Chapter 6. Growth and yield of native forest in southern New England

6.1. Introduction

The sustained yield of a forest stand can be defined as the maximum level of harvest of commercial timber that can be maintained in perpetuity from a given area under a given management regime (RAC 1992). To avoid a rate of harvesting which diminishes the timber resource and forest values, rational decisions about treatment, harvesting intensity and timing must be made. Growth and yield studies are the means to this end (Alder 1980), providing a basis for evaluating the options for silvicultural treatment, harvesting schedules, and allowable cut in forest stands (Hann and Zumrawi 1991).

Fundamental to the perpetuation of forest ecosystems is the process of natural regeneration, which includes reproduction of plants from seed, vegetative recovery of plants after canopy loss (fire, cutting, browsing), epicormic growth (e.g. coppicing from damaged stumps), and resprouting from lignotubers, rhizomes or roots (Cremer *et al.* 1990). Coppicing is a natural regenerative strategy in many eucalypt species that permits survival after mechanical damage or fire. It is used in eucalypt management worldwide, particularly in short-rotation fuelwood and pulpwood production in which several coppice rotations can been obtained from the cut stumps of the original tree crop (Blake 1983; Jones *et al.* 1983; Davidson 1987).

Most yield studies are founded on the analysis of DBH increment to establish the mean annual increment (MAI), defined as the average rate of weight or volume increment over a given time. Tree ring analysis and permanent growth plots are often employed because they enable direct estimation of tree age, from which DBH increment and MAI can be calculated. This chapter aims to determine the MAI of fuelwood biomass in trees and uneven-aged mixed stands in southern New England. Tree stump assessment is undertaken to determine MAI of coppice stems of stringybark, yellow box, red gum, ironbark and grey box. Tree ring analysis is used at sites A and B and site 64 (Figure 2.1), in conjunction with tree volume estimation (Chapter 3) and stand density assessment (Chapter 4), to establish and compare the MAI of stringybarks in closed and open forest. Natural regeneration is sampled to determine the capacity for regrowth and long-term forest survival in areas of varying cover and land tenure.

6.2. Methods

6.2.1. Natural regeneration

Natural regeneration was sampled within forest inventory sites (Chapter 4). Four 50 x 20 m transects were used at each of the 72 point-centred sampling sites (total 288 x 0.10 ha plots) and a 10 x 10 m quadrat was extended in a north-east direction from every point within 24 horizontal point sampling sites (total 560 points x 0.01 ha plots). All eucalypt and acacia saplings 2-5 m height were tallied within each of the 848 plots (total area = 34.40 ha). Eucalypts were grouped into species and *Angophora floribunda* was included in the sample. The count was expanded during horizontal sampling to include eucalypt and acacia juveniles (0.5-2 m) and all eucalypt seedlings (< 0.5 m). Juveniles and seedlings were sampled at 24 sites (560 plots) and 18 sites (487 plots), respectively (Table 6.1). Time constraints prevented the sampling of natural regeneration at all 52 sites during horizontal point sampling.

Table 6.1. Number of sites and plots within which eucalypt and acacia regeneration was sampled on private land, state forest and travelling stock reserve of varying forest cover.

		Eucalypt seedlings (< 0.5 m)		Eucalypt and acacia juveniles (0.5-2.0 m)		Eucalypt and acacia saplings (2.0-5.0 m)	
Cover	LT	sites	plots	sites	plots	sites	plots
Closed forest	Priv.	2	54	3	60	3	60
	SF	3	114	3	114	6	126
	TSR	1	18	1	18	4	30
Open forest	Priv.	8	235	13	300	13	300
	SF	-	-	-	-	2	8
	TSR	4	66	4	66	21	134
Woodland	TSR	-	-	-	-	28	112
Scattered trees	TSR	-	-	-	-	16	64
Isolated trees	TSR	-	-	-	-	3	12
		18	487	24	560	96	848

The number and density of seedlings, saplings and juveniles were calculated for each plot (and each site). Because the results exhibited a high degree of between-plot variation, non-parametric analyses using either the Mann-Whitney test or the Kruskal-Wallis AOV (Zar 1984) were used to test the effect of tree cover and land tenure on density of regenerating seedlings, saplings and juveniles. Further non-parametric AOVs were used to test for variation between density of seedlings, saplings and juveniles in different combinations of land tenure-cover class. Two-factor AOV was not undertaken due to disproportionate replication between treatments.

6.2.2. Tree stump assessment

Tree stumps were sampled at 96 sites in conjunction with regenerating saplings (Table 6.1). Each stump was assessed for species, age, diameter, height, and coppice factors.

Identification of stump species

A number of techniques were used to identify stump species. Visual indicators included coppicing, presence of bark (particularly in younger stumps), tangential and radial wood patterns and form, relics of the felled tree, and tree species associations in the surrounding forest. Wood fragments were cut from the stump, providing clues in terms of hardness, grain and colour of the exposed timber. Red gum, yellow box and ironbark are all hard timbers and each has a distinctive hue. The timber of stringybark can be separated longitudinally into long slender splinters, typifying the ease with which it is split for firewood. Yellow box, to which it is most similar in colour, is much more difficult to slice with a knife due to its more rippled or convoluted grain. The stumps of low-density species (e.g. white gum, apple box) were often too difficult to distinguish, being similar in colour (cream to pale pink) and ease of cutting, and were classified as 'unknown low-density' stumps.

Establishment of stump age (time since cutting)

Stump age was defined as the number of years since the tree was harvested. Aging or dating of tree stumps in most forestry disciplines is assisted by historical logging records and maps. However, information of this kind was unavailable in this study due to the uncoordinated and *ad hoc* manner in which felling is practiced. A subjective procedure was employed to estimate the age of stumps in southern New England. A rural property about 25 km south of Armidale, "Harlow Park", was visited in 1992 to establish a set of visual criteria for estimating the age of cut stumps. The landholder was able to recognise each of the stumps on his property in terms of species and year of felling dating back 30 years, and a visual model was constructed. Table 6.2 lists the age-classes used :

Table 6.2. Age class (AC) and assumed mean age (AMA) for sampled stumps

AC	Age (yrs)	AMA (yrs)	AC	Age (yrs)	AMA (yrs)
1	0-1	0.5	6	15-20	17.5
2	1-2	1.5	7	20-30	25
3	2-5	3.5	8	30-50	40
4	5-10	7.5	9	50-100	75
5	10-15	12.5	10	100+	125

Condition of the cut surface was the principal visual criterion used for dating stumps. Recently cut stumps had a smooth, untarnished surface. A small amount of radial cracking was observed in all species after 1 year, particularly in the heartwood. The sapwood of most species had begun to deteriorate after 5 years. The roughness became more pronounced as the heartwood weathered around the cracks; after 10 years the cut surface had a coarse texture and after 20 years the surface was distinctively dimpled. Exterior bark exfoliated after 5 years in red gum and yellow box, although persistent bark adhered to stringybark stumps for up to 15 years. The extent to which cracking and interior shrinkage occurred depended largely on species. The cut surface of high-density species was intact after 30 years despite the increasing roughness, whereas interior rot was evident in low-density species. Roughness advanced from a dimpled to a pitted, knobbly or nodular form between 30 and 50 years, after which the heartwood rotted progressively from the interior outwards. Plate 6.1 (i-x) shows the condition of the cutting surface of stumps in all age classes to 100 years.

A number of other factors assisted in the aging of stumps. Deterioration of stumps was influenced by climatic factors such as degree of exposure to sunlight, wind and moisture. Stumps exposed to the elements deteriorated more rapidly than those in less exposed sites. Close proximity to swamps or watercourses tended to accelerate stump decomposition. Presence of wood shavings or sawdust supported an age of less than 2 years and the condition of the felled tree often presented clues in terms of leaf and branch retention and log rot. The diameter of coppice stems, if present, also assisted age estimation.

Allometric measurements

Each stump was measured for cut-height above ground level (HC, cm) and diameter underbark at cut-height (DUB, cm). HC was measured as a vertical distance from mean ground surface to mean level of stump cut. DUB was obtained using either a single circumferential or double cross-sectional measurement of the cut surface. For stumps in with intact bark, an overbark diameter (DOB, cm) was measured in the same way as DUB.

Stump density

Stump density (stumps.ha^{-1}) was calculated at each site. The inter-site variation in stump density was subsequently investigated using single-variate non-parametric AOV (Kruskal and Wallis test; Zar 1984) on 12 categorical site factors (Figures 6.2 to 6.4). Each test was performed separately, and a Bonferonni adjusted probability of $P/n = 0.05/12 = 0.004$ was used as the critical significance level for each test.

i. *Eucalyptus laevopinea* aged < 1 yr
DOB = 48 cm ; DUB = 40 cm
(note: retention of wood colour)

ii. *E. laevopinea* aged 1-2 yrs
DOB = 80 cm ; DUB = 68 cm

iii. *E. melliodora* aged 2-5 yrs
DUB = 47 cm
(note: bark shedding)

iv. *E. melliodora* aged 5-10 yrs
DUB = 22 cm
(note: most bark shedded)

v. *E. laevopinea* aged 10-15 yrs
DUB = 36 cm
(note: 3 major coppice stems
with DBHs 12,8 and 6 cm)

vi. *E. laevopinea* aged 15-20 yrs
DUB = 29 cm
(note: most bark shedded)

Plate 6.1. Cut stump surfaces of various species and age-classes

vii. *E. laevopinea* aged 20-30 yrs
DUB = 36 cm
(note : pitted surface with heart-wood relatively intact)

viii. *E. laevopinea* aged 30-50 yrs
DUB = 46 cm
(note: interior decay and presence of lichen)

ix. *E. melliodora* aged 30-50 yrs
DUB = 44 cm
(note: convoluted grain)

x. *E. blakelyi* aged 50-100 yrs
DUB = 50 cm

Plate 6.1. cont'd

Coppicing

In addition to the allometric measurements outlined above, three separate variables were measured for coppicing stumps: number of major stems; overbark DBH of each stem; and maximum height of the coppicing tree. AOV with Tukey's test was used to determine inter-species variation in coppice stump height, diameter, age and number of stems, and height and diameter distribution curves were constructed for selected species groups.

