Chapter 4. Forest inventory for fuelwood estimation
I. Forest sampling

4.1. Introduction

Forest inventory is a systematic procedure for collecting mensurational data on forest biomass and land attributes and a summary presentation of the quantitative estimates themselves (Cunia 1981). The procedural aspect of forest inventory consists of two parts; stand assessment and tree mensuration. Stand assessment involves rapid measurement of forest variables across a region using direct sampling and remote sensing techniques. Tree mensuration is more intensive, involving formulation of site-specific regression equations relating biomass to tree and stand characteristics. The 'two-phase' nature of this approach to forest inventory is a form of double sampling (Cunia 1981; Matney and Parker 1991; Catchpole and Wheeler 1992), in which a large sample of forest variables obtained through stand assessment (site quality, stand basal area, stand density, and tree DBH distribution) is augmented by a smaller, more intensive phase of tree mensuration.

A number of biomass studies outside Australia have used double sampling to estimate fuelwood biomass. Bird and Shepherd (1989) and Deshmukh (1992) obtained 'best estimates' of wood biomass in the bushlands and woodlands of Somalia by extrapolating tree regression functions of above-ground biomass to stocking data at field monitoring sites. Tietema (1993) constructed multiple-species or 'combi-line' regression functions, providing opportunities to conduct regional ground surveys of tree standing biomass in Botswana.

While the principal goal of many biomass studies in the developing world is achievement of a sustainable supply of fuelwood or charcoal, most studies using the double-sampling approach to forest inventory in Australia have been undertaken to assess stand composition, biomass accumulation and nutrient cycling. Stewart *et al.* (1979), Attiwill (1979, 1980), Feller (1980) and Applegate (1982) have each constructed regression equations from measurements of felled eucalypts thence extrapolated the equations to stand data for estimation of forest biomass. In this Chapter, the regression equations assembled for fuelwood eucalypts in Chapter 3 are applied to a dataset of independent tree and stand variables collected at various sites in the study region. Estimates of fuelwood biomass are derived for eucalypt stands of varying site quality, species composition and cover class.

4.2. Methods

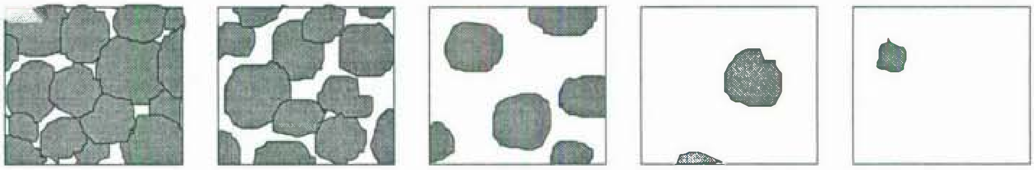
4.2.1. Classification of cover classes

Crown cover is a measure of the proportion of a sample stand within the vertical projection of the periphery of tree crowns, and can be estimated and classed using aerial photograph interpretation (API). Walker and Hopkins (1990) used arbitrary crown cover classes to coincide with projective cover classes defined by Specht *et al.* (1974). These are defined in Table 4.1 and illustrated in Figure 4.1, and were used for tree cover classification at inventory sites in the present study.

Table 4.1. Cover classes selected for woody vegetation in the Armidale region (adapted from Walker and Hopkins 1990; Specht *et al.* 1974).

Closure	CSR *	PCC **	Crown Description	Type
closed	< 0	> 75	touching	closed forest
mid-dense	0-0.5	35-75	slightly separated	open forest
sparse	0.5-1.5	13-35	well separated	woodland
very sparse	1.5- 20	0.2-13	highly separated	scattered trees
isolated	> 20	0-0.2	trees >100 m apart	isolated trees

* CSR = crown separation ratio
** PCC = projected crown cover (%)



Closed Forest   Open Forest   Woodland   Scattered Trees   Isolated Trees

Figure 4.1. Aerial crown cover for tree cover classes in southern New England.

4.2.2. Stand basal area, density and species composition

Background

A quantitative analysis of forest vegetation is required to determine the extent to which timber extraction depletes the regional timber resource, and to appraise the suitability of nominated stands for providing future supplies of green-cut fuelwood. The most appropriate parameter in ecology and plant sociology is population density, which conveys an absolute measure of the number of individuals per unit area. In forest sampling, 'total number of stems per unit area' is an imperfect expression of stand density because it fails to account for the wide variation in form, size and age of trees in a population (Loetsch *et al.*

1973). This problem is countered by sampling within pre-determined 'cover classes' or 'forest types' and for each type, sampling within a set of species and diameter classes. Basal area is a measure of the cross-sectional area of timber at breast height per unit area of forest, usually expressed in $m^2.ha^{-1}$. It is more useful for generating an index of stand productivity because timber biomass and basal area are positively correlated. The combined use of density and basal area provides an indication of average tree diameter, a useful criterion in the appraisal of stands for fuelwood silviculture.

Plotless sampling

Contrary to conventional sampling procedures in which plots or quadrats are used to assess forest stand parameters, plotless sampling includes a set of techniques which does not use predefined plots (Loetsch *et al.* 1973). Plotless sampling enables a more rapid assessment of stand density across large study regions and avoids the practical difficulties of delineating sample plots. Two plotless sampling techniques were employed in this study to estimate forest stand density. The point-centred quarter method was used in the early phase of forest inventory to determine absolute and relative tree densities for the five cover classes (Table 4.1, Figure 4.1). A more effective method, the horizontal point sampling or Bitterlich sampling method, was subsequently adopted for inventory in closed and open forests. It enabled more rapid measurement of many trees across a larger area of the stand, and was important for the subsequent calculation of tree density for each species within a number of DBH classes.

Point-centred quarter method

The point-centred quarter method (Cottam and Curtis 1956) involves measuring the distance from a sampling point to the nearest tree in each of four quadrants extending from that point (Greig-Smith 1983; Goldsmith *et al.* 1986) (Figure 4.2). Of all distance methods, it is considered the most efficient and has gained widespread acceptance, providing information on species frequency, dominance and density (Mueller-Dombois and Ellenberg 1974).

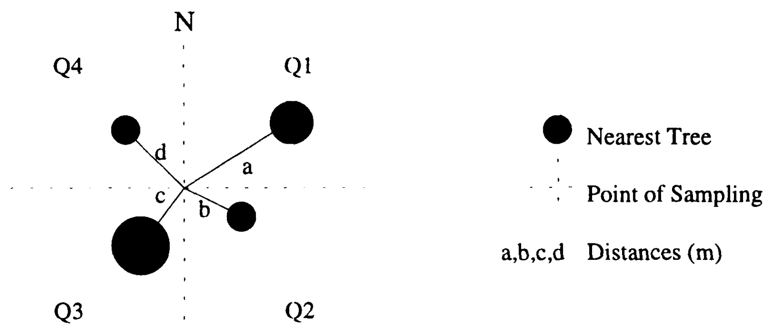


Figure 4.2. Distances measured using the point-centred quarter method.

