Chapter 7. Growth and yield of native trees planted in shelterbelts and woodlots in southern New England

7.1. Introduction

Tree planting has been undertaken on the Northern Tablelands since European settlement in the mid-1800s. European trees such as oak, elm and birch were established for homestead beautification, willow was planted adjacent to dams and streams, and windbreaks and copses of cypress, conifer, pine and poplar were planted along roadsides throughout the region. The establishment of native species, however, was not practiced in earnest until about 20 years ago and has generally occurred under drought conditions in the past 10 years. Most native plantings have been activated by Government assistance schemes such as the Eucalyptus Regeneration Program (ERP; Ford *et al.* 1993), the National Afforestation Program (NAP; Gaynor 1991) and the Natural Resources Management Strategy (NRMS; Gaynor and Allen 1992). These programs evolved essentially from concerns about dieback and land degradation, motivating on-farm establishment of windbreaks to provide shade and shelter for domestic stock. The rate of establishment of native trees in the study region since 1985 has been 10-20 $ha.yr^{-1}$. None have been initiated for fuelwood production.

This chapter examines the weight and yield of native tree species grown in the study region. Allometric measurements are undertaken and weight and volume relationships are developed. Fuelwood volume curves are constructed, growth performances are analysed and compared with respect to site factors and species differences, stand yields are determined and plantation energetics are investigated. The study is a preliminary analysis of the growth of fuelwood plantings in southern New England, and serves as a guide for future work. Analysis is limited to data collected from eight native species and 18 plantations in the region. A more exhaustive study would be needed to clarify issues of species and site selection, including long term monitoring of a wide range of species planted over a range of environments.

7.2. Methods

7.2.1. Species selection

Various Australian genera in addition to *Eucalyptus* yield high-quality fuelwood. The US National Research Council highlighted the desirability of *Casuarina* spp., being easy to split, burning slowly with ample heat and little smoke, and leaving only a fine white ash (Gough *et al.* 1989). *Casuarina* has also been described as an excellent fuelwood by Boland and Turnbull (1981), Midgley *et al.* (1981), El-Lakany (1986) and Boland (1986). Although *Acacia* spp. may crackle during ignition and emit small sparks and fine ash during the flaming phase (Gough *et al.* 1989), *Acacia* has been described by Wilson (1980) as 'magnificent fuelwood species'. Government and private industry have shown interest in establishing *A. dealbata* for industrial fuelwood production in New Zealand (Frederick *et al.* 1985b).

Eight native fuelwood species were selected from various plantings in the study region : *A. dealbata*; *C. cunninghamiana*; *C. littoralis; E. caliginosa*; *E. laevopinea*; *E. melliodora*; *E. sideroxylon;* and *E. youmanii*. Each occurred in sufficient numbers to enable solid statistical analysis of growth rate and other factors. Certain other premium species such as *E. albens*, *E. blakelyi* and *E. moluccana* were planted infrequently and in low numbers, and monitoring was not undertaken. Exotic hardwood species of good burning quality such as willow (*Salix* spp.) and poplar (*Populus* spp.) occurred in large numbers in the region, yet were not sampled due to labour and time constraints and a desire to focus on local natives.

7.2.2. Site selection and description

Green (1991) reported the results of a 2-stage mail questionnaire distributed to 101 landholders on the Northern Tablelands in 1990, in which information on private plantings was sought. The report was used in this study to identify 25 farmers who had planted target acacias, casuarinas or eucalypts (section 7.2.1). After telephoning each farmer, 17 plantation sites were selected for tree monitoring. Of these, 14 contained trees established as shelterbelts on grazing land prior to 1992 (sites 1,2,4,5,6,7,10,12,13, 14,15,16,17,18) and three comprised trees established round homesteads prior to 1992 (sites 3,8,11). Site 9 occurred within the college grounds of UNE. Location of the 18 plantation monitoring sites is shown in Figure 2.1.

Each site was classified in terms of geology, position on slope, elevation, MAR and plantation age (Table 7.1). Geology was described by landholders, checked in the field by observation, and validated using geological maps. Elevation was interpreted from topographic maps and rainfall data were estimated using BIOCLIM (section 5.2.1). Position on slope was assessed in the field and checked on topographic maps. All plantings were established on slopes < 10°, and most were < 5°. Plantation age was calculated from the month and year of establishment. Variation in geology, position on slope and age was observed for trees at sites 1,3,4,5,6,7,10,13 and 14, requiring separation into 23 individual plantings at these 9 sites (Table 7.1)

Table 7.1. Summary information on shelterbelt plantations monitored in the study region.

Site	Geology	Position on slope	Elevation (m)	MAR (mm)	Age (mnths)	Species monitored **
* P1 i	basalt	upper	1290	900	58	*Cc*
ii	basalt	upper	1290	900	64	*Ec*
* P2	basalt	lower	1180	830	90	*Ad, El*
P3 i	granite	mid	1180	820	102	*Em*
ii	granite	mid	1180	820	115	*Es*
iii	granite	mid	1180	820	210	*Ad, Cc*
* P4 i	sediments	mid	1000	745	50	*Cc*
ii	sediments	mid	1000	745	62	*Ad, Cc*
* P5 i	granite	lower	1000	800	52	*Ad, Cl, El*
ii	granite	mid	1080	820	65	*Ad, Ey*
P6 i	granite	upper	1080	805	30	*Ad, Em*
ii	granite	upper	1080	805	51	*Cc, Ec, El*
iii	granite	upper	1080	805	52	*Cc*
iv	granite	upper	1080	805	55	*Cl, Es*
v	granite	upper	1080	805	67	*Ad, Em*
* P7 i	sediments	lower	1020	780	56	*Cl*
ii	sediments	upper	1020	810	62	*Ad, Cl*
iii	sediments	lower	1020	780	62	*Ad, Cl*
P8	basalt	upper	1060	810	162	*Ad*
P9	granite	upper	990	775	300	*Es*
* P10 i	basalt	upper	1050	770	73	*Ad, Cl, Ec, Em*
ii	sediments	mid	1050	770	73	*Ad, Cl, Ec, Em*
P11	sediments	mid	1020	770	197	*Cc*
* P12	sediments	mid	780	730	42	*Ad, Cc, Es*
* P13 i	granite	mid	1010	780	42	*Ad, Cc, El, Em*
ii	sediments	mid	1010	780	42	*Ad, Cl, Es, Ec, Em*
* P14 i	basalt	lower	1060	790	64	*Ad, Cc*
ii	basalt	lower	1060	790	197	*Ad*
P15	sediments	mid	1020	740	64	*Ad*
P16	granite	mid	1080	745	102	*Ad, Cc, Es, Em*
* P17	sediments	upper	1080	745	52	*Ad, Cc, Ec*
* P18	sediments	lower	1080	735	50	*Cc, Em*

* planted through the ERP (Ford *et al.* 1993), NAP (Gaynor 1991) or NRMS (Gaynor and Allen 1992)

** *Ad = A. dealbata, Cc = C. cunninghamiana, Cl = C. littoralis, Ec = E. caliginosa, El = E. laevopinea, Em = E. melliodora, Es = E. sideroxylon, Ey = E. youmanii.*

Trees at each of the Government funded sites (Table 7.1) as well as site P6 were planted into prepared rip lines, guarded using milk cartons, mulched with sawdust, fertilised and watered. Chemical weed control was carried out prior to planting and the sites were fenced from stock. Planting technique varied at the other six sites: none were pre-ripped, but all were mulched and most were watered. The trees in most plantings were spaced at 2 m within rows and 3 m between rows, representing a stocking density of 1670 trees.ha^{-1}.

7.2.3. Tree measurements

All trees of target species were measured except multi-stem individuals in which the original stem had died after planting.

Diameter of the main stem was measured using a diameter tape at 30 cm a.g.l. (D) and 130 cm a.g.l. (d = DBH). For trees with more than one main stem, the diameter of each stem was measured and a cumulative value of D (D_{TOT}) and DBH (DBH_{TOT}) was calculated using the formula (same as eq. 3.24):

$$DBH_{TOT} \text{ or } D_{TOT} = \left(\sum_{s=1}^{n} (D_s)^2 \right)^{1/2} \qquad 7.1$$

where : n = number of stems
D_s = diameter of stem 's'

Height (HT) measurements using the clinometer require direct measurement of the horizontal distance to the tree from the point of sighting. To increase the efficiency of height measurement undertaken by a single person, a clinometric technique independent of distance from tree was developed in which only the base and canopy angle were recorded (Figure 7.1). I stood at a convenient distance from the tree and remained on the same contour. The height of my eyes above ground level was 1.81 m.

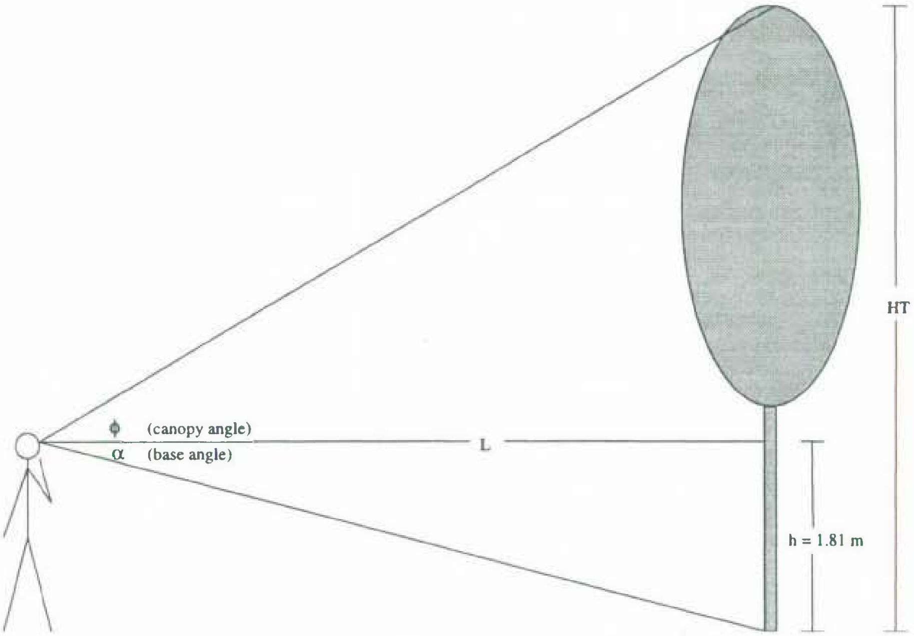


Figure 7.1. Measurements of the base and canopy angles

It can be shown from Figure 7.1 that:

$$\tan\alpha = \frac{1.81}{L} \quad \textit{and} \quad \tan\phi = \frac{HT - 1.81}{L}$$

$$\therefore L = \frac{1.81}{\tan\alpha} = \frac{HT - 1.81}{\tan\phi}$$

$$\therefore HT = 1.81 \cdot \left(\frac{\tan\phi}{\tan\alpha}\right) + 1.81 \quad \text{.......... 7.2}$$

Fuelwood volume (VOL) was calculated for *E. sideroxylon* at site P9 using the function derived in section 3.3.7. VOL for all other trees to a minimum end diameter of 5 cm was estimated by considering two components, V_1 and V_2. The volume of the bole between 0.3 m and 1.3 m a.g.l. (V_1) was calculated using one of two equations based on the Smalian function (Loetsch *et al.* 1973). Where $d \geq 5$ cm, then :

$$V_1 = \frac{\pi \cdot \left(D^2 + D \cdot d + d^2\right)}{12} \quad \text{.......... 7.3}$$

Where $D > 5$ cm and $d < 5$ cm, then :

$$V_1 = \frac{\pi \cdot (D - 0.05) \cdot \left(D^2 + 0.05 \cdot D + 0.0025\right)}{12 \cdot (D - d)} \quad \text{.......... 7.4}$$

where V_1 = stem volume between 0.3 and 1.3 m a.g.l. (m^3)
D = diameter at 0.3 m a.g.l. (m)
d = DBH = diameter at 1.3 m a.g.l. (m)

Where $d > 5$, volume of the main stem above 1.3 m a.g.l. (V_2) was calculated as follows :

$$V_2 = \frac{\pi \cdot (H - 1.3) \cdot (d - 0.05) \cdot \left(d^2 + 0.05 \cdot d + 0.0025\right)}{12 \cdot d} \quad \text{.......... 7.5}$$

where V_2 = stem volume above 1.3 m a.g.l. (m^3)
d = DBH = diameter at 1.3 m a.g.l. (m)
H = tree height (m)

Based on stem : branch biomass ratios determined for young plantation eucalypts and acacias in various studies (Cromer *et al.* 1975; Frederick *et al.* 1985a, 1985b, 1986; Whitesell *et al.* 1988; Ranasinghe and

Mayhead 1991), average branchwood volume was assumed to be 20% of the stemwood volume of each tree. Thus, VOL (≥ 5 cm diam.) was estimated to be:

$$\mathrm{VOL} = 1.2 \cdot (V_1 + V_2) \tag{7.6}$$

The number of main stems was counted and recorded, a ‘main stem’ being defined as a dominant upright stem contributing to foliage growth. A form factor was used to describe subjectively the form of each tree (Plate 7.1 (i-iii)). A form factor of one denoted a healthy tree with a vertical growth form and moderate branching. A form factor of two was reserved for trees with a rapidly tapering main stem or moderate distortion of the main stem. A form factor of three described trees with poor form associated with stem malformation.

Form = 1
D = 18.0 cm; DBH = 14.5 cm
HT = 6.6 m; VOL ~ 0.049 m^3

Form = 2
D = 17.0 cm; DBH = 12.0 cm
HT = 4.8 m; VOL ~ 0.025 m^3

Form = 3
D = 8.5 cm; DBH = 3.0 cm
HT = 1.9 m ; VOL = 0.000 m^3

Plate 7.1. Form factors for 6-year *E. laevopinea* (site P5).

7.2.4. Statistical analyses

Within-plantations

Of a total of 20 plantings containing two or more target species (Table 7.1), 17 were chosen for analysis of growth variation between species (P2, P3iii, P4i, P5i,ii, P6ii,v, P7ii,iii, P10i,ii, P12, P13i,ii, P14i, P16, P17). Three plantings (P6i, P6iv, P18) were not selected due to unusually poor growth performance in one or more species. A single-factor AOV with Tukey's multiple comparison test was carried out using the four growth variables (D, DBH, HT and VOL) to test for growth differences between species in each planting.

Within-grouped plantations

Growth comparisons were undertaken using 2 x 2 factorial AOVs to determine the effect of tree form and number of main stems on each growth variable (D, DBH, HT and VOL) for each species within three plantation age groups (30-59 months; 60-89 months; ≥ 90 months). The factors were 1 stem vs. 2 stems (data from trees with 3 or more stems were not included) and form factor 1 vs. form factor 2 or 3 (data from trees with a form factor of 2 or 3 were combined).

Between-plantations

Mean values of DBH, HT and VOL were calculated for each species in each planting (Appendix XXVII) before pooling plantings into major geological classes (Table 7.2) for analyses of covariance of DBH-age, HT-age and VOL-age^2 data. The parabolic nature of the VOL-age data required that it be transformed to VOL-age^2 for AOCV, and poor geological representation of certain plantings of *Casuarina* spp. and *Eucalyptus* spp. (Table 7.2) required that four species groups be used: *A. dealbata* (acacia); *C. cunninghamiana - C. littoralis* (casuarina); *E. melliodora - E. sideroxylon* (box-ironbark); and *E. caliginosa - E. laevopinea - E. youmanii* (stringybark).