As diameter is the most important measurement for computing volume and weight of standing trees, diameter increment is the most important tool for determining volume and weight increment (Loetsch *et al.* 1973; Avery 1975). The relationship between total DBH (calculated from individual coppice DBHs using eq. 3.24) and assumed mean age (Table 6.2) of each coppice tree was used to construct a logarithmic diameter increment curve for each firewood species, from which a MAI curve for each species was also developed.

6.2.3. Tree ring analysis

Estimation of tree age was carried out on stringybark and yellow box trees during mensuration at site A and B (Chapter 3) by counting and averaging the number of growth rings along two axes of the freshly cut stump. The results were compared with tree ring analysis carried out on stringybark at site 64 (Baldwin 1994). Baldwin felled 20 stringybarks (15 *E. laevopinea* and 5 *E. youmanii*) and removed a single disc from each stump. Two perpendicular transects dissecting the pith were defined and tree rings counted on each of the four radii to obtain a mean count, translated directly to age. Each tree was described in terms of form, health and dominance. Form was based on stem straightness and angle, height of branching and presence of forks and other defects and health was based on canopy vigour (Baldwin 1994).

Tree age was plotted against overbark DBH to obtain a measure of DBH increment for each species. Because the rate of tree growth is best described by the signioidal growth curve (Avery 1975), Näslund's height curve (eqs. 3.26 and 3.27; Loetsch *et al.* 1973) was adapted to the age-diameter data of each species. Appropriate dry-weight equations from Tables 3.10 and 3.26 were subsequently used with the derived regression equations (diameter curves) to produce respective MAI curves, thus establishing yield estimates for each species.

6.2.4. Permanent growth plots

Five disturbed stands in TSRs were used in 1991 or 1992 to sample several small trees for DBH and HT. Trees were coded according to species, positioned according to a bearing and distance from a reference point, and tagged for future identification. The sites were re-visited in mid-1994 and trees re-sampled for DBH and HT. Time elapsed between samplings was recorded and a DBH and HT increment for each species in each site was calculated. The 86 trees sampled included 19 ironbark, 18 yellow box, 18 red gum, 18 grey box and 13 stringybark.

6.3. Results

6.3.1. Natural regeneration

General

A total of 3142 eucalypts and 354 acacias was sampled in a 34.40 ha area (96 sites) during the survey of regenerating saplings (2-5 m height). The mean density of eucalypt and acacia saplings was 89 ± 11 and 15 ± 3 plants.ha^{-1}, respectively. A total of 647 eucalypt and 105 acacias was counted in a 5.60 ha area (24 sites) during sampling for regenerating juveniles (0.5-2 m height). Mean density of eucalypt juveniles was 123 ± 13 plants.ha^{-1} ; mean density of acacia juveniles was 20 ± 4 plants.ha^{-1}. Eucalypt seedling density was highest of the three classes of immature trees sampled. A total of 1648 seedlings was counted within a combined area of 4.87 ha (18 sites). Mean density was 265 ± 72 plants.ha^{-1}. Appendices XXIII and XXIV summarise the seedling, juvenile and sapling data on a site basis. The variation in absolute numbers and density between sites was large, emphasising the likely influence of recruitment factors such as grazing regimes, timing of natural seedfall, seedbed conditions and site and climatic factors.

Influential factors

Variation in plant density was tested separately for tree cover and land tenure. Statistical results of the various tests are listed in Appendix XXV. Several trends evident from these analyses are illustrated in Figure 6.1. Density of eucalypt seedlings, juveniles and saplings on freehold land was significantly greater in closed forest than open forest. Conversely, density of eucalypt seedlings on TSR was significantly greater in open than closed forest. There was no significant difference between open and closed forest in the density of eucalypt juveniles or saplings on TSR and eucalypt saplings in state forest. There were significantly more eucalypt and acacia saplings in TSRs comprising forest and woodland than in TSRs containing stands of scattered and isolated trees.

With the exception of acacia juveniles in open forest, freehold land and state forest contained a higher density of seedlings and juveniles than TSRs. In contrast, TSRs contained a higher density of eucalypt saplings than freehold land. Eucalypt density was generally highest for seedlings and lowest for saplings under similar conditions, although density of saplings was higher than that of juveniles on TSR.

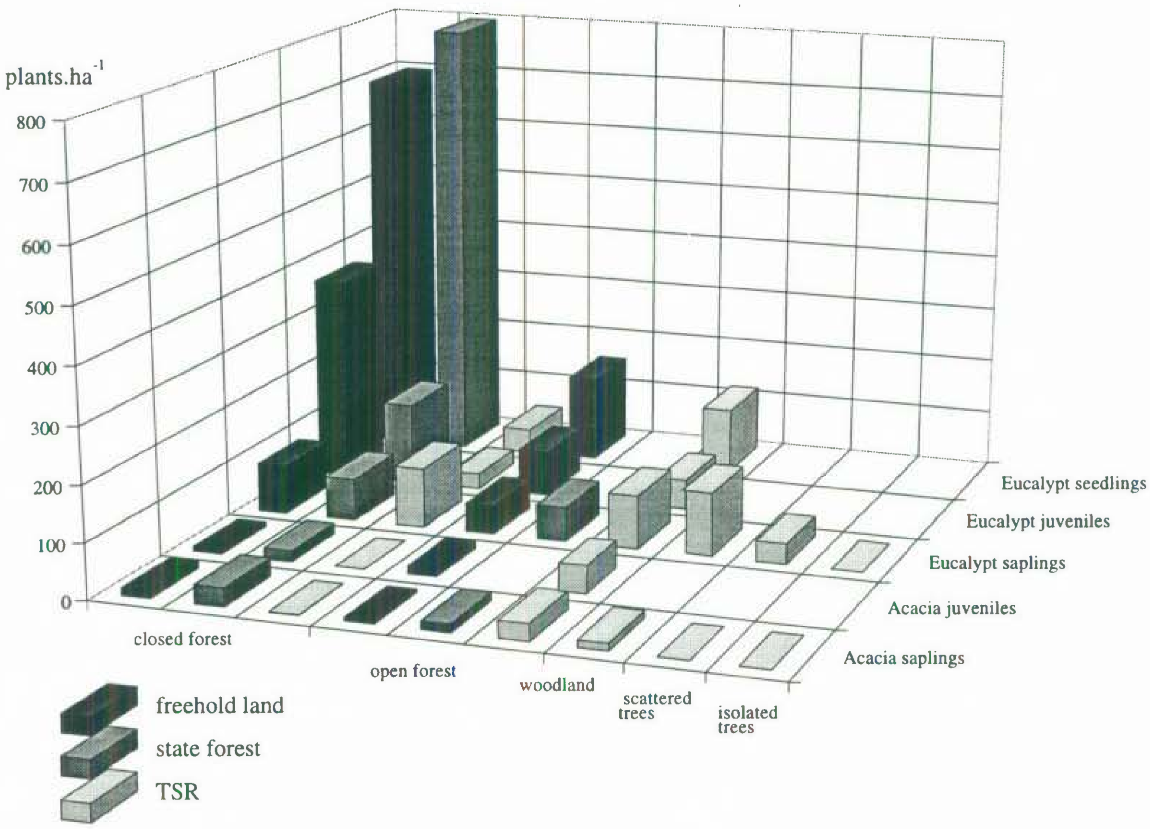


Figure 6.1. Influence of tree cover and land tenure on natural regeneration.
(note : absence of a bar indicates no that sampling was undertaken)

6.3.2. Stump assessment

General

A total of 2014 stumps was sampled at 96 inventory sites in state forest and TSR over an area of 34.4 ha. Stump density varied from 0 ha^{-1} at nine sites to 305 ha^{-1} at site 83, with an average of 62 ± 7 ha^{-1}. The stumps were cut from a total of 1674 trees, averaging 1.2 stumps per harvested tree. Mean DUB was 23.9 ± 0.4 cm, identical to that recorded for *E. sideroxylon* in TSR west of Armidale (23.9 ± 2.5 cm; Arrow 1991). Mean stump age, as weighted by mean age-class, was 24.5 ± 0.2 years. The height of cut stems averaged 65 ± 1 cm above ground level. A total of 221 stumps (11% of sampled stumps) were observed coppicing. Appendix XXVI summarises stump data on a site basis.

Stump density

According to Kruskal-Wallis tests and Bonferonni adjustments, 4 of the 12 site factors tested influenced stump density at P = 0.004 ; position on slope, dominant eucalypt species, cover class and stand basal area (Table. 6.3). Geology and stand density were near-significant.

Table 6.3. Influence of site-factors on stump density in southern New England (n = 95).