As depicted in Figure 4.2, a,b,c and d are the distances from the point of sampling to the closest tree in each quadrant. When the four distances are averaged then squared, the outcome is equal to the mean area occupied by each tree (Mueller-Dombois and Ellenberg 1974). Overall stand density is estimated using the following relationship:

$$D = 10000 \cdot \left(\frac{\sum_{p=1}^{n} (a+b+c+d)}{4 \cdot n} \right)^{-2} = 10000 \cdot \left(\frac{\sum_{p=1}^{n} (r)}{4 \cdot n} \right)^{-2} \qquad 4.1$$

where D = density (stems.ha^{-1})
Σr = sum of all distances for all points
n = number of sampling points
(note: $\Sigma r/4n$ = mean distance)

Calculation of D in this manner affords no indication of the size distribution of trees within the stand and is of little silvicultural value. Stand basal area (BA) is more useful for estimating stand volume, and if used in conjunction with D, can provide key information on stand structure. If the area of a plane passing through the stem of a tree at right angles to its longitudinal axis is defined as its cross-sectional area (Husch *et al.* 1972), basal area is simply the sum of all tree cross-sectional areas (m^2 at overbark DBH height) per hectare. Mean BA can be calculated from point-centred sampling as follows:

$$\overline{BA} = \frac{\pi \cdot \sum_{t=1}^{4n} (DBH_t)^2}{4 \cdot \sum_{t=1}^{4n} (r_t)^2} \qquad 4.2$$

where t = number of trees
n = number of sampling points
r = distance to tree
DBH = overbark diameter at breast height (cm) of tree

Stands of native vegetation in TSRs and state forests within 50 km of Armidale were chosen for point-centred quarter sampling. A proportionately high intensity of fuelwood extraction occurs in these areas, particularly in the larger reserves. A total of 288 potential sites were located within the study region, of which 72 sites (25%) were selected at random for sampling (Figure 2.1). Each site was assigned a cover class using 1:25 000 colour aerial photographs (Table 4.2).

A 200 x 20 m transect was laid out at each site, within which point-centred quarter sampling was conducted at five points located at 50 m intervals (Figure 4.3). A total of 20 trees was sampled at each site. This ensured that enough data were collected to analyse stand density and basal area after pooling the site data of each cover class (Table 4.2). Orientation of quadrants at each point was fixed using magnetic north such that Q1, Q2, Q3 and Q4 subtended 0-90°, 90-180°, 180-270° and 270-360°, respectively (Figure 4.2). Distance to the nearest tree in each quadrant was measured, tree species recorded, and allometric parameters DBH, HT and CNVOL measured (section 3.2.2). Trees under 5 m height were not recorded and trees on the border of two quadrants were allocated to the left hand quadrant. Saplings and stumps were counted and classified within the transect at each site (sections 6.2.1 and 6.2.2).

Table 4.2. Number of sites, points and trees sampled within each cover class using point-centred quarter sampling.

Cover class	Sites (Figure 2.1)	Total sites	Total points	Total trees
closed forest	2,76,83,84,95,103	6	30	120
open forest	6,7,12,15,21,28,31,33,34,35, 52,63,66,67,77,78,101,108,110	19	95	380
woodland	1,4,14,22,23,25,32,36,38, 39,40,51,53,56,57,58,59,68,69, 82,87,96,97,105,106,107,109,123	28	140	560
scattered trees	24,37,46,47,48,49,54, 55,62,70,71,72,73,81,88,93	16	80	320
isolated trees	50,86,89	3	15	60
		72	360	1440

Note : Sites 76,77,78,83 and 84 in state forest.
All other sites in TSR.

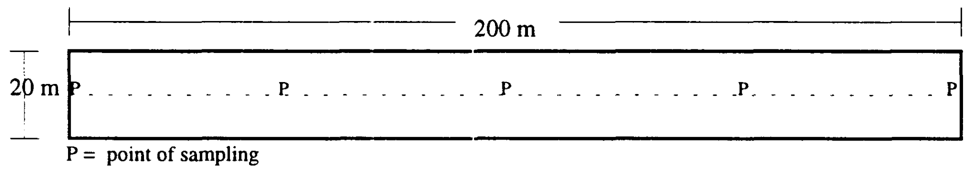


Figure 4.3. A 200 x 20 m transect (public forest sites).

Horizontal point sampling method

Horizontal sampling was developed in 1948 by Walter Bitterlich and is widely used in forest inventory. Unlike point-centred sampling, the basal area information generated using the Bitterlich method enables stands to be classified in terms of species and diameter class. Used in conjunction with volume and yield tables, the data are useful for determining the structure and age-class of natural stands. The procedure is simple. From any point a 360° horizontal 'sweep' is made in which trees that exceed a critical angle at DBH cross-section are tallied (Figure 4.4). The probability of tallying a given tree depends on its DBH, its distance from the sample point, and the sighting angle used (Avery 1975).

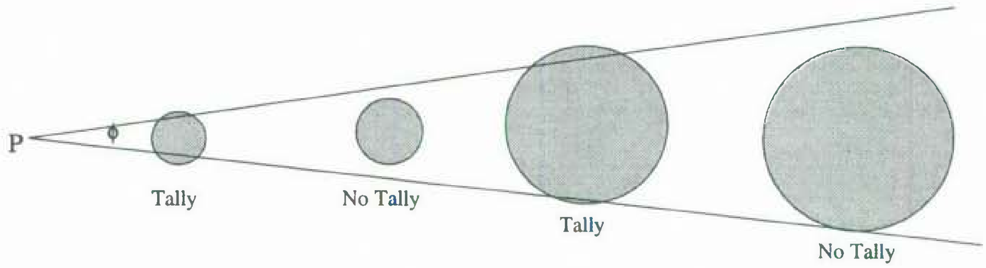


Figure 4.4. Dependence of tree tallying (based on stem DBH) on critical angle (ϕ).

The tree count for a sample point is subsequently multiplied by a pre-determined basal area factor (BAF) to determine the basal area ($m^2.ha^{-1}$) of the stand. Selection of the BAF depends principally on initial appraisal of stand density. A low BAF, say 1.0 (represented by a small critical angle, ϕ = 1°08'45") is recommended in stands of relatively low density whereas a high BAF, say 10 (ϕ = 3°37'37") should be applied to high density forests. The theory and practice of horizontal point sampling is discussed at length by Mueller-Dombois and Ellenberg (1974), Husch *et al.* (1972), Loetsch *et al.* (1973) and Avery (1975), and is outlined in Appendix XX.

API was used to select accessible stands of closed and open forest containing at least 9 ha of continuous canopy cover within the study region. Other cover classes (woodland, scattered and isolated trees) were adequately sampled using the point-centred quarter method. Some 200 potential sites were located on maps and aerial photographs (90% dominated by stringybark), of which 51 (~ 25%) were selected for horizontal sampling (Figure 2.1). Sites were selected with the proviso that each species-SQ class (Table 4.3) was represented as best as possible within the constraints of stand accessibility and travel and time costs of survey. No stringybark open forest in SQ4 was located for sampling, and little closed forest ironbark was available. Continuous stands of box-gum forest were also infrequent, with sites 26 and 27 containing some of the best forest of this type in the study region. Sites were visited in 1993-94 for Bitterlich sampling. A BAF of 1 was selected for the low density forest in the central and western parts of the study region, in which each tallied tree represented 1 $m^2.ha^{-1}$ basal area of surrounding forest. A BAF of 2 was used for some heavily timbered sites in State Forest, particularly in the east, in which each tallied tree represented 2 $m^2.ha^{-1}$. Sample points were located at 100 m intervals within the stand. The number of points and trees sampled within sites of similar character are listed in Table 4.3.

