# Chapter 5. Forest inventory for fuelwood estimation
# II. Aerial photographic interpretation

## 5.1. Introduction

Remote sensing is the acquisition of information about an object without physical contact, and is useful in the provision of large numbers of data over extensive areas at relatively low cost. Aerial photography is the most commonly used system of remote sensing, providing a natural photographic image of a land area from which interpretations of vegetation cover can be made by contrasting aspects of colour, tone, size, shape, texture and pattern. Specific applications to forestry include map preparation, access road location, forest fuel assessment and bushfire control and prevention, delineation of site quality classes, identification of individual species and stand associations, vegetation classification and area and volume estimation (Husch *et al.* 1972; Avery and Berlin 1985).

Aerial photograph interpretation (API) has been used in association with tree and forest sampling as the basis for estimation of regional fuelwood resources in a number of modern investigations (Bird and Shepherd 1989; Brockhaus and Pillsbury 1992; Deshmukh 1992). This chapter reports the estimation of timber biomass in Armidale's fuelwood catchment using API in conjunction with stand biomass estimates obtained in Chapter 4. An estimate of total standing fuelwood biomass is derived for forest stands in the study region suited to harvesting.

## 5.2. Methods

### 5.2.1. Land assessment - mapping

A total of 2000 Australian Map Grid points within the study region was generated at random using a computer program. Selection of a high number of points (1 point per 5.8 $km^2$) ensured adequate sampling in poorly represented areas such as TSR (Figure 2.4) and SQ2 land (Figure 3.3). Each point was located and plotted on 1:25 000 topographic maps and colour 1:25 000 aerial photographs. Using a combination of mapping and API, the following biophysical variables were recorded for each point.

***Mean annual rainfall (MAR)***

BIOCLIM is a bioclimatic model developed from a rainfall prediction technique in which Laplacian smoothing spline surfaces are fitted to rainfall records from meteorological stations of known elevation, latitude and longitude (Wahba and Wendelberger 1980; Hutchinson and Bischof 1983). Given a set of geocoded latitude, longitude and elevation data, BIOCLIM estimates a number of climatic variables for a specified point in the landscape, assisting in analyses of the potential biogeographic distribution of fauna and flora (Nix 1986; Busby 1986) and in tree species selection for fuelwood and agroforestry in Australia and abroad (Booth 1985; Booth *et al.* 1987, 1988, 1989; Booth and Jovanovic 1988; Booth and Pryor 1991). MAR was estimated for each of the 2000 points in the study region by applying values of elevation, latitude and longitude to the BIOCLIM model. A site-quality (SQ) index was subsequently assigned to each point based on its MAR (section 3.2.6).

***Biophysical data***

The following biophysical attributes were recorded at each point : geology, elevation, slope, position on slope, terrain element and aspect.

The Dorrigo-Coffs Harbour and Manilla 1:250 000 geological mapsheets were used to ascribe a geology code to each point according to the major rock unit on which it was located. Over 40 geological types were recorded, from which nine major groups were established for this study (Table 5.1).

Table 5.1. Major geological groups in the study region.

| Code | Geological group |
|---|---|
| 1. | Major igneous suite - various granites, adamellites, leuco-adamellites and granodiorites |
| 2. | Permian volcanics - pyroclastics, rhyolite, trachyte |
| 3. | Tertiary basalts |
| 4. | Metamorphosed - undifferentiated schistose material |
| 5. | Sedimentary - mudstone, siltstone beds |
| 6. | Sedimentary - conglomerate, breccia, sandstone beds |
| 7. | Sedimentary - Armidale beds - gravel, sand, clay beds |
| 8. | Sedimentary - Sandon beds - low grade, regionally metamorphosed beds of greywacke, chert and jasper |
| 9. | Quaternary alluvial - mud, silt, sand deposits |

Elevation was measured to the nearest 5 m and land slope was calculated as percentage from 1 : 25 000 topographic maps. The equation used to calculate slope was :

$$S = 100 \cdot \left( I / D \right) \qquad \text{5.1}$$

where: S = slope (%),
I = contour interval (10 m in the 1:25 000 series)
D = horizontal distance between contours (m)

Each point was assigned an elevation, slope, position on slope, aspect and terrain category (Table 5.2). Terrain categories were rated subjectively with respect to topographical form and relief of surrounding landscape.

Table 5.2. Categories used for elevation, slope, position on slope, terrain element and aspect.

| Elevation (m) | Slope (%) | Position on slope | Terrain element | Aspect |
|---|---|---|---|---|
| 1. ≤ 500 | 1. 0 - 2 | 1. crest/ridge | 1. flat to gently undulating | 1. N |
| 2. 501 - 600 | 2. 3 - 5 | 2. upper slope | 2. undulating to rolling | 2. NE |
| 3. 601 - 700 | 3. 6 - 10 | 3. midslope | 3. hilly | 3. E |
| 4. 701 - 800 | 4. 11 - 20 | 4. lower slope | 4. very hilly | 4. SE |
| 5. 801 - 900 | 5. 21 - 50 | 5. valley floor | 5. mountainous | 5. S |
| 6. 901 - 1000 | 6. 51 - 100 | 6. midslope (watercourse) | | 6. SW |
| 7. 1001 - 1100 | 7. > 100 | 7. valley floor (watercourse) | | 7. W |
| 8. 1101 - 1200 | | 8. lower slope (watercourse) | | 8. NW |
| 9. 1201 - 1300 | | 9. valley floor (wetland) | | 9. flat |
| 10. 1301 - 1400 | | 10. upper slope (watercourse) | | |
| 11. > 1400 | | | | |

***Other features***

The major intersection at Marsh and Barney Streets in Armidale (AMG 372075E 6622950N; Armidale 1 : 25 000 topographic map 9236-IV-N) was used to measure bearing, straight line distance and travel distance to each point. Topographic maps were also used to establish the distance from each point to the nearest waterway (m) and road or track (m). Distance categories are shown in Table 5.3.