Factor	DF	KW. stat.	*P*	Factor	DF	KW. stat.	*P*
elevation	3	6.619	0.085	stand density (stems.ha^{-1})	5	15.694	0.008
position on slope	2	12.511	0.002	average stand DBH (cm)	6	12.039	0.061
site-quality	3	3.803	0.283	stand basal area (m^2.ha^{-1})	5	17.176	0.004
geology	4	13.937	0.007	land tenure	2	3.938	0.140
dominant species	3	39.919	0.000	land province	9	19.314	0.023
cover-class	4	16.168	0.003	distance from Armidale (km)	5	2.662	0.752

KW stat. = Kruskal-Wallis statistic

Figure 6.2 illustrates the variation in stump density with respect to each of the significantly contributing factors. Stump density was greater on upper and midslopes and in areas dominated by prime fencing and fuelwood species (stringybark and ironbark). Stump density also increased with increasing timber volume, indicating the vigorous regenerative nature of local stands under regimes of selective cutting.

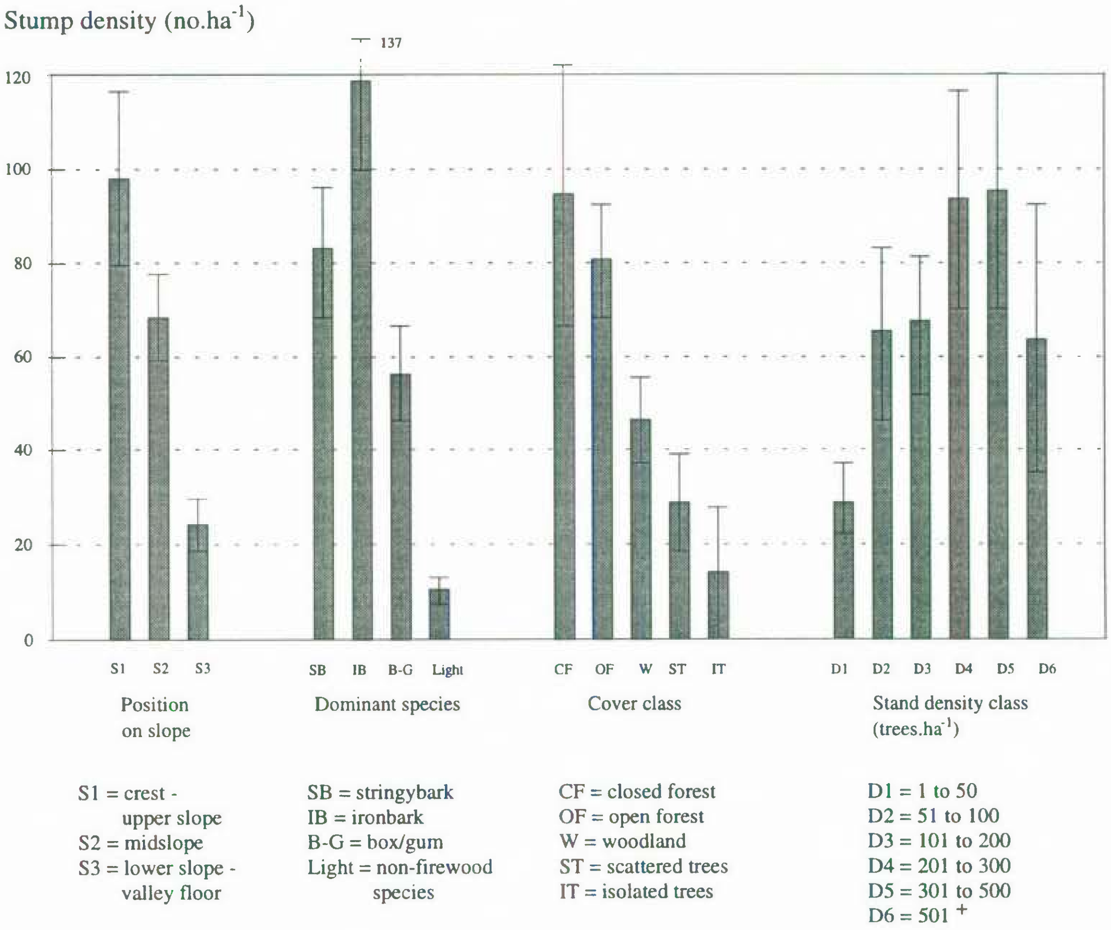


Figure 6.2. Effect of position on slope, dominant species, cover class and stand density on stump density in southern New England.

Coppicing

A total 221 of the 2014 sample stumps (11.0%) were observed coppicing, two of which are illustrated in Plates 6.2 and 6.3. Figure 6.3, which shows the proportion of coppice stumps of each species, does not necessarily reflect coppice ability because it was unknown whether the original trees of non-coppicing stumps were felled live or dead. Rather, it provides evidence of the minimum proportion of live-felled trees of each species. At least 35% of the stumps sampled in ironbark, 14% of the stumps in stringybark, 8% of those in yellow and grey box, 6% of red gum stumps and 5% of 'light' stumps were derived from live-felled trees. The high proportion of coppicing ironbark stumps reflects the high demand for green cut timber for rural timber products such as sleepers and fenceposts. A higher proportion of the stumps of other species were probably cut from dead standing trees in which fuelwood production was the primary objective.

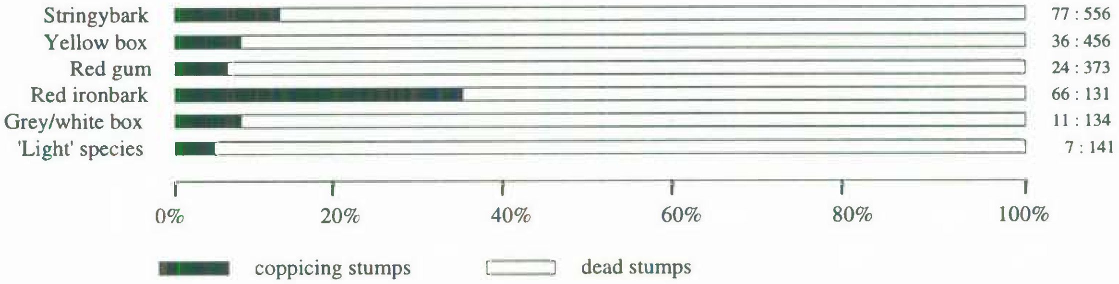


Figure 6.3. Proportion of coppice stumps sampled for each species.

While no significant difference was observed in the above-ground height of coppicing stumps, the diameter, age and number of coppice stems varied significantly between fuelwood species (Table 6.4). The mean underbark diameter of coppicing stumps and mean number of coppice stems was significantly lower in red gum (15.4 cm; 1.5 stems) than other species (23.0 cm; 2.3 stems), and average age of coppice stumps in yellow box and red gum was significantly less than that of stringybark, ironbark and grey box (15.6 and 29.1 years, respectively).

Table 6.4. Statistical parameters for analysis of variance of four coppice parameters according to fuelwood species.

				Pooled species groups [1]	
VARIABLE	N	F-ratio	P	Group(s)	Mean
Ht.cut (cm)	214	0.730	0.574 (ns)	SB,YB,RG,IB,GB	67.4 ± 2.1
Diam.cut (cm, UB)	210	2.571	0.039 (*)	SB,YB,IB,GB	23.0 ± 0.9
				RG	15.4 ± 1.8
Av. age (yrs)	214	8.621	0.000 (***)	SB,IB,GB	29.1 ± 2.7
				YB,RG	15.6 ± 0.9
No.stems	213	3.392	0.010 (**)	SB,YB,IB,GB	2.3 ± 0.1
				RG	1.5 ± 0.2

1. groups established using Tukey's multiple comparison analysis

Plate 6.2. Coppicing *E. sideroxylon* at site 20.
(stump DUB ~ 30 cm; age ~ 20 yrs)

Plate 6.3. Coppicing *E. caliginosa* at site 98
(stump DUB ~ 75 cm; age ~ 4 yrs)

Figures 6.4 to 6.6 provide pooled-species histograms of coppice-stump height and diameter; Figure 6.7 shows the DBH-age relationship of each coppicing species. While coppice viability appeared largely independent of stump cut height within a broad range of about 30 to 100 cm a.g.l. (Figure 6.4), it was more dependent on stump diameter; the majority of stems sprouted from stumps of 10-20 cm (Figures 6.5 and 6.6). This supports the observation that young trees are more suited to coppicing than old trees (Cremer *et al.* 1990).

Of the increment curves generated from age class data in Figure 6.7, ironbark possessed the highest rate of DBH increment to 30 years and red gum the lowest (0.92 and 0.58 cm.yr^{-1}, respectively). This could reflect the greater average stump diameter (and thus greater root biomass) in ironbark and the relatively low number of coppice stems in red gum.

