Yellow box SQ7 contained significantly more woody biomass than yellow box SQ5 and SQ6 due to higher branchwood biomass. Table 3.22 lists the 'adjusted' dry-weight equations for stringybark and yellow box and Figure 3.17 compares them to the respective weight functions derived for other fuelwood eucalypts. Green-weight and volume equations are listed in Appendix XVIII.

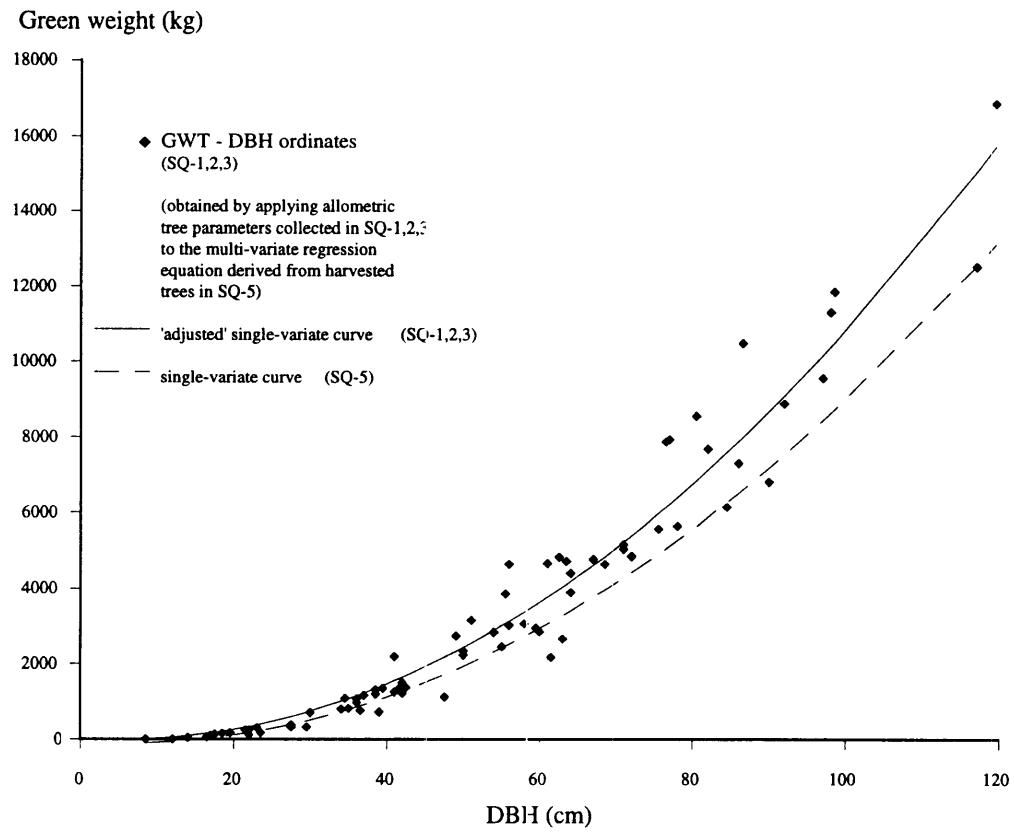


Figure 3.16. Adjustment of a single-variate expression in stringybark.

Table 3.21. Statistical assessment of site quality differences in biomass-DBH relations of stem, branch and tree for stringybark and yellow box (from *q*-statistic).

	Stringybark						Yellow box		
Test #	A x B	A x C	A x D	B x C	B x D	C x D	E x F	E x G	F x G
Stem	*** (+)	*** (+)	*** (+)	*** (+)	* (+)	*** (-)	*ns*	*ns*	? (-)
Branch	? (+)	? (+)	*ns*	*ns*	* (-)	* (-)	*ns*	*** (-)	*** (-)
TREE	*** (+)	*** (+)	*** (+)	*** (+)	*ns*	*** (-)	*ns*	** (-)	*** (-)

ns non-significant
? marginally significant (0.05<P<0.1)
* 0.01 < P < 0.05
** 0.001 < P < 0.01
*** P < 0.001

\# A = SQ1-2-3 B = SQ4 C = SQ5 D = SQ6-7
E = SQ5 F = SQ6 G = SQ7
\+ trees of better site-quality with higher weights and volumes
\- trees of better site-quality with lower weights and volumes

Table 3.22. Least square single-variate regression equations for dry-weight of stringybark and yellow box.