A wedge prism was used to tally tree stems. This is a tapered wedge of glass or perspex that deflects light rays at a specific offset angle (Loetsch *et al.* 1973; Avery 1975), in this case about 68' (BAF1) or 97' (BAF2). When a vertical portion of bole at DBH height was viewed through the prism, it was displaced to one side. If the displacement was complete, then the stem was not counted by virtue of its distance : DBH ratio being greater than 50 (BAF1) or 35.5 (BAF2). If the displacement was not complete (where image and upper and lower intact portions of the stem touched or overlapped), the stem was tallied. Every stem

Table 4.3. Number of sites, points and trees sampled in closed and open forest of various species-SQ classes using the Bitterlich method.

Cover class	Species	SQ	Sites (Figures 2.2 and 2.4)	Total sites	Total points	Total trees
closed forest	SB	1-2-3	64,113,114,115,121,122	6	148	3285
		4	60,61,111,112,118,119,120	7	210	3400
		5-6-7	29,30,42,43,79,85,91,99,100	9	177	4582
	IB	7	17,18	2	32	656
	B-G	6	44	1	9	175
			Total for closed forest	25	576	12 098
open forest	SB	1	116,117	2	66	834
		5-6-7	41,45,65,74,75,80,94,98,102,104	10	176	3388
	IB	6-7	3,5,8,9,10,11,13,16,19,20	10	206	3163
	B-G	6-7	26,27	2	26	461
	light	6	90,92	2	18	404
			Total for open forest	26	492	8250
			Grand Total	**51**	**1068**	**20 348**

Sites in state forest = 60,61,79,80,85,99,115,116,117,118,119,120,121,122; Sites in TSR = 3,9,13,17,20,26,27; All other sites on private land.

not entirely displaced from its vertical alignment when viewed through the wedge prism was counted within a 360° sweep around each sampling point, yielding an estimation of basal area for that point in the stand (basal area ($m^2.ha^{-1}$) = 1 * no.counts for BAF1 and 2 * no.counts for BAF2). The DBH of every tallied stem was measured using a diameter tape and its individual basal area ($BA_t = m^2.ha^{-1}$) and density ($d = stems.ha^{-1}$) were calculated using the respective expressions :

$$BA_t = \frac{\pi \cdot (DBH_t)^2}{40000} \quad \text{.......... 4.3}$$

$$d = \frac{BAF}{BA_t} \quad \text{.......... 4.4}$$

From equations 4.3 and 4.4, total stand density (D) was calculated to be :

$$D = \sum_{i=1}^{n} \sum_{j=1}^{s} \left(\frac{d_{ij}}{n} \right)$$

$$\text{or } D = \sum_{i=1}^{n} \sum_{j=1}^{s} \left(\frac{40000 \cdot BAF}{\pi \cdot n \cdot (DBH_{ij})^2} \right) = \frac{40000 \cdot BAF}{\pi \cdot n} \cdot \sum_{i=1}^{n} \sum_{j=1}^{s} \left(\frac{1}{(DBH_{ij})^2} \right) \quad \text{.......... 4.5}$$

where
- D = tree density ($stems.ha^{-1}$)
- d ij = density of tree 'j' at point 'i'
- n = number of points
- s = number of sample trees at point 'i'
- BAF = basal area factor
- (DBHij) = diameter of tree 'j' at point 'i'

Stand composition and stand classes

Stand composition is a measure of the tree species present and the DBH classes into which they are distributed. Tree data collected from all Bitterlich sites in closed and open forest and all point-centred quarter sites in woodland and stands of scattered and isolated trees were pooled into stand classes according to tree association, cover class, site quality and land tenure (Table 4.4). Data obtained from point-centred quarter sampling in closed and open forest was excluded from analysis due to insufficient data within stand classes. A composite value of basal area and stand density within each stand class was calculated for live and dead trees of the following species or species groups and DBH classes :

stringybark-blackbutt, yellow box, red gum, red ironbark, grey-white box, 'light' species (e.g. white gum, black sallee), acacia species (live and dead), casuarina species (live and dead)

5-15 15.5-25 25.5-35 35.5-45 45.5-55 55.5-75 75.5-105 > 105

4.2.3. Stand biomass

The relative contribution of each species to the total standing dry-weight of timber and bark within each of the stand classes listed in Table 4.4 was estimated by applying dry-weight functions derived in Chapter 3 to species-DBH data collected during field sampling. The standing weight of timber and bark of every sampled fuelwood tree (not including 'light' species, acacia or casuarina) was calculated separately by applying the DBH data to the species-specific dry-weight equation. The cumulative dry-weight of each species was partitioned into tree diameter classes, and an estimate of dry timber and bark biomass within each diameter class for each fuelwood species made on a per hectare basis. The estimate was refined to include the dry-weight of fuelwood-sized billets 5 to 55 cm diameter within trees greater than 15 cm DBH. This involved the omission of weights calculated for trees < 15 cm DBH and the omission of stem weights calculated in trees > 55 cm DBH. An estimate of the total standing woody biomass of all species (including non-fuelwood species) was derived by assuming that a 'light' species weighed about 60% of a fuelwood species for a given DBH.

Table 4.4. Stand classes within which composite and total stand basal area and density were calculated.

Stand class				No. sites				
Species	Type	Site-quality	Land tenure/location	HS [1]	PCQS [2]	No.points	No.trees	Sites Numbers
Stringybark	Closed forest	1	Styx River State Forest	1	-	30	405	115
		2-3-4	Winterbourne State Forest	4	-	120	2211	119,120,121,122
		4	Enmore State Forest	1	-	30	407	118
		4	Boorolong State Forest	2	-	60	1087	60,61
		5	Avondale State Forest	1	-	35	1139	99
		6	Eastwood State Forest	1	-	50	1113	85
		6	Hillgrove Creek State Forest	1	-	29	532	79
		3-4	Freehold; nr Hillgrove and 10km n.Armidale	5	-	98	2575	64,111,112,113,114
		5	Freehold; 15 km s.w.Uralla	2	-	29	928	29,30
		6	Freehold; 15 km w.Armidale	2	-	19	571	42,43
		6-7	Freehold; 20 km s.e.Uralla & 35 km n.e.Armidale	2		15	298	91,100
	Open forest	1	Styx River State Forest (post-logging)	2	-	66	834	116,117
		5-6-7	Freehold; various locations	10	-	174	3379	41,45,65,74,75,80,94,98,102,104
	Woodland	3-6	TSR; various locations	-	5	25	100	32,69,87,105,106
Ironbark	Closed & open forest	6-7	TSR and Freehold; various locations nr. Bundarra	12	-	238	3819	3,5,8,9,10,11,13,16,17,18,19,20
Box-gum	Closed & open forest	6-7	Freehold 10 km w.Armidale; TSR 30 km w.Uralla	3	-	35	636	26,27,44
	Woodland	5-6-7	TSR; various locations	-	14	70	280	1,4,14,22,23,25,38,39,40,68,82,107,109,123
Box-gum & 'light'	Scattered trees	4-5-6-7	TSR; various locations	-	16	80	320	24,37,46,47,48,49,54,55,62,70,71,72,73,81,88,93
'light' timber	Open forest	6-7	Freehold; 20 km s.e.Uralla	2	-	18	404	90,92
	Woodland	3-4-5-6	TSR; various locations	-	9	45	180	36,51,53,56,57,58,59,96,97
	Isolated	6	TSR; 15-40 km s.w.Armidale	-	3	15	60	50,86,89
				51	47	1281	21278	

1. horizontal sampling
2. point-centred quarter sampling only

4.3. Results

4.3.1. Basal area, density and stand composition

Eucalypt stands in the study region comprised trees of various species and diameters, and are identified as uneven-aged, mixed-species forests. A value of stand basal area ($m^2.ha^{-1}$) and stand density ($stems.ha^{-1}$) was calculated from forest inventory data collected at each site (Appendix XXI) and within each stand class listed in Table 4.4 (Appendix XXII). The latter includes estimates within each species-diameter class (e.g. stringybark, 35-45 cm DBH). Table 4.5 lists characteristics of stands of different site quality, cover class and dominant species and Figures 4.5, 4.6 and 4.7 illustrate the effects of site quality and cover class on stand density, basal area and average tree DBH respectively. Photographs of various cover class and forest types are shown in Plates 4.1 to 4.6.