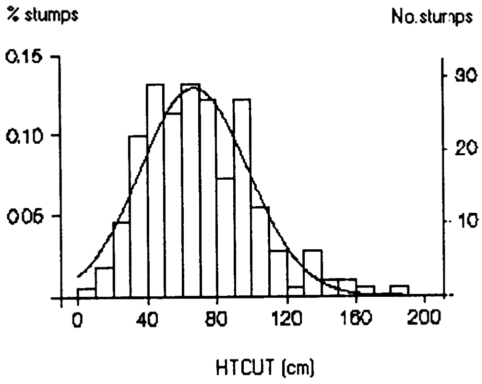


Figure 6.4. Height distribution of coppice stumps for all fuelwood species sampled

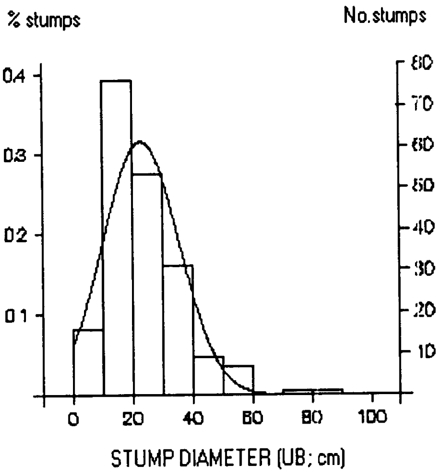


Figure 6.5. Diameter (underbark) distribution of coppice stumps for all species but red gum

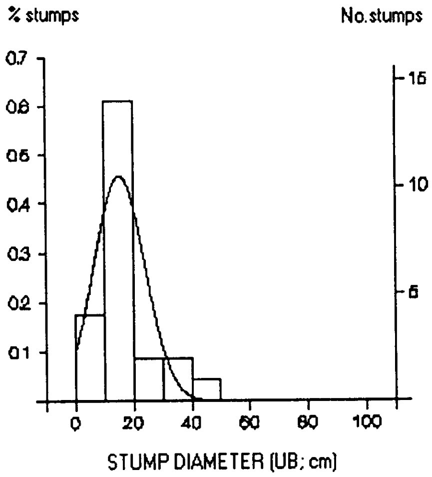
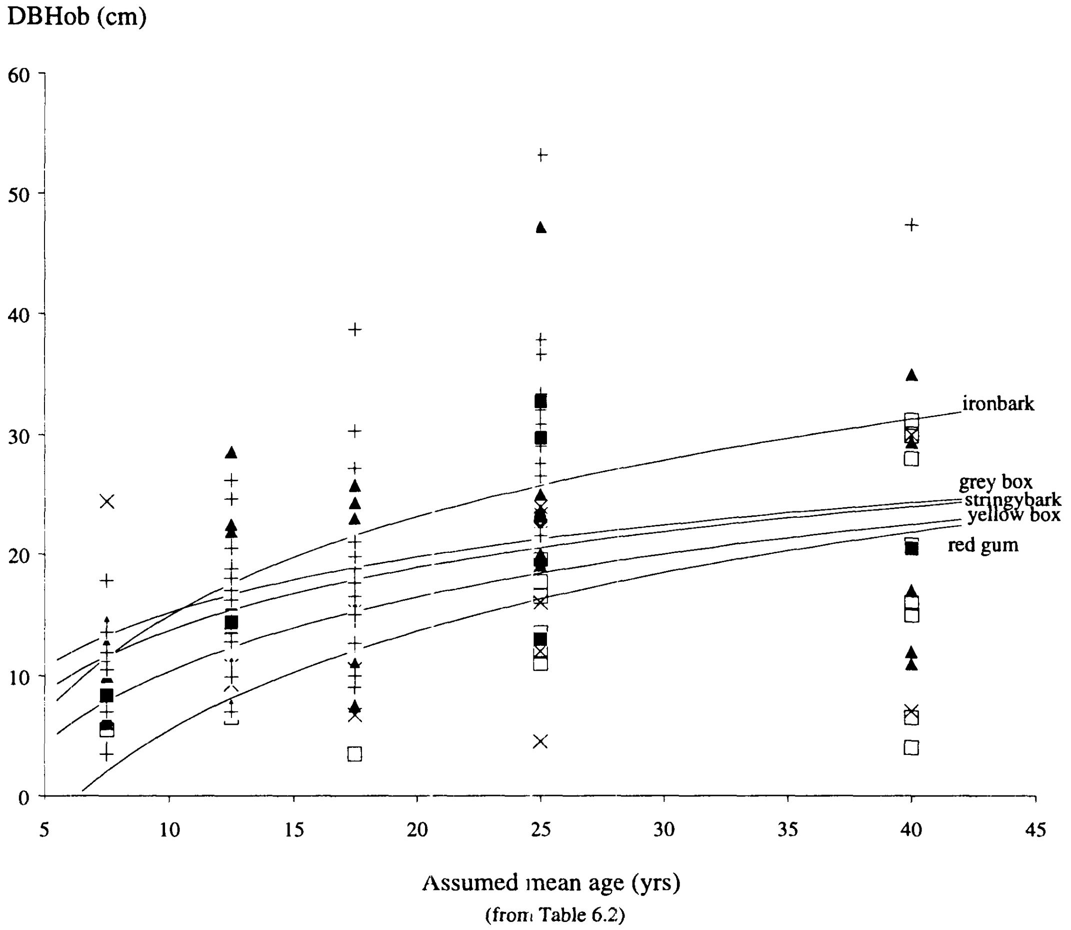


Figure 6.6. Diameter (underbark) distribution of coppice stumps for red gum



▲ stringybark : DBH = 7.40*Ln(AGE) - 3.32 (adjr^2= 0.45, P = 0.000)
× yellow box : DBH = 8.76*Ln(AGE) - 9.82 (adjr^2= 0.39, P = 0.000)
□ red gum : DBH = 11.81*Ln(AGE) - 21.74 (adjr^2= 0.39, P=0.001)
– ironbark : DBH = 11.80*Ln(AGE) - 12.27 (adjr^2= 0.46, P=0.000)
■ grey box : DBH = 6.59*Ln(AGE) (adjr^2= 0.90, P=0.001)

Figure 6.7. Diameter curves for the coppice stems of five firewood species in southern New England.

Stem weight functions for trees in SQ6-7 (Tables 3.22 and 3.26) were used in conjunction with diameter curves in Figure 6.7 to produce MAI curves of coppice growth as depicted in Figure 6.8. Ironbark had by far the greatest rate of fuelwood production, accruing an average 12.85 kg.tree^{-1}.yr^{-1} over 18 years. Grey box incremented 7.09 kg.tree^{-1}.yr^{-1} over 22 years and stringybark produced 5.28 kg.tree^{-1}.yr^{-1} in 23 years. The slower growing yellow box and red gum did not acquire maximum MAI until much later, yellow box reaching 4.38 kg.tree^{-1}.yr^{-1} after 38 years and red gum 3.03 kg.tree^{-1}.yr^{-1} after 67 years.