While DBH-age and HT-age plots of plantings of each species group were roughly linear, regression equations describing DBH and HT were derived using the hyperbolic growth functions :

$$Y = \frac{\text{AGE}^2}{(a + b \cdot (\text{AGE}))^2} \quad \text{......} \quad 7.7$$

$$\text{or} \quad Y = a + b \cdot \sqrt{\text{AGE}} \quad \text{......} \quad 7.8$$

where Y = dependent variable (DBH, HT)

Table 7.2. Number of plantings of each species and species group within each major geological type.

Geology	Species	Plantings	No. plantings per spp.	No. plantings per spp. group
Basalt	*A. dealbata*	P2; P8; P10i; P14i,ii	5	5
	C. cunninghamiana	P1i; P14i	2	3
	C. littoralis	P10i	1	
	E. caliginosa	P1ii; P10i	2	3
	E. laevopinea	P2	1	
	E. youmanii	-	0	
	E. melliodora	P10i;	1	1
	E. sideroxylon	-	0	
Granite	*A. dealbata*	P3iii; P5i,ii; P6i,v; P13i; P16	7	7
	C. cunninghamiana	P3iii; P6ii,iii; P13i; P16	5	7
	C. littoralis	P5i; P6iv;	2	
	E. caliginosa	P6ii;	1	5
	E. laevopinea	P5i; P6ii; P13i	3	
	E. youmanii	P5ii	1	
	E. melliodora	P3i; P6i; P13i; P16	4	8
	E. sideroxylon	P3ii; P6iv; P9; P16	4	
Sediment	*A. dealbata*	P4ii; P7ii,iii; P10ii; P12; P13ii; P15; P17	7	7
	C. cunninghamiana	P4i,ii; P11; P12; P17; P18	6	11
	C. littoralis	P7i,ii,iii; P10ii; P13ii	5	
	E. caliginosa	P10ii; P13ii; P17	3	3
	E. laevopinea	-	0	
	E. youmanii	-	0	
	E. melliodora	P10ii; P13ii; P18	3	5
	E. sideroxylon	P12; P13ii	2	

Regression equations describing fuelwood volume were derived using the parabolic growth function :

$$\mathrm{VOL} = a + b \cdot (\mathrm{AGE})^2 \quad \ldots\ldots \quad 7.9$$

Refer to Chapter 3 for discussion of the various regression functions.

The *E. sideroxylon* planting at UNE (P9) was the oldest, aged 300 months (25 years). Only eight plantations exceeded 96 months (8 years), with 24 plantations (75%) aged 8 years or less. The comparatively small number of older plantations reflected a lack of planting prior to 1987, and reduced confidence with respect to volume analysis. As such, the regression functions derived for each species, particularly the exponential volume function, should be interpreted with caution. Better relationships will become available as monitored plantations mature and as further data are collected from more recent plantings.

7.3. Results

7.3.1. General

A total of 1603 trees were sampled in the study region, comprising 733 *A. dealbata* in 20 plantings, 233 *C. cunninghamiana* in 13 plantings, 150 *C. littoralis* in 9 plantings, 122 *E. caliginosa* in 6 plantings, 91 *E. laevopinea* in 4 plantings, 134 *E. melliodora* in 9 plantings, 112 *E. sideroxylon* in 6 plantings, and 28 *E. youmanii* in 1 planting. Appendix XXVII lists mean and maximum values of DBH, HT and VOL for each species at each planting.

7.3.2. Between-species comparisons

According to single-variate AOVs (Tables 7.3 and 7.4), DBH, HT and VOL of *A. dealbata* was significantly greater than for other species in plantings aged < 100 months, with the exception of *E. youmanii* at site P5ii, in which only HT of *A. dealbata* was significantly greater. In plantings aged > 100 months (P3 iii, P8, P16), *A. dealbata* measurements were not significantly greater than those for other species. On the contrary, HT of *C. cunninghamiana* at site P3 iii (210 months) and VOL of *C. cunninghamiana* at site P16 (102 months) were significantly greater than the respective HT and VOL of *A. dealbata*. Base diameter (D) of *A. dealbata* was significantly greater than that of the *Casuarina* spp. and *E. melliodora* in all plantings aged < 100 months where they co-occurred. However, base diameter of *A. dealbata* was significantly greater than that of *E. caliginosa* or *E. laevopinea* in only three of seven plantings where they co-occurred, suggesting a higher degree of taper in stringybark than in other species during early growth, and possibly thicker bark around the lower stemwood of stringybark.

Species other than *A. dealbata* were compared in eight plantings (P5i; P6ii; P10i,ii; P13i,ii; P16, P17; Table 7.3). Stringybark species were compared with casuarina species in seven plantings: stringybark showed a significantly greater D, DBH. HT and VOL in six, four, two and five plantings respectively, and were never out-performed by casuarina. Stringybark was compared with yellow box in four plantings: the former consistently out-performed the latter. Casuarina demonstrated similar or superior growth to yellow box in five plantings. Neither D nor DBH differed significantly between the species, but VOL of *C. cunninghamiana* was significantly greater than yellow box in one planting (P16) and HT of *C. cunninghamiana* was significantly greater in two plantings (P10ii and P16).

7.3.3. Within-species comparisons

Table 7.5 shows the number of trees of each species in each age class with 1 or 2 stems and a form factor of 1, 2 or 3. Over 80% of *A. dealbata*, *C. cunninghamiana*, *C. littoralis* and *E. laevopinea* in each

Table 7.3. Between-species comparisons of four growth variables at each site using single factor AOV and Tukey's test.

				Mean ± s.e.						Statistical parameters			
Site	Age (mnths)	No.& Spp.	Var.	*Ad*	*Cl*	*Cc*	*Ec*	*El*	*Em*	F-ratio	P	signif.	Tukey's
P2	90	157x*Ad*, 33x*El*	D (cm)	15.4 ± 0.3				13.2 ± 0.7		8.936	0.000	***	*Ad* > *El*
			DBH (cm)	12.4 ± 0.3				9.4 ± 0.5		22.561	0.000	***	*Ad* > *El*
			HT (m)	8.1 ± 0.1				5.4 ± 0.2		93.640	0.000	***	*Ad* > *El*
			VOL (m^3)	0.055 ± 0.003				0.025 ± 0.003		25.909	0.000	***	*Ad* > *El*
P3 iii	210	2x*Ad*, 21x*Cc*	D (cm)	38.0 ± 0.0		33.2 ± 1.3				1.142	0.297	*ns*	*Ad* ≈ *Cc*
			DBH (cm)	32.3 ± 2.8		27.5 ± 1.2				1.364	0.256	*ns*	*Ad* ≈ *Cc*
			HT (m)	9.8 ± 1.2		14.7 ± 0.4				10.907	0.003	***	*Cc* > *Ad*
			VOL (m^3)	0.400 ± 0.094		0.427 ± 0.047				0.029	0.866	*ns*	*Ad* ≈ *Cc*
P4 ii	63	20x*Ad*, 29x*Cc*	D (cm)	8.3 ± 0.6		5.2 ± 0.4				20.344	0.000	***	*Ad* > *Cc*
			DBH (cm)	5.8 ± 0.5		2.2 ± 0.3				44.434	0.000	***	*Ad* > *Cc*
			HT (m)	5.0 ± 0.3		2.7 ± 0.2				45.556	0.000	***	*Ad* > *Cc*
			VOL (m^3)	0.008 ± 0.001		0.001 ± 0.000				30.215	0.000	**	*Ad* > *Cc*
P5 i	52	131x*Ad*, 70x*Cl*, 23x*El*	D (cm)	7.8 ± 0.3	4.2 ± 0.2			6.9 ± 0.5		51.702	0.000	***	(*Ad* ≈ *El*) > *Cl*
			DBH (cm)	5.9 ± 0.2	1.9 ± 0.2			3.8 ± 0.4		73.404	0.000	***	*Ad* > *El* > *Cl*
			HT (m)	4.0 ± 0.1	2.6 ± 0.1			3.1 ± 0.2		37.209	0.000	***	*Ad* > (*Cl* ≈ *El*)
			VOL (m^3)	0.008 ± 0.001	0.001 ± 0.000			0.003 ± 0.001		34.402	0.000	***	*Ad* > (*Cl* ≈ *El*)
P6 ii	51	8x*Cc*, 9x*Ec*, 5x*El*	D (cm)			4.2 ± 0.6	4.7 ± 1.3	8.9 ± 1.3		4.103	0.033	*	*El* > (*Cc* ≈ *Ec*)
			DBH (cm)			1.7 ± 0.3	3.1 ± 1.1	5.9 ± 1.9		3.185	0.064	*ns*	*Cc* ≈ *Ec* ≈ *El*
			HT (m)			2.9 ± 0.4	2.9 ± 0.6	3.9 ± 0.7		0.851	0.443	*ns*	*Cc* ≈ *Ec* ≈ *El*
			VOL (m^3)			0.000 ± 0.000	0.004 ± 0.002	0.011 ± .004		4.604	0.023	*	*El* > (*Cc* ≈ *Ec*)
P6 v	67	30x*Ad*, 8x*Em*	D (cm)	15.7 ± 0.6					6.7 ± 1.3	39.722	0.000	***	*Ad* > *Em*
			DBH (cm)	13.3 ± 0.5					2.9 ± 0.9	87.579	0.000	***	*Ad* > *Em*
			HT (m)	8.1 ± 0.3					2.4 ± 0.4	72.343	0.000	***	*Ad* > *Em*
			VOL (m^3)	0.060 ± 0.005					0.003 ± 0.001	31.633	0.000	***	*Ad* > *Em*
P7 ii	62	5x*Ad*, 6x*Cl*	D (cm)	16.2 ± 0.6	8.9 ± 0.8					47.333	0.000	***	*Ad* > *Cl*
			DBH (cm)	11.7 ± 1.0	5.7 ± 0.6					30.151	0.000	***	*Ad* > *Cl*
			HT (m)	6.5 ± 0.4	4.5 ± 0.3					18.518	0.001	**	*Ad* > *Cl*
			VOL (m^3)	0.041 ± 0.007	0.007 ± 0.002					24.429	0.002	**	*Ad* > *Cl*

Table 7.3. cont'd

				Mean ± s.e.						Statistical parameters			
Site	Age (mnths)	No.& Spp.	Var.	*Ad*	*Cl*	*Cc*	*Ec*	*El*	*Em*	F-ratio	P	signif.	Tukey's
P7 iii	62	12x*Ad*, 16x*Cl*	D (cm)	10.3 ± 1.6	5.5 ± 0.8					8.851	0.006	**	*Ad* > *Cl*
			DBH (cm)	7.3 ± 1.4	2.4 ± 0.5					14.318	0.000	***	*Ad* > *Cl*
			HT (m)	4.0 ± 0.4	2.5 ± 0.2					12.701	0.001	**	*Ad* > *Cl*
			VOL (m^3)	0.017 ± 0.007	0.002 ± 0.001					6.034	0.021	*	*Ad* > *Cl*
P10 i	73	30x*Ad*,13x*Cl*, 48x*Ec*,20x*Em*	D (cm)	12.7 ± 0.9	8.5 ± 0.6		12.3 ± 0.7		6.0 ± 0.9	42.180	0.000	***	(*Ad* ≈ *Ec*) > (*Cl* ≈ *Em*)
			DBH (cm)	10.3 ± 0.8	5.1 ± 0.6		8.5 ± 0.7		2.3 ± 0.7	54.259	0.000	***	*Ad* > *Ec* > (*Cl* ≈ *Em*)
			HT (m)	6.7 ± 0.5	4.7 ± 0.4		4.5 ± 0.2		1.9 ± 0.3	42.556	0.000	***	*Ad* > *Ec* > (*Cl* ≈ *Em*)
			VOL (m^3)	0.085 ± 0.008	0.002 ± 0.001		0.041 ± 0.003		0.007 ± 0.002	42.775	0.000	***	Ad > Ec > (Cl ≈ Em)
P10 ii	73	22x*Ad*,18x*Cl*, 31x*Ec*,15x*Em*	D (cm)	17.2 ± 0.7	6.0 ± 0.8		15.4 ± 0.6		8.6 ± 0.6	15.349	0.000	***	(*Ad* ≈ *Ec*) > (*Cl* ≈ *Em*)
			DBH (cm)	15.1 ± 0.7	3.1 ± 0.5		11.2 ± 0.5		5.0 ± 0.6	21.365	0.000	***	(*Ad* ≈ *Ec*) > (*Cl* ≈ *Em*)
			HT (m)	8.6 ± 0.4	4.3 ± 0.5		6.1 ± 0.3		3.2 ± 0.2	26.623	0.000	***	*Ad* > (*Ec* ≈ *Cl*) > *Em*
			VOL (m^3)	0.085 ± 0.008	0.002 ± 0.001		0.041 ± 0.003		0.007 ± 0.002	13.871	0.000	***	*Ad* > *Ec* > (*Cl* ≈ *Em*)
P12	42	17x*Ad*, 15x*Cc*	D (cm)	7.9 ± 0.6		4.5 ± 0.5				21.456	0.000	***	*Ad* > *Cc*
			DBH (cm)	4.7 ± 0.5		2.0 ± 0.4				17.303	0.000	***	*Ad* > *Cc*
			HT (m)	3.9 ± 0.2		2.5 ± 0.2				17.598	0.000	***	*Ad* > *Cc*
			VOL (m^3)	0.005 ± 0.001		0.001 ± 0.000				9.572	0.004	**	*Ad* > *Cc*
P13 i	42	13x*Ad*,32x*Cc*, 30x*El*,7x*Em*	D (cm)	7.7 ± 0.9		3.9 ± 0.2		7.5 ± 0.2	5.3 ± 0.4	27.968	0.000	***	(*Ad* ≈ *El*) > (*Cc* ≈ *Em*)
			DBH (cm)	5.5 ± 0.8		1.4 ± 0.2		4.0 ± 0.3	1.0 ± 0.3	33.345	0.000	***	*Ad* > *El* > (*Cc* ≈ *Em*)
			HT (m)	3.8 ± 0.3		2.2 ± 0.1		2.7 ± 0.1	1.7 ± 0.2	19.479	0.000	***	*Ad* > *El* > (*Cc* ≈ *Em*)
			VOL (m^3)	0.007 ± 0.002		0.000 ± 0.000		0.003 ± 0.000	0.000 ± 0.000	22.202	0.000	***	*Ad* > *El* > (*Cc* ≈ *Em*)
P13 ii	42	18x*Ad*,9x*Cl*, 13x*Ec*,32x*Em*	D (cm)	10.0 ± 0.7	4.0 ± 0.6		7.2 ± 0.4		5.7 ± 0.2	24.114	0.000	***	*Ad* > *Ec* > (*Cl* ≈ *Em*)
			DBH (cm)	6.7 ± 0.6	1.4 ± 0.3		2.6 ± 0.4		1.6 ± 0.2	36.970	0.000	***	*Ad* > (*Ec* ≈ *Cl* ≈ *Em*)
			HT (m)	4.3 ± 0.2	2.2 ± 0.2		2.5 ± 0.2		1.9 ± 0.1	53.260	0.000	***	*Ad* > (*Ec* ≈ *Cl* ≈ *Em*)
			VOL (m^3)	0.011 ± 0.003	0.000 ± 0.000		0.002 ± 0.000		0.001 ± 0.000	16.226	0.000	***	*Ad* > *Ec* > (*Cl* ≈ *Em*)
P14 i	64	12x*Ad*, 20x*Cc*	D (cm)	14.8 ± 0.8		7.9 ± 0.5				58.241	0.000	***	*Ad* > *Cc*
			DBH (cm)	11.9 ± 0.8		4.0 ± 0.5				91.693	0.000	***	*Ad* > *Cc*
			HT (m)	5.4 ± 0.3		3.5 ± 0.3				23.562	0.000	***	*Ad* > *Cc*
			VOL (m^3)	0.037 ± 0.005		0.004 ± 0.001				61.724	0.000	***	*Ad* > *Cc*