Site quality was the most influential factor on stand basal area and density within any cover class (Figures 4.5 and 4.6). Of the closed forest systems, Styx River State Forest (SQ1) contained the highest basal area (40.5 $m^2.ha^{-1}$), representing over 850 $stems.ha^{-1}$, and Hillgrove Creek State Forest (SQ6) contained the lowest basal area (18.3 $m^2.ha^{-1}$), with just over 250 $trees.ha^{-1}$. Stand composition had little effect on stand basal area in areas of similar site quality, although values of tree density were observed to vary in some instances. Ironbark and box-gum forest had similar basal areas (16.2 and 18.2 $m^2.ha^{-1}$ respectively), with respective densities of about 300 and 400 $stems.ha^{-1}$. Open forest on private land dominated by stringybark had a similar basal area and density to that dominated by 'light' species (19.3 vs. 22.5 $m^2.ha^{-1}$ and 461 vs. 426 $stems.ha^{-1}$, respectively). There was little difference in basal area between stringybark, 'light' and box-gum woodland (3.1, 3.9 and 4.3 $m^2.ha^{-1}$ respectively). However, the density of stringybark woodland (26 $stems.ha^{-1}$) was markedly less than that of 'light' and box-gum woodland (83 and 82 $stems.ha^{-1}$, respectively). This reflects a predominance of mature to over-mature trees in the former (Figures 4.6 and 4.7), suggesting that the box-gum and 'light' stands have a better regenerative capacity or the smaller trees in stringybark stands are prone to extraction for fencing and possibly fuel timber. Average DBH was higher in stands of scattered and isolated trees (Figure 4.7). This possibly reflects a low rate of natural tree recruitment due to an increased rate of grazing by domestic stock.

Table 4.5. Estimates of basal area, density and average DBH for eucalypt stands in southern New England.

Species	Type	SQ	n [1]	BA ($m^2.ha^{-1}$)	Dens.($n.ha^{-1}$)	Av.DBH (cm)
Stringybark	Closed forest	1	30	40.5 ± 1.4	865.3 ± 141.8	24.4 ± 4.8
		2-3-4	120	37.1 ± 0.9	990.7 ± 104.8	21.8 ± 2.8
		4	30	27.2 ± 1.3	623.0 ± 68.3	23.6 ± 3.7
		4	60	36.2 ± 1.3	645.0 ± 68.2	25.7 ± 3.6
		5	35	32.6 ± 1.2	696.7 ± 73.3	24.4 ± 3.5
		6	50	22.3 ± 0.7	496.4 ± 46.7	23.9 ± 3.0
		6	29	18.3 ± 0.9	251.5 ± 36.7	30.4 ± 5.9
		3-4	98	26.4 ± 0.8	727.5 ± 76.0	21.5 ± 2.9
		5	29	32.0 ± 1.5	708.2 ± 97.8	24.0 ± 4.4
		6	19	30.2 ± 1.7	334.9 ± 62.3	33.9 ± 8.2
		6-7	15	19.9 ± 2.2	514.6 ± 111.6	22.2 ± 7.3
	Open forest	1	66	25.3 ± 1.1	410.6 ± 57.3	28.0 ± 5.1
		5-6-7	174	19.3 ± 0.6	461.2 ± 38.1	23.1 ± 2.6
	Woodland	3-6	25	3.1 ± 0.6	25.5 ± 5.2	39.3 ± 15.6
Ironbark	Closed & open forest	6-7	238	16.2 ± 0.4	294.9 ± 18.9	26.4 ± 2.3
Box/gum	Closed & open forest	6-7	35	18.2 ± 0.8	399.0 ± 50.1	24.1 ± 4.1
	Woodland	5-6-7	70	4.3 ± 0.9	81.7 ± 22.1	25.9 ± 12.4
Box-gum & 'light'	Scattered trees	4-5-6-7	80	1.0 ± 0.2	7.6 ± 1.6	40.9 ± 14.3
'light' timber	Open forest	6-7	18	22.5 ± 1.5	426.0 ± 76.6	25.9 ± 6.4
	Woodland	3-4-5-6	45	3.9 ± 0.7	82.8 ± 45.9	24.5 ± 18.2
	Isolated	6	15	0.3 ± 0.04	2.2 ± 0.53	41.7 ± 16.1

1. n = sample size = number of points for point-centre quarter and Bitterlich sampling
(note: site numbers are listed in Table 4.4)

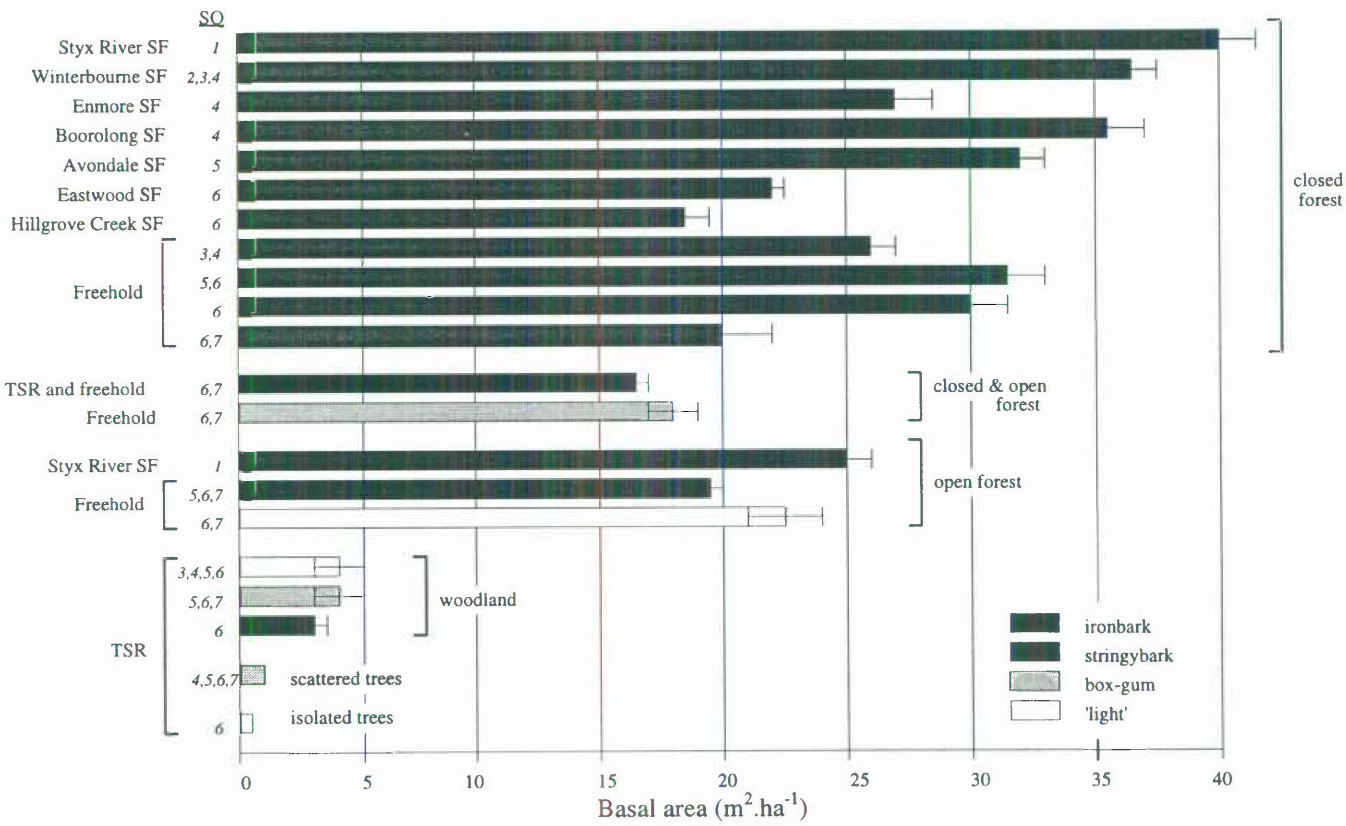


Figure 4.5. The effect of forest type, tree association and site quality on basal area of stands in southern New England.