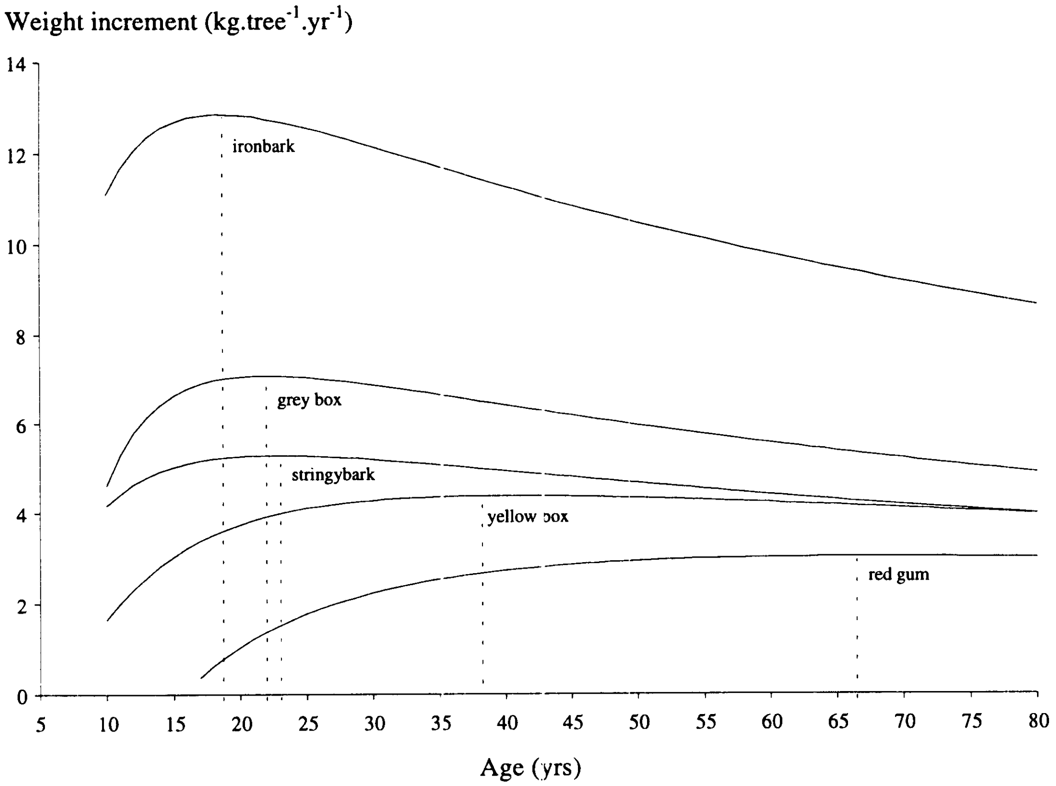


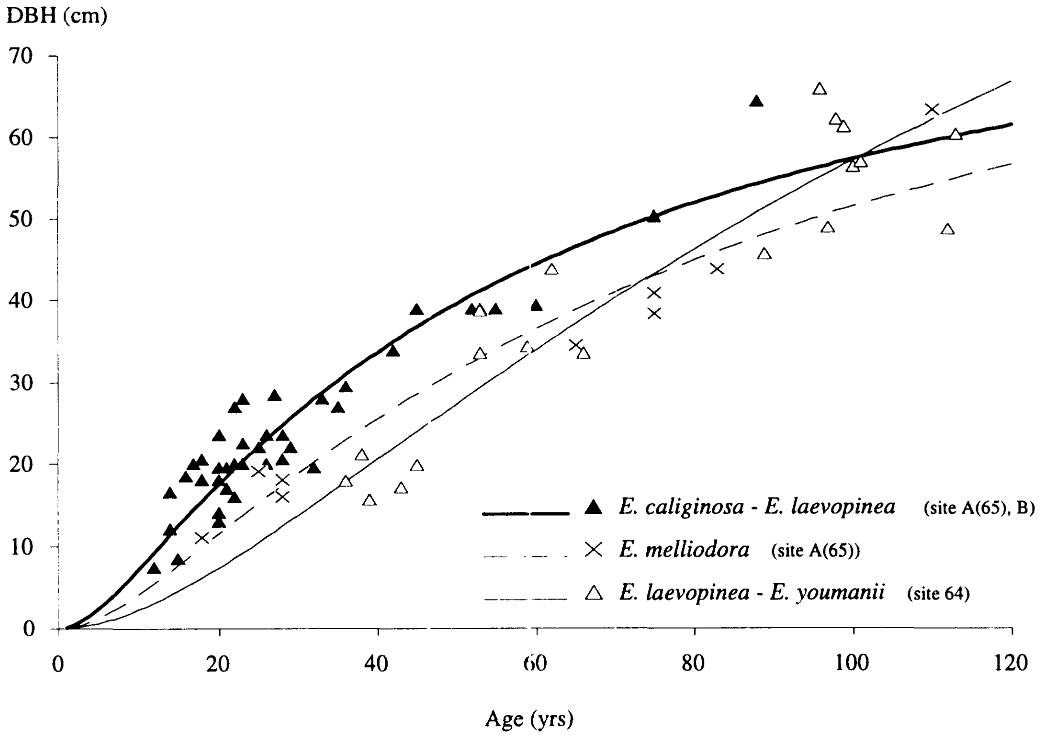
Figure 6.8. MAI curves for coppice stems of five firewood species in southern New England (SQ6-7).

6.3.3. Tree ring analysis

Table 6.5 lists the age estimates and corresponding DBH measurements obtained for trees felled during mensuration studies (Chapter 3), and tree ring analysis at site 64 (Baldwin 1994). The growth rings of several large *E. laevopinea* at site A were not assessed at the time of harvesting due to heartwood deterioration. An analysis of covariance was performed on the data for stringybarks less than 30 cm DBH at sites A and B (all sampled *E. caliginosa* were less than 30 cm; Table 6.5), which showed no significant variation between species ($P > 0.5$). Stringybark data were thus pooled to produce a composite diameter curve which was plotted with the respective curve for *E. melliodora* at site A (Figure 6.9). An analysis of covariance was also performed on the DBH-age data for *E. laevopinea* and *E. youmanii* at site 64 (Baldwin 1994). This showed no significant difference in DBH increment between species, and neither tree form, health nor dominance were shown to affect growth increment significantly. Thus all stringybark data at site 64 were pooled to construct the DBH-age relationship for *E. laevopinea* - *E. youmanii* (Figure 6.9).

Table 6.5. DBH-age data from harvested stringybark and yellow box.

SITE A (SITE 65)				SITE B		SITE 64 (data from Baldwin 1994)			
E. melliodora		*E. laevopinea*		*E. caliginosa*		*E. laevopinea*		*E. youmanii*	
DBH (cm)	AGE (yrs)	DBH (cm)	AGE (yrs)	DBH (cm)	AGE (yrs)	DBH (cm)	AGE (yrs)	DBH (cm)	AGE (yrs)
38.5	75	39	45	17	21	52.2	101	61.4	99
18	28	12	14	22	29	17.9	36	38.8	53
16	28	13	20	16	22	17.1	43	45.9	89
63.5	110	7.5	12	14	20	44.0	62	48.9	112
44	83	8.5	15	16	22	62.3	98	49.1	97
41	75	18	20	20	22	19.9	45		
11	18	19.5	20	27	22	15.6	39		
19	25	64.5	88	23.5	26	21.1	38		
34.5	65	39	52	29.5	36	34.4	59		
		34	42	20.5	18	33.6	53		
		19.5	32	16.5	14	39.0	53		
		27	35	18	18	60.5	113		
		39	55	18	18	33.6	66		
		50.5	75	23.5	20	56.6	100		
		22	25	18.5	16	52.9	96		
		28	33	20	17				
		20.5	28	20	23				
		28	23	19.5	21				
		23.5	28	22.5	23				
		20	26	28.5	27				
		39.5	60						



E. laevopinea - E. youmanii (site 64) : $\mathrm{DBH} = (\mathrm{AGE}^2/_{(5.911+0.073\bullet(\mathrm{AGE}))})^2$ (adj.$r^2 = 0.84$)
E. caliginosa - E. laevopinea (sites A ,B) : $\mathrm{DBH} = (\mathrm{AGE}^2/_{(2.692+0.105\bullet(\mathrm{AGE}))})^2$ (adj.$r^2 = 0.92$)
E .melliodora (site A) : $\mathrm{DBH} = (\mathrm{AGE}^2/_{(3.919+0.100\bullet(\mathrm{AGE}))})^2$ (adj.$r^2 = 0.96$)

Figure 6.9. Diameter curves for three eucalypt groups in native forest in southern New England.

According to analyses of covariance, the relationship between tree age and DBH varied significantly between *E. laevopinea - E. caliginosa* (sites A, B), *E. laevopinea - E. youmanii* (site 64), and *E. melliodora* (site A), as shown by the position of the respective curves in Figure 6.8. The overall rate of DBH increment to 120 years was highest in stringybark at site 64 (0.56 cm.yr^{-1}), marginally less in stringybark at sites A and B (0.51 cm.yr^{-1}), and least in yellow box at site A (0.47 cm.yr^{-1}). Maximum rates of DBH increment were 0.58 cm.yr^{-1} at 81 years in stringybark at site 64, 0.88 cm.yr^{-1} at 25 years in stringybark at sites A and B, and 0.64 cm.yr^{-1} at 39 years in yellow box at site A.

6.3.4. Permanent growth plots

While the experimental rigour of data collected from permanent growth plots was limited in terms of site replication and species and size class representation, the data offered an insight into the growth rate of native fuelwood species under drought conditions. Little difference in the mean growth increment of the five eucalypt species was observed, although red gum grew more slowly (Table 6.6). There was marked variation in growth increment within each species, particularly in red gum and ironbark, emphasising the influence of growth factors (shading, water availability, rockiness, pests, mistletoe, etc.) at the individual tree level.

Table 6.6. Growth increments in young trees for five eucalypt species.

			DBH increment (cm.yr^{-1})			HT increment (m.yr^{-1})		
spp.	no.	av.dbh (cm)[1]	min.	max.	mean	min.	max.	mean
stringybark	13	10.3	0.25	1.50	0.85 ± 0.11	0	0.8	0.44 ± 0.06
yellow box	18	10.6	0.25	1.69	0.95 ± 0.08	0	1.0	0.58 ± 0.06
red gum	18	10.1	- 0.35	1.75	0.54 ± 0.11	0	0.9	0.37 ± 0.06
ironbark	19	14.6	- 0.06	1.78	0.73 ± 0.13	- 0.1	1.1	0.59 ± 0.06
grey box	18	11.1	0.15	1.42	0.75 ± 0.08	0	0.9	0.65 ± 0.06

1. initial measurement

6.4. Discussion

6.4.1. Natural regeneration

Land use practices including grazing, clearing, and fertiliser application have hindered if not eliminated the natural regenerative capacity of many areas in the New England region (Curtis 1989). In this study, natural eucalypt regeneration was most prolific in closed forest environments (700-800 seedlings.ha^{-1}; Figure 6.1). This could reflect a higher degree of protection and superior seedbed conditions for young trees since grazing is generally less intensive and less frequent. Although seedlings and juveniles were not sampled in woodland, scattered or isolated cover, the trend for eucalypt and acacia saplings suggests a paucity of regeneration in open country. The density of eucalypt saplings differed little between closed and open forest and woodland, with an average of about 90 stems.ha^{-1}, but declined in areas of scattered trees (37 stems.ha^{-1}) and isolated trees (0 stems.ha^{-1}). Suppression of natural recruitment in areas of scattered trees has also been observed under similar landuse patterns in the Southern Tablelands (Morse 1985a). A good sapling density in forest systems is important for 'advance growth' after logging (Cremer *et al.* 1990)

6.4.2. Yield of coppice stems

Since MAI curves (Figure 6.8) were derived from stands in which thinning and fertilising of coppice stems was absent, the rate of fuelwood production from intensively managed coppice stands is likely to be considerably higher. This is promising given an ironbark coppice increment of 12.85 kg.tree^{-1}.yr^{-1} after 17 years, equivalent to 12.9 t.ha^{-1}.yr^{-1} of air-dry fuelwood at a stocking rate of 1000 trees.ha^{-1}.

The silvicultural regime used in many production forests involves clearcut rotation in even-aged stands using a rotation length equal to the realisation of maximum MAI of a forest stand. Coppice management lends itself to this type of regime and the role of short-rotation coppice plantations, and the economic implications for the local area, are discussed in Chapter 9.

6.4.3. DBH increment from stump and permanent plot data

Mean DUB of sampled stumps was 23.9 ± 0.4 cm and mean stump age, as weighted by mean age-class, was 24.5 ± 0.2 years (section 6.3.2). According to stump analysis, it follows that mean diameter increment of local trees was just under 1 cm.yr^{-1}. This is supported by data collected from permanent growth plots (section 6.3.4) which provide diameter increment rates of between 0.54 cm.yr^{-1} for red gum and 0.95 cm.yr^{-1} for yellow box (Table 6.6). In a study of the effect of mistletoe on growth and survival of yellow box and red gum north of Armidale, Reid *et al.* (1994) observed that the DBH of 'disinfected' yellow box and red gum incremented an average 2.2 ± 0.25 and 1.2 ± 0.20 cm in 33 months. The results are similar to the above, indicating a consistency in species growth across the central study region.