Table 5.3. Categories used for distance variables.

| Bearing (°) | SLD (km) [1] | TD (km) [2] | DNWC (m) [3] | DNR/T (m) [4] |
|---|---|---|---|---|
| 1. 1 - 30 | 1. 0 - 10 | 1. 0 - 10 | 1. 0 - 20 | 1. 0 - 20 |
| 2. 31 - 60 | 2. 11 - 20 | 2. 11 - 20 | 2. 21 - 50 | 2. 21 - 50 |
| 3. 61 - 90 | 3. 21 - 30 | 3. 21 - 30 | 3. 51 - 100 | 3. 51 - 100 |
| 4. 91 - 120 | 4. 31 - 40 | 4. 31 - 40 | 4. 101 - 200 | 4. 101 - 200 |
| 5. 121 - 150 | 5. 41 - 50 | 5. 41 - 50 | 5. 201 - 500 | 5. 201 - 500 |
| 6. 151 - 180 | 6. 51 - 60 | 6. 51 - 60 | 6. 501 - 1000 | 6. 501 - 1000 |
| 7. 181 - 210 | 7. 61 - 70 | 7. 61 - 70 | 7. 1001 - 2000 | 7. 1001 - 2000 |
| 8. 211 - 240 | 8. 71 - 80 | 8. 71 - 80 | | 8. 2001 - 5000 |
| 9. 241 - 270 | 9. 81 - 90 | 9. 81 - 90 | | |
| 10. 271 - 300 | | 10. 91 - 100 | | |
| 11. 301 - 330 | | 11. 101 - 110 | | |
| 12. 331 - 360 | | 12. 111 - 120 | | |
| | | 13. > 120 | | |

1 = straight line distance
2 = travel distance
3 = distance to nearest watercourse
4 = distance to nearest road or track

The proximity of each point to the nearest road or track was observed on aerial photographs with respect to mountains, hills, rocky terrain, swamps and rivers, all of which can form impassible barriers. The accessibility of each point was classified as 1. readily accessible (accessible to 2-wheel drive vehicles); 2. limited accessibility (unnavigable to trucks and requiring 4-wheel drive in wet weather); and 3. inaccessible (not accessible by 4-wheel drive).

In a study of the conservation value of vegetation systems on the New England Tablelands, Morgan and Terrey (1990) mapped and described 19 land provinces. The area ($km^2$) of each of 11 provinces occurring in the study region, in addition to the eastern gorge system and the western Nandewaars not defined by Morgan and Terrey (1990) (Figure 5.1), was determined by digitising and each point was coded for land province and land tenure (Table 5.4).

Table 5.4. Categories used for land province and land tenure.

| Land Province | | Land Tenure | |
|---|---|---|---|
| 1. | Armidale plateau | 1. | Freehold |
| 2. | Glen Innes/Guyra basalts | 2. | Leasehold |
| 3. | Walcha plateau | 3. | Travelling Stock Route/Reserve |
| 4. | Wongwibinda plateau | 4. | State Forest |
| 5. | Nightcap | 5. | Nature Reserve |
| 6. | Round Mountain | 6. | National Park |
| 7. | Ebor basalts | 7. | Urban |
| 8. | Yarrowyck-Kentucky downs | | |
| 9. | Bundarra downs | | |
| 10. | Eastern Nandewaars | | |
| 11. | Western Nandewaars | | |
| 12. | Moredun volcanics | | |
| 13. | Gorge | | |

note : shaded provinces not included in the classification by Morgan and Terrey (1990).

## 5.2.2. Assessment of vegetation cover using API

Panchromatic colour 1:25 000 aerial photographs (1988 to 1992) of the New England region were available for assessment at the Armidale Lands Office. The location of each grid point on the topographic map was cross-referenced with the corresponding aerial photograph to ascertain its position on the photo using a viewing stereoscope. Once the 'photo-point' was identified, a 'photo-grid' etched permanently onto transparent paper was aligned centrally on the photo-point and oriented to the Australian Map Grid. The photo-grid was drawn to a 1:25 000 scale (4 x 4 cm) representing 1 $km^2$ on the ground, and consisted of 100 individual 'photo-cells' of size 4 x 4 mm, representing 1 ha on the ground (Figure 5.2). Each photocell was numerically coded (using a water-soluble ink pen) according to the cover class identified stereoscopically from the photograph. Stereoscopic interpretation of cover was favoured because small openings in the forest canopy can go undetected when viewed monoscopically (Brockhaus and Pillsbury 1992). The vegetation cover classes were those described in section 4.2.1 (closed forest, open forest, woodland, scattered trees and isolated trees) with the addition of classes for open water and urban areas. In addition to cover class, land tenure (Table 5.4) was recorded for each cell.