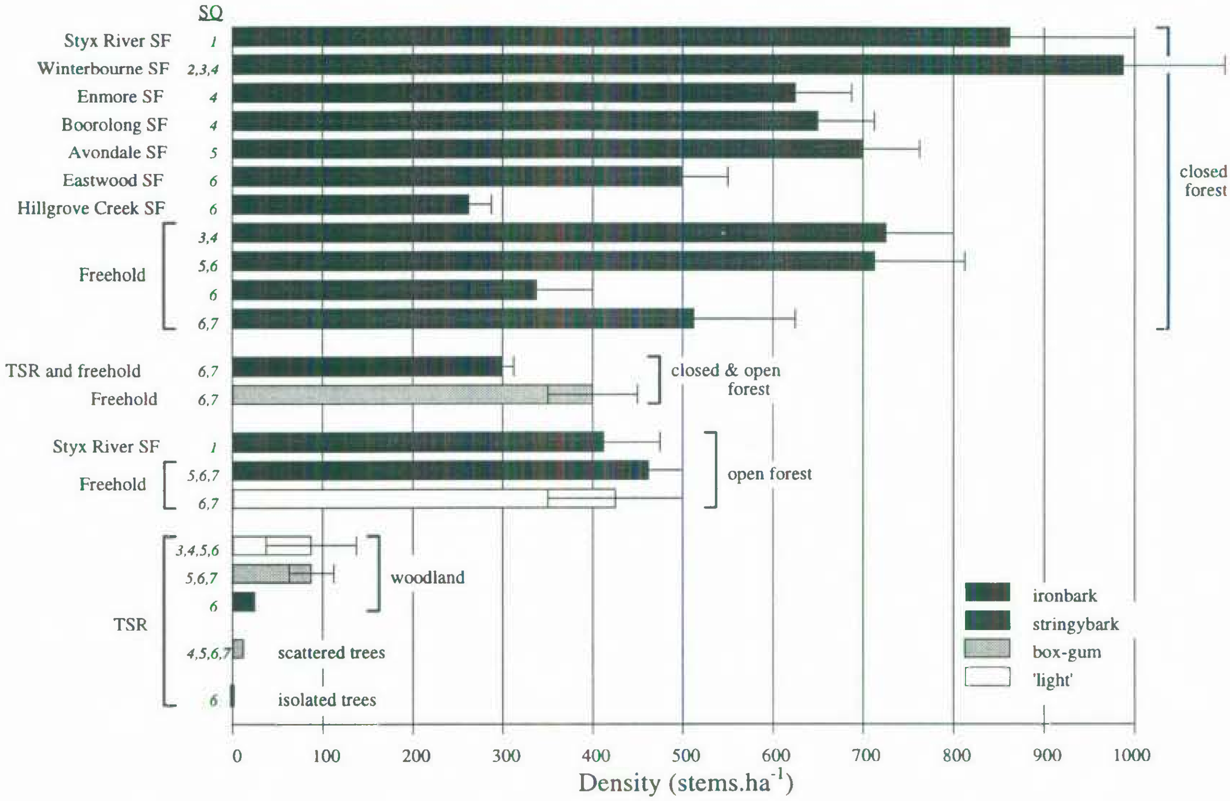


Figure 4.6. The effect of forest type, tree association and site quality on density of stands in southern New England.

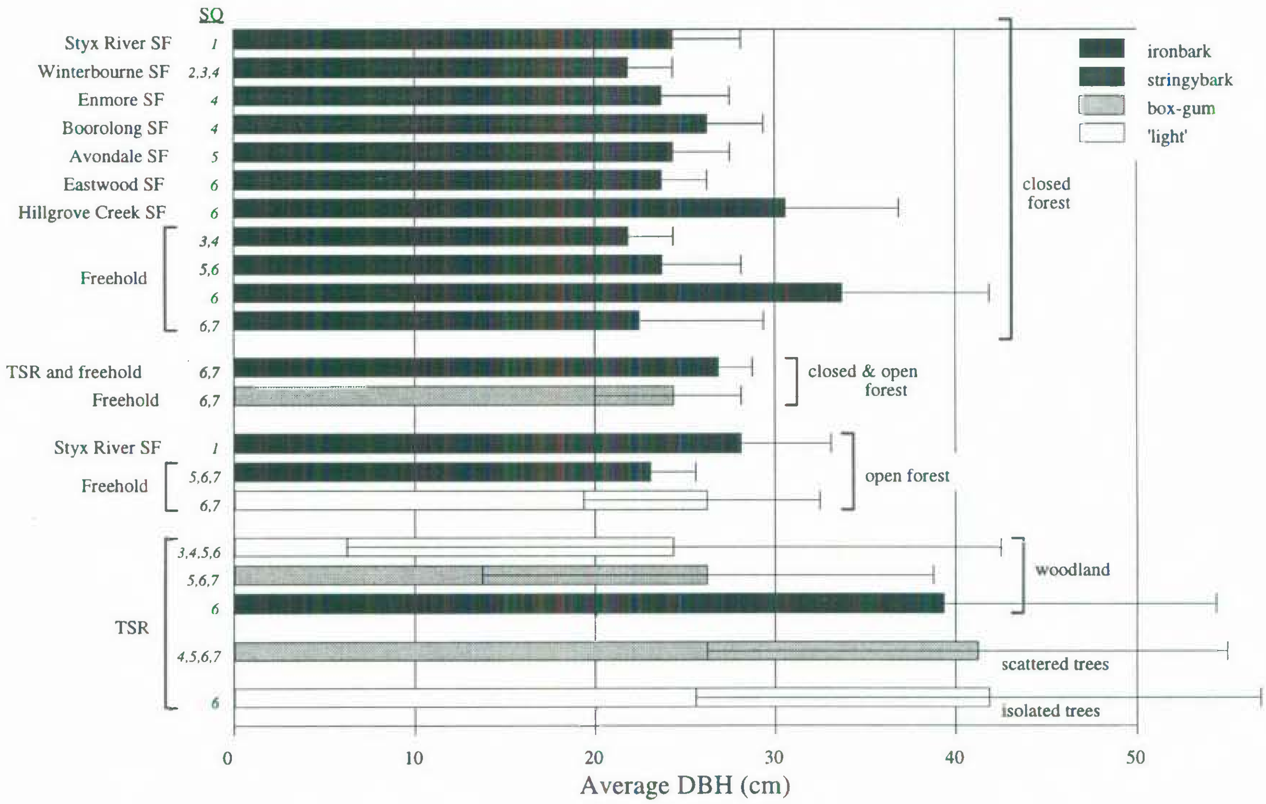


Figure 4.7. The effect of forest type, tree association and site quality on the average DBH of stands in southern New England.