6.4.4. Yield of forest trees

Diameter curves

The rate of change of tree DBH determines the respective rate of volume or weight increment. The stringybark and yellow box curves derived from trees harvested at sites A and B (Chapter 3) have similar form, but the diameter curve for stringybark at site 64 (Baldwin 1994) is appreciably different in form.

Mean stump density was 25.0 stumps.ha^{-1} at site 64 and 32.2 stumps.ha^{-1} at site 65; mean stump DUB was 22.7 cm at site 64 and 33.1 cm at site 65 (Appendix XXVI). Application of this data to timber : bark ratios and weight functions derived in Chapter 3 reveals a relatively light logging history at each site; 400 kg.ha^{-1}.yr^{-1} at site 64 and 700 kg.ha^{-1}.yr^{-1} at site 65 (0.25% and 0.67% of the standing timber dry-weight per year, respectively). This suggests that variation in annual growth increment between forests at sites 64 and 65 is influenced by factors other than competition release from logging disturbance.

Site 64 is a tall closed forest of high site quality (SQ3); site 65 comprises open forest of lower quality (SQ5). While stand density is similar at sites 64 and 65 (417 *cf.* 400 trees.ha^{-1}), trees at site 64 are an average 3.1 cm larger in diameter than trees at site 65 (25.2 *cf.* 28.3 cm) and constitute about 25% more basal area (Appendix XXI). Timber biomass is estimated to be 150 t.ha^{-1} at site 64 and 103 t.ha^{-1} at site 65 (Appendix XXII) while projected canopy cover is 60-70% and 40-60%, respectively (N. Reid unpubl. data). A corollary effect of the greater canopy cover and stand biomass in closed forest at site 64 is the limited opportunity for young tree growth and development, in which trees can be suppressed for long periods in the absence of disturbance factors such as natural attrition or senescence, windfall, lightening strike, fire or tree harvesting. Competition for sunlight and space at site 65 is less intense, encouraging early canopy development, photosynthetic activity and tree growth.

The average DBH for a 40-year stringybark is 33.7 cm at site 65 and 20.5 cm at site 64 (Figure 6.9), yet the average height of 40-year stringybark is 14.7 m at site 65 and 15.0 m at site 64 (Table 3.15). This illustrates the influence of site-quality and cover class on tree growth and form. Early growth in closed forest is dominated by height increment, while that in open forest and woodland is dominated by canopy, DBH and thus biomass increment. As tree age surpasses 60 years, however, the relative rate of diameter increment increases in site 64 with respect to site 65 (Figure 6.9). Extrapolating the diameter curves in Figure 6.9 to 200 years, the average DBH of a stringybark at site 64 is 95.1 cm compared with 71.3 cm at site 65; the corresponding height estimates are 34.3 m at site 64 and 21.7 m at site 65. After 200 years, yellow box at site 65 has an average DBH of 69.9 cm and an average height of 22.1 m, almost identical to stringybark at the same site.

The above observations suggest that site quality plays an increasingly important role in tree growth at a later stage in tree development, while canopy cover and forest disturbance play a major role during early tree development.

MAI and CAI curves

DBH is an important factor in the selection of desirable fuelwood trees and those less than 15 cm or greater than 60 cm are considered sub-optimal. Small trees contain a relatively high proportion of lower-density sapwood and have not yet attained optimal growth rate; large trees yield billets too thick and heavy to handle, increasing risk of personal injury during felling, sectioning, loading and splitting. They are also more prone to piping and decay.

Figures 6.10 and 6.11 provide weight increment curves for forest trees derived from functions of dry-weight (Table 3.22) and diameter curves (Figure 6.9). Figure 6.10 shows the relationship between MAI and tree age, while Figure 6.11 depicts the relationship between CAI (current annual increment is the weight or volume increment over a particular 12 month period) and tree age. Similar to DBH increment, the maximum values of CAI and MAI for a forest tree (and the age at which it is achieved) is dependent on site quality and forest cover. In the open forest environment, stringybark yields a maximum MAI of 19.4 kg.yr^{-1} after 87 years at a mean DBH of 54.1 cm, and yellow box produces a maximum MAI of 18.1 kg.yr^{-1} after 119 years at a mean DBH of 56.6 cm. In each case, maximum MAI is realised within the optimum diameter range for fuelwood trees (15-60 cm), although closed stringybark forest at site 64 does not reach its maximum MAI of 35.8 kg.yr^{-1} until 259 years at a mean DBH of 108.9 cm.

By considering the area under the $15 \leq \text{DBH} \leq 60$ cm portion of each CAI curve in Figure 6.11, *E. laevopinea* at site 64 has a harvest time frame of 74 years (age 32-105), over which an individual tree accumulates a total 2505 kg (33.9 kg.yr^{-1}). The harvest time frames for lower quality stringybark and yellow box are 95 years (age 18-112) and 111 years (age 25-135), with respective increments of 26.4 and 20.8 kg.yr^{-1}. Closed forest trees at site 64 produce more fuelwood biomass over the harvesting time frame, although open forest stringybark trees at sites A and B produce more biomass to an age of about 80 years (Figure 6.10). While it is unrealistic to commit fuelwood harvesting to a particular tree size in the management of uneven-aged stands, the best MAI for all species occurs in trees greater than 50 cm DBH, suggesting the adoption of long rather than short rotations in the future management of fuelwood forests.

6.4.5. Forest MAI

Weight increment results from tree ring analysis (Figure 6.10) were applied to the species-density data of closed and open stringybark forest (Appendix XXII ((nos.8 and 13)) to obtain estimates of stand MAI. Stringybark closed forest (SQ3) had an air-dry MAI of about 2.61 t.ha^{-1}.yr^{-1} or 3.7 m^{3}.ha^{-1}.yr^{-1}; stringybark open forest (SQ5) had an air-dry MAI of 2.28 t.ha^{-1}.yr^{-1} or 3.2 m^{3}.ha^{-1}.yr^{-1}. These values represented all fuelwood timber to a minimum diameter of 5 cm. Inferior or 'light' fuelwood species were not included. Given an average growth rate of 2.5 t.ha^{-1}.yr^{-1} and an area of 17 180 ha of forest available for harvesting (section 5.4.4), then annual fuelwood turnover is approximately 43 000 t.yr^{-1}, enough to supply the region on a sustained yield basis.

Calculation of confident limits for annual fuelwood turnover was not possible given that logging history, as measured by stand age-structure and stump density, was only quantified within a handful of eucalypt stands in southern New England. While MAI of most stands probably varies between 2 and 3 t.ha^{-1}.yr^{-1}

depending on forest type and site quality, CAI could be as high as 10 t.ha^{-1}.yr^{-1} in more intensively or recently logged forest. Given the relatively undisturbed nature of the two stands analysed for weight increment, and the potential for improved increment using more intensive silviculture, it is possible that regional fuelwood productivity in southern New England is presently greater than 43 000 t.yr^{-1}

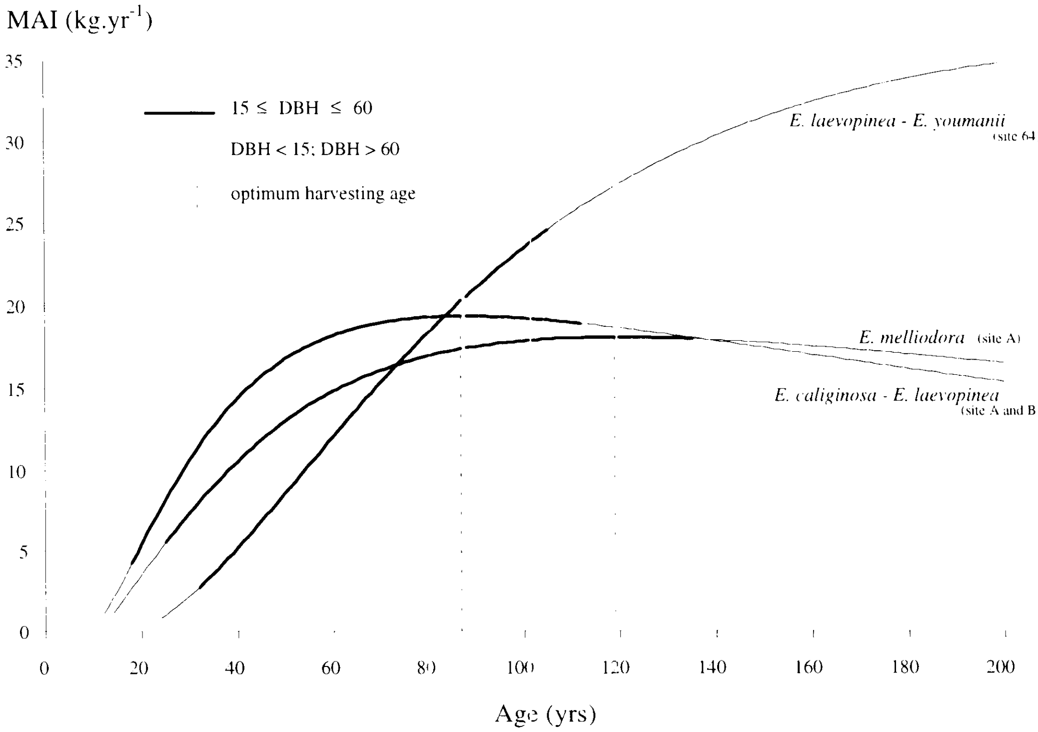


Figure 6.10. Dry-weight MAI curves for three eucalypt groups in southern New England.