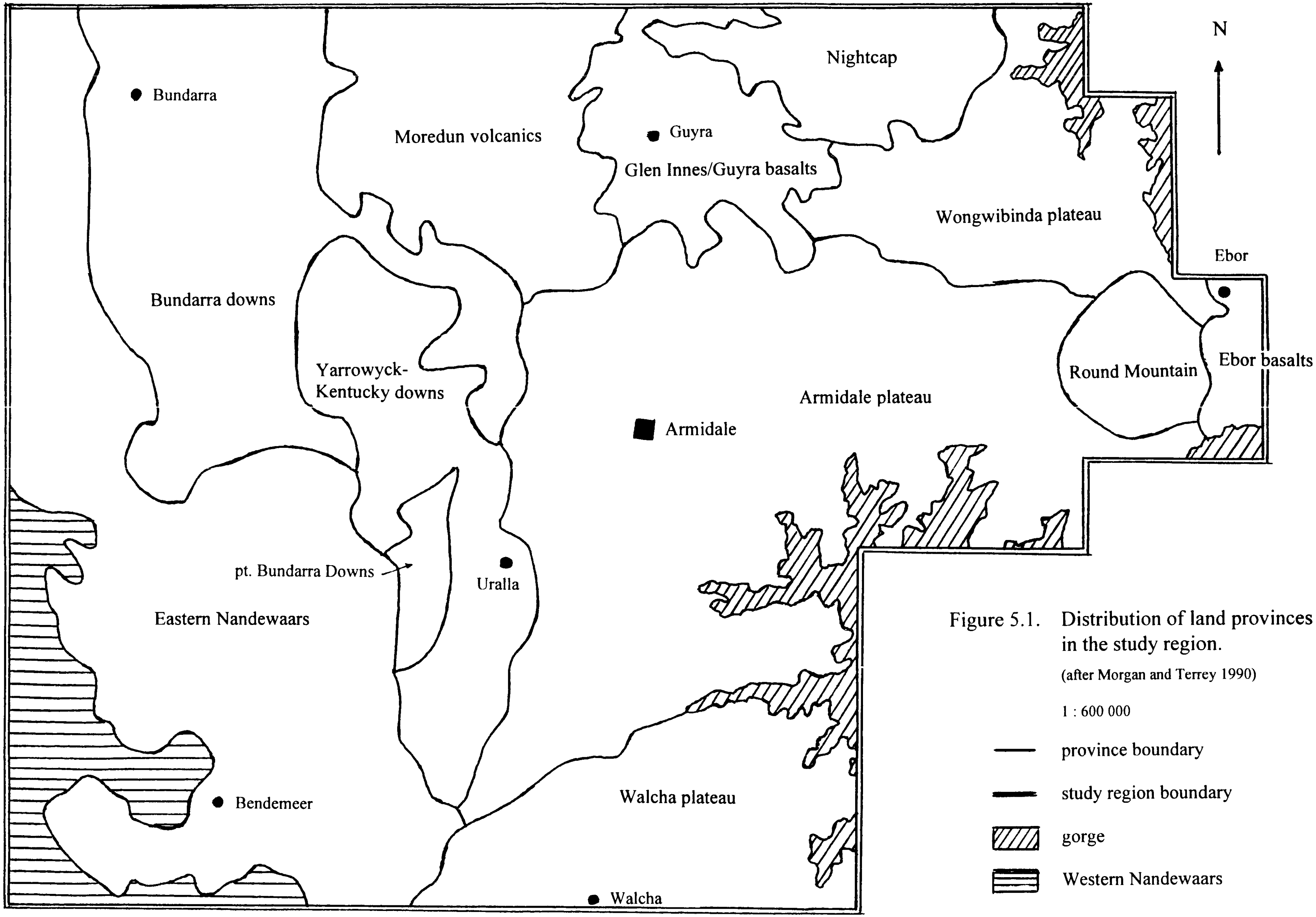


Figure 5.1. Distribution of land provinces in the study region.
(after Morgan and Terrey 1990)

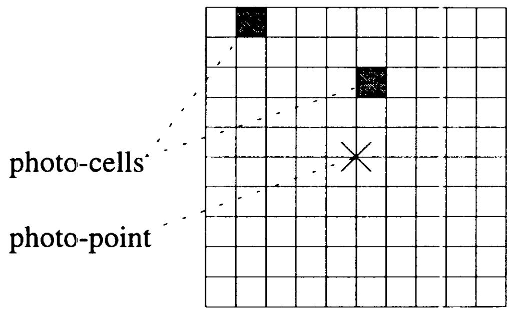


Figure 5.2. Photo-grid used for remote sampling of New England eucalypt stands.

The photo-grid was removed from the photo after coding and placed on a blank white page, upon which grid-cell codes were tallied to ascertain the area of each cover class within each land tenure category around the photo-point. A total of 200 000 cells were classified, representing 2000 km$^2$ in the study region. The proportion of photo-cells in each cover and land tenure class was assumed to equal the respective proportion of each cover and land tenure class in the study region.

### 5.2.3. Regional assessment of fuelwood biomass

***Stand biomass parameters***

Regional quantification of standing fuelwood was carried out using 193 493 tableland photo-cells, representing 11 222.6 km$^2$ or 96.7% of the study region. The remaining 6507 cells (377.4 km$^2$) contained gorge data and were not included in biomass analysis. Vegetation of the precipitous eastern gorge system, much of which is encompassed by Oxley Wild Rivers National Park and almost all of which is inaccessible, is dominated by low sclerophyllous scrub on exposed rocky faces, interlaced with patches of dry rainforest and wet eucalypt forest in sheltered gullies. Differing markedly from forest systems on the tableland, it was deemed inappropriate to estimate gorge biomass from tableland inventory data, and inappropriate to include gorge biomass in quantifying the regional fuelwood resource.

Each of the 193 493 tableland cells was coded for land tenure, site-quality and cover class (section 5.2.2). A value of fuelwood biomass (t) was subsequently assigned to each cell based on cover class and site quality (Table 5.5; derived from Table 4.6). Individual biomass values were then tallied and magnified by a factor of 5.8 (11 222.60 / 1934.93) to obtain an estimate of total standing fuelwood biomass in Armidale's fuelwood catchment (excluding gorges). This estimate was apportioned to various factors including accessibility, distance to town, land tenure and land attributes.

Table 5.5. Estimated values of standing fuelwood biomass (t.ha$^{-1}$) in native eucalypt stands of different cover class and site quality in southern New England (from Table 4.6).

| SQ | Closed Forest | Open Forest | Woodland | Scattered trees | Isolated trees |
|---|---|---|---|---|---|
| 1 | 190 | 130 | 20 | 4 | 1 |
| 2 | 180 | 120 | 15 | 4 | 1 |
| 3 | 170 | 110 | 15 | 4 | 1 |
| 4 | 170 | 110 | 15 | 4 | 1 |
| 5 | 170 | 105 | 15 | 4 | 1 |
| 6 | 125 | 100 | 15 | 4 | 1 |
| 7 | 110 | 100 | 15 | 4 | 1 |

***Dead trees***

Because dead trees cannot be recorded using standard colour API, two alternative techniques were used to estimate the biomass of dead standing timber, the results of which were compared with biomass estimates obtained using forest sampling (Chapter 4). First, landholders were asked in the telephone survey (section 2.3.3) to estimate the number of dead trees remaining on their properties. Second, a computerised GIS (Environmental Resource Mapping System ERMS developed by NSW National Parks and Wildlife Service) was used to calculate the mean number of dead trees ≥ 5 cm DBH (stems.ha$^{-1}$) for different tree associations and cover classes across the UNE research laboratory, "Newholme" (S. Andrews, unpubl. data).

### 5.2.4. Statistical analyses

A general linear model was employed to establish which biophysical factors contributed significantly to regional variation in standing fuelwood biomass. The model included six numeric factors (slope, elevation, straight-line distance, travel distance, distance to nearest watercourse, and distance to nearest road or track) and eight categorical factors (site quality, geology, position on slope, terrain element, aspect, bearing, accessibility, and land province). Tukey's multiple comparison was performed on each significant factor to determine its influence on regional variation in fuelwood biomass.