Table 7.3. cont'd

				Mean ± s.e.						Statistical parameters			
Site	Age (mnths)	No.& Spp.	Var.	*Ad*	*Cl*	*Cc*	*Ec*	*El*	*Em*	F-ratio	P	signif.	Tukey's
P16	102	3x*Ad*, 15x*Cc*, 37x*Em*	D (cm)	18.3 ± 2.1		22.5 ± 1.4			19.8 ± 0.7	2.298	0.111	*ns*	*Ad* ≈ *Cc* ≈ *Em*
			DBH (cm)	13.8 ± 1.6		17.9 ± 1.2			15.9 ± 0.6	1.896	0.160	*ns*	*Ad* ≈ *Cc* ≈ *Em*
			HT (m)	7.7 ± 0.2		7.9 ± 0.2			6.4 ± 0.2	8.783	0.001	**	(*Ad* ≈ *Cc*) > *Em*
			VOL (m^3)	0.063 ± 0.017		0.113 ± 0.012			0.076 ± 0.008	3.568	0.035	*	*Cc* > (*Ad* ≈ *Em*)
P17	52	67x*Ad*, 18x*Cc*, 8x*Ec*	D (cm)	9.2 ± 0.3		5.3 ± 0.4	6.2 ± 0.6			19.945	0.000	***	*Ad* > (*Cc* ≈ *Ec*)
			DBH (cm)	6.9 ± 0.3		2.6 ± 0.4	2.8 ± 0.6			28.651	0.000	***	*Ad* > (*Cc* ≈ *Ec*)
			HT (m)	4.5 ± 0.1		2.7 ± 0.2	2.5 ± 0.2			28.196	0.000	***	*Ad* > (*Cc* ≈ *Ec*)
			VOL (m^3)	0.012 ± 0.001		0.001 ± 0.000	0.001 ± 0.001			15.683	0.000	***	*Ad* > (*Cc* ≈ *Ec*)

Table 7.4. Between species comparisons of four growth variables using single factor AOV and Tukey's test (includes *Eucalyptus youmanii*)

				Mean ± s.e.		Statistical parameters			
Site	Age (mnths)	No.& Spp.	Var.	*Ad*	*Ey*	F-ratio	P	signif.	Tukey's
P5 ii	65	74x*Ad*, 28x*Ey*	D (cm)	10.3 ± 0.4	10.7 ± 0.7	0.282	0.597	*ns*	*Ad* ≈ *Ey*
			DBH (cm)	7.4 ± 0.4	7.1 ± 0.6	0.250	0.619	*ns*	*Ad* ≈ *Ey*
			HT (m)	5.3 ± 0.2	4.1 ± 0.2	16.779	0.000	***	*Ad* > *Ey*
			VOL (m^3)	0.016 ± 0.002	0.014 ± 0.002	0.471	0.494	*ns*	*Ad* ≈ *Ey*

age class possessed a solitary stem; over 30% of *E. caliginosa* and *E. melliodora* in each age class possessed more than 1 stem. *Casuarina* spp. had the highest proportion of trees with superior form in all age classes (~ 80%); *E. melliodora* had the lowest (~ 40%). Plantations aged ≥ 90 months comprised a higher proportion of well formed trees than plantations < 90 months (~80% vs. ~63%). There was no apparent variation between different aged plantings in the proportion of trees with a single stem (~ 84%).

Table 7.5. Number of stems and form factors for sampled trees in each species

		form = 1		form = 2		
Age (mnths)	Spp.	1 stem	2 stems	1 stem	2 stems	Total
30 - 59	*Ad*	92	8	91	27	218
	Cl	74	2	13	5	94
	Cc	99	6	16	4	125
	Ec	19	2	1	7	29
	El	35	4	10	6	55
	Em	13	4	15	11	43
	Ey	-	-	-	-	-
	All	332	26	146	60	564
60 - 89	*Ad*	112	7	71	17	207
	Cl	42	4	4	3	53
	Cc	34	1	8	6	49
	Ec	48	11	16	16	91
	El	-	-	-	-	-
	Em	8	1	16	15	40
	Ey	24	3	1	0	28
	All	268	27	116	57	468
≥ 90	*Ad*	184	21	40	16	261
	Cl	-	-	-	-	-
	Cc	43	5	9	1	58
	Ec	-	-	-	-	-
	El	29	1	2	1	33
	Em	18	6	3	10	37
	Ey	-	-	-	-	-
	All	274	33	54	28	389
	Total	874	86	316	145	1421

Two-factor (2 x 2) AOVs determined the effect of form and number of stems on DBH, HT and VOL in three plantation age classes. Statistical information is provided in Appendix XXVIII and typical trends are shown in Figure 7.2 using *E. caliginosa* aged 60-89 months. DBH, HT and VOL of all species were generally greatest in two-stem trees with superior form, and least in single-stem trees with poor form. In the case of *E. caliginosa*, well-formed trees with two stems possessed nearly four times the volume of poorly formed trees with one stem (Figure 7.2). Stem number was most influential on the growth of *A. dealbata* aged ≥ 60 months; double-stem trees possessed over twice the volume of single-stem trees of the same form (Appendix XXVIII). Tree form was most influential on the growth of *E. caliginosa*, *E. melliodora* and young *A. dealbata*. Neither form nor stem number significantly affected the volume of fuelwood biomass in *Casuarina* spp. and *E. laevopinea* of any age.

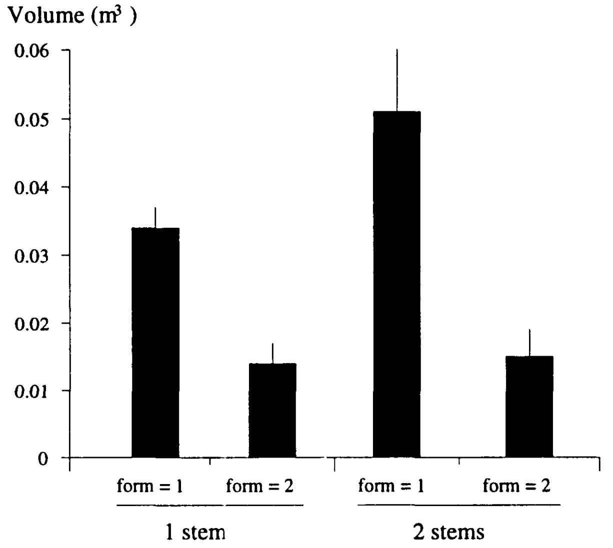


Figure 7.2. Influence of number of stems and tree form on VOL in 60-89 month *E. caliginosa* grown in plantations in southern New England (data are means ± s.e.).

7.3.4. Species diameter, height and volume curves

Table 7.6 lists the results of analysis of covariance carried out on four species groups. No significant difference in the DBH-age or HT-age relationship of acacia, box-ironbark or stringybark was observed between basalt, granite and sediment. Data were therefore pooled within species groups and single DBH and HT curves derived for each (Figures 7.3, 7.5 and 7.6, respectively). No significant difference between geological types was observed in the HT-age relationship of the casuarina group, and a single height curve was constructed (Figure 7.4). The DBH-age relationship in casuarina varied significantly between granitic and sedimentary parent material ($0.01 < P < 0.05$; Table 7.6). However, the number of plantings aged ≥ 90 months (2 on granite and 1 on sediment) was insufficient to provide conclusive evidence and a single diameter curve for casuarina was constructed (Figure 7.4). No significant geological difference in the VOL-age^2 relationship was found in any species group (Table 7.6), and a single volume curve was constructed for each (Figure 7.7).

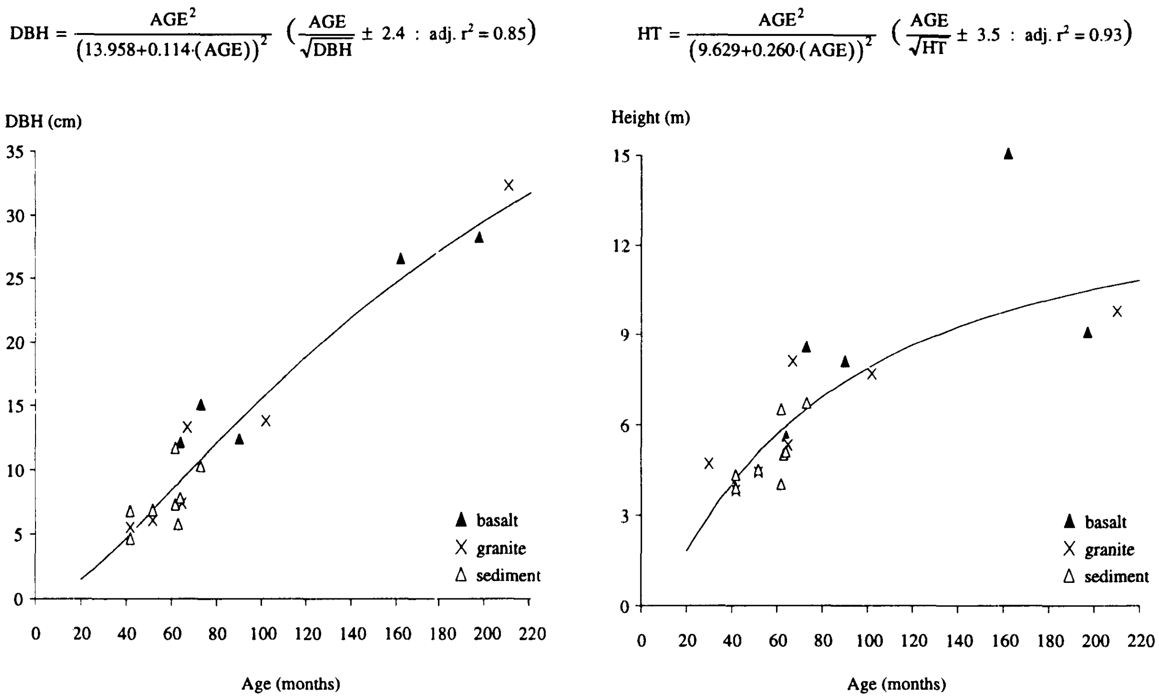
Table 7.6. Analyses of covariance of DBH-age, HT-age and VOL-age^2 (transformed) in four species groups as influenced by geology.

			AOCV (DBH-age)			AOCV (HT-age)			AOCV (VOL-age^2)		
Group	Geology	No. sites	DF	*F*	signif.	DF	*F*	signif.	DF	*F*	signif.
acacia	basalt granite sediment	5 6 8	2	1.792	*ns*	2	1.192	*ns*	2	0.015	*ns*
casuarina	basalt granite sediment	3 8 11	2	5.875	*	2	4.359	*ns*	2	0.016	*ns*
box-ironbark	granite sediment	7 4	1	0.096	*ns*	1	0.004	*ns*	1	0.599	*ns*
stringybark	basalt granite sediment	3 5 3	2	0.188	*ns*	2	0.513	*ns*	2	0.182	*ns*

note: 30 month acacia and box at P6i not included in AOCV due to the absence of DBH data.
* $0.01<P<0.05$

According to Figures 7.3 to 7.6, DBH increment of plantation-grown casuarina, box-ironbark and stringybark at 100 months was similar; 1.32, 1.24 and 1.46 cm.yr^{-1}, respectively. That of acacia was greater; 1.87 cm.yr^{-1}. Similarly, DBH increment of casuarina, box-ironbark and stringybark (extrapolated) aged 220 months was similar (1.41, 1.35 and 1.37 cm.yr^{-1}, respectively) while that of acacia was larger (1.73 cm.yr^{-1}). Unlike DBH increment, HT increment of each group varied considerably, and HT increment of acacia decreased with respect to that of other species as trees aged (Figures 7.3 to 7.6). HT increment of acacia aged 100 months (0.95 m.yr^{-1}) was greater than that of casuarina, box-ironbark and stringybark of the same age (0.81, 0.58 and 0.75 m.yr^{-1}, respectively). Conversely, HT increment of acacia at 220 months (0.59 m.yr^{-1}) was less than or similar to that of casuarina, box-ironbark and stringybark (extrapolated) of the same age (0.73, 0.60 and 0.58 m.yr^{-1}, respectively).

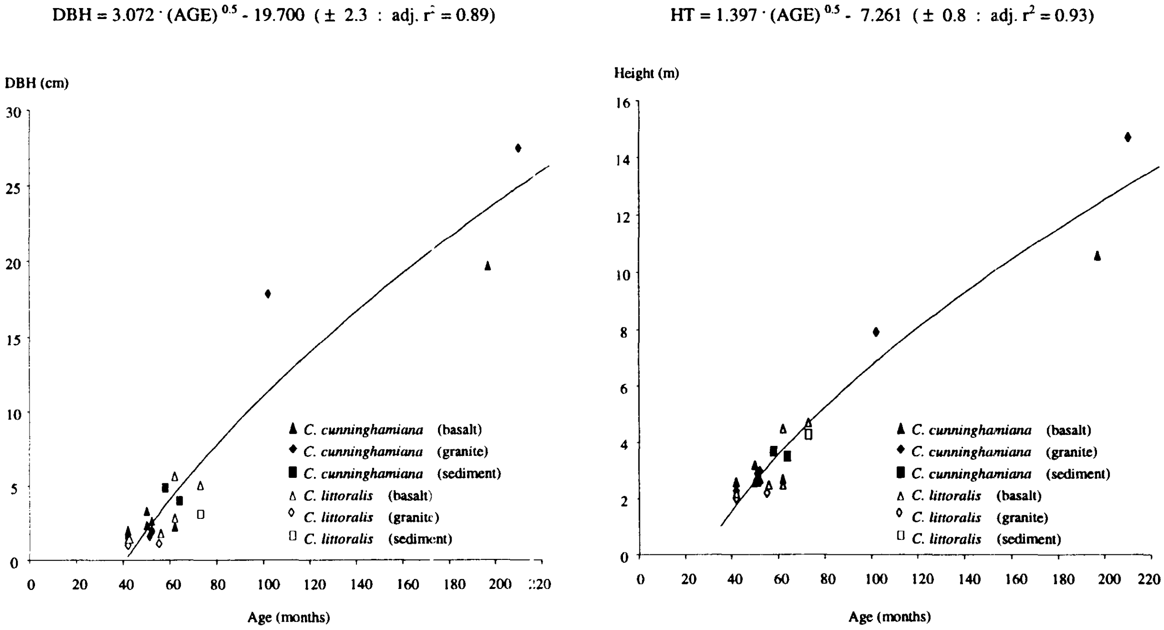
Of the four species groups shown in Figure 7.7, *A. dealbata* comprised the greatest volume at all ages. VOL increment for acacia aged 100 and 220 months was 0.012 and 0.026 m^3.yr^{-1}, respectively. Casuarina and box-ironbark had similar VOL increments at all ages; 0.009 and 0.010 m^3.yr^{-1} aged 100 months, and 0.021 and 0.022 m^3.yr^{-1} aged 220 months. Stringybark possessed an average 0.049 m^3 after 100 months (VOL increment; 0.006 m^3.yr^{-1}).



$$DBH = \frac{AGE^2}{(13.958+0.114 \cdot (AGE))^2} \quad \left(\frac{AGE}{\sqrt{DBH}} \pm 2.4 \ : \ \text{adj. } r^2 = 0.85\right)$$

$$HT = \frac{AGE^2}{(9.629+0.260 \cdot (AGE))^2} \quad \left(\frac{AGE}{\sqrt{HT}} \pm 3.5 \ : \ \text{adj. } r^2 = 0.93\right)$$

Figure 7.3. Diameter and height curves for *Acacia dealbata* planted in southern New England.



$$DBH = 3.072 \cdot (AGE)^{0.5} - 19.700 \ (\pm 2.3 \ : \ \text{adj. } r^2 = 0.89)$$

$$HT = 1.397 \cdot (AGE)^{0.5} - 7.261 \ (\pm 0.8 \ : \ \text{adj. } r^2 = 0.93)$$

Figure 7.4. Diameter and height curves for casuarina planted in southern New England.