TC*	Tree	SQ	n	Regression equation	r	Adj. r^2	SE(est)
S-t	SB	1-2-3	75	$= 0.673*(DBH-5)^2$	0.991	0.981	379.4
		4	74	$= 0.562*(DBH-5)^2$	0.986	0.973	206.1
		5	75	$= 0.410*(DBH-5)^2$	0.993	0.987	81.2
		6-7	319	$= 0.450*(DBH-5)^2$	0.989	0.978	186.3
	YB	5-6	246	$= 0.487*(DBH-5)^2$	0.984	0.968	205.2
		7	26	$= 0.537*(DBH-5)^2$	0.988	0.975	199.7
S-b	SB	1-2-3	75	$= 0.147*(DBH-5)^2$	0.990	0.980	86.1
		4	74	$= 0.124*(DBH-5)^2$	0.989	0.977	41.2
		5	75	$= 0.089*(DBH-5)^2$	0.993	0.987	17.5
		6-7	319	$= 0.097*(DBH-5)^2$	0.989	0.978	39.7
	YB	5-6	246	$= 0.035*(DBH-5)^2$	0.939	0.881	29.5
		7	26	$= 0.039*(DBH-5)^2$	0.953	0.909	28.6
B-t	SB	1-2-3-6-7	394	$= 0.026*(DBH-15)^2 + 5.858*(DBH-15)$	0.972	0.944	65.3
		4-5	149	$= 0.035*(DBH-15)^2 + 4.834*(DBH-15)$	0.982	0.965	34.1
	YB	5-6	118	$= 0.268*(DBH-5)^2 + 2.349*(DBH-5)$	0.985	0.969	123.4
		7	18	$= 0.410*(DBH-5)^2$	0.994	0.988	119.8
B-b	SB	1-2-3-6-7	394	$= 0.009*(DBH-15)^2 + 1.856*(DBH-15)$	0.968	0.937	22.5
		4-5	149	$= 0.012*(DBH-15)^2 + 1.504*(DBH-15)$	0.980	0.959	11.7
	YB	5-6	118	$= 0.039*(DBH-5)^2 + 0.439*(DBH-5)$	0.983	0.965	19.8
		7	18	$= 0.063*(DBH-5)^2$	0.993	0.987	19.8
S	SB	1-2-3	75	$= 0.820*(DBH-5)^2$	0.991	0.981	464.3
		4	74	$= 0.685*(DBH-5)^2$	0.987	0.974	246.8
		5	75	$= 0.499*(DBH-5)^2$	0.993	0.987	98.5
		6-7	319	$= 0.548*(DBH-5)^2$	0.989	0.978	225.5
	YB	5-6	246	$= 0.517*(DBH-5)^2$	0.982	0.963	233.4
		7	26	$= 0.573*(DBH-5)^2$	0.986	0.972	228.4
B	SB	1-2-3-6-7	394	$= 0.035*(DBH-15)^2 + 7.714*(DBH-15)$	0.971	0.943	87.8
		4-5	149	$= 0.048*(DBH-15)^2 + 6.338*(DBH-15)$	0.982	0.963	45.8
	YB	5-6	118	$= 0.308*(DBH-5)^2 + 2.838*(DBH-5)$	0.985	0.969	143.2
		7	18	$= 0.473*(DBH-5)^2$	0.994	0.988	139.6
t	SB	1-2-3	75	$= 0.706*(DBH-5)^2$	0.986	0.972	489.7
		4-6-7	393	$= 0.609*(DBH-5)^2$	0.969	0.939	410.9
		5	75	$= 0.574*(DBH-5)^2$	0.986	0.971	168.3
	YB	5-6	118	$= 0.649*(DBH-5)^2 + 9.998*(DBH-5)$	0.988	0.976	290.9
		7	18	$= 1.009*(DBH-5)^2$	0.995	0.989	285.6
b	SB	1-2-3	75	$= 0.136*(DBH-5)^2 + 1.566*(DBH-5)$	0.986	0.971	109.7
		4-6-7	393	$= 0.118*(DBH-5)^2 + 0.865*(DBH-5)$	0.969	0.938	88.4
		5	75	$= 0.124*(DBH-5)^2$	0.988	0.975	33.6
	YB	5-6	118	$= 0.032*(DBH-5)^2 + 2.921*(DBH-5)$	0.978	0.955	39.9
		7	18	$= 0.070*(DBH-5)^2 + 2.386*(DBH-5)$	0.990	0.978	43.2
TOT	SB	1-2-3	75	$= 0.859*(DBH-5)^2$	0.986	0.972	595.7
		4-6-7	393	$= 0.741*(DBH-5)^2$	0.969	0.939	499.7
		5	75	$= 0.699*(DBH-5)^2$	0.986	0.971	204.6
	YB	5-6	118	$= 0.681*(DBH-5)^2 + 12.920*(DBH-5)$	0.987	0.974	330.1
		7	18	$= 0.995*(DBH-5)^2 + 6.575*(DBH-5)$	0.995	0.988	327.9

* TC = tree component (S = stem; B = branch; t = timber; b = bark)

3.3.7. Single-variate expressions for other fuelwood species

Derivation of volume equations

The following assumptions were used to assemble volume functions for ironbark, grey box and red gum, based on results of the effects of site quality on tree height and form (section 3.3.5) :

- ironbark assumes the same form and height as yellow box SQ5-6 (section 3.3.5) and its volume is estimated using the same function (Appendix XVIII).
- grey and white box assume the same height as yellow box and ironbark (section 3.3.5), yet the same crown dimensions as stringybark SQ6-7 (J. Wall 1995, unpubl. data), and thus acquire a composite volume function (see Appendix XIX, i).
- the crown dimensions and height of red gum are significantly less than all other fuelwood species (section 3.3.5). A volume function is thus derived for red gum by modifying the volume function for stringybark SQ5 according to HT and CNVOL ratios between stringybark SQ5-6-7 and red gum SQ6-7 (see Appendix XIX, ii).
- based on observed similarities in the field, blackbutt assumes the same within-site volume and weight functions as stringybark.