## 5.3. Results

### 5.3.1. Total cover and biomass

The number of photo-cells and estimated land area for each cover-tenure class are listed in Table 5.6 and estimates of standing fuelwood biomass for each class are shown in Table 5.7. Total fuelwood biomass in the study region was estimated to be 31.720 Mt. Private property contained 27.669 Mt (87.2%) within 10 814 km$^2$ of the tableland area (96.4%). Crown land other than leasehold contained the remaining

Table 5.6. Number of photo-cells and estimated land area according to land tenure and cover class (percentages in parentheses).

| | | Closed forest | Open forest | Woodland | Scattered trees | Isolated trees | Open water | Urban | ALL |
|---|---|---|---|---|---|---|---|---|---|
| Freehold [1] | No. cells | 13 333 (6.89) | 17 848 (9.22) | 34 083 (17.62) | 51 501 (26.62) | 69 313 (35.82) | 372 (0.19) | - | 186 450 (96.36) |
| | *Area (km²)* | *773.3* | *1035.2* | *1976.8* | *2987.1* | *4020.1* | *21.6* | | *10 814.1* |
| Travelling Stock Reserve | No. cells | 156 (0.08) | 578 (0.30) | 784 (0.41) | 436 (0.23) | 322 (0.17) | 4 (0.00) | - | 2280 (1.19) |
| | *Area (km²)* | *9.0* | *33.5* | *45.5* | *25.3* | *18.7* | *0.2* | | *132.2* |
| State Forest | No. cells | 1634 (0.84) | 325 (0.17) | 41 (0.02) | 6 (0.00) | 1 (0.00) | - | - | 2007 (1.03) |
| | *Area (km²)* | *94.8* | *18.9* | *2.4* | *0.3* | *0.1* | | | *116.5* |
| National Park [2] | No. cells | 1555 (0.80) | 310 (0.16) | 78 (0.04) | 35 (0.02) | 14 (0.01) | - | - | 1992 (1.03) |
| | *Area (km²)* | *90.2* | *18.0* | *4.5* | *2.0* | *0.8* | | | *115.5* |
| Urban | No. cells | - | - | - | - | - | - | 764 (0.39) | 764 (0.39) |
| | *Area (km²)* | | | | | | | *44.3* | *44.3* |
| ALL [3] | No. cells | 16 678 (8.61) | 19 061 (9.85) | 34 986 (18.09) | 51 978 (26.87) | 69 650 (36.00) | 376 (0.19) | 764 (0.39) | 193 493 (100.00) |
| | *Area (km²)* | *967.3* | *1105.6* | *2029.2* | *3014.7* | *4039.7* | *21.8* | *44.3* | *11 222.6* |

1. includes ~1% leasehold 2. includes nature reserves 3. total area 11 222.6 km² (excludes gorges)

Table 5.7. Estimated fuelwood biomass (Mt) in the study region according to land tenure and cover class (percentages in parentheses).

| | Closed forest | Open forest | Woodland | Scattered trees | Isolated trees | ALL |
|---|---|---|---|---|---|---|
| Freehold [1] | 12.187 (38.42) | 10.894 (34.35) | 2.990 (9.43) | 1.195 (3.77) | 0.402 (1.27) | 27.669 (87.24) |
| Travelling Stock Reserve | 0.125 (0.39) | 0.352 (1.11) | 0.071 (0.22) | 0.010 (0.03) | 0.002 (0.01) | 0.560 (1.76) |
| State Forest | 1.636 (5.16) | 0.217 (0.68) | 0.004 (0.01) | 0.000 (0.00) | 0.000 (0.00) | 1.857 (5.85) |
| National Park [2] | 1.431 (4.51) | 0.195 (0.62) | 0.007 (0.02) | 0.001 (0.00) | 0.000 (0.00) | 1.634 (5.15) |
| ALL [3] | 15.379 (48.48) | 11.658 (36.76) | 3.073 (9.68) | 1.206 (3.80) | 0.404 (1.28) | 31.720 (100.00) |

1. includes ~1% leasehold 2. includes nature reserves 3. total area 11 222.6 km² (excludes gorges)

4.051 Mt (12.8%) and covered 365 $km^2$ (3.2%) of the region. Urban land covered 44 $km^2$ (0.4%) and major water storages, natural wetlands, farm dams and streams and rivers accounted for 22 $km^2$ (0.2%).

A total of 7054 $km^2$ of the region (62.9%) contained stands of scattered and isolated trees comprising 1.610 Mt (5.1%) of the standing fuelwood biomass. Woodland covered an area of 2029 $km^2$ (18.1%) and comprised 3.073 Mt (9.7%), while closed and open forest covered 2073 $km^2$ (18.4%) and contributed 27.037 Mt (85.2%) to regional fuelwood biomass. Mean fuelwood biomass (standing dry-weight) was calculated from Tables 5.6 and 5.7 to be 25.6 $t.ha^{-1}$ on private land, 42.4 $t.ha^{-1}$ on TSR, 159.4 $t.ha^{-1}$ in state forest and 141.5 $t.ha^{-1}$ in national parks and nature reserves (Figure 5.3). Mean biomass for all tenures was 28.4 $t.ha^{-1}$ (not including urban and open water).

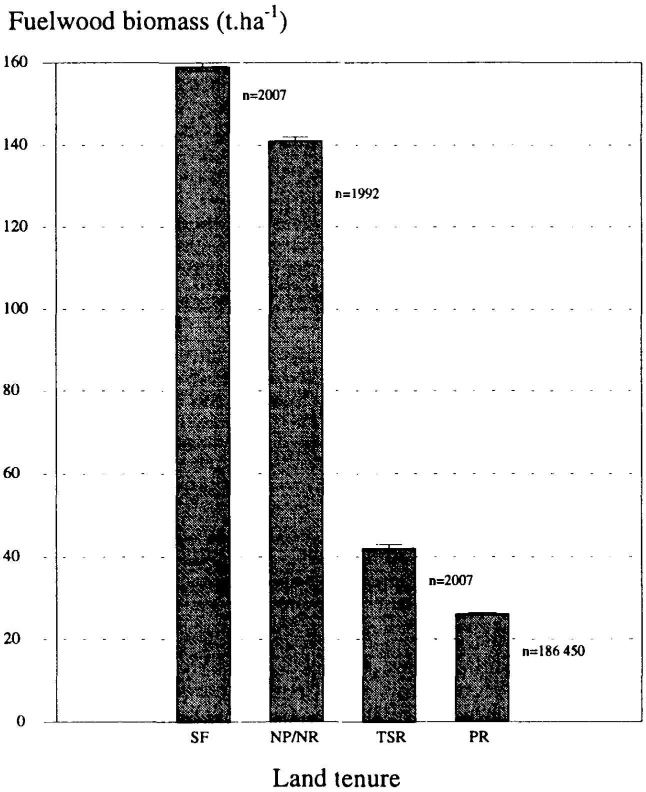


Figure 5.3. Effect of land tenure on standing fuelwood biomass in the study region.