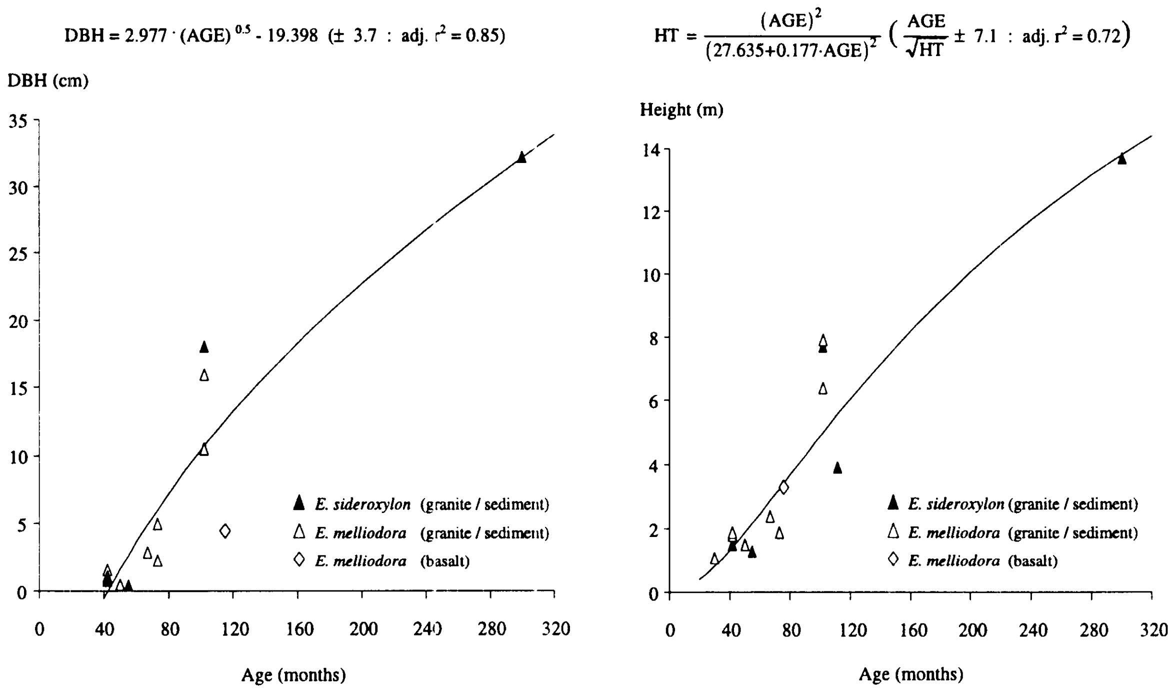


Figure 7.5. Diameter and height curves for box-ironbark planted in southern New England.

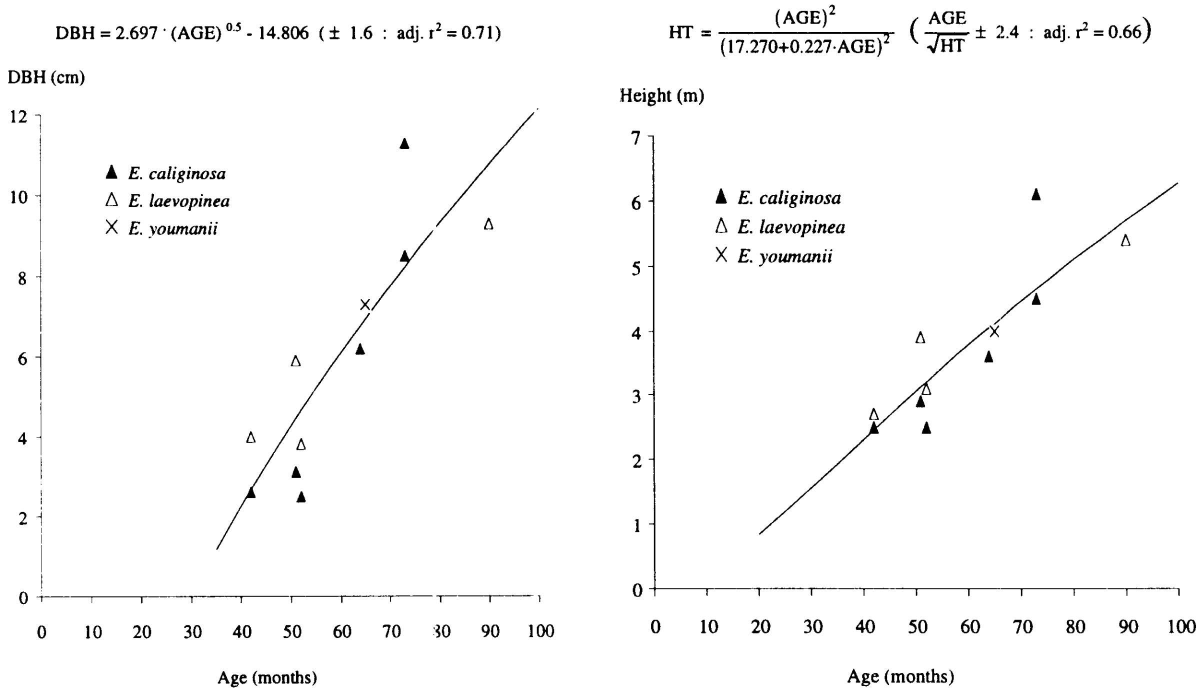
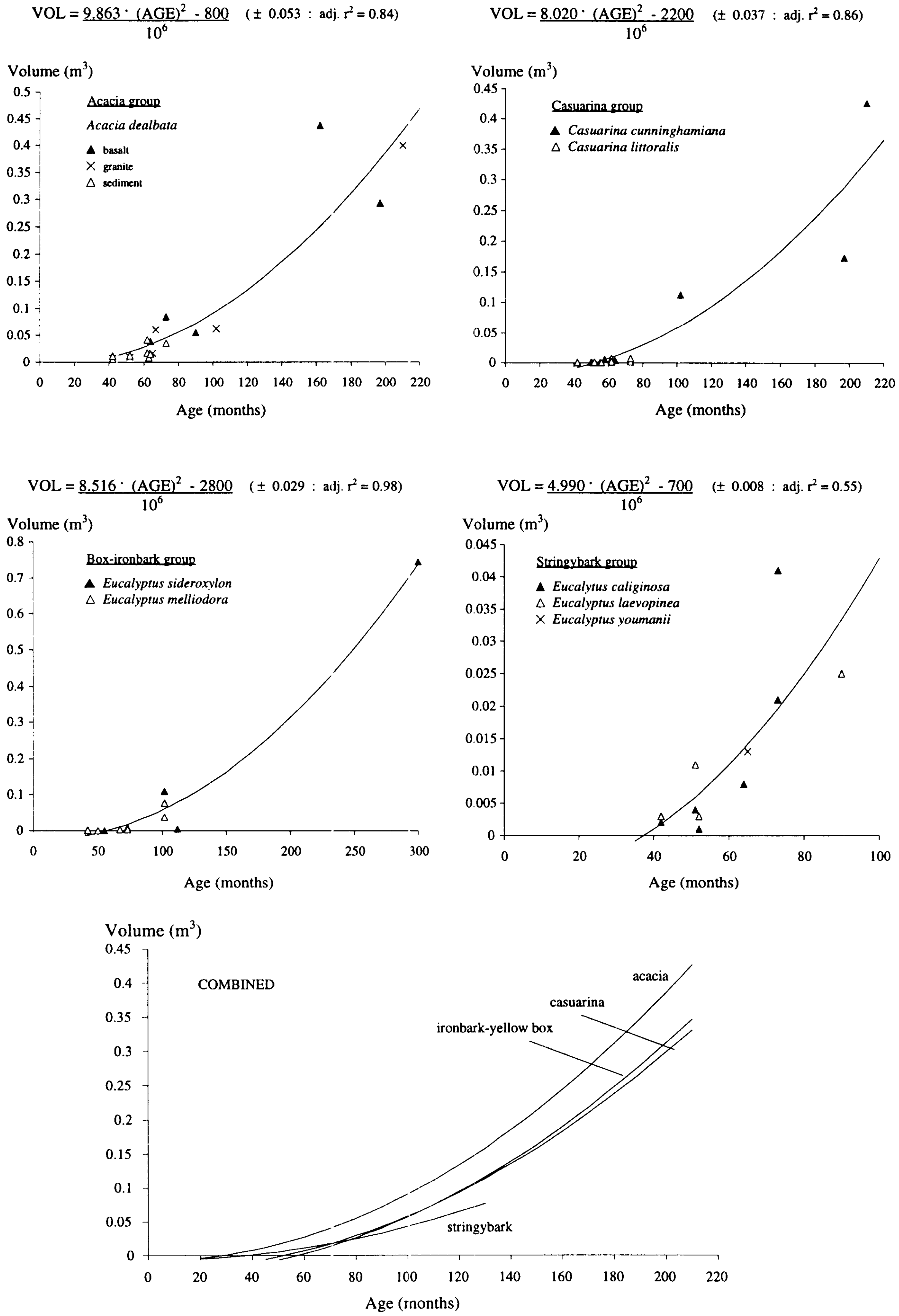


Figure 7.6. Diameter and height curves for stringybark planted in southern New England.



$$VOL = \frac{9.863 \cdot (AGE)^2 - 800}{10^6} \quad (\pm\ 0.053\ :\ \text{adj. } r^2 = 0.84)$$

$$VOL = \frac{8.020 \cdot (AGE)^2 - 2200}{10^6} \quad (\pm\ 0.037\ :\ \text{adj. } r^2 = 0.86)$$

$$VOL = \frac{8.516 \cdot (AGE)^2 - 2800}{10^6} \quad (\pm\ 0.029\ :\ \text{adj. } r^2 = 0.98)$$

$$VOL = \frac{4.990 \cdot (AGE)^2 - 700}{10^6} \quad (\pm\ 0.008\ :\ \text{adj. } r^2 = 0.55)$$

Figure 7.7. Fuelwood volume curves for trees planted in southern New England.

7.4. Discussion

While eucalypt plantations have achieved growth rates up to 70 $m^3.ha^{-1}.yr^{-1}$ overseas (Jacobs 1979; Davidson 1987), realistic expectations for biomass production from temperate plantations are of the order of 8 to 12 $t.ha^{-1}.yr^{-1}$ harvestable dry-weight (Hummel 1988). The use of *Acacia* spp. for short rotation fuelwood production is receiving attention worldwide in the light of exceptional growth rates. Irrigated *A. nilotica* plantations in Pakistan have produced up to 40 $t.ha^{-1}.yr^{-1}$ above-ground biomass after 6 years, rivalling some of the most productive forest systems in the world (Maguire *et al.* 1990). Naturally seeded *A. dealbata* grown in New Zealand acquired an MAI of about 8 $t.ha^{-1}.yr^{-1}$ after 7 years (Hosking 1981) and directly seeded *A. dealbata*, also grown in New Zealand, attained an MAI of 21.9 $t.ha^{-1}.yr^{-1}$ after 8 years (Frederick *et al.* 1982).

Acacia dealbata grown in southern New England had a DBH and HT increment of 1.89 $cm.yr^{-1}$ and 0.86 $m.yr^{-1}$, respectively, accumulating an average 0.014 $m^3.yr^{-1}$ (Figures 7.3 and 7.7). Assuming a stocking density of 1670 $stems.ha^{-1}$ at establishment with 20% mortality, a stand of *A. dealbata* could produce 190 $m^3.ha^{-1}$ of firewood timber after 10 years (fuelwood volume to a small diameter of 5 cm). If the stand was thinned by 50% at 10 years to a density of 670 $stems.ha^{-1}$ (yielding 95 m^3 after 10 years), a further 380 $m^3.ha^{-1}$ would be available for final harvest 10 years later. Total harvest after 20 years would be 475 $m^3.ha^{-1}$, representing an MAI of 23.8 $m^3.ha^{-1}.yr^{-1}$. This is encouraging given the prevalence of drought in the last 10 years, and contradicts a widely held perception that native plantings in the region are slow growing. Considering that none of the plantings had been thinned or burnt since establishment, and that superior *Acacia* growth has been attained under regimes of thinning (Birk and Turner 1992) and forest fires (Attiwill 1994b), larger volume increment might be expected under appropriate regimes of thinning and controlled burning.

Weight increment of *A. dealbata* can be estimated from the air-dry density (ADD) and volume ratio of the timber and bark, as in Chapter 3 for native forest trees. Neither ADD nor timber : bark volume ratio of shelterbelt trees were measured in this study, but other literature provide data for calculating weight increment. Frederick *et al.* (1985b) assessed the dry matter, energy and nutrient content of an 8-year *A. dealbata* stand in New Zealand. Total volume under bark was 367 $m^3.ha^{-1}$ and above-ground dry-weight excluding leaves and stem bark was 159.6 $t.ha^{-1}$, indicating an ADD of about 0.435 $g.cm^{-3}$. This is considerably less than the range given by Bootle (1983) in Australian native stands (0.54-0.72 $g.cm^{-3}$); plantation-grown trees are generally less dense than naturally regenerated stands due to faster growth, a more open vascular structure and a greater proportion of sapwood (Davidson 1987; Birk and Turner 1992). For stems and branches less than 25 cm diameter, bark density was about 55% of wood density in *E. laevopinea* and *E. melliodora* (Tables 3.5 and 3.6) and mean timber : bark volume ratio in five eucalypt species varied from 1.08 to 4.88 (Table 3.24). Assuming a timber ADD of 0.435 $g.cm^{-1}$, a bark ADD of 0.240 $g.cm^{-1}$ and a timber : bark volume ratio of 3:1 (25% bark by volume) for *A. dealbata*, the MAI of 23.8 $m^3.ha^{-1}.yr^{-1}$ after 20 years corresponds to 9.2 $t.ha^{-1}.yr^{-1}$ on an air-dry basis.