The following volume equations were constructed :

Tree	SQ	Fuelwood volume (m^3)
grey box	6-7	$= 0.001*(0.575*(DBH-5)^2 + 0.075*(DBH-15)^2 + 13.107*(DBH-15))$
ironbark	6-7	$= 0.001*(0.760*(DBH-5)^2 + 15.875*(DBH-5))$
red gum	5-6-7	$= 0.001*(0.643*(DBH-5)^2 + 5.083*(DBH-15))$

Derivation of dry-weight functions

Measurements of underbark diameter (DUB) obtained from disc and stump data were regressed against the corresponding values of overbark diameter (DOB) (section 3.2.8). Strong linear relationships were obtained for all species (Table 3.23), supporting the assumption of proportionality between bark thickness and stem or branch diameter.

Table 3.23. Linear regression parameters for the DUB-DOB relationship in five fuelwood species across three diameter classes (DUB = a.(DOB)).

	(D1) 5 - 15 cm			(D2) 5 - 55 cm			(D3) 5 - 90 cm		
	n	a	r^2	n	a	r^2	n	a	r^2
SB	114	0.762	0.993	168	0.801	0.993	175	0.815	0.993
YB	44	0.862	0.994	62	0.886	0.997	-	-	-
RG	4	0.813	0.986	-	-	-	-	-	-
IB	10	0.650	0.982	30	0.692	0.988	32	0.721	0.987
GB	4	0.811	0.998	-	-	-	-	-	-

The DOB coefficient increased slightly (and consistently) with respect to DUB for all species as the diameter range increased. The coefficient ratios for stringybark, yellow box and ironbark were :

SPECIES	D2 : D1	D3 : D2
stringybark	1.051	1.017
yellow box	1.028	-
ironbark	1.065	1.042
ALL	1.048	1.030

Using the above ratios in conjunction with established coefficients listed in Table 3.23, a set of DUB-DOB functions and timber : bark volume ratios were estimated for the D3 category (5-90 cm) of each fuelwood species. These are listed in Table 3.24 with values of air-dry timber and bark density. Data in Table 3.24 enable the modification of volume equations into air-dry timber and bark weight equations for grey box, ironbark and red gum (Table 3.25).

Table 3.24. Air-dry density and timber : bark volume ratio in five fuelwood eucalypts in southern New England.

			ADD ($g.cm^{-3}$)	
Tree	Relationship	Timber : bark volume ratio	Timber	Bark
stringybark	DUB = 0.815*DOB	0.664 : 0.336 (1.98)	(section 3.3.1)	
yellow box	DUB = 0.911*DOB	0.830 : 0.170 (4.88)	(section 3.3.1)	
red gum	DUB = 0.878*DOB	0.771 : 0.229 (3.37)	0.95	0.60
ironbark	DUB = 0.721*DOB	0.520 : 0.480 (1.08)	1.10	0.56
grey box	DUB = 0.875*DOB	0.766 : 0.234 (3.32)	1.05	0.60

Table 3.25. Dry-weight equations for the timber and bark components of grey box, ironbark and red gum.

	SQ	TC	Regression equation
grey box	6,7	Timber	$= 0.462*(DBH-5)^2 + 0.060*(DBH-15)^2 + 10.542*(DBH-15)$
		Bark	$= 0.081*(DBH-5)^2 + 0.011*(DBH-15)^2 + 1.840*(DBH-15)$
		Total	$= 0.543*(DBH-5)^2 + 0.071*(DBH-15)^2 + 12.382*(DBH-15)$
ironbark	6,7	Timber	$= 0.435*(DBH-5)^2 + 9.081*(DBH-5)$
		Bark	$= 0.204*(DBH-5)^2 + 4.267*(DBH-5)$
		Total	$= 0.639*(DBH-5)^2 + 13.348*(DBH-5)$
red gum	5,6,7	Timber	$= 0.471*(DBH-5)^2 + 3.723*(DBH-15)$
		Bark	$= 0.088*(DBH-5)^2 + 0.698*(DBH-15)$
		Total	$= 0.559*(DBH-5)^2 + 4.421*(DBH-15)$

TC = tree component

In conjunction with appropriate stem : branch volume ratios, weight of timber and bark of the above species was determined separately for stem and branches (Table 3.26) by comparing coordinates of the CNVOL functions in Figure 3.15. The CNVOL relationship of grey box did not vary significantly from that of stringybark SQ7 (J. Wall 1995, unpubl. data), thus its stem : branch volume ratio was assumed the same (1 : 0.263 using a mean tree diameter of 55 cm). The CNVOL relationship for ironbark was most similar to that of yellow box SQ5-6, with which it is also similar in HT (J. Wall 1995, unpubl. data); thus the stem : branch volume ratio for ironbark was 1 : 0.754. The HT : CNVOL ratio for red gum was similar to that of yellow box SQ5 (J. Wall 1995, unpubl. data); the stem : branch volume ratio for red gum was assumed to be 1 : 0.730.

Table 3.26. Dry-weight equations for the timber and bark components of the stem and branchwood of grey box, ironbark and red gum.