Plate 4.1. Paddock of scattered trees dominated by *Eucalyptus caliginosa* (near site 99).

Plate 4.2. Eucalypt woodland dominated by *E. caliginosa* (near site 45).

Plate 4.3. Stringybark open forest dominated by *E. caliginosa* (Avondale State Forest - site 99).

Plate 4.4. Closed forest dominated by *E. laevopinea - E. andrewsii* (Boorolong State Forest - site 60).

Plate 4.5. Open forest dominated by *E. melliodora* and *E. blakelyi* (site 27).

Plate 4.6. Open forest dominated by *E. viminalis* (site 92).

4.3.2. Stand biomass

Standing biomass was calculated by applying dry-weight expressions (Chapter 3) to stand density and composition data (Appendix XXII). Table 4.6 provides three measures of air-dry fuelwood biomass in terms of t.ha^{-1} measured to a minimum of 5 cm diameter:

i. total biomass: all woody components of all green and standing dead trees.

ii. total fuelwood biomass: all woody components of all standing fuelwood species (stringybark, yellow box, red gum, ironbark, grey box).

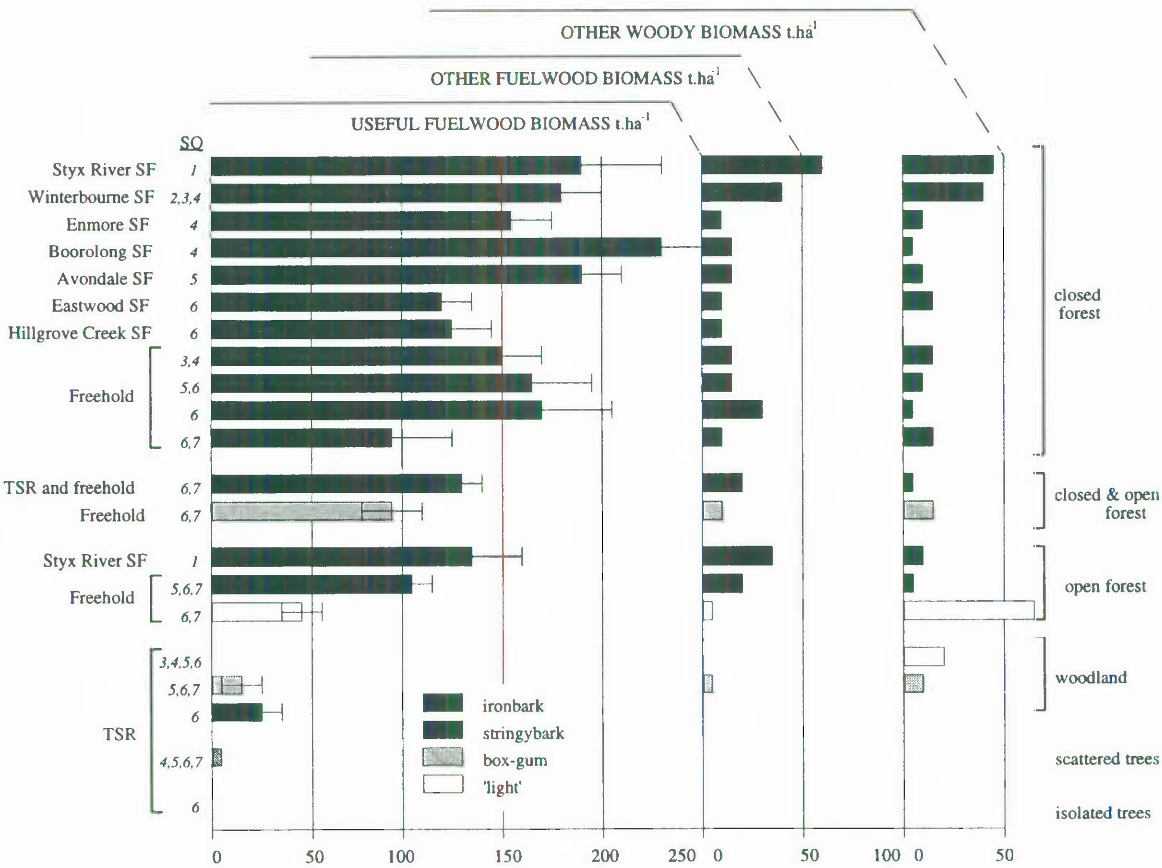
iii. useful fuelwood biomass: the wood of all dead standing trees of fuelwood species to 55 cm DBH, and the wood and bark of all stems and branches (diameter 5 to 55 cm) of all green trees of fuelwood species greater than 15 cm DBH (does not include dead fallen timber).

Table 4.6. Estimates of total standing, total fuelwood, and useful fuelwood biomass of eucalypt stands in southern New England.

				Biomass (t.ha^{-1}) [2]		
Species	Type	SQ	n [1]	Est.Tot. [3]	Fuel [4]	Useful Fuel [5]
Stringybark	Closed forest	1	30	296.6 ± 58.3	249.5 ± 49.1	187.5 ± 37.9
		2-3-4	120	256.0 ± 33.3	216.8 ± 28.2	178.9 ± 23.3
		4	30	171.8 ± 27.0	161.6 ± 25.4	153.8 ± 24.2
		4	60	248.8 ± 35.2	246.6 ± 34.9	232.3 ± 32.9
		5	35	213.3 ± 30.3	203.3 ± 28.9	188.7 ± 26.8
		6	50	143.2 ± 18.0	126.2 ± 15.9	120.0 ± 15.1
		6	29	136.8 ± 26.7	135.4 ± 26.5	127.5 ± 24.9
		3-4	98	181.4 ± 24.4	165.3 ± 22.3	149.5 ± 20.2
		5	29	187.2 ± 34.6	177.3 ± 32.8	162.7 ± 30.1
		6	19	201.6 ± 48.8	196.3 ± 47.5	167.4 ± 40.5
		6-7	15	119.3 ± 39.1	106.6 ± 34.9	95.4 ± 31.2
	Open forest	1	66	173.0 ± 31.7	167.4 ± 30.6	130.9 ± 24.0
		5-6-7	174	124.6 ± 14.2	119.7 ± 13.6	103.1 ± 11.7
	Woodland	3-6	25	23.5 ± 9.3	23.4 ± 9.3	22.7 ± 9.0
Ironbark	Closed & open forest	6-7	238	152.6 ± 13.6	150.7 ± 13.4	132.3 ± 11.7
Box/gum	Closed & open forest	6-7	35	120.5 ± 20.4	105.4 ± 17.9	92.6 ± 15.7
	Woodland	5-6-7	70	28.7 ± 13.8	19.7 ± 9.5	16.4 ± 7.8
Box/gum & 'light'	Scattered trees	4-5-6-7	80	6.8 ± 2.4	5.4 ± 1.9	4.5 ± 1.6
'light' timber	Open forest	6-7	18	114.0 ± 28.1	50.9 ± 12.5	45.1 ± 11.1
	Woodland	3-4-5-6	45	19.8 ± 14.7	0	0
	Isolated	6	15	1.4 ± 0.54	0.4 ± 0.15	0.2 ± 0.08

1. n = sample size = number of points for point-centred quarter and Bitterlich sampling (note: site numbers are listed in Table 4.4).
2. Above-stump dry-weight of timber/bark sections ≥ 5 cm diameter (ob). The standard error of basal area, as a percentage of basal area, was used to generate standard errors for biomass variables in the above table - these errors encompass the predictive errors associated with regression functions.
3. Includes all species, where density of 'light' species ≈ 60% density of fuelwood species.
4. Includes all fuelwood species.
5. Includes 'useable' portion of fuelwood trees (i.e. diameters 5-55 cm).