Casuarina grew at 1.40 cm.yr^{-1} in DBH and 0.80 m.yr^{-1} in HT over 10 years, accumulating an average 0.011 m^3.yr^{-1} (Figures 7.4 and 7.7). Assuming a stocking density of 1670 stems.ha^{-1} at establishment with 20% mortality, a casuarina plantation could produce about 150 m^3.ha^{-1} of firewood timber after 10 years. If the planting was thinned by 50% after 10 years to a stocking density of 670 stems.ha^{-1} (yielding 75 m^3 after 10 years), a further 310 m^3.ha^{-1} would be available for final harvest 10 years later. Total harvest after 20 years would be 385 m^3.ha^{-1}, representing an MAI of 19.3 m^3.ha^{-1}.yr^{-1}. This is higher than 14 m^3.ha^{-1}.yr^{-1} reported for *Casuarina* spp. grown on 'moderate' sites in the tropics (Pandey 1983; cited in Schroeder 1992) and 4-12 m^3.ha^{-1}.yr^{-1} reported for *C. equisetifolia* grown mainly in China (Midgley *et al.* 1986). Assuming a timber ADD of 0.60 g.cm^{-3} (Bootle 1983 measured 0.77 g.cm^{-3} in native forest), a bark ADD of 0.30 g.cm^{-3} and a timber to bark volume ratio of 3:1, then 20-year MAI of casuarina on a dry-weight basis is about 10.1 t.ha^{-1}.yr^{-1} in southern New England.

Comparing species' growth performance within and between plantings reveals an inconsistency in stringybark growth. Between-species comparisons of stringybark with *Casuarina* spp. and *E. melliodora* demonstrated superior early growth in stringybark (section 7.3.2). Yet in Figure 7.7 (section 7.3.4), stringybark was the least successful species after 80 months. This discrepancy reflects the absence of stringybark in older plantings. The oldest sampled was 90 months compared with the oldest *A. dealbata* and *C. cunninghamiana* at 210 months, and the oldest *E. sideroxylon* at 300 months. As suggested by the comparative growth rates of naturally grown *E. laevopinea* and *E. melliodora* (Figure 6.9), inclusion of VOL-age ordinates of older stringybark plantings could have changed appreciably the form of the regression in Figure 7.7. Based on results in section 7.3.2, stringybark growth is therefore assumed to be similar if not superior to that of other eucalypts and casuarinas to 220 months.

Few yield data are available from which to compare the growth performance of stringybark planted in southern New England with that planted elsewhere in Australia. Cotterill *et al.* (1985) measured early growth in 36 eucalypt species near Mt Gambier, South Australia. Five stringybark species (*E. baxteri*, *E. agglomerata*, *E. laevopinea*, *E. muellerana* and *E. phaeotricha*) demonstrated relatively slow growth after 18 months, *E. laevopinea* accumulating an average 0.0014 m^3.tree^{-1}, about 1.5 times more than predicted for *E. laevopinea* in New England using the volume function in Figure 7.7. An *E. laevopinea* plantation stocked with 1741 stems.ha^{-1} at Chichester, NSW, yielded 43 m^3.ha^{-1} or 0.025 m^3.stem^{-1} of merchantable underbark volume to the base of the live crown after 7 years (Borough *et al.* 1984). *E. laevopinea* in southern New England comprised 0.035 m^3.stem^{-1} of fuelwood timber after 7 years (Figure 7.7).

Perhaps the most surprising growth result was that of *E. sideroxylon* established at UNE in 1970 (site P9). The average fuelwood biomass in each tree was 0.488 m^3 after 20 years (Figure 7.7). Given a timber : bark volume ratio of 1.08, and an ADD of 1.10 and 0.56 g.cm^{-3} for timber and bark, respectively (Table 3.24), it follows that the weight of an average tree was about 400 kg. Since tree spacing was roughly 4 x 5 m or 500 stems.ha^{-1}, standing biomass after 20 years was 200 t and MAI thus 10 $t.ha^{-1}.yr^{-1}$. While this growth may reflect a generous rate of watering at the University, it is encouraging given the desirable qualities of red ironbark as a fuelwood and fencing timber. Similar results have been observed for high-density eucalypts elsewhere in Australia. A 9-year plantation of *E. bosistoana* yielded 8.6 $t.ha^{-1}.yr^{-1}$ in the 900 mm rainfall belt of South Australia (Lay *et al.* 1987) and a double-row windbreak of *E. cladocalyx* near Esperance, Western Australia (MAR; 600 $mm.yr^{-1}$) produced more than 1.0 t per tree after 25 years (Moore 1992).

7.5. Conclusions

The 20-year MAI of indigenous species such as *A. dealbata*, *C. cunninghamiana* and *E. sideroxylon* planted on the Northern Tablelands was about 10 $t.ha^{-1}.yr^{-1}$ on a range of sites. Well-formed trees with two stems yielded most fuelwood biomass; poorly formed single-stem trees yielded least. Growth rates were promising given the prevalence of cold winters and recent drought and the absence of post-planting management. The results suggest that intensively managed plantations could provide an economically viable means of producing fuelwood for sale in Armidale (Chapter 9). They also support adoption of a more exhaustive study, involving more species, sites and silvicultural treatments.

Chapter 8. Fuelwood management in southern New England
I. Native forests

8.1. Introduction

Projecting the demand for fuelwood requires various assumptions. Three factors could reduce fuelwood consumption in rural centres such as Armidale. First, market forces could encourage use of other common forms of heating energy if wood prices escalate. Second, concerns about the health effects of woodsmoke might result in legislative control on residential wood combustion, acting as a disincentive for continued use. Third, fuelwood may be partially or entirely displaced by development of some alternative form of space heating such as a solar or geothermal based technology. However, society should not be complacent about formulating management strategies because of these possibilities. National demand for fuelwood in Australia is increasing (Quraishi 1987; FTS and UT 1989) and supply in many areas is unsustainable (Morse 1985b; Maxwell 1991). Two forestry options could be introduced to ensure sound management of fuelwood resources in the Armidale region: fuelwood forestry and agroforestry. The latter is associated with planting trees on farms to produce fuelwood and other benefits, and is examined in Chapter 9. The former focuses on the manipulation of existing stands of native timber, and is examined presently.

Given that regional fuelwood consumption in southern New England is roughly 40 000 $m^3.yr^{-1}$ (section 2.5.1) and MAI of local forest is about 3.2 $m^3.ha^{-1}.yr^{-1}$ (section 6.4.5), a total of 12 500 ha (125 km^2) of native forest would be required to meet regional demand on a sustained yield basis. An estimated 2.387 Mt of fuelwood biomass is available from a combined 17 200 ha (172 km^2) of suitable fuelwood forest on private land and state forest, excluding all inaccessible lands, conservation reserves, TSRs, riparian vegetation, small forest patches (< 40 ha), open woodland, scattered and isolated trees, ironbark and casuarina stands, and areas with sub-standard timber species (Chapter 5). It follows that regional demand could be met entirely from native forests on a sustained yield basis. This is encouraging for landholders considering that retention of native vegetation can cost less than 10% of the cost incurred by tree planting on a per tree basis (Scanlan *et al.* 1992).

Reducing the quantity of dead fuelwood removed from local forest and establishing an accountable production system in southern New England may be important for embracing the objectives of ecological sustainability, in which wood is supplied on a sustained yield basis, and biodiversity and ecological processes are protected and possibly restored. Using local knowledge and experience from abroad, this chapter aims to construct a silvicultural and institutional portfolio for fuelwood forestry in the region, pivotal to biological conservation and agricultural sustainability (section 2.5.2). Various production scenarios are proposed and economic analyses of fuelwood forestry operations are presented.

8.2. Silvicultural considerations

8.2.1. Background

RAC (1992) emphasised that achievement of ecologically sustainable forest use, in which equitable and long-term material and non-material benefits from forests are realised, requires maintenance of the basic ecological processes and biological diversity of forest systems. This achievement is the focus of both conservation biology and silviculture, the former by addressing the protection, restoration and perpetuation of the variety of living organisms and life processes (Gall and Orians 1992), the latter embracing the set of forest management treatments applied to a stand throughout a rotation (Opie *et al.* 1984). Silviculture prescribes the application of ecological, social and economic knowledge to manipulate a forest for specific objectives (Squire *et al.* 1991; Squire 1993), where wood production is the major objective (RAC 1992).

8.2.2. Clearfell vs. selection

Clearfell

Clearcutting or clearfelling involves the felling and regenerating of compartments in the forest which have reached a predetermined age of maturity or rotation (Matthews 1989). Also referred to as even-aged silviculture, clearcutting involves the manipulation of forests for periodic regeneration of desirable species and the orderly growth and development of trees to a given size in each stand, and progressive development of harvestable stands to provide sustained yield timber (Morrison 1992). As a result of operational efficiency associated with co-production of sawlogs and woodchips, clearcutting has become a standard silvicultural practice used in the management of Australian forests (Florence 1993).

There is much conjecture on the adequacy of even-aged clearcut systems in Australian forestry (Florence 1993; Squire 1993). Clearcut operations produce the greatest volume of timber per unit area (Assman 1970), yet lack the inherent resilience against climatic extremes and insect plagues and the suite of non-wood benefits, such as soil conservation, wildlife habitat and recreational potential, of more diverse uneven-aged stands (Assman 1970; Harris 1984). They fail to exploit the synergy between different uses (Shea 1993) and are not autogenic (Harris 1984). The extractive nature of clearcut operations in Australia and their periodicity, typically 40 to 80 years (Dickman 1991), contravenes the contention by Attiwill (1994a) that management of natural forests should be based on an understanding of the ecological processes of natural disturbance. It is improbable that a wildfire, no matter how intense, would cause biomass loss in a forest to the same extent as a clearfell operation (e.g. RAC 1992). Much of the forest architecture, including large trees and hollows, is retained after severe fire and rapid recolonisation by fauna is possible. In contrast, a report by the Victorian Forests Commission in Boola Boola State Forest claimed virtually no recolonisation by arboreal mammals in eucalypt regeneration stands 40 to 70 years after clearfelling (Biggins 1983). Lindenmayer *et al.* (1993) cited literature suggesting that the period required to develop suitable nesting sites for some hollow-dependent species may be several hundred years, four or more times the present rotation length in high productivity Victorian forest. Forestry programs which selectively remove larger trees from a forest or woodland ecosystem (large trees contain a greater abundance of holes, fissures and hollow branches than smaller trees; Lindenmayer *et al.* 1993) are likely to affect profoundly the populations of hollow-using species, especially those dependent on hollows for breeding, roosting and refuge.

Maintenance of evolutionary process within forest systems requires that wood fibre production be kept less than maximum, avoiding the eventual elimination of some important seral stages and loss of structural elements in the forest paramount to the survival of certain fauna species (Shea 1993). An important criterion for fuelwood silviculture is thus the maintenance of a reasonably balanced forest structure and its assemblage of species. This is of particular relevance in southern New England, where past fragmentation and disturbance have been extensive, because the long-term viability of a species is founded on the conservation of ecotypes throughout its geographical range (Harris 1984). Further reduction of forest cover would diminish the size of regional populations of native species, so increasing their vulnerability to local extinction (Bennett 1990). Recent introduction of 'SEPP 46' to the Environment Planning and Assessment Act 1979 by the NSW Government prohibits the unlicensed clearing of native vegetation on private land. This is important for retaining habitat in continuous forest, but fuelwood managers must also safeguard against extraction of isolated trees of significant habitat value.

In relation to the operational context of fuelwood forestry, clearcutting is considered an inferior alternative for three reasons. First, excessive canopy openings associated with clear felling in areas of New England prone to severe frost may inhibit natural regeneration either by frost-burn or by encouraging grass to spread rapidly (Baur 1983). Second, large trees (> 60 cm DBH) are undesirable for handling and processing (section 6.4.4) and should be retained *in situ* regardless of species, form and health. Third, most stringybark and yellow box trees in the study region attain a maximum MAI, and are thus suitable for harvesting, before acquiring 60 cm DBH (section 6.4.4). Clearcutting is thus discounted as a viable silvicultural option for fuelwood production.

Selection and group selection

Selection systems differ from clearcut systems in that felling and regeneration are distributed throughout the entire forest instead of within discrete coupes (Matthews 1989) and only a minor component of the existing growing stock within an area is harvested (RAC 1992). Selective logging involves the manipulation of forest for continuous high cover, regeneration of desirable species, and growth and development of trees through a range of age or diameter classes to provide sustained yield timber (Morrison 1992). It requires the cutting of snig tracks and the movement of forestry infrastructure throughout the forest each harvest, sustaining a moderate level of disturbance. While this may be useful in diameter-limit cutting for sawlog production in which large trees of optimal form are targeted for felling each year (RAC 1992), it is inappropriate for fuelwood production because a large proportion of trees within the forest system comply with harvesting specifications.

Group selection involves the removal of trees in small groups within the stand and is applied to light demanding species where small openings are created to encourage rapid regeneration (Matthews 1989). It resembles clearcutting in its association with discrete compartments, yet it resembles selective logging in terms of tree retention. This is important in the context of retention of old-growth trees within regrowth forest, essential to the maintenance of nocturnal bird and arboreal marsupial species (Lindenmayer *et al.* 1993; Lindenmayer 1994; Kutt 1994). Timber harvesting with mature tree retention, and the forest's response to it, can be managed to mimic catastrophic natural disturbance events (e.g. wildfire and hurricane) fundamental to the development of structure and function of forest ecosystem (Attiwill 1994a,b).

Little evidence exists in Australia for the ecological effects of disturbance caused by fuelwood cutting, but overseas work is relevant. Chadwick *et al.* (1986) studied the impact of fuelwood cutting on avifauna in private forests in the New England region of Massachusetts, US. They found more species in cut than uncut stands, but fewer species requiring mature forest and tree hollows in cut stands. Stands cut for fuelwood had several vegetation stages present at the same time, allowing coexistence of both early, mid, and late successional bird species and providing evidence of the positive effect of fuelwood cutting. Recher *et al.* (1985) argued the importance of habitat stratification for producing a range of feeding substrates for bird species in eucalypt forests of south-eastern Australia and Kutt (1994) emphasised the importance of stand structure for arboreal mammals in eucalypt forests in East Gippsland. The uneven-aged nature of mixed eucalypt forests in southern New England (Chapter 4) suggests that variation in cutting intensities and selection of certain habitat components using a group selection fuelwood forestry regime could stimulate a range of vegetation structures and attract a more diverse bird and mammal community.

Group selection accommodates multiple forest benefits or integrated forest management (Shea 1993), in which several benefits (e.g. wood, water, recreation) are provided by a single stand. Ecological stagnation resulting from clearfelling destroys the aesthetic appeal of forest systems. Roche (1992) described the ancient production forest of Bellême, France, in which the forest's structural hierarchy has been retained for centuries. 'The forest provides a great diversity of habitats for the natural flora and fauna of the region, and is a source of spiritual replenishment for urban-based and spiritually impoverished citizens' (Roche 1992). Group selection perpetuates the uneven-aged nature of forest stands yet confines the annual movement of machinery, and is considered the best system for fuelwood logging in the New England region.

Allocation of coupes within fuelwood forests

Allocation of forest coupes within which annual fuelwood offtake is permitted is proving successful in Australia and overseas. In Newfoundland, Canada, blocks are established in over-mature and insect-damaged stands in Forest Management Units (FMUs) in which domestic fuelwood cutters can operate legally after purchasing a permit (Roy 1989). A location map of the appropriate compartment is issued with each permit sold, and sign-posts are placed in the FMU to assist location. In natural woodlands of the Kaduna State of Northern Nigeria, the Forestry Department allocates 16-ha coupes to fuelwood contractors at a cost reflecting the density of trees in the coupe (Hyman 1993). Trees are managed on a coppice rotation of at least 20 years. A forest block system has also been trialed by the Department of Natural Resources (DNR) in Victoria. All firewood collectors on public land must advance-purchase a harvesting license for the quantity of fuelwood they wish to consume. This entitles them to remove an agreed volume of timber within a nominated forest compartment (Read Sturgess and Associates RSA 1995). Legislative control with significant fines could be introduced for unpermitted cutting. Council signs were erected to deter indiscriminate fuelwood cutting in roadside reserves in Mornington Shire, Victoria, resulting in a dramatic reduction in the removal of live and dead trees from roadsides (McArthur 1987).