### 5.3.2. Inventory of dead timber

The average number of dead trees was 3230 per property according to New England landholders, equivalent to 2.36 $trees.ha^{-1}$, or 2.63 million trees in total. Results from forest inventory (Appendices XXI and XXII) and the Newholme GIS (S. Andrews, unpubl. data) suggested the dead standing resource was appreciably greater, with a mean 89 $trees.ha^{-1}$ in closed forest, 59 $trees.ha^{-1}$ in open forest, 19 trees.ha$^{-1}$ in woodland, 29 trees.ha$^{-1}$ in stands of scattered trees, and 9 trees.ha$^{-1}$ in stands of isolated trees; a total of 31.4 million trees (28.1 ha$^{-1}$). This is over 11 times the number estimated by landholders, a discrepancy that may reflect a low rate of removal of dead trees from Newholme compared to other properties, and landholders estimating only large or prominent dead trees on open land.

Air-dry biomass of useable dead trees in isolated and scattered stands in the study region was estimated to be 1 t.ha$^{-1}$, or 0.7 Mt in total. No estimate of dead fallen timber was available, although the quantity of useable deadwood in a scattered stand dominated by *Eucalyptus blakelyi* and *E. melliodora* near Canberra was estimated to be 2.16 m$^3$.ha$^{-1}$, of which 0.96 m$^3$ was dead standing (0.53 dead trees.ha$^{-1}$) and 1.20 m$^3$ was dead fallen (Morse 1985a). Most firewood used in Armidale is derived from dead standing trees, although a considerable amount is collected from the ground (Wall and Reid 1993).

### 5.3.3. Determinants of total standing biomass

Table 5.8 lists the results of the general linear model used to select factors contributing to regional variation in standing fuelwood biomass. Four independent factors - slope, position on slope, aspect, and distance to the nearest watercourse - had no significant influence on the regional distribution of fuelwood biomass. Elevation was significant at P = 0.047 while all other factors had a strongly significant effect on biomass (P ≤ 0.001). Differences in land tenure have been reviewed in section 5.3.1.

Table 5.8. AOV statistics generated from a general linear model of dependent variable 'fuelwood biomass' (t.ha$^{-1}$) on 15 independent variables.

| | | Analysis of variance (n = 1939, $r^2$ = 0.524) | | | | |
|---|---|---|---|---|---|---|
| Independent Variable | Type [1] | SS | DF | MS | F-ratio | *P* |
| Bearing from Armidale | c | 470 260 000 | 11 | 42 750 900 | 6.026 | 0.000 |
| Straight line distance | n | 86 144 800 | 1 | 86 144 800 | 12.143 | 0.001 |
| Travel distance | n | 160 676 000 | 1 | 160 676 000 | 22.648 | 0.000 |
| Distance to nearest watercourse | n | 1 723 300 | 1 | 1 723 300 | 0.243 | 0.622 |
| Distance to nearest road or track | n | 224 670 000 | 1 | 224 670 000 | 31.668 | 0.000 |
| Geological class | c | 310 243 000 | 8 | 38 780 400 | 5.466 | 0.000 |
| Site quality | c | 1 096 370 000 | 6 | 182 729 000 | 25.757 | 0.000 |
| Elevation | c | 27 908 800 | 1 | 27 908 800 | 3.934 | 0.047 |
| Slope | n | 11 109 300 | 1 | 11 109 300 | 1.566 | 0.211 |
| Position on slope | c | 85 307 500 | 9 | 9 478 600 | 1.336 | 0.213 |
| Terrain element | c | 1 099 110 000 | 4 | 274 778 000 | 38.731 | 0.000 |
| Aspect | c | 67 850 300 | 8 | 8 481 300 | 1.195 | 0.298 |
| Accessibility class | c | 145 746 000 | 2 | 72 872 900 | 10.272 | 0.000 |
| Land province | c | 1 182 690 000 | 11 | 107 517 000 | 15.155 | 0.000 |
| ERROR | - | 13 288 000 000 | 1873 | 7 094 500 | | |

1. c = categorical n = numeric

Results of Tukey's multiple comparison tests carried out on 10 factors contributing to variation in mean fuelwood biomass are listed in Table 5.9. Biomass was greater in hilly to mountainous areas with high rainfall (site quality) and low accessibility, at greater distances from roads or tracks, and at greater distances from Armidale. Figure 5.4 illustrates the variation in standing fuelwood biomass with respect to terrain, accessibility, site-quality, and distance factors.

Table 5.9. Independent categories contributing to spatial variation in standing fuelwood biomass in southern New England (air-dry t.ha$^{-1}$) (derived from Tukey multiple comparison tests).