The results presented in Table 4.6 are depicted in Figure 4.8 as the relative contribution of useful fuelwood biomass to total biomass. Of the stringybark forest stands, the better quality Styx River and Winterbourne State Forests contain a proportionally greater quantity of non-useful fuelwood (i.e. that harboured in large stems and non-premium species), such that the overall quantity of useful fuelwood is only marginally greater than that found in lower quality stringybark sites which contain a higher proportion of target-sized trees (15-55 cm DBH). Enmore State Forest contains a relatively small quantity of biomass for eastern state forests as a result of recent logging. The lower quality Eastwood and Hillgrove Creek State Forests each contain about 125 $t.ha^{-1}$. They are the nearest forests to Armidale and are used by the local community for recreation and licensed fuelwood and fencewood acquisition. Boorolong and Avondale State Forests contain a relatively high biomass, especially the former, which is only 15 minutes drive from Armidale. Both require landholder permission for access via private land.



note: the percentage error of any value of USEFUL FUELWOOD BIOMASS (the standard error as a proportion of the given value) is equal to the percentage error of the corresponding values of OTHER FUELWOOD BIOMASS and OTHER WOODY BIOMASS for which error bars are not included.

Figure 4.8. Contribution of useful fuelwood, other fuelwood and other biomass to total standing woody biomass in eucalypt stands in southern New England.

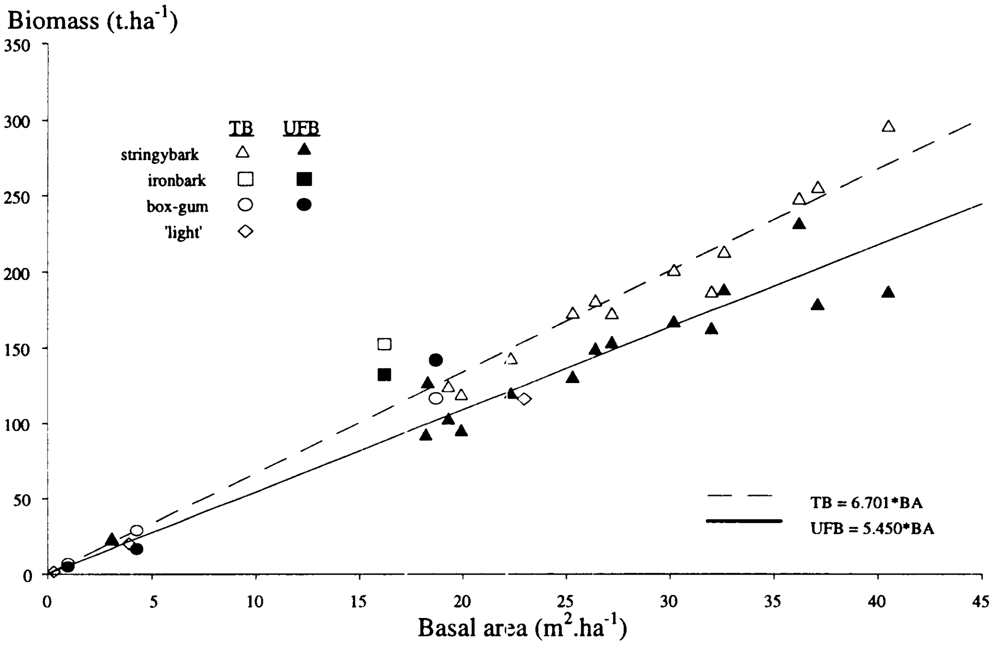
Useful fuelwood biomass comprises over 80% of total biomass in stringybark, ironbark and box-gum stands on private land, indicating the potential for private forest to play a pivotal role in sustainable fuelwood production. Box-gum forests contain about the same fuelwood biomass as stringybark forests on private land in SQ6-7 areas (92.6 vs. 95.4 $t.ha^{-1}$); ironbark forests contain significantly more (132.3 $t.ha^{-1}$). Woodland contains little fuelwood compared with open and closed forest. Stringybark and box-gum woodland contain 22.7 and 16.4 $t.ha^{-1}$ respectively, less than 25% of the fuelwood biomass contained in corresponding stringybark and box-gum forest.

4.4. Discussion

4.4.1. Interpretation of forest inventory

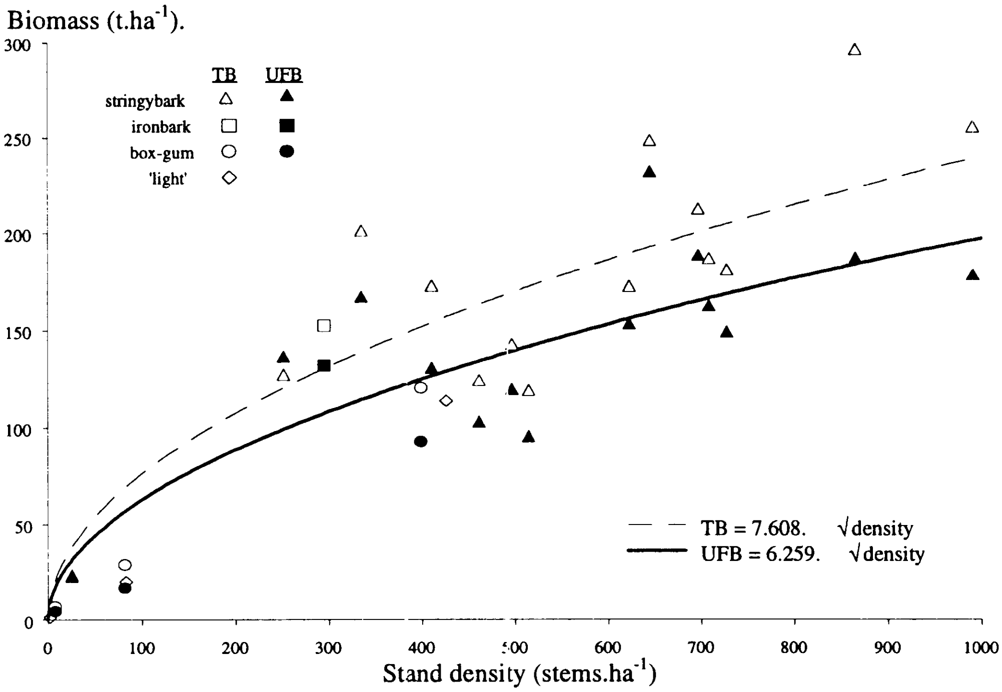
The biomass of stems and branches in New England forest stands (to a minimum end diameter of 5 cm) ranges from 114 $t.ha^{-1}$ in open forest dominated by 'light' species (*E. viminalis, E. pauciflora, E. nova-anglica*) to almost 300 $t.ha^{-1}$ in high quality stringybark-blackbutt closed forest in Styx River State Forest. Large differences in forest biomass have been observed between other eucalypt stands in Australia (Feller 1980; Birk and Turner 1992), and are influenced primarily by the effect of site quality on stand density and basal area. The biomass of individual trees of different eucalypt species within a stand is not a function of site quality, however, since yellow box and ironbark trees on the western slopes contain significantly more biomass than stringybarks of similar DBH in other parts of the region (Chapter 3).