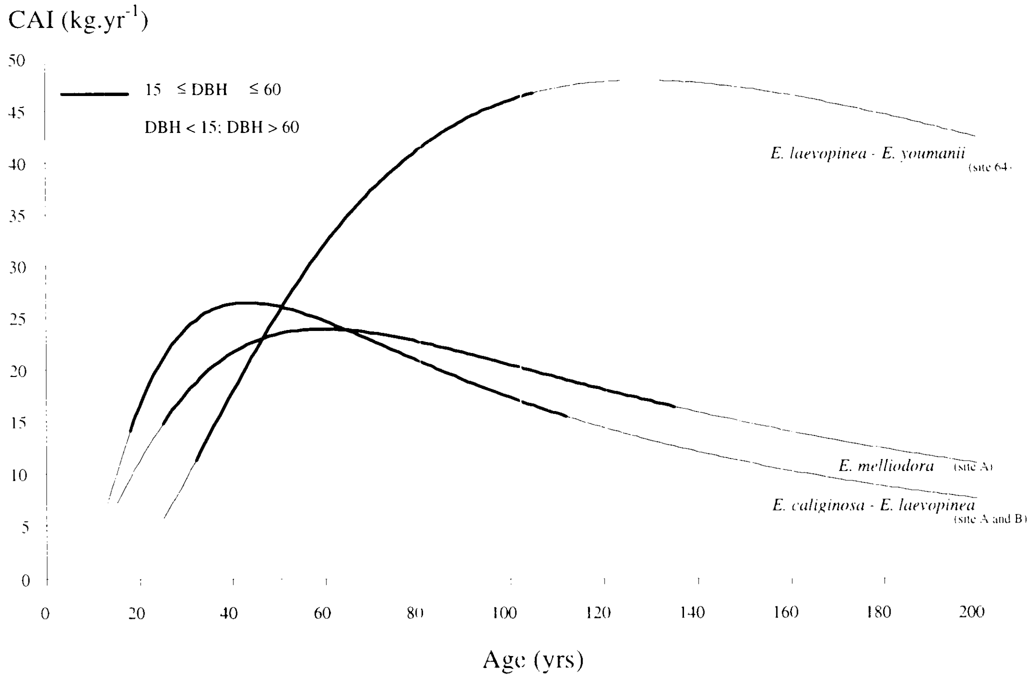


Figure 6.11. Dry-weight CAI curves for three eucalypt groups in southern New England.

Figures 6.12 and 6.13 show the relationship between stand density and dry-weight increment for different tree diameter classes in stringybark forest. The most significant aspect of the MAI-DBH distribution from a silvicultural viewpoint is that ~82% of the annual weight increment in eucalypt closed and open forest is accumulated by trees in the DBH range 15-60 cm. Figures 6.14 and 6.15 show the relationship between stand density and dry-weight increment for different age classes in stringybark forest. Over 90% of MAI in closed forest accrues in trees less than 110 years; over 90% of MAI in open forest accrues in trees aged less than 80 years. This suggests that manipulation of stringybark forest for domestic fuelwood production should occur on an 80-year rotation, although this is probably conservative given the potential improvement in stand productivity under a system of fuelwood forestry using coppice regrowth. It also suggests that mean annual increment of local stands would decrease in the absence of periodic timber removal.

6.4.6. Comparison with other yield statistics

There are two fundamental differences between New England and other Australian forest yield estimates. First, the yield statistics derived for local forests incorporate total wood and bark volume to a minimum end diameter of 5 cm. This contrasts with estimates of MAI in other forests which consider only the merchantable volume, restricted to a commercial section of timber in the main bole of forest trees. Bark, branches, and upper stem are discounted from analysis of merchantable MAI with respect to sawlog production, but perhaps account for 50% of the quota tree volume and 100% of the total merchantable stand volume. Second, yield estimates for New England stands consider uneven-aged mixed eucalypt forest in which logging activities have been relatively light in the last 50 years, while the primary objective of most growth and yield studies is the quantification of forest production in response to treatment and harvesting (Alder 1980). The majority of yield data in Australia are derived from even-aged regrowth stands, comprising one dominant species harvested on a clearcut basis with or without intermediate thinnings.

The MAI of merchantable timber reported for most eucalypt forest in Australia seems low compared to fuelwood increment. Jacobs (1955) considered that most Australian forest had deteriorated under a cut that never exceeded an MAI of 0.42 $m^3.ha^{-1}.yr^{-1}$. In separate studies, Parsons *et al.* (1991) estimated an MAI of 0.33 to 0.53 $m^3.ha^{-1}.yr^{-1}$ in riverine red gum forests of the Murray Valley, Curtin *et al.* (1991) claimed an MAI of 0.4 $m^3.ha^{-1}.yr^{-1}$ for dry hardwood on the north coast of NSW, RAC (1991) claimed an MAI of 0.25 $m^3.ha^{-1}.yr^{-1}$ in south-east dry eucalypt forest, and FCNSW (1984) reported an MAI of 0.27 $m^3.ha^{-1}.yr^{-1}$ in Styx River State Forest. These estimates represent 5 to 15% of the fuelwood MAI achievable from New England stands. Other estimates of merchantable MAI include 1.5 $m^3.ha^{-1}.yr^{-1}$ for low elevation mixed-eucalypt forest in Victoria (Kellas and Hateley 1991), 2.0 $m^3.ha^{-1}.yr^{-1}$ for ash and brown barrel sites on the Southern Tablelands of NSW (Hamilton and Cowley 1991), and 3.2 $m^3.ha^{-1}.yr^{-1}$ in the karri forest of Western Australia (Borough *et al.* 1984).

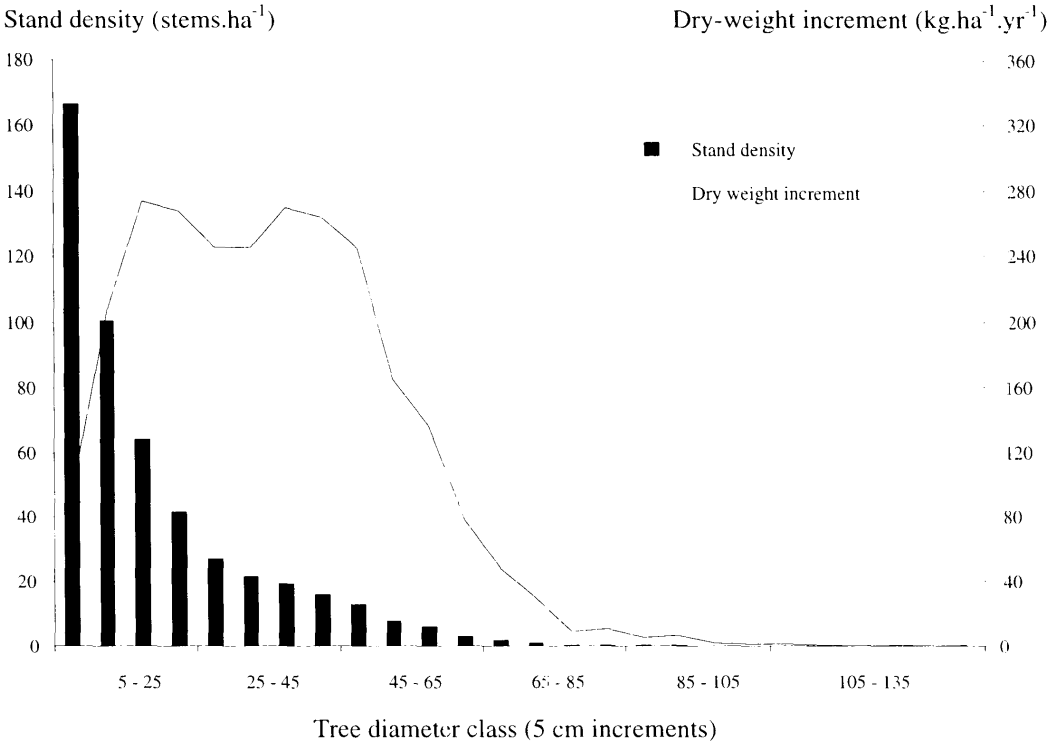


Figure 6.12. Stand density and annual weight increment for trees of varying DBH in stringybark closed forest.