| Independent variable | Category [1] | Description | n | Mean fuel biomass [2] |
|---|---|---|---|---|
| Site Quality | 1 | SQ1 | 63 | 75.2 ± 8.2 |
| | 2 | SQ2 | 34 | 52.7 ± 7.8 |
| | 3,4,5 | SQ3-4-5 | 747 | 37.6 ± 1.6 |
| | 6,7 | SQ6-7 | 1096 | 17.2 ± 0.7 |
| Elevation (m a.s.l) | 1,2,5,6 | 401- 600 ; 801 - 1000 | 553 | 37.1 ± 1.7 |
| | 3 | 601 - 700 | 121 | 13.0 ± 1.5 |
| | 4,7,8,9,10 | 701 - 800 ; 1001 - 1400 | 1261 | 24.2 ± 1.0 |
| | 11 | > 1400 | 5 | 151.7 ± 12.1 |
| Geology | 1,2,5,6 | Igneous intrusions and Permian volcanics, beds of mudstone, siltstone, conglomerates, breccia and sandstone | 1165 | 36.3 ± 1.2 |
| | 3,4,7,8,9 | Tertiary basalts, Armidale, Sandon and alluvium beds and metamorphosed sediments | 775 | 14.4 ± 0.8 |
| Terrain element | 1,2 | flat - undulating - rolling | 1069 | 13.2 ± 0.7 |
| | 3 | hilly | 697 | 39.7 ± 1.5 |
| | 4,5 | very hilly - mountainous | 174 | 67.1 ± 3.6 |
| Accessibility | 1 | accessible | 1146 | 16.6 ± 0.7 |
| | 2 | limited access | 349 | 29.3 ± 2.0 |
| | 3 | inaccessible | 445 | 54.5 ± 2.3 |
| Land Province | 1,2,8 | Armidale plateau<br>Glen Innes - Guyra basalts<br>Yarrowyck-Kentucky Downs | 657 | 13.8 ± 0.9 |
| | 4,5,7,12 | Wongwibinda plateau, Nightcap<br>Ebor basalts, Moredon volcanics | 364 | 33.4 ± 1.9 |
| | 3,9 | Walcha plateau, Bundarra Downs | 407 | 20.0 ± 1.6 |
| | 6 | Round Mountain | 30 | 120.2 ± 10.8 |
| | 10,11 | Nandewaars | 482 | 42.7 ± 1.8 |
| Bearing (°) | 1,7,12 | 331 - 360/0 - 30 ; 181 - 210 | 346 | 12.1 ± 1.0 |
| | 2,3,4,5,6,8,9,10,11 | 31 - 180 ; 211 - 330 | 1594 | 30.9 ± 1.0 |
| Straight line distance (km) | 1,2 | 0 - 20 | 227 | 11.2 ± 1.2 |
| | 3,4,5 | 21 - 50 | 998 | 21.4 ± 0.9 |
| | 6,7,8,9 | 51 - 90 | 715 | 41.3 ± 1.7 |
| Travel [3] distance (km) | 1,2,3,4 | 0 - 40 | 447 | 14.0 ± 1.0 |
| | 5,6,7 | 41 - 70 | 838 | 21.9 ± 1.0 |
| | 8,10 | 71 - 80 ; 91 - 100 | 390 | 34.6 ± 2.0 |
| | 9,11,12 | 81 - 90 ; 101 - 120 | 253 | 56.2 ± 3.3 |
| | 13 | > 120 | 12 | 97.5 ± 14.9 |
| Distance to nearest road or track (m) | 1,2,3,4,5 | 0 - 500 | 1088 | 20.3 ± 0.9 |
| | 6 | 501 - 1000 | 487 | 30.8 ± 1.6 |
| | 7,8 | 1001 - 500 | 365 | 44.9 ± 2.7 |

1. biomass significantly different between categories of a given variable.
2. based on average dry fuelwood biomass (t.ha$^{-1}$)
3. Travel distance = total distance from photo-point to Armidale = road and track distance + distance to nearest road or track (measured to nearest km).

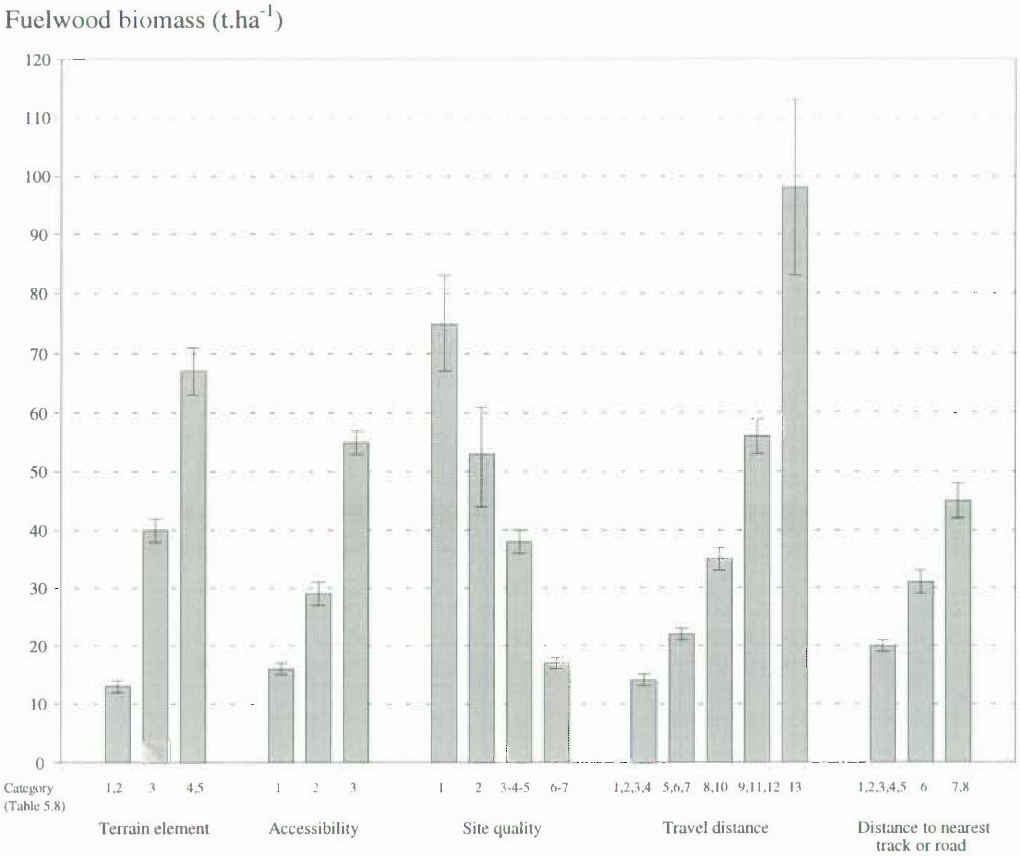


Figure 5.4. Effect of terrain, accessibility, site quality, and distance factors on standing fuelwood biomass in the study region.

## 5.4. Discussion

### 5.4.1. Influence of land factors on fuelwood biomass

Tables 5.10, 5.11 and 5.12 characterise Morgan and Terrey's (1990) land provinces according to factors contributing to regional variation in standing fuelwood biomass. Data therein support the contention that spatial variation in timber biomass is governed mainly by terrain and accessibility, land productivity, distance from Armidale, and land tenure. For example, the first province category listed in Table 5.8 (Armidale plateau, Glen Innes-Guyra basalts, and Yarrowyck-Kentucky Downs) comprises a relatively flat and productive expanse of land in the centre of the study region (Figure 5.1) in which clearing and pasture development have been prolific and dieback has been widespread and relatively severe. Only 4.2% of the combined 3929 $km^2$ (33.9% of the study region) comprises very hilly or mountainous terrain, while 16.3% is inaccessible. Mean distance from the nearest road is 520 m and mean distance to Armidale is 34.5 km. The area contains 8.2% closed and open forest, restricted to small pockets of crown land and local hilltops. Mean fuelwood biomass is 13.8 $t.ha^{-1}$.