	SQ	TC	Regression equation
grey box	6-7	stem timber	$= 0.366*(DBH-5)^2 + 0.048*(DBH-15)^2 + 8.347*(DBH-15)$
		stem bark	$= 0.064*(DBH-5)^2 + 0.009*(DBH-15)^2 + 1.457*(DBH-15)$
		branch timber	$= 0.096*(DBH-5)^2 + 0.012*(DBH-15)^2 + 2.195*(DBH-15)$
		branch bark	$= 0.017*(DBH-5)^2 + 0.002*(DBH-15)^2 + 0.383*(DBH-15)$
ironbark	6-7	stem timber	$= 0.248*(DBH-5)^2 + 5.177*(DBH-5)$
		stem bark	$= 0.116*(DBH-5)^2 + 2.433*(DBH-5)$
		branch timber	$= 0.187*(DBH-5)^2 + 3.904*(DBH-5)$
		branch bark	$= 0.088*(DBH-5)^2 + 1.834*(DBH-5)$
red gum	5-6-7	stem timber	$= 0.272*(DBH-5)^2 + 2.152*(DBH-15)$
		stem bark	$= 0.051*(DBH-5)^2 + 0.403*(DBH-15)$
		branch timber	$= 0.199*(DBH-5)^2 + 1.571*(DBH-15)$
		branch bark	$= 0.037*(DBH-5)^2 + 0.295*(DBH-15)$

TC = tree component

Summary

This section has adapted the single-variate equations derived for stringybark and yellow box to other fuelwood species occurring in the region by comparing measures of timber and bark density, bark thickness, and crown volume and height. While the predictive power associated with using each of the functions listed in Tables 3.25 and 3.26 is unknown, and model validation is required using destructive harvesting, it is reasonable to assume that their broadscale utilisation will provide a reasonable estimate of standing dry-weight in stands in which stringybark or yellow box do not dominate.

3.4. Discussion

3.4.1. Dry-weight of New England eucalypts

Total tree weight

Regression equations describing the dry-weight of total woody biomass are more useful than volume or green-weight equations in fuelwood management because they enable direct assessment of the number of trees required to produce a certain weight of fuel, and because calorific content can be applied to estimate fuel energy values (Madgwick *et al.* 1991). It is logical that trees be measured in the same units as those in which timber purchases and sales are transacted (Avery 1975), and dry-weight is the standard unit for quantifying fuelwood. The following discussion is based on the dry-weight functions determined for New England eucalypts.

Figure 3.17 illustrates the relationship between dry-weight and DBH, and Table 3.27 provides a 'weight table' for the major fuelwood species. For a given DBH, stringybark and yellow box trees in SQ7 have more wood than in SQ5, even though annual rainfall in the latter is, on average, 100 mm.yr^{-1} greater. It is possible that the health and vigour of trees in SQ5 are relatively low because of recent dieback episodes in this part of the region. It is also possible that less dense stands in sites of lower rainfall (SQ6-7) provide greater opportunity for canopy expansion, generating proportionally more woody biomass as branchwood (suggested by CNVOL relationships in yellow box; Figure 3.15). Finally, it is possible that more intensive manipulation of forests in SQ5 in the past has promoted highly stocked regrowth stands with little branch development.

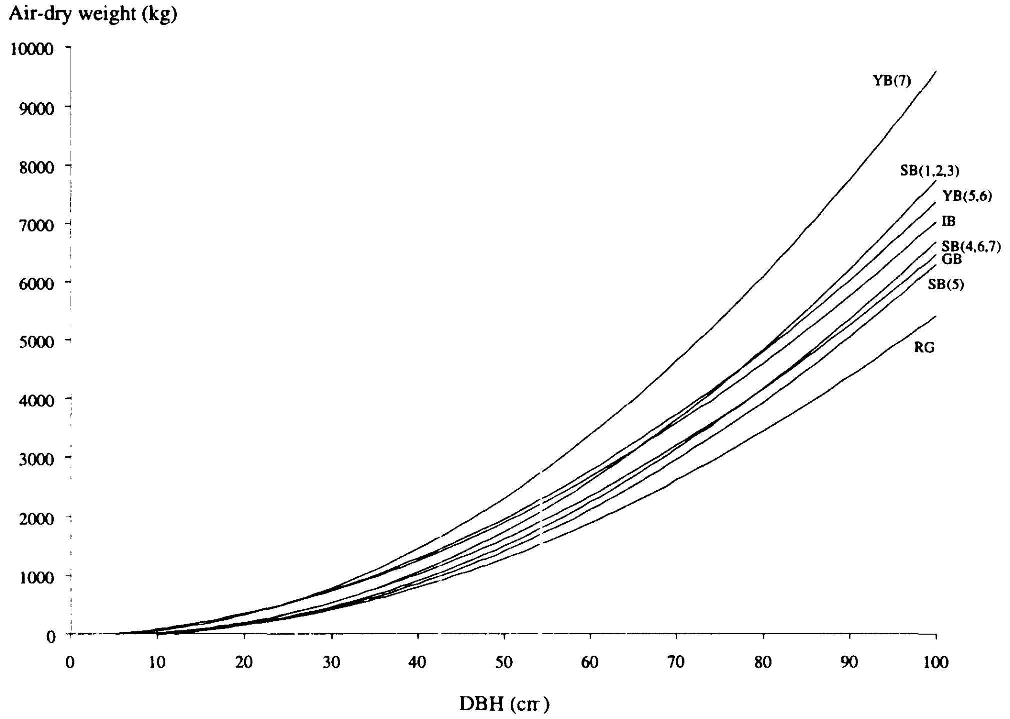


Figure 3.17. Dry-weight curves for fuelwood eucalypts in southern New England.

Yellow box trees occurring at sites with rainfall less than 750 mm.yr^{-1} (SQ7) are the heaviest in the study region for most values of DBH. An average yellow box of 50 cm DBH located near Bundarra comprises an estimated 2.31 t of dry fuelwood biomass, 54% more than a coexisting stringybark of the same DBH and 33% more than a stringybark of the same DBH located near Ebor (SQ1-2-3). Yellow box has relatively thin bark compared with stringybark, possessing a greater volume of timber per unit stem or

Table 3.27. Fuelwood weight-table for New England eucalypts (weights in kg).