8.2.3. Coppice management

Coppice forestry utilises the ability of the stump and root system of certain species to produce successive crops of above-ground biomass after the previous crop has been harvested (Blake 1983). The ability of many eucalypts to coppice provides several advantages in fuelwood forestry. Vigorous coppicing has been observed in all local firewood eucalypts (section 6.3.2), assisting in stand regeneration and reducing markedly the cost of restocking. The growth form of young coppice stems is usually straight and slender (Plate 8.1), enhancing operational efficiency with respect to the cutting, billeting and splitting of firewood. Coppice vigour is independent of stump cut height within a range of 30 to 100 cm a.g.l. (Figure 6.4), so fuelwood loggers can select the most convenient stump height for tree felling without impeding coppice potential. Most important is that first rotation coppice shoots are faster growing than the original tree (Pearce 1982; Davidson 1987) because established roots have ready access to soil water and nutrients, and contain stored energy in the form of carbohydrates (Steinbeck 1982). Coppice management thus provides a greater quantity of fuelwood over a shorter period.

'Coppice with standards' is a silvicultural technique practised in Europe since the Middle Ages (Jacobs 1955) in which certain trees (the standards) are permitted to mature while all others are coppiced. The system has been trialed successfully in a box-ironbark stand dominated by *E. microcarpa*, *E. leucoxylon* and *E. polyanthemos* in Knowsley State Forest, Victoria, with 50-100 standards retained per hectare and three rotations achieved to date (Jones *et al.* 1983). European forests subjected to the coppice with

Plate 8.1.

Vigorous coppice regeneration in *Eucalyptus caliginosa* open forest (site 41). Most stumps have been docked close to ground level.

Note the slender coppice stems ideal for cutting and billeting.

standards method for many centuries support the richest variety of vertebrates and invertebrates of all western European terrestrial communities (Orians and Millar 1992). The system is worthy of trial for fuelwood production in southern New England.

8.2.4. Forest regeneration

Fire

In the production forests of eastern New England, fire is used as a post-felling treatment to encourage natural regeneration (Baur 1983), as a fire hazard reduction treatment every 3-7 years to prevent intense wildfires (Dickman 1991; Smith *et al.* 1992), and as a tool used by landholders every 2-3 years to encourage grass growth for livestock (Smith *et al.* 1992). While post-harvest and prescribed burning are standard practice in state forests along the eastern escarpment, the former can destroy viable seed in the fruit capsules of felled trees, often the main source of regeneration (Baur 1983), and the latter has a profound effect on forest structure, maintaining an open grassy understorey, preventing shrub development and forest regeneration, and disadvantaging various birds, reptiles and mammals (Smith *et al.* 1992). Repeated prescribed burning has an adverse effect on the shrub and dead timber components of rural forest systems, impacting on habitat stability in terms of loss of nesting and forage sites for ground dwelling mammals, birds and reptiles (Braysher 1983; Breckwoldt 1986; Dickman 1991; Recher and Serventy 1991; Smith *et al.* 1992). While there is always a threat of wildfire in the absence of prescribed burning, frequent burning itself can increase fire hazard by encouraging thick regeneration of flammable species such as *Acacia* spp. (Breckwoldt 1986). The fire risk to local fuelwood supply is likely to be small given the relatively large number of disjunct stands targeted for production, and that many eucalypts native to the area can tolerate wildfires (Opie *et al.* 1984). Regular burning in fuelwood forests is not recommended as part of fuelwood management.

Grazing

The grazing of domestic livestock restricts tree regeneration and can significantly change the cover and composition of understorey grasses and shrubs (Breckwoldt 1986; Curtis 1989). It is associated with weed infestation (Curtis 1989), soil structure decline (Willatt and Pullar 1983; Proffitt *et al.* 1995) and local extinction of native mammals (Suckling 1982) and insectivorous birds (Ford and Bell 1980; Ford 1981,1985; Loyn and Suckling 1987). Habitat simplification caused by grazing and burning in various state forests of eastern New England has a greater impact on faunal biodiversity than logging (Smith *et al.* 1992). Retention or restoration of understorey vegetation and the exclusion of livestock to enable native grass and legume establishment should protect and enhance species richness in remnant patches of vegetation on the Northern Tablelands (Barrett *et al.* 1994). It is strongly advised that grazing be excluded from forest stands designated for fuelwood production.

8.2.5. Seasoning and storing

Wood is a hygroscopic material which loses or gains moisture until reaching an equilibrium moisture content relative to the temperature and humidity of surrounding air (Jacobs 1979). Because the green timber of freshly felled stringybark weighs almost twice the air-dry timber of stringybark (section 3.3.1), retention of fuelwood billets for seasoning in the forest has the advantage of reducing handling and transport costs. However, the cutting, splitting and possible debarking of logs in the forest would increase the cost of manual labour, and because the resource would be spread throughout the forest, eventual extraction costs and the risk of theft would be high. These factors must be considered as part of the fuelwood supply system. A large scale fuelwood forestry operation could alternatively involve one or more central depots located close to town to receive green-felled firewood logs for splitting, seasoning and subsequent sale. The depot could include a mill for sectioning, splitting and debarking logs using hydraulic machinery, thus reducing processing costs and promoting accountability and efficiency.

Increasing the rate of seasoning is important from a production viewpoint. Brennan and Doust (1988) assessed changes in the field moisture content of different sized residue logs of jarrah *E. marginata* over varying periods, finding the rate of moisture loss increased in smaller-diameter logs. Regression analyses predicted a 17% moisture content in the smallest diameter class (15-30 cm) after 10 summers, although debarking and splitting would have greatly increased the drying rate and rainfall may have restricted drying rate (Brennan and Doust 1988). Barnacle *et al.* (1967) assessed moisture loss in the sapwood and outer heartwood of *E. viminalis* poles and fenceposts under various treatments. In contrast to the jarrah study, in which bark was retained on logs, the average moisture content of sapwood of all debarked poles (as a percentage of the oven-dry wood weight) decreased from 100% to 22% after just 2 months of air-drying during summer. The drying behaviour of outer heartwood was similar to that of sapwood, although drying rate and rate of response to climatic variation was slower, with heartwood losing about half its moisture during the first summer (Barnacle *et al.* 1967).

Fuelwood timber in the Armidale region should be dried for at least 18 months (over two summer seasons) to attain a moisture content of between 15-25% prior to sale. Fuelwood should be stacked to enable adequate air circulation and uniform drying, the cut ends of individual billets should be oriented towards the prevailing winds, and the stacks or rows should be separated by at least 1 m to enhance air circulation in the yard. Wood should be cut into firewood-length billets prior to seasoning (moisture moves 10 to 25 times faster along the grain than across it; Bootle 1983), and larger pieces should be split longitudinally (Minckler 1975). The woodstack should be situated on an unprotected north-facing slope to receive maximum exposure to sunlight, and should be protected from rain in the colder months (Barnacle *et al.* 1967) and when drying is complete (Minckler 1975). The site should have good drainage, preferably with sandy soil, and a relatively low mean annual rainfall (Anon. 1949). In terms of climate (warmer and drier) and proximity to consumers, the preferable site for a fuelwood depot in the study region is immediately west of Armidale.

8.3. Institutional considerations

8.3.1. Background

Inadequate operational control, in which logging standards are either misconstrued or ignored, has been a major obstacle to the achievement of sustainable forestry worldwide (Cassells 1993). Fuelwood harvesting throughout much of the developing world takes place in the absence of harvesting schedules, resulting in the loss of forest, woodland and shrubland and subsequent land degradation and loss of agricultural potential (NAS 1980; Pimentel *et al.* 1986; Gregersen *et al.* 1989). There are several institutional means to arrest the problem.

8.3.2. Fuelwood price and royalty

The greatest impediment for landholders wishing to sell fuelwood in Armidale is the negligible royalty or stumpage paid for standing trees. Most merchants extract timber from private land without paying timber rights, and payment never exceeds \$5 t^{-1} (section 2.4.2). It is essential that land owners are paid a fair sum for extraction of their trees if fuelwood forestry is to be adopted. In state forests in Victoria, the Department of Conservation and Natural Resources require that private collectors pay a license fee of \$9 m^{-3} for durable species or \$5.80 m^{-3} for 'common species', with an extra charge of \$4 m^{-3} for felled firewood (RSA 1995). A similar royalty of \$15 t^{-1} in private forests in the study region would provide an incentive for landholder cooperation.

The adoption of a royalty hinges on consumer acceptance of a surge in the price of domestic fuelwood. Environmentally responsible management of fuelwood forests (and plantations) requires that Armidale prices be increased to \$85-\$120 t^{-1} depending on species and mode of acquisition. This represents an average increase of about 65% on actual current prices, although the real price paid for a genuine tonne will only increase by about 30% (the average consumer receives about 0.75 t at \$60 t^{-1}; section 2.4.1). An educational package targeting environmental and personal health issues (the latter relates to wood-smoke emissions for which wood quality is important; Appendix XXX) could help facilitate public acceptance of price increases under a regional fuelwood strategy. A typical justification for low prices is to provide social benefits to consumers, but the resultant overcutting has an adverse and costly effect on future generations (Hyman 1993).

8.3.3. Merchant licensing

While merchant licenses have never been issued in NSW, probably because of the high cost associated with monitoring activities and the political and administrative hurdles to securing convictions, licensing has been undertaken elsewhere in Australia. A system of licensed cutting was introduced in Alice Springs in 1960, whereby suppliers had to extract wood from outside a 60 km zone to avoid further denudation of land where mulga *A. aneura* had been cut indiscriminately (Stewart *et al.* 1986). The Forests Department in Perth has also issued licenses to fuelwood operators, allowing them access to metropolitan forests (Annandale *et al.* 1983).

Merchant licensing is important from both a harvesting control and accountability viewpoint, and requires that merchants operate under specified conditions. Residents wishing to purchase wood from a licensed operator at a set price (~\$100.t^{-1}) would be ensured the correct tonnage of high quality firewood. Buyers would receive a weigh-bridge and fuelwood moisture certificate upon receipt of sale, obtained from the central fuelwood depot. A further step would be the formation of a cadre of professional fuelwood merchants, or a merchant cooperative. This is essentially a union of merchants whose product is certified by regulatory procedure. Licensed merchants advertising fuelwood for domestic consumption could be identified by a merchant cooperative emblem or signature.

A parallel production system could arise in reaction to restrictions placed on licensed wood merchants, whereby unlicensed individuals supply firewood on an itinerant basis at prices below the regulated value. This problem was discussed by Hosier and Milukas (1992) in relation to the Somali woodfuel market, where a deflection in production from cooperatives to private individuals benefited present consumers but degraded the environment. The issuing of licenses to private collectors, in which collectors pay a \$15-\$25 t^{-1} royalty (depending on species) for the right to harvest in state forest, is a positive step to negate this problem. The monies could subsidise fuelwood forestry management and the establishment of plantations on private land. Controlling unlicensed individuals who haul wood from their own or other people's properties at deflated prices is a more difficult proposition, although a merchant licensing strategy geared towards genuine tonnage, better quality wood, improved air quality and responsible extraction could capture a large component of the market when certifications of quantity and quality are issued on delivery. Because Armidale's woodsmoke problem is exacerbated *inter alia* by the combustion of poor quality timber entering the township due to the uncontrolled nature of wood supply (Appendix XXX), the community at large might respond by entrusting licensed merchants, even if prices are higher.

8.3.4. Community forestry

Community forestry has been defined by FAO as forestry activity which intimately involves local people (Bartlett and Malla 1992). It hinges on the active participation of local people in planning and executing tree management to meet their own needs (Arnold 1983). It is proving effective for managing local forest stands in Nepal, where control is being transferred from government to the village *panchayat* (council), entrusting local users with protection and management (Bartlett 1992). Nepalese community forestry is progressive because it is founded on the philosophy of resource ownership; the community itself is the beneficiary of income and resources derived from community forests, encouraging sustainable management (Bartlett 1992; Bartlett and Malla 1992). The community forestry model in Newfoundland (Roy 1989) also highlights a successful transition from a 'common property rights' ethic to a community project fostering responsibility and accountability in the wood-cutting public. The Forest Stewardship Program in Pennsylvania (Egan and Jones 1993) offers a model for eliciting change in the attitudes of both forest owners and users. Silvicultural information focuses on timber harvesting as a means to achieve broader resource objectives such as wildlife, soil and water management, as well as future income, and is geared towards the stewardship of biological resources beyond those directly associated with production of timber.

Because the adoption of a user-harvest system in public fuelwood forests of southern New England would be constrained by the proposed group-selection management of the fuelwood resource, responsibility for activities associated with community forestry should rest with a management agency. This is the case in Korea, where the local village forestry association has substantial rights over forest product flows, but is obliged to maintain forest stocks under the technical auspices of the government forest service (Gregersen *et al.* 1989). A transfer of responsibility from state to local government for the management of small state forests in southern New England is worthy of exploration. Alternatively, SF NSW could form a Division of Rural Forest Management responsible for coordinating community-directed management of rural timber in native stands and plantations on the tablelands, western slopes and western rangelands of NSW.

There are several alternatives regarding the choice of personnel (i.e. forestry contractors, wood merchants or consumers) to carry out different components of fuelwood supply from sawlog production state forest, fuelwood production state forest and freehold forest. In the case of fuelwood as a by-product of sawlogs (e.g. Styx River State Forest), Brennan (1988) suggested employing forestry contractors to cut, billet and split thinnings and other low-grade residual biomass before haulage to roadside landings for public sale. This would link fuelwood collection to forest management (Brennan 1988).

In public forests earmarked for fuelwood supply (Avondale, Boorolong, Enmore, Hillgrove and Eastwood State Forests), trees marked by forest managers could be felled, billeted and carted to a collection point by merchants, who receive a stipend upon delivery. Alternatively, household cooperatives could be established whereby fewer wood gatherers in fewer vehicles visit collection points. This would reduce collection costs for the user and management costs for the forestry depot or landholder (Force 1985), reduce greenhouse emissions (Hinkel 1989), and reduce public and private road maintenance. A household cooperative comprising say ten households could foster a sense of community good will (an important part of community forestry), in which a group of 10 to 20 residents visit a compartment or collection point to harvest, cut, and load fuelwood using fewer vehicles and chainsaws. The recreational and educational potential of household cooperatives should be explored in full.

Landholders wishing to sell fuelwood from their own properties could conduct all or part of the above process. Trees could be marked by a fuelwood silviculturist (or landholder), felled and billeted by a logger (or landholder), thence moved to a storage point on the property which affords easy access to private collectors, who pay the landholder upon receipt of fuelwood. Conversely, a royalty system could be implemented in which farmers receive at least \$15 t^{-1} (section 8.3.2). Trees would be marked by a fuelwood silviculturist thence cut, billeted and hauled to a major depot by licensed fuelwood merchants for seasoning and subsequent distribution (section 8.2.6). Landholders would be paid the appropriate royalty upon receipt and weighing of cut loads at the depot.