The Walcha plateau and Bundarra downs comprise two major provinces with a combined area of 2382 $km^2$ (20.5% of the study region). Mean fuelwood biomass is 20.0 $t.ha^{-1}$, confined to the more rugged western fringes of the Bundarra downs and eastern and western margins of the Walcha plateau. Some 10.5% of the area contains closed and open forest, 7.7% comprises very hilly to mountainous terrain and 20.2% is inaccessible. Mean distance from the nearest road is 579 m and mean distance to Armidale is 69.3 km.

Four provinces in the north and north-east of the study region - Moredun volcanics, Wongwibinda plateau, Nightcap, and Ebor basalts - comprise 2095 $km^2$ (18.1% of the study region) in which pastoralism is confined to broad valleys. About 18.8% is inaccessible and 11.5% comprises very hilly to mountainous terrain. Mean distance to the nearest road or track is 671 m and mean distance to Armidale is 62.3 km. The four provinces contain an average 21.5% of closed and open forest, much occurring on the eastern margins of the Wongwibinda plateau adjacent to the gorges, with Nightcap and Moredun containing extensive areas of cover in more rugged terrain throughout. Mean fuelwood biomass is 33.4 $t.ha^{-1}$.

Provinces 10 and 11 (Nandewaar ranges; Figure 5.1) incorporate 2590 $km^2$ (22.3% of the study region) and contain over a third of the region's fuelwood. Clearing has been restricted to relatively flat areas, particularly in the east, and the majority of land remains largely undeveloped as a consequence of the ruggedness and rockiness of the landscape and low productivity of the mainly igneous parent materials. Despite a forest cover of 30.7% and a mean fuelwood biomass of 42.7 $t.ha^{-1}$, fuelwood extraction has been limited by travel distance (average 77.5 km from Armidale) and better acquisition opportunities closer to town.

The small province of Round Mountain covers 226 $km^2$ (2.0% of the study region), yet contains about 8.8% of the region's fuelwood biomass with a mean of 120.2 $t.ha^{-1}$. Unlike other provinces comprising over 94% freehold land and TSR, Round Mountain contains nearly 19.5% conservation reserves (Cathedral Rocks National Park and Serpentine Nature Reserve), 11.6% state forest (Yooroonah State Forest), and significant tracts of leasehold land. A total of 68.9% of the area contains closed and open forest, much of which is inaccessible.

### 5.4.2. Constraints to biomass availability

***Preamble***

Two biomass estimates have been presented for the study region; 31.72 Mt (Table 5.7) and 30.80 Mt (Table 5.12). The former is derived from a total areal assessment, and is used for the basis of further discussion; the latter results from random differences in sampling intensity between land provinces. Assuming that standing biomass is equivalent to 40 $Mm^3$, and given that around 40 000 $m^3$ of rural timber is consumed for fuelwood each year (Chapter 2), it follows that about 0.1% of the region's

Table 5.10. Biophysical characteristics of land provinces (LPs) in the study region.

| LP | No. points | Area (km²) | Main geol. groups [1] | Mean elev. (m) | Mean slope (%) | % Site Quality | | | | | | | % Terrain Element [2] | | | | | % Accessibility [3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | SQ1 | SQ2 | SQ3 | SQ4 | SQ5 | SQ6 | SQ7 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 |
| 1 | 449 | 2664.5 | 1,3,5,8 | 1051 ± 4 | 8.8 ± 0.4 | 4.0 | 0.7 | 3.1 | 6.9 | 16.9 | 53.2 | 15.2 | 2.7 | 59.2 | 33.9 | 4.0 | 0.2 | 63.9 | 18.7 | 17.4 |
| 2 | 74 | 500.7 | 3 | 1291 ± 4 | 7.0 ± 0.8 | - | 1.3 | 24.3 | 62.2 | 12.2 | - | - | 10.8 | 46.0 | 40.5 | 2.7 | - | 78.4 | 12.2 | 9.4 |
| 3 | 145 | 824.1 | 5,8 | 1111 ± 6 | 9.8 ± 1.0 | 2.1 | 4.8 | 10.3 | 8.3 | 9.0 | 33.1 | 32.4 | 0.7 | 62.1 | 32.4 | 4.8 | - | 65.5 | 17.9 | 16.6 |
| 4 | 130 | 722.9 | 5 | 1159 ± 8 | 12.8 ± 1.1 | 1.5 | 9.2 | 10.0 | 31.6 | 29.2 | 15.4 | 3.1 | 0.8 | 38.4 | 48.5 | 10.8 | 1.5 | 54.6 | 24.6 | 20.8 |
| 5 | 74 | 390.5 | 1 | 1241 ± 11 | 13.4 ± 2.4 | 6.8 | 4.0 | 29.7 | 28.4 | 25.7 | 5.4 | - | 1.4 | 32.4 | 54.0 | 9.5 | 2.7 | 48.6 | 28.4 | 23.0 |
| 6 | 30 | 226.3 | 1 | 1268 ± 24 | 11.2 ± 2.0 | 53.4 | 26.7 | 3.3 | 13.3 | 3.3 | - | - | - | 40.0 | 46.7 | 13.3 | - | 33.3 | 16.7 | 50.0 |
| 7 | 19 | 114.1 | 3 | 1301 ± 10 | 11.3 ± 2.8 | 100.0 | - | - | - | - | - | - | 5.3 | 36.8 | 42.1 | 15.8 | - | 63.2 | 10.5 | 26.3 |
| 8 | 134 | 764.0 | 1,8 | 951 ± 11 | 7.9 ± 0.7 | - | - | - | 6.7 | 5.2 | 58.2 | 29.9 | 3.7 | 62.0 | 29.1 | 4.5 | 0.7 | 65.6 | 17.2 | 17.2 |
| 9 | 262 | 1558.0 | 8 | 794 ± 8 | 8.9 ± 0.7 | - | - | - | 5.0 | 14.5 | 52.3 | 28.2 | 6.1 | 61.0 | 23.7 | 8.4 | 0.8 | 65.7 | 12.2 | 22.1 |
| 10 | 395 | 2266.0 | 1 | 872 ± 5 | 11.8 ± 0.6 | - | - | - | 6.1 | 22.8 | 57.7 | 13.4 | 0.8 | 56.4 | 34.4 | 7.1 | 1.3 | 53.9 | 19.8 | 26.3 |
| 11 | 87 | 324.4 | 1,5 | 720 ± 17 | 31.6 ± 2.4 | - | - | - | 9.2 | 28.8 | 26.4 | 35.6 | - | 4.6 | 54.0 | 39.1 | 2.3 | 9.2 | 13.8 | 77.0 |
| 12 | 141 | 867.1 | 1,2,3,8 | 1125 ± 9 | 10.8 ± 0.9 | - | - | 5.7 | 73.1 | 19.8 | 1.4 | - | 0.7 | 47.5 | 41.9 | 9.2 | 0.7 | 68.1 | 17.7 | 14.2 |
| gorge | 60 | 377.4 | 5 | 744 ± 26 | 70.3 ± 4.4 | 20.0 | 3.3 | 21.7 | 20.0 | 20.0 | 11.7 | 3.3 | - | - | 5.0 | 8.3 | 86.7 | - | 1.7 | 98.3 |
| Tot. [4] | 1960 | 11 222.6 | 1,3,5,8 | 997 ± 4 | 11.0 ± 0.3 | 3.3 | 1.7 | 4.7 | 16.1 | 17.7 | 40.2 | 16.3 | 2.5 | 52.6 | 35.9 | 8.2 | 0.8 | 59.1 | 18.0 | 22.9 |