	SB			YB		GB	IB	RG
DBH (cm)	SQ1-2-3	SQ4-6-7	SQ5	SQ3-5-6	SQ7	SQ6-7	SQ6-7	SQ5-6-7
15	85.9	74.1	69.9	197.3	165.3	54.3	197.4	55.9
16	103.9	89.7	84.6	224.5	192.7	78.2	224.1	72.1
17	123.7	106.7	100.7	253.1	222.2	103.2	252.2	89.3
18	145.2	125.2	118.1	283.0	253.6	129.6	281.5	107.7
19	168.4	145.2	137.0	314.4	287.1	157.1	312.1	127.2
20	193.3	166.7	157.3	347.0	322.5	185.9	344	147.9
21	219.9	189.7	178.9	381.1	359.9	215.9	377.2	169.6
22	248.3	214.1	202.0	416.4	399.3	247.1	411.6	192.5
23	278.3	240.1	226.5	453.2	440.7	279.5	447.3	216.5
24	310.1	267.5	252.3	491.3	484.1	313.2	484.3	241.6
25	343.6	296.4	279.6	530.8	529.5	348.1	522.6	267.8
26	378.8	326.8	308.3	571.6	576.9	384.3	562.1	295.2
27	415.8	358.6	338.3	613.8	626.2	421.6	602.9	323.6
28	454.4	392.0	369.8	657.4	677.6	460.2	645	353.2
29	494.8	426.8	402.6	702.3	730.9	500	688.4	383.9
30	536.9	463.1	436.9	748.6	786.3	541.1	733.1	415.7
31	580.7	500.9	472.5	796.3	843.6	583.4	779	448.6
32	626.2	540.2	509.6	845.3	902.9	626.9	826.2	482.7
33	673.5	580.9	548.0	895.7	964.2	671.6	874.7	517.8
34	722.4	623.2	587.9	947.4	1027.5	717.6	924.5	554.1
35	773.1	666.9	629.1	1000.5	1092.8	764.7	975.5	591.5
36	825.5	712.1	671.7	1055.0	1160.0	813.2	1027.9	630
37	879.6	758.8	715.8	1110.8	1229.3	862.8	1081.5	669.7
38	935.5	806.9	761.2	1168.0	1300.5	913.7	1136.4	710.4
39	993.0	856.6	808.0	1226.5	1373.8	965.8	1192.5	752.3
40	1052.3	907.7	856.3	1286.4	1449.0	1019.1	1250	795.3
41	1113.3	960.3	905.9	1347.7	1526.2	1073.7	1308.7	839.4
42	1176.0	1014.4	956.9	1410.3	1605.4	1129.4	1368.7	884.6
43	1240.4	1070.0	1009.4	1474.3	1686.6	1186.5	1429.9	931
44	1306.5	1127.1	1063.2	1539.7	1769.8	1244.7	1492.5	978.4
45	1374.4	1185.6	1118.4	1606.4	1855.0	1304.2	1556.3	1027
46	1444.0	1245.6	1175.0	1674.5	1942.2	1364.9	1621.4	1076.7
47	1515.3	1307.1	1233.0	1743.9	2031.3	1426.8	1687.8	1127.5
48	1588.3	1370.1	1292.5	1814.7	2122.5	1489.9	1755.5	1179.5
49	1663.0	1434.6	1353.3	1886.9	2215.6	1554.3	1824.4	1232.5
50	1739.5	1500.5	1415.5	1960.4	2310.8	1619.9	1894.6	1286.7
51	1817.6	1568.0	1479.1	2035.3	2407.9	1686.8	1966.1	1342
52	1897.5	1636.9	1544.1	2111.6	2507.0	1754.8	2038.9	1398.4
53	1979.1	1707.3	1610.5	2189.2	2608.1	182 4.1	2113	1455.9
54	2062.5	1779.1	1678.3	2268.2	2711.2	1894.6	2188.3	1514.6
55	2147.5	1852.5	1747.5	2348.5	2816.3	1966.4	2264.9	1574.3
56	2234.3	1927.3	1818.1	2430.2	2923.3	2039.4	2342.8	1635.2
57	2322.7	2003.7	1890.1	2513.3	3032.4	2113.6	2422	1697.2
58	2412.9	2081.5	1963.5	2597.7	3143.4	2189	2502.4	1760.3
59	2504.8	2160.8	2038.3	2683.5	3256.5	2265.7	2584.1	1824.6
60	2598.5	2241.5	2114.5	2770.6	3371.5	2343.5	2667.1	1889.9

branch volume; yellow box timber is denser than stringybark timber, possessing a greater biomass per unit volume; and yellow box contains more branchwood than stringybark, reflecting the greater extent to which its canopy is able to occupy space in open forest and woodland with low stand densities (e.g. Krajicek *et al.* 1961). Despite a similarity in timber and bark density and tree form, ironbark weighs considerably less than yellow box. This is attributed to a marked difference in timber : bark volume ratio. Yellow box possesses 0.2 cm^3 of bark for every 1.0 cm^3 of timber; ironbark possesses almost 1.0 cm^3 of bark for every 1.0 cm^3 of timber (Table 3 24).