8.3.5. A 'Fuelwood Forestry Code of Practice'

Regional planning in forestry should consider both public and private forest (Florence 1993), in which the relevant government department assesses private forest holdings for potential timber supply, carries out silviculture, and monitors environmental standards. Tasmania is the only Australian state to assert environmental control in private forestry. The Forest Practice Code for private forests in Tasmania was established primarily for woodchipping, and covers various aspects of harvesting including regeneration, roading, soil, water, flora, fauna, landscape and special features (Rolley 1993). A 'Code of Practice for Fuelwood Forestry' is suggested for the achievement of responsible fuelwood forestry in southern New England, where silviculturists, foresters, landholders and consumers act as custodians of rural forest and its values by adhering to accepted standards. Silvicultural techniques and individual responsibilities would be instructed explicitly under the Code. It might also address the risk of injury to private collectors unskilled in the felling of trees and use of chainsaws by requiring a chainsaw operation certificate. Three people died and many others were injured during private fuelwood collection in an Idaho forest in 1983 (Matejko and Slagle 1984).

8.3.6. 'Debt-for-conservation' swaps

The role of 'debt-for-conservation' swaps in Australian agriculture has been reviewed briefly by Parton (1993), in which an environmental agency purchases discounted debt from a landholder in return for on-farm conservation services. In terms of the interactive role of fuelwood and biological conservation, the thrust of 'debt-for-conservation' offers inspiration for farmers wishing to diversify farm enterprise, and conservation agencies or even private investors wishing to manage and conserve native vegetation. The scenario is simple. The private investor or environmental agency purchases the right to manage a parcel of forest located on the farmer's property for a given period. This could be organised either as a lump sum 'write off' of rural debt (e.g. \$20,000), or an annual instalment paid directly to the farmer, essentially an opportunity cost for forgone grazing (e.g. \$50 $ha^{-1}.yr^{-1}$). The designated parcel would be subsequently fenced by the investor to exclude stock and managed for biological conservation and rural timber production (fuelwood, fencewood, sawlogs). The farmer would benefit in three ways: revenue from an initial sale of stock to counter the loss of grazing land; a debt reduction or annual income; and improvement of farm diversity and biodiversity. The investor would benefit from the direct sale of timber products (e.g. at an MAI of 5 $t.ha^{-1}.yr^{-1}$ under group-selection coppice rotation and a domestic fuelwood price of \$100 t^{-1}). Similar to sharefarming (section 9.7.2), the system offers great financial flexibility for both the farmer and investor in terms of input and output. A farmer, for example, could purchase the silvicultural expertise and equipment and reap the benefits of timber production.

8.3.7. Public education

The fact that urban residents cut fuelwood illegally from public land suggests that educating the urban sector is as important as educating farmers. Forest management is likely to be driven increasingly by public perception of forest utility (Squire 1993), and dissemination of appropriate information is required in Armidale. Perhaps the most powerful catalyst for attitude change is human welfare. The Brundtland report recognised that the environment cannot be conceived in a way which is separate from human actions, ambitions and needs, and emphasised the dependency of human welfare on the natural environment and our capacity as a species to protect it (WCED 1987). Fuelwood is a renewable and 'greenhouse benign' energy source under appropriate management (Appendix XXIX), and has the potential to play a major role in regional, national and global sustainable development. That is, unlike its contemporary non-renewable competitors (coal, oil and gas), fuelwood can 'meet the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). So why do wood and other forms of renewable energy remain segregated from energy policy at local, regional, state and national levels? Perhaps, as Soussan *et al.* (1992) identified, real tensions exist between long-term development goals and short-term economic necessities, so that access to capital for investments in small-scale, dispersed energy systems has been repeatedly sacrificed to large, centralised investment, with the electrical power sector dominating. The recognition of fuelwood as an important contributor to domestic energy use in temperate Australia, and the formulation of appropriate energy policy, offers an opportunity to invest in farm forestry and wood energy research and development.

8.4. Fuelwood forestry in southern New England

8.4.1. Production scenarios

Preamble

The silvicultural and institutional framework within which fuelwood forestry should function in southern New England has been discussed in sections 8.2 and 8.3. It is recommended that a coppice-based group selection system be adopted for silvicultural manipulation of nominated forests for production of urban firewood, in which the use of prescribed burning and grazing and the extraction of dead fallen timber is prohibited. This section applies the recommendations to four state forests in the study region. Biomass estimates used throughout were calculated from forest inventory data (Chapter 4).

Eastwood State Forest

Eastwood State Forest (sites 83-85; Figure 2.1) is located 10 km south-east of Armidale and comprises a small remnant stand of closed forest (215 ha) dominated by stringybark, with yellow box, white gum, red gum and a scattered acacia understorey. MAR is about 780 mm.yr^{-1} and yellow podzolic soils predominate. The stand provides a small amount of firewood and fencewood, and is held under permanent occupancy for grazing (FCNSW 1984). Fallen dead timber is constantly removed, and little dead standing timber remains. Eastwood is visited frequently by Armidale residents for recreation, including walking and horse riding. The approximate density of *E. caliginosa* in the range 15-60 cm DBH is 174 stems.ha^{-1}, representing a basal area of 14.1 m^2.ha^{-1} and a standing air-dry weight of 97.5 t.ha^{-1}. *E. blakelyi* adds 33 stems.ha^{-1} (8.5 t.ha^{-1}) and *E. melliodora* adds 12 stems.ha^{-1} (7.5 t.ha^{-1}) to viable fuelwood biomass (15-60 cm DBH: estimated from Appendix XXII (no.6)). Total standing fuelwood biomass in Eastwood is approximately 24 400 t (3.05 x 10^8 MJ), about the same quantity of fuelwood consumed by the urban sector in the study region every year.

It is proposed that a total 200 ha of Eastwood State Forest be managed for fuelwood production (14 ha retained uncut for riparian considerations). A 4 ha compartment would be treated each year using the group selection regime with a 50-year rotation. To ensure an adequate post-harvest representation of different sized trees, not more than 75% of fuelwood trees in each 5-cm diameter class within the 15-60 cm range would be harvested. The projected production from Eastwood State Forest is 342 t.yr^{-1}, yielding a gross value of $20,520 at $60.t^{-1}. Eastwood could provide enough fuelwood to supply about 70 residences each year, equivalent to 1.9% of Armidale's annual consumption. A single thinning operation may be required in logged coupes after 10 to 20 years if natural regeneration is prolific, providing a possible 10 t of fencing timber and 20 t of fuelwood timber each subsequent year.

Boorolong State Forest

Boorolong State Forest (sites 60 and 61; Figure 2.1) is located 20 km north-east of Armidale and contains 766 ha of forest cover (FCNSW 1984), of which 250 ha are inaccessible due to steep terrain. Boorolong was selectively logged between 1955 and 963, and contains an estimated 1500 m^3 of sawlogs (FCNSW 1984). It is better quality forest than Eastwood State Forest, comprising approximately 355 stems.ha^{-1} of stringybark and blackbutt in the range 15-60 cm DBH, representing 29.6 m^2.ha^{-1} basal area and 206 t.ha^{-1} (Appendix XXII (no.4)).

It is proposed that 500 ha be nominated for urban fuelwood supply using either a single 10 ha compartment or 2 x 5 ha compartments each year over a rotation of 50 years. A 25% tree retention is proposed similar to Eastwood State Forest, although retained trees in Boorolong would include 1500 m^3 of sawlog trees as well as smaller trees of potential sawlog value. Potential fuelwood harvest is estimated to be 1550 t.yr^{-1}, yielding a gross value of \$93,000 at \$60.t^{-1}. According to these guidelines, Boorolong State Forest could provide enough fuelwood to supply 314 households each year, or 8.6% of Armidale's annual consumption.

The group selection regime in Boorolong State Forest could comprise a second and third harvest in each compartment to remove overwood (large trees). An average 12.5 stems.ha^{-1} of trees of DBH > 60 cm could be thinned to about 5 stems.ha^{-1} after 10 years as part of the second overwood cut. This would promote regrowth and create additional income, with the extraction of an estimated 2 m^3.ha^{-1} sawlog timber and 15 t.ha^{-1} fuelwood timber, yielding about 20 m^3 sawlogs and 150 t of fuelwood over the 10 ha area. Regrowth thinning would constitute the third cut in each coupe after about 20 years, providing 5 t.ha^{-1} of fencing material and 15 t.ha^{-1} of fuelwood, or 50 t.yr^{-1} and 150 t.yr^{-1} respectively after 20 years. In summary, Boorolong State Forest could supply 1850 t.yr^{-1} of domestic fuelwood, 50 t.yr^{-1} of rural fencing timber and 20 m^3 of sawlog timber on a sustained yield basis after 20 years, in which up to 30 ha (~ 4%) of the total 766 ha would be manipulated to varying degrees every year.

Hillgrove State Forest

Hillgrove State Forest is located 5 km east of Armidale (sites 76-80; Figure 2.1) and comprises 101 ha of low quality open eucalypt forest dominated by *E. caliginosa*, with *E. melliodora* and *E. blakelyi* (FCNSW 1984). It contains 141 stems.ha^{-1} *E. caliginosa*, 20 stems.ha^{-1} *E. melliodora* and 9 stems.ha^{-1} *E. blakelyi* within the DBH range 15-60 cm. This represents a combined total of 15 m^3.ha^{-1} basal area and 112 t.ha^{-1} standing fuelwood biomass (Appendix XXII (no. 7)). Using the same silvicultural strategy suggested for Eastwood State Forest, which has similar stand characteristics, Hillgrove could produce 168 t.yr^{-1} of fuelwood, supplying about 34 households in Armidale. While this is a feasible option, Hillgrove State Forest is uniquely positioned within about 3 km of Armidale's sewage treatment works, and affords a possible alternative for the disposal of Armidale effluent. Chapter 10 details issues associated with an effluent-irrigated fuelwood plantation in Armidale. The following section describes briefly issues associated with sewage effluent in Hillgrove State Forest.

Apart from carbon (C), hydrogen (H) and oxygen (O) available from atmospheric CO_2 and soil moisture, the six macronutrients essential for plant growth are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) (Harris 1983). N is a fundamental component of protein and chlorophyll which controls the rate of production of wood and foliage (Schönau and Herbert 1989; Lehane 1992), P is important for root development, and K activates physiological functions (Schönau and Herbert 1989). Eucalypt growth responses are driven primarily by N and P (Cromer *et al.* 1981), the latter being a major limiting factor in soil fertility. The high organic N concentration in Armidale's treated effluent (21.9 mg.L^{-1}) (section 10.2) suggests the potential for a considerable increase in biomass increment in Hillgrove State Forest under effluent disposal. Irrigation of a mixed forest in Georgia, US, at the rate of 3950 mm.yr^{-1} loaded an average 520 kgN.ha^{-1}yr^{-1} over a 10 year period (Nutter and Red 1985). The authors reported a 95% increase in diameter and height increment of overstorey trees, suggesting an annual biomass increase of at least 500%. Iwatsubo and Nagayama (1994) tested the influence of six sewage-water spraying episodes over three years in a small pine forest growing on infertile soil in Japan. A total of 95% of input N was retained in the treated forest system, which yielded a 1500% increase in biomass accumulation compared with non-treated forest after 13 years. Some 244 mm treated effluent were sprayed over 122 days at a hydraulic rate of 730 mm.yr^{-1}, providing a total N loading of 724 kg.ha^{-1} (Iwatsubo and Nagayama 1994).

While groundwater and subsoil nitrate concentrations in each study did not exceed the 10 mg.L^{-1} standard given by Haith *et al.* (1992), other investigations contend that N-leaching and associated groundwater contamination provides one of the greatest limitations to wastewater disposal. Effluent research in Pennsylvania (Hook and Kardos 1978) showed that leaching (mainly NO_3^-) was dependent on hydraulic loading. When a hardwood stand was sprayed with treated effluent at an average rate of 2600 mm.yr^{-1} for 9 years (equivalent to 750 kg.ha^{-1}.yr^{-1}), 83% N leached from the site in the final 6 years and sub-surface leachate concentration exceeded 15 mg.L^{-1}. Aschmann *et al.* (1992) monitored the rate of NO_3-N accumulation in subsoil under different amendments of liquid wastewater sludge in a Maryland hardwood forest, concluding that an application rate of 200 kg.ha^{-1}.yr^{-1} would not increase groundwater nitrate levels. Haith *et al.* (1992) developed a mathematical model which predicted safe N-application rates of 70 to 115 kg.ha^{-1} for hardwood forest.

Armidale sewage treatment facility produces 5.5 ML.day^{-1} of untreated sewage containing an average 117.3 kgN. Based on water budget calculations, a minimum feasible land area across which to expel all effluent is 235.5 ha (section 10.4.2), of which Hillgrove State Forest could contribute 43%. It follows that an estimated 182 kgN.ha^{-1}.yr^{-1} would be applied each year, a modest loading compared with some of the US rates reported above. Assuming a 500% increase in stand productivity, Hillgrove State Forest could produce an estimated 12 t.ha^{-1}.yr^{-1} or 1210 t.yr^{-1}. This is about 6.7% of Armidale's annual demand, enough to supply 245 households.

Styx River State Forest

Considering that 65% of tree biomass is 'discarded and burnt as useless' in commercial forestry operations in Australian (Annandale *et al.* 1983), there is great potential for redirecting fuelwood supply from rural deadwood to logging residues (FTS and UT 1989). This has proven successful in Perth, WA (Brennan 1988). Styx River State Forest (sites 115-117; Figure 2.1) is located 60 km east of Armidale on the eastern edge of the escarpment of the Northern Tablelands at the head of the Macleay Valley, and contains 15 800 ha of 'New England hardwood' type forest (FCNSW 1984). Early bush mills were established at Styx River around the turn of the century, where logging was selective and confined to gentle topography (Baur 1983). Since the first working plan was produced in 1917, almost all accessible areas of Styx River have been logged within its 79 compartments. Based on assessment of timber production in the forest management area, total gross yield of sawlog timber from 1945 to 1983 was 16 500 $m^3.yr^{-1}$. Total gross yield of quota and ex-quota sawlogs from Styx River between 1987 and 1993 was at least 115 650 and 42 650 m^3, respectively, or a total of 19 800 $m^3.yr^{-1}$ (SF NSW Walcha District Office, unpubl. data). At least 5000 $m^3.yr^{-1}$ of residue have been left in the forest.

Various post-logging treatments have been carried out in Styx River State Forest to encourage regrowth. Treatments included the pre-1970 felling or ringbarking of unmerchantable trees and the post-1970 salvage logging of defective over-mature trees, yielding an average 9170 $m^3.yr^{-1}$ in recent years (SF NSW Walcha District Office, unpubl. data), and the recent burning of 'logging slash' (FCNSW 1984). Imminent onset of the second cutting cycle in Styx River State Forest at a projected rate of 11 500 $m^3.yr^{-1}$ for quota logs and 4500 m^3yr^{-1} for regrowth thinnings (FCNSW 1984) potentially enables co-production of domestic fuelwood using blackbutt and stringybark. Assuming a mean diameter of 80 cm DBH for second-cut quota logs, an estimated 12 500 m^3 or 7000 t (air-dry) of non-merchantable biomass (branches, upper stem, bark) would be generated each year from the extraction of 11 500 m^3 of quota logs alone.

Marketing arrangements for public sector logs can have a major influence on the marketability of privately grown logs (Bhati *et al.* 1991), and artificially low royalties paid for timber extracted from public land can deter private forestry investors (RAC 1992). This is not a major problem at present because the nature of supply is decentralised and there are no public or private fuelwood forests in NSW. It should be stressed, however, that development of a fuelwood supply strategy through utilisation of forest residues in Styx River State Forest cannot afford to flood the market with subsidised fuelwood at the expense of supply from private forests. Nor should public industry create uncertainty for investors about the future marketability of fuelwood.