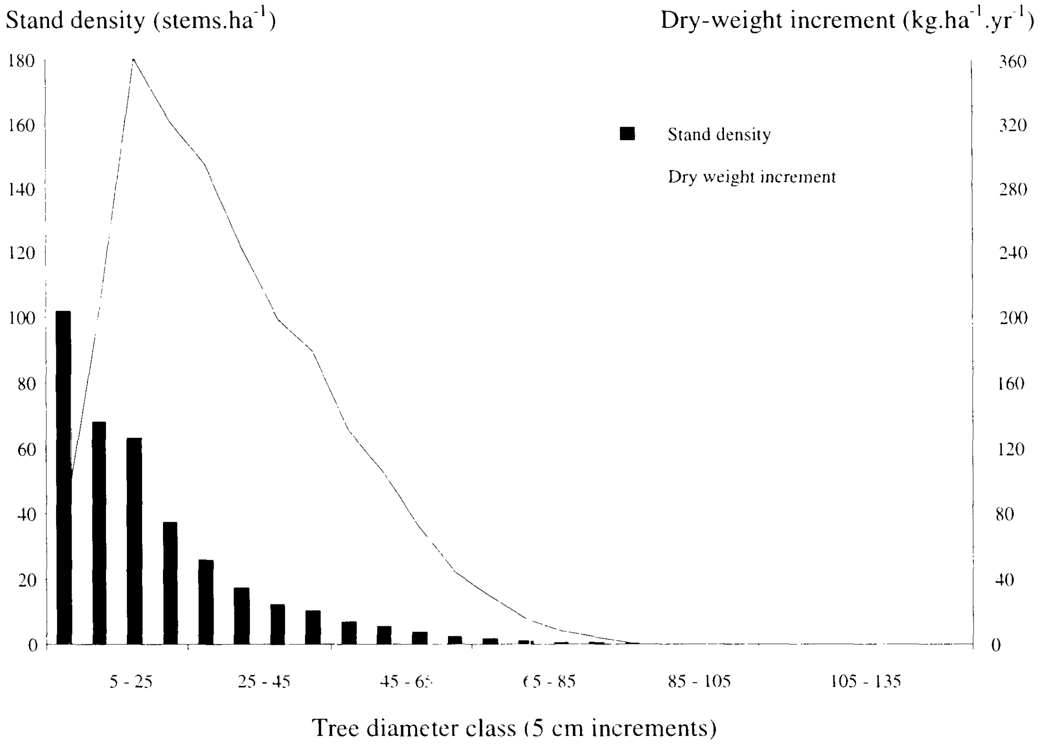


Figure 6.13. Stand density and annual weight increment for trees of varying DBH in stringybark open forest.

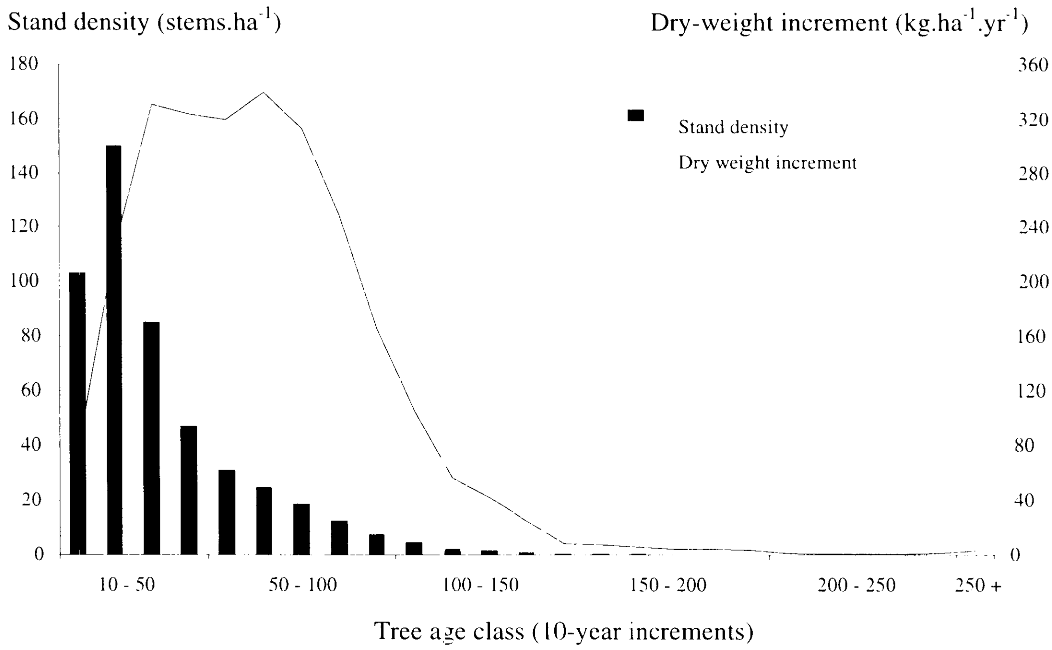


Figure 6.14. Stand density and annual weight increment for trees of varying age in stringybark closed forest.

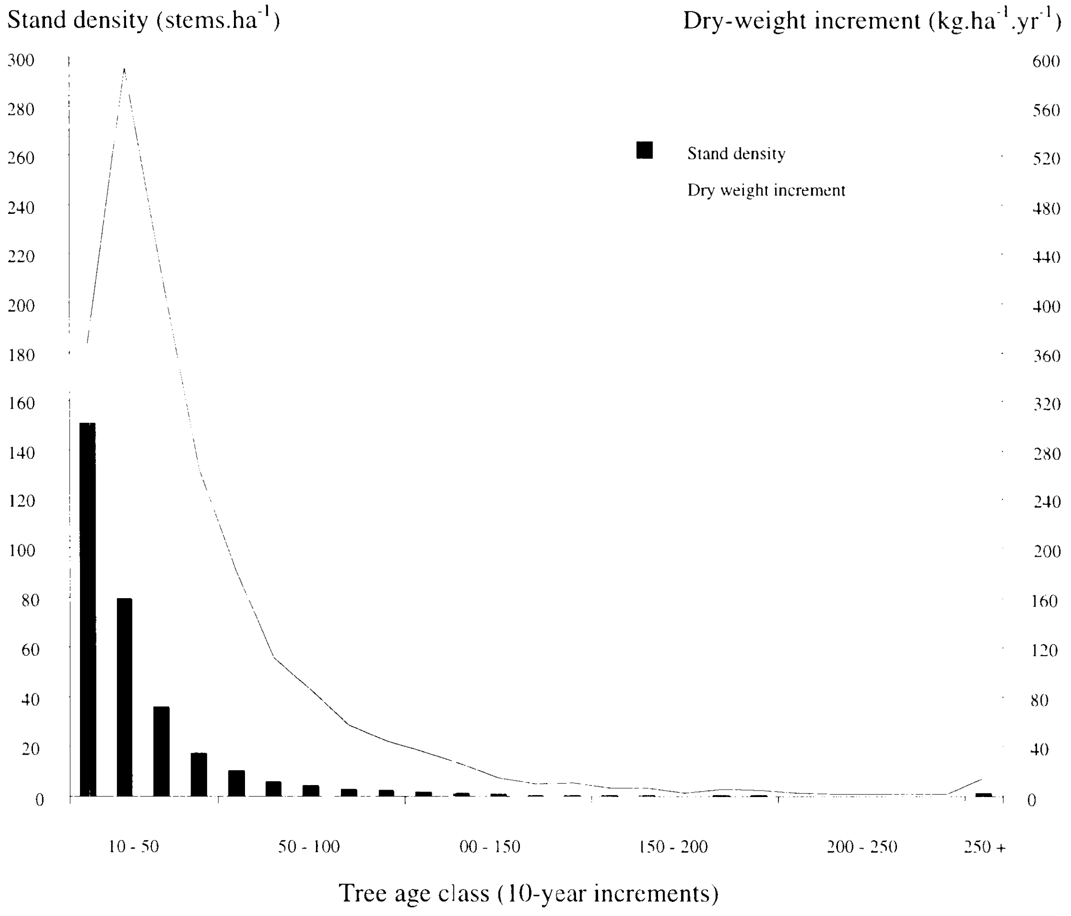


Figure 6.15. Stand density and annual weight increment for trees of varying age in stringybark open forest.

With respect to total timber biomass, Cannell (1982; cited in Cannell 1989) compiled an international dataset on dry matter production in stems, branches and foliage of 204 broad-leaved forest stands managed for timber production. Over 90% of stands produced less than 12 $t.ha^{-1}.yr^{-1}$ above-ground woody biomass, with an average of approximately 7 $t.ha^{-1}.yr^{-1}$. This is roughly twice the fuelwood MAI of stringybark stands in southern New England, which possibly reflects the limited growing season experienced on the Tablelands as a result of winter cold, and the absence of silviculture to encourge timber growth.

6.5. Conclusions

Tree ring analysis was used in conjunction with tree volume estimation and stand density assessment to investigate the productivity of stringybark closed forest of relatively high site quality and stringybark open forest of moderate site quality. Closed forest had an MAI of 2.6 $t.ha^{-1}.yr^{-1}$ (3.7 $m^3.ha^{-1}.yr^{-1}$), 15% more than the MAI for open forest (2.3 $t.ha^{-1}.yr^{-1}$ or 3.2 $m^3.ha^{-1}.yr^{-1}$). These values are small compared with other estimates of fuelwood increment the literature, although the impact of forest manipulation on the growth and yield of New England stands is little understood. Nonetheless, given the availability of 17 200 ha of suitable stringybark forest in the study region, the values suggest that green-cut supply of fuelwood to Armidale may be achieved on a sustained yield basis: regional consumption is 30 800 $t.yr^{-1}$; regional productivity is 43 000 $t.yr^{-1}$, possibly higher. Since sustained yield is fundamental to ecological sustainability, these findings do not refute the main hypothesis that ecologically sustainable production of fuelwood on the Northern Tablelands is achievable through appropriate management of rural timber resources.

A number of observations suggest the desirability of introducing silvicultural regimes in stringybark stands for production of domestic fuelwood. Over 80% of total biomass in closed and open forest resided in trees of suitable DBH range for fuelwood production ($15 \leq DBH \leq 60$ cm). Stands with high fuelwood biomass contained a higher density of both cut stumps and eucalypt seedlings and saplings, indicating their potential regenerative capacity under regimes of selective logging. Coppice stems were more productive than non-coppice stems in relatively young trees and attained a maximum MAI more rapidly. Appropriate silvicultural regimes for fuelwood production are developed in Chapter 8.