The dry-weights of red gum, grey box and stringybark in SQ4-5-6-7 (MAR < 850 $mm.yr^{-1}$) are within 20% of each other for most values of DBH. Red gum weighs least due to its low height and grey box is heaviest due to its high timber density. The dry-weight of yellow box (SQ5-6) is similar to that of the eastern stringybarks (SQ1-2-3).

The fuelwood weight table (Table 3.27) is useful for estimating the dry-weight of wood biomass in an individual tree from its DBH, and should assist the fuelwood manager or landholder in the selection of trees to meet local fuelwood demands. To meet average annual household demand of 8.85 t in rural areas (section 2.4.2), for example, a landholder living near Bundarra (SQ7) could fell either 58 stringybarks of 20 cm DBH, 19 stringybarks of 30 cm DBH or 6 stringybarks of 50 cm DBH. A species mix might be more desirable, such as 10 stringybarks of 25 cm DBH, 5 yellow box of 30 cm DBH, and 2 ironbarks of 35 cm DBH. An equivalent 39 000 stringybark or 23 000 yellow box trees (30 cm DBH; SQ7) would have been required to supply the 17 940 t of fuelwood consumed in Armidale in 1994. Caution is required in the use of the weight table for small or poorly formed trees, especially with grey box, ironbark and red gum, the weights of which were derived from regression functions of stringybark and yellow box.

Partial tree weights

The distribution of fuelwood biomass in the stems and branches of New England eucalypts varies markedly between species groups (Figures 3.18 and 3.19). Yellow and grey box contain the highest biomass in stems and red gum the least; yellow box and ironbark possess the highest biomass in branches and stringybark and grey box the least (Figure 3.18). The stem weights of grey box, yellow box and stringybark are similar, although yellow box possesses far more branchwood. The branch weight of ironbark exceeds the stem weight of red gum in trees of similar DBH. Stringybark and grey box possess the highest stem : branch weight ratios (4 : 1 and 3.8 : 1, respectively (at 60 cm DBH)); yellow box, ironbark and red gum possess the lowest stem : branch weight ratios (~ 1.2 : 1, 1.3 : 1 and 1.4 : 1, respectively (at 60 cm DBH)).

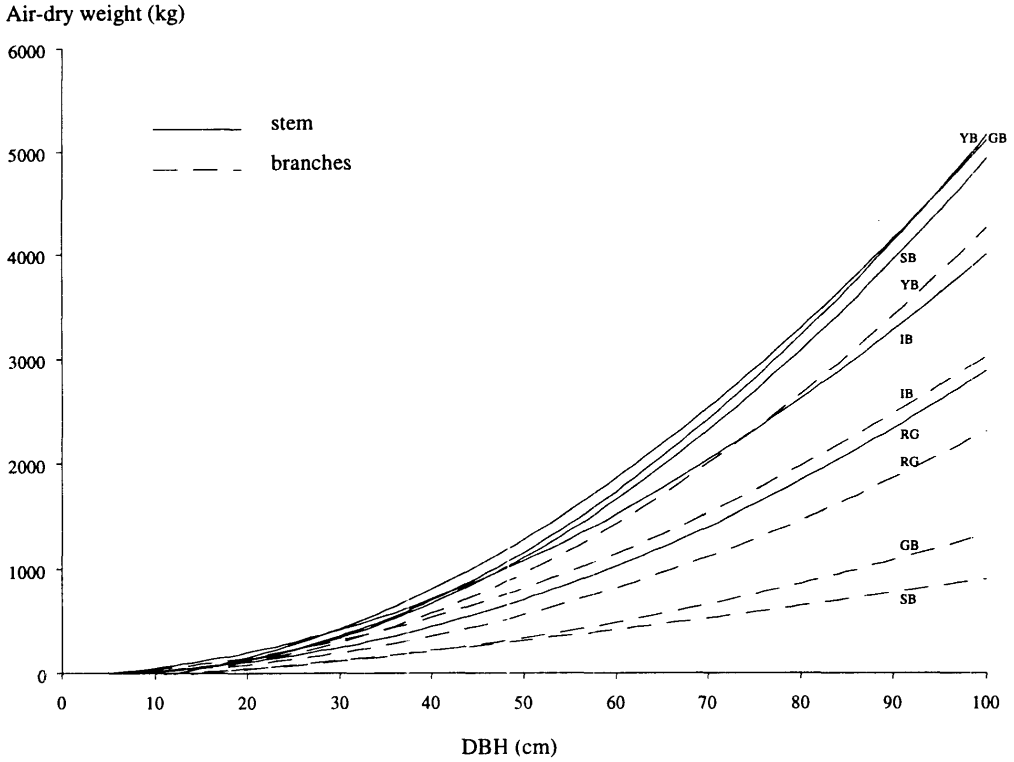


Figure 3.18. Distribution of dry-weight in the stem and branches of five fuelwood eucalypts in southern New England (SQ7).

Branchwood is attractive for fuelwood because of the high proportion of ideal diameter lengths and the ease with which it can be cut, billeted and handled. Selling branchwood for fuel can provide an additional source of income to that derived from the sale of stemwood for posts or sawlogs (Corbyn *et al.* 1988). The contemporary practice of fencewood extraction from the main stem(s) of rural trees on private land is often wasteful from the viewpoint of timber utilisation. Plates 3.5 and 3.6 provide typical examples of standard tree felling practice, in which the 'heads' of large trees are left *in situ* after stem extraction. Residual crownwood can weigh up to 3 t in large ironbark and yellow box trees, providing an opportunity for profit from both fuelwood and fencing timber. Commercial logging of the high-quality stringybark and blackbutt stands along the eastern escarpment of the study region also ignores the opportunity for fuelwood production, with all branchwood and some stemwood left *in situ* after sawlog extraction.