8.4.2. A preliminary economic budget

Preamble

Two economic scenarios for fuelwood forestry in the Armidale region are presented. The first is a government-operated scenario, in which management is carried out by SF NSW. Competition with private merchants and collectors limits potential annual cut to 5000 $t.yr^{-1}$. The second is a landholder-operated system involving different levels of outside involvement, in which SF NSW oversees silvicultural aspects.

An important aspect in determining the net present value (NPV) of forestry projects is selecting the appropriate discount rate by considering the real rate of interest, adjusted for inflation, together with the perceived risk of the venture (Brandle *et al.* 1984). Many project analysts ask governments to set discount rates for them and others compute the break-even discount rate which equals the internal rate of return (Hoekstra 1985). A discount rate of 7% is used in this analysis. Intergenerational inequity is not considered a hindrance to investment decisions in fuelwood forestry as in plantations (section 9.6.2) because returns on investment are realised on an annual basis after the first two years (allowing for air-drying of first harvest). A regular cash flow can be obtained immediately using forest regulation to schedule harvests on different parts of the forest at different times (Mills 1988). Fuelwood forestry in this respect could offer a short to medium term 'interim' supply of fuelwood while plantations attain harvestable age, and an 'investment boost' for plantation establishment.

Fencing costs

A robust rural fenceline about 1.2 m in height is required for the protection of native forest against livestock. The fenceline should be constructed using timber strainers and stays, and steel picket posts and wire. The quantity of fencing material required per kilometre is adapted from analysis by Wall (1996, in prep.): 10 strainer posts, 9 stays, 140 steel posts and 5250 m wire. At a retail price of \$12 per strainer, \$6 per stay, \$3 per steel post and \$68 per 750 m role of wire, cost of fencing material is \$1,070 km^{-1}, or \$1,270 km^{-1} including 2 steel gates.

Government operation

The capital cost of developing and establishing a fuelwood system managed by SF NSW is estimated broadly at \$1,000,000, and includes the cost of an Environmental Impact Assessment, the purchase of land for a fuelwood depot close to town, the purchase of two trucks (4 and 8 t capacity), one 4WD utility, one fork-lift truck and a weighing bridge. It also includes the design and construction of a portable fuelwood mill and mounting trailer, purchase of all related equipment including hydraulic splitter, drying slats and chainsaws, and development of a comprehensive educational package for landholders and domestic fuelwood consumers. A minimum of nine people would be employed, including a central depot manager and fork-lift driver, two truck drivers, four fuelwood foresters and a professional fuelwood silviculturist. Yearly employment costs would be approximately \$300,000, including 25% on-costs.

Approximately 2000 ha of native forest would be required to supply 5000 air-dry tonnes of stringybark fuelwood (30% of Armidale's annual consumption). Some 800 ha could be allocated in nearby Boorolong, Eastwood, and Hillgrove State Forests, the remainder extracted from the more distant Avondale, Enmore, Styx River and Winterbourne State Forests. Average round trip distance would be about 100 km. Assuming chainsaw fuel consumption is 2.2 $L.t^{-1}$ (Hinkel 1989), truck fuel consumption is 0.25 $L.km^{-1}$, and truck haulage capacity is 4 t, total fuel cost associated with cutting and haulage would be \$32,000 yr^{-1} plus maintenance. Since fuel costs associated with operation of the fork-lift truck, fuelwood mill and hydraulic splitter are unknown, \$50,000 yr^{-1} is suggested for total petrol and oil costs. Assuming a further \$50,000 yr^{-1} for machinery maintenance costs and \$50,000 yr^{-1} for administration, insurance and miscellaneous costs, total annual operating cost would be \$150,000.

An annual fuelwood revenue of about \$500,000 yr^{-1} is achievable if at least 30% of Armidale households are willing to pay \$100 t^{-1} for genuine loads of premium-grade firewood. This generates a \$50,000 yr^{-1} profit after employment and operational costs which could be re-invested in various ways: land purchase for establishment of fuelwood plantations; employment of additional personnel; community education; improved marketing; exploration of potential diversification of markets; ecological research and development; and capital expenditure. The enterprise would break even at a delivered price of \$90 t^{-1}.

Landholder operation

The following analysis considers a farmer who wishes to produce firewood from a 100 ha eucalypt forest at a rate of 300 t.yr^{-1} using a group selection regime. The farmer has three harvesting options: owner operation; owner/contractor operation; merchant operation. Each is assessed given the assumptions listed in Table 8.1.

Table 8.1. Assumptions used for economic appraisal of options for fuelwood silviculture.

Activity	Assumptions	
Fencing	1	Fence length: 5 km
	2	Fence requirements: 50 strainers, 45 stays, 700 steel posts, 4 gates, and 35 roles of wire (750 m.role^{-1}) (no rabbit netting required).
	3	All stays and strainers cut from about 50 large trees (total 70 t air-dry weight) in the fuelwood forest in year 1, yielding a fuelwood biomass (mainly branchwood) of about 25 t.
	4	Fencing cost (wire, steel posts, gates): ~ \$5,000
	5	Labour cost for fencing assistant: ~ \$1,300 (10 days at \$130 day^{-1})
	6	Fence maintenance: \$60 km^{-1}.yr^{-1} (carried out by farmer)
Harvesting	1	Time of harvest: winter-spring
	2	Field retention time for seasoning: 18-21 months
	3	No. tonnes cut in year 1: 255 t
	4	No. tonnes cut each year after year 1: 300 t
	5	No. tonnes harvested, billeted and stacked per farmer.day^{-1}: 5
	6	No. tonnes harvested, billeted and stacked per contractor.day^{-1}: 10
	7	Royalty: \$20 t^{-1}
Other	1	Forest silviculturist: \$500 day^{-1} (for 1 day)
	2	Forest contractor (+ assistant) fees: \$400 day^{-1} (for 30 days)
	3	Opportunity cost of excluding grazing in eucalypt forest: \$30 ha^{-1}.yr^{-1}
	4	Transport using 4-t truck with operational costs: 30¢.km^{-1}
	5	Chainsaw costs: \$2 t^{-1}
	6	Travel distance to Armidale: 25 km (one-way)
	7	Fuelwood price: \$65-\$105 t^{-1}

The owner operation envisages all forestry being undertaken by the farmer, requiring 60 days for harvesting, billeting, and stacking on-site and 40 days for loading and hauling wood to market, or a total of 4-5 working months. The owner/contractor scenario involves hiring a forest contractor and assistant at \$400 day^{-1} for 30 days to harvest, billet and stack wood at a rate of 10 t.day^{-1}. Forty days of farmer labour are required for loading and haulage. The merchant scenario involves no farmer labour and receipt of \$20.t^{-1} royalty.

Figure 8.1 illustrates the annual NPV of each management scenario over 20 years. While all scenarios return a positive NPV after 20 years, the outlay of contractor fees in the farmer/contractor operation results in a NPV of just \$74 yr^{-1}. This is unattractive given the farmer labour of 40 days.yr^{-1}. An NPV of \$613 yr^{-1} under the merchant scenario is considerably more attractive given that no labour is required by the farmer. As inferred in the sensitivity analysis below, royalties of \$20.t^{-1} will only be possible in Armidale given a significant rise in the domestic price of fuelwood. Total farmer involvement achieves by far the largest NPV: \$6,875 yr^{-1}. This is an appreciable addition to total farm income, but must be weighed against the cost of farmer input (4-5 months.yr^{-1}).

The sensitivity of NPV and breakeven age on fuelwood price and royalty is shown in Figure 8.2. NPV of the merchant operation increases from -\$777 yr^{-1} at \$10 t^{-1} royalty to \$3,394 yr^{-1} at \$40 t^{-1} royalty. Royalties of \$40 t^{-1} are achievable in cities such as Canberra and Adelaide where fuelwood prices are over \$100 t^{-1}. However, at Armidale's current price, royalties are less than \$10 t^{-1} and a merchant-managed native forest enterprise is economically unattractive, given the cost of fencing and the opportunity cost of grazing. The \$4,478 yr^{-1} NPV of a farmer-input scenario at a fuel price of \$65 t^{-1} is more attractive than the \$2,471 yr^{-1} NPV of a farmer/contractor scenario at \$105 t^{-1}, emphasising the financial constraint in employing a forest contractor to fell, billet and stack timber. The farmer-input scenario at a fuelwood price of \$105 t^{-1} provides an NPV of \$9,273 yr^{-1} with a breakeven age after the first fuelwood sale, by far the best economic performance of all scenarios.

Given correct fuelwood pricing, the above analysis suggests that a farmer can diversify farm output and achieve good returns while incorporating the ideals of on-farm biological conservation. This demonstrates the desirability of regulating the fuelwood industry to promote biological conservation in private forest.

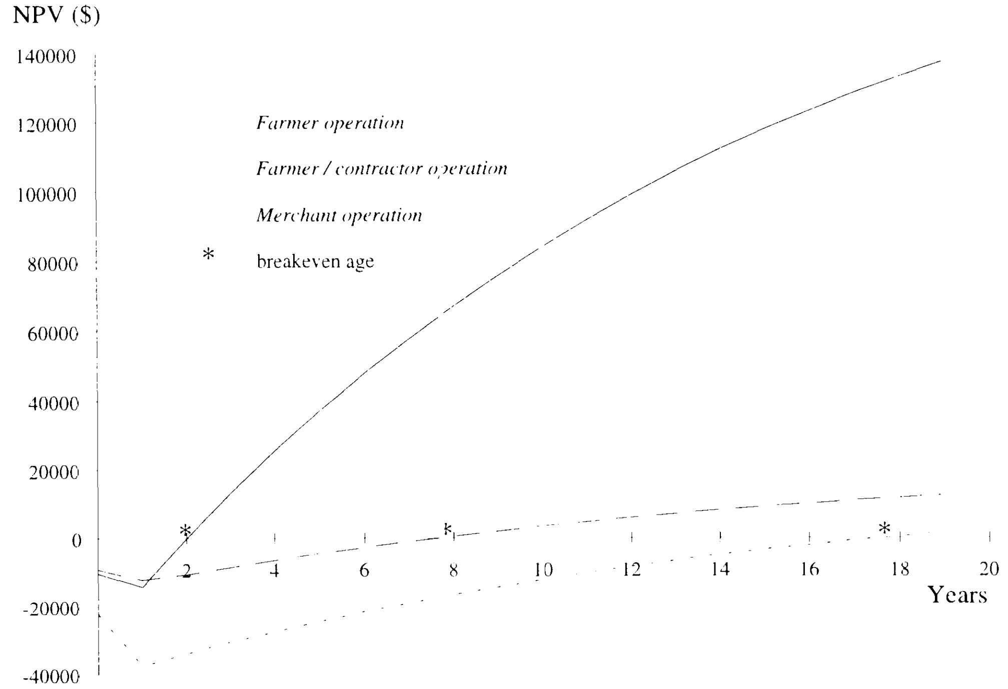


Figure 8.1. Effect of type of operation on NPV and breakeven age for a fuelwood forestry project on private land (discount rate = 7%, fuelwood price = $85 t^{-1}).

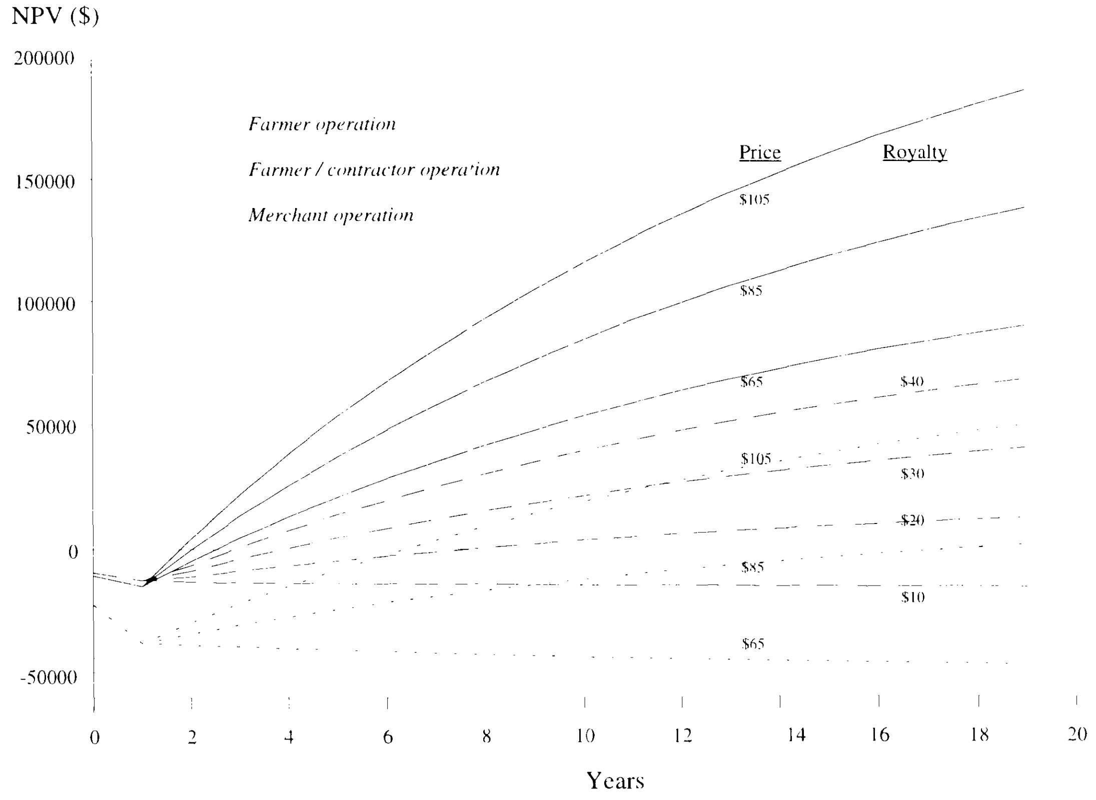


Figure 8.2. Effect of fuelwood royalty and price on NPV and breakeven age for three types of fuelwood forestry project on private land (discount rate = 7%).

8.6. Conclusions

The possibility that fuelwood supply is ecologically unsustainable (section 2.5.2) suggests a need for regulatory and silvicultural reform in the fuelwood industry. It has been clearly demonstrated from inventory and yield data in Chapters 3 to 6 that live-felled fuelwood could be supplied to Armidale on a sustained yield basis. This chapter provides further evidence that fuelwood could be supplied on an ecologically sustainable basis, embracing biological conservation and sustained yield. The main hypothesis of this thesis - that ecologically sustainable production of fuelwood on the Northern Tablelands is achievable through appropriate management of rural timber resources - has thus been supported. The achievement of sound financial returns from group selection management of small forest coupes, in the absence of grazing and dead timber extraction, attests to the ecological and economic credentials of fuelwood forestry in the region.

Adoption of fuelwood forestry hinges largely on price restructuring to reflect the environmental cost of harvesting and burning trees, and the introduction of voluntary merchant licensing to ensure delivery of genuine quality and quantity merchandise. A price of \$85 to \$120 t^{-1}, depending on species and mode of acquisition, is suggested to ensure attractive on-farm royalties and merchant incomes, and finance for capital reinvestment in machinery, fencing and sharefarming ventures. This is less than the equivalent price paid for other forms of energy (section 2.5.4), and is no more than fuelwood tariffs paid in Canberra and other large centres.