The influence of basal area and density on standing fuelwood biomass is summarised by linear regressions in Figures 4.9 and 4.10. Biomass and basal area are linearly related, with each 1.0 $m^2.ha^{-1}$ basal area increment providing an average 5.45 $t.ha^{-1}$ additional fuelwood biomass. Biomass and stand density are non-linearly related by the square-root transformation, in which dry-weight increment of eucalypt stands decreases as stocking density increases. A stand with 1000 $stems.ha^{-1}$ contains twice the biomass (~ 200 $t.ha^{-1}$) of a stand with 250 $stems.ha^{-1}$. This relationship reflects the influence of stand density on average stand DBH. Woodland and scattered stands comprise a high proportion of large trees (Figure 4.6), each of which contributes greatly to stand biomass. Closed forest contains a larger proportion of smaller trees, each contributing little to overall biomass. Figures 4.9 and 4.10 are useful in estimating rapidly from measurements of forest basal area or stand density the total biomass (TB) of eucalypt stands in the study region, including those dominated by 'light' species, and the useful fuelwood biomass (UFB) of stands dominated by premium fuelwood species.



	Coeff. of BA	n	r^2 value	SE estimate
TB	6.701 ± 0 149	21	0.990	16.464 t.ha^{-1}
UFB	5.450 ± 0 178	18	0.982	19.193 t.ha^{-1}

Figure 4.9. Influence of basal area on total biomass (TB) and useful fuelwood biomass (UFB) in native eucalypt stands in southern New England.



	Coeff. of √Density	n	r^2 value	SE estimate
TB	7.608 ± 0.389	21	0.950	36.977 t.ha^{-1}
UFB	6.259 ± 0.346	18	0.951	31.923 t.ha^{-1}

Figure 4.10. Influence of stand density on total biomass (TB) and useful fuelwood biomass (UFB) in native eucalypt stands in southern New England.

4.4.2. Comparison with other biomass literature

Several intensive studies on biomass apportionment and nutrient cycling in mixed eucalypt forests have been conducted in the last two decades, particularly in coastal and montane stands in south-eastern Australia. A comparison of results serves to illustrate the influence of site factors on the above ground biomass of forest ecosystems. Baker and Attiwill (1985) contrasted the biomass of two adjacent stands of *E. obliqua* forest in Victoria's Gippsland. Both had similar values of basal area (53.0 and 48.6 $m^2.ha^{-1}$) and tree density (320 and 490 $stems.ha^{-1}$), yet values of above ground biomass were 401 and 255 $t.ha^{-1}$, respectively. The discrepancy was attributed to mean dominant tree height (40 vs. 25 m) as dictated by soil type. MAR was 1000 $mm.yr^{-1}$ in each stand. In *E. obliqua* forest in Victoria (basal area 57.6 $m^2.ha^{-1}$) (Attiwill 1979,1980), *E. muellerana* mixed forest in Victoria (basal area 54.3 $m^2.ha^{-1}$) (Turner *et al.* 1992) and old-growth *E. pilularis* forest on Fraser Island (basal area 68 $m^2.ha^{-1}$) (Applegate 1982), above-ground biomass was determined at 298, 670 and 1784 $t.ha^{-1}$, respectively. MAR in each study was 1000, 940 and 1500 $mm.yr^{-1}$, respectively, suggesting that factors other than rainfall such as soil and forest history influenced stand biomass.

The above examples concern forests with basal areas much higher than those in southern New England, and cannot realistically be compared with local data. A number of other studies, however, include assessment of stands of similar basal area, affording between-region comparisons (Table 4.7).

Table 4.7. Comparison of biomass of mixed eucalypt forests in southern New England with biomass of mixed eucalypt forests of similar basal area in eastern Australia.

Species	Source	BA [1]	Biomass [2]	Local biomass [3]
E. muellerana / E. agglomerata	Stewart *et al.* 1979,1990	30.1	326	202
E. muellerana / E. consideniana	Turner *et al.* 1992	22.0	176	147
E. sieberi / mixed	Turner *et al.* 1992	40.6	375	272
E. dives / E. rubida	Lambert 1979 cited Birk and Turner 1992	16.0	71	107
E. rossii / E. rubida	Lambert 1979 cited Birk and Turner 1992	10.2	62	68

1. $m^2.ha^{-1}$
2. $t.ha^{-1}$
3. from New England Total Biomass function (Figure 4.9)

Montane forest stands dominated by *E. muellerana* and *E. sieberi* contain more biomass per unit basal area than stands in the study region. In contrast, stands co-dominated by *E. rubida* contain similar or less biomass than local stands. This species (and *E .dives* and *E. rossii*) is typically associated with forest and woodland of the Central and Southern Tablelands. The comparisons suggest that montane forests produce more biomass per unit basal area than high altitude, colder, and often drier tableland forests. Stand dominant height is probably the most influential factor with respect to fuelwood biomass.

In Chapter 3, weight tables generated for a eucalypt species in one area were applied to the same species in another area where site quality differences impacted relatively little on standing dry-weight of individual trees of similar DBH. The application of New England basal area and density charts (Figures 4.9 and 4.10) to forest stands in other regions, however, is ill-advised, given the variability in forest biomass due to site variation.

4.4.3. Standing energy

Assuming an urban cost of \$60 t^{-1}, the standing gross fuelwood value of a forest stand of 25 m^2ha^{-1} basal area (stand density ~ 475 $stems.ha^{-1}$; mean DBH ~ 25.9 cm) is about \$8,200 ha^{-1}, or \$17.30 $stem^{-1}$. Using a gross energy content of 16.4 $MJ.kg^{-1}$ for air-dry wood (section 2.5.4), it follows that 1.35×10^6 $MJ.ha^{-1}$ is enclosed within the woody biomass of the forest (2.84×10^3 $MJ.stem^{-1}$), of which 8.10×10^5 $MJ.ha^{-1}$ (1.71×10^3 $MJ.stem^{-1}$) would be released as effective heat from a 60% efficient woodheater. Each unit increment of basal area thus represents an increase of 3.23×10^4 MJ of effective household heat.

4.5. Conclusions

The quantity of woody biomass contained in forest stands in southern New England varies with respect to site quality and tree cover. The eastern stringybark forests contain the largest total biomass, almost 300 $t.ha^{-1}$, while stands of isolated and scattered trees common in the region contain less than 10 $t.ha^{-1}$. Variation in 'useful fuelwood biomass' (biomass in the 5-55 cm diameter portion of stems and branches) between forest stands of different site quality is less than variation in 'total biomass' (all stem and branchwood ≥ 5 cm diameter), suggesting the potential for extracting significant quantities of fuelwood-sized timber from a large number of widely distributed stands in the study region.

The woody biomass of native eucalypts in southern New England can be estimated at three levels with a view to sustainable fuelwood management. At the individual tree level, biomass can be estimated by application of weight and volume functions (Chapter 3) to DBH and other tree measurements, facilitating tree selection for on-farm fuelwood production. At the stand level, biomass can be estimated by application of basal area and density measurements to biomass functions (Figures 4.9 and 4.10), facilitating stand selection for urban fuelwood production. The third level of biomass estimation is regional, and, used in conjunction with timber consumption data (Chapter 2), provides a basis from which to appraise the potential long-term sustainability of native forests and their rural timber products. These matters are discussed in Chapters 5, 6 and 8.