Figure 3.19 shows timber and bark weight functions in the fuelwood eucalypts. The weight of timber is highest in yellow box due to its high timber density, high timber : bark volume ratio and high proportion of crownwood. Timber weight is similar in grey box and stringybark, and is relatively low in ironbark (thick bark) and red gum (smaller trees). Ironbark contains most bark while red gum and yellow box contain least. Ironbark possesses the lowest timber : bark weight ratio (2.1 : 1 at 60 cm DBH) and yellow box the highest (8.9 : 1 at 60 cm DBH).

Plate 3.5. Residual crownwood of felled stringybark. Site 41 (Figure 2.1), July 1993; SQ6; DBH ~ 60 cm

Plate 3.6. Residual crownwood of felled ironbark. Site 20 (Figure 2.1), Jan. 1994; SQ7; DBH ~ 50 cm

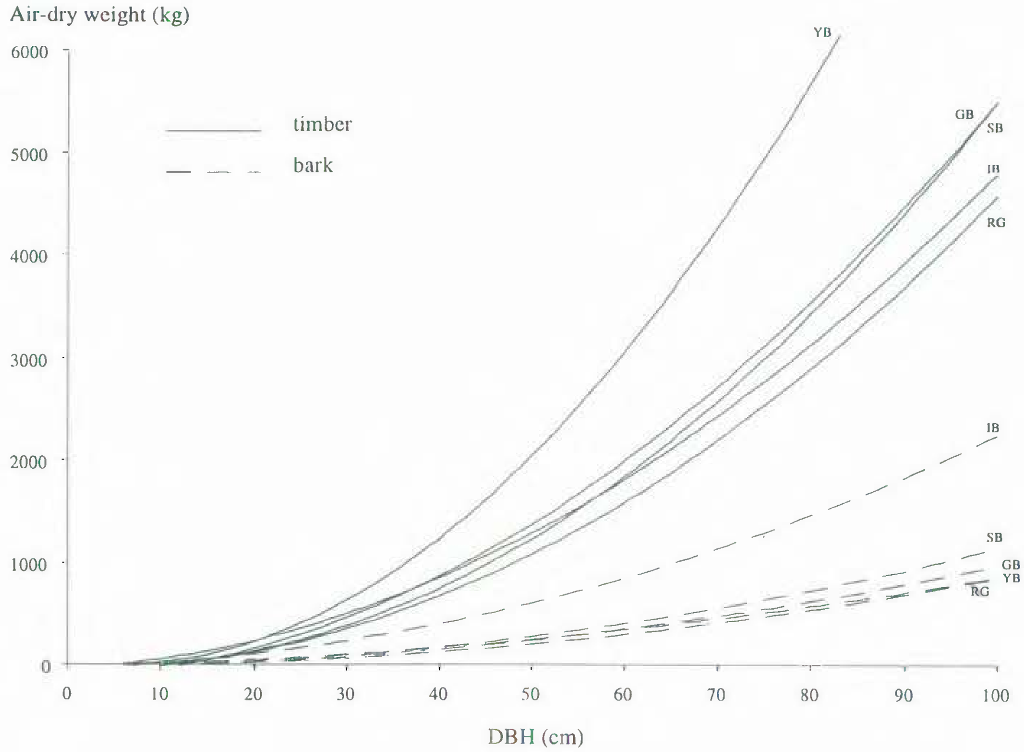
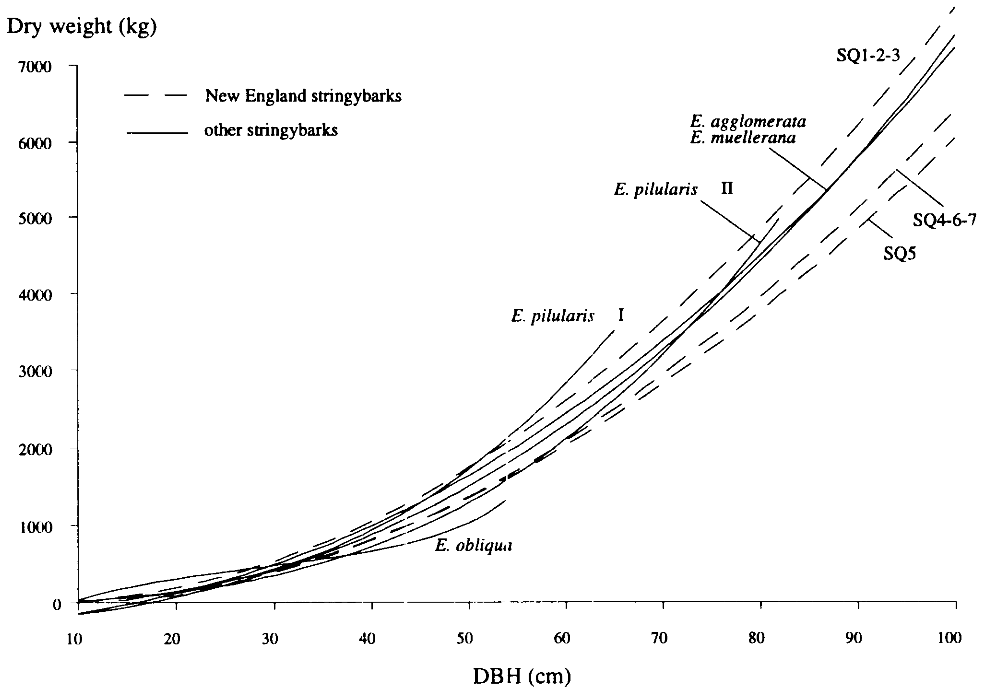


Figure 3.19. Distribution of dry-weight in the timber and bark of five fuelwood eucalypts in southern New England (SQ7).

3.4.2. Weight comparisons with other eucalypts

The time consuming and expensive nature of destructive harvesting has limited the number of studies undertaken in Australian native forests which derive estimates of stand biomass from tree weight functions, especially for the lesser-known species such as ironbark, yellow box and grey box. A few studies have been cited, however, from which comparisons with local stringybark functions are possible (Figure 3.20). Dry-weight functions using DBH as independent variable were established by Stewart *et al.* (1979) and Feller (1980) for similar species (section 3.2.2), and Applegate (1982) sampled coastal blackbutt *E. pilularis* at two sites on Fraser Island. Dry-weight functions for *E. agglomerata* and *E. muellerana* assembled by Stewart *et al.* (1979) are very similar to those derived for *E. laevopinea* - *E. caliginosa* on the Northern Tablelands, in terms of both magnitude and form. Victorian stringybarks are slightly heavier than local stringybarks situated in areas receiving a MAR < 900 mm.yr^{-1}, and marginally lighter than local stringybarks in areas of MAR 900-1100 mm.yr^{-1}. *E. agglomerata* and *E. muellerana* were sampled in an uneven-aged forest 10 km from Genoa, which receives 923 mm.yr^{-1} (Stewart *et al.* 1979). The similarity in tree weight between stringybarks of New England and those from similar rainfall areas in Victoria is encouraging from a fuelwood management perspective, since weight equations assembled for stringybark in one area might be used to predict weights of those in other areas.



E. agglomerata	$DWt = 10^{(2.237.\log(DBH)-1.388} + 10^{(2.316.\log(DBH)-0.941)}$	(Stewart *et al.* 1979)
E. muellerana	$DWt = 10^{(2.520.\log(DBH)-1.283} + 10^{(1.991.\log(DBH)-1.143)}$	(Stewart *et al.* 1979)
E. pilularis (I)	$DWt = 10^{(2.591.\log(DBH)-1.225} + 10^{(3.572.\log(DBH)-3.738)}$	Applegate (1982)
E. pilularis (II)	$DWt = 10^{(2.223.\log(DBH)-0.841} + 10^{(3.467.\log(DBH)-3.258)}$	Applegate (1982)
E. obliqua	$DWt = 376.5.\ln(DBH) + 13.4.e^{(0.130.(DBH)-3.14)} - 828.5$	(Feller 1980)

Figure 3.20. Dry-weight curves for stringybarks of southern New England and Victoria, and blackbutts of Fraser Island.

Site and stand characteristics in the *E. obliqua* and *E. pilularis* studies differ considerably from the above. Feller (1980) used six *E. obliqua* trees in closed eucalypt forest receiving an MAR of 1200 $mm.yr^{-1}$, the largest of which was less than 40 cm DBH. The stand was well stocked (1200 $stems.ha^{-1}$) and stem biomass constituted 93% of total woody biomass. For DBH values < 25 cm, *E. obliqua* is comparatively heavier than other species (Figure 3.20), possibly reflecting a rapid height increment in relation to competition for canopy light. Above 30 cm DBH, *E. obliqua* weight decreases with respect to other stringybarks, reflecting a greater opportunity for branch development in the latter. *E. pilularis* was sampled within vigorous regeneration stands receiving an MAR of about 1500 $mm.yr^{-1}$ (Applegate 1982). The initial rate of weight increment is low at both sites compared with New England stringybarks, then increases more rapidly after acquiring a DBH of about 40 to 45 cm.

The magnitude and trend differences in the weight relationships of stringybarks in southern New England, *E. obliqua* in Victoria and *E. pilularis* on Fraser Island illustrate the need to confine the use of weight and volume tables to areas of similar site quality and stand structure. Cross validation should be undertaken as a matter of precaution in any event, providing a directive for subsequent research.

3.5. Conclusions

Destructive harvesting and whole tree weighing were used to construct regression functions for two groups of eucalypts; stringybark *E. caliginosa - E. laevopinea* and yellow box *E. melliodora*, relating various components of their fuelwood biomass to easily measured allometric variables DBH, HT and CNVOL. The equations were subsequently modified on the basis of between-species and between-site comparisons of HT-DBH and CNVOL-DBH relationships in trees, to produce a final set of site-specific single-variate expressions for stringybark, yellow box and three other fuelwood eucalypts, red ironbark *E. sideroxylon*, grey and white box *E. moluccana - E. albens* and Blakely's red gum *E. blakelyi*. The expressions were thence used to construct a dry-weight table based on tree DBH.

The weight table is useful for determining the dry-weight of individual trees and appraising the number of trees of different sizes required for provision of a quantity of dry fuelwood. It also serves as a first step in forest inventory, providing a base from which to quantify the standing biomass within individual forests and whole regions. These matters are addressed in the following chapters, providing information from which to formulate silvicultural regimes with a view to sustainable fuelwood production in the New England region.