1. refer to Table 5.1 for geology notation
2. refer to Table 5.2 for terrain element notation
3. 1=accessible; 2=limited access; 3=inaccessible
4. excluding the eastern gorge system

Table 5.11. Land tenure and distance measures of land provinces in the study region.

| LP | Area (km²) | % land tenure [1] | | | | | % bearing from Armidale [2] | | | | | | | | | | | | DNR [3] or T (m) | TD [4] (km) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PR | TSR | SF | NP/NR | Urban | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | |
| 1 | 2664.5 | 96.3 | 1.0 | 1.4 | 0.1 | 1.2 | 4.7 | 8.2 | 22.1 | 13.8 | 8.2 | 10.0 | 13.8 | 5.4 | 2.4 | 2.7 | 4.7 | 4.0 | 484 ± 22 | 30.8 ± 0.8 |
| 2 | 500.7 | 97.0 | 2.6 | - | - | 0.4 | 73.0 | 9.4 | - | - | - | - | - | - | - | - | - | 17.6 | 469 ± 65 | 44.8 ± 1.1 |
| 3 | 824.1 | 94.4 | 0.4 | 3.2 | 1.1 | 0.9 | - | - | - | - | 1.4 | 55.9 | 42.7 | - | - | - | - | - | 585 ± 45 | 72.4 ± 0.9 |
| 4 | 722.9 | 98.0 | 1.0 | 1.0 | - | - | - | 67.7 | 32.3 | - | - | - | - | - | - | - | - | - | 787 ± 64 | 64.3 ± 1.0 |
| 5 | 390.5 | 98.4 | 1.6 | - | - | - | 50.0 | 43.2 | 6.8 | - | - | - | - | - | - | - | - | - | 782 ± 75 | 65.8 ± 0.9 |
| 6 | 226.3 | 66.8 | 2.1 | 11.6 | 19.5 | - | - | - | 100.0 | - | - | - | - | - | - | - | - | - | 1383 ± 201 | 73.6 ± 1.9 |
| 7 | 114.1 | 84.6 | 9.7 | 5.3 | 0.3 | 0.1 | - | - | 100.0 | - | - | - | - | - | - | - | - | - | 799 ± 168 | 77.4 ± 1.0 |
| 8 | 764.0 | 98.5 | 1.4 | - | 0.1 | - | - | - | - | - | - | - | 3.0 | 35.0 | 23.9 | 36.6 | 1.5 | - | 679 ± 65 | 40.7 ± 0.7 |
| 9 | 1558.0 | 96.3 | 2.1 | - | 1.5 | 0.1 | - | - | - | - | - | - | - | 4.2 | 13.3 | 42.0 | 40.5 | - | 576 ± 32 | 67.6 ± 1.3 |
| 10 | 2266.0 | 97.5 | 0.6 | - | 1.8 | 0.1 | - | - | - | - | - | - | 1.8 | 36.2 | 41.2 | 16.0 | 4.8 | - | 612 ± 28 | 74.6 ± 0.9 |
| 11 | 324.4 | 99.2 | - | 0.7 | 0.1 | - | - | - | - | - | - | - | - | 50.6 | 49.4 | - | - | - | 578 ± 49 | 97.5 ± 1.5 |
| 12 | 867.1 | 98.7 | 0.6 | 0.1 | 0.6 | - | - | - | - | - | - | - | - | - | - | - | 51.8 | 48.2 | 532 ± 38 | 57.0 ± 1.3 |
| gorge | 377.4 | no data available | | | | | - | 16.7 | 8.3 | 23.3 | 33.4 | 18.3 | - | - | - | - | - | - | 1799 ± 130 | 63.8 ± 3.0 |
| Tot. [5] | 11 222.6 | 96.4 | 1.2 | 1.0 | 1.0 | 0.4 | 5.8 | 8.4 | 10.1 | 3.2 | 2.0 | 6.5 | 6.9 | 13.9 | 14.6 | 12.1 | 11.4 | 5.1 | 599 ± 13 | 58.6 ± 0.6 |

1. PR = private property (includes leasehold); TSR = travelling stock reserve; SF = state forest; NP/NR = national park/nature reserve.
2. refer to Table 5.3 for bearing notation
3. distance to nearest road or track
4. travel distance to Armidale
5. excluding the eastern gorge system

Table 5.12. Forest cover and biomass of land provinces in the study region.

| LP | Area ($km^2$) | MAR (mm) | % cover class [1] | | | | | | | Biomass (Mt) | Biomass ($t.ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cl.For. | Op.For. | Woodl. | Scatt. | Isol. | OW | Urban | | |
| 1 | 2664.5 | 802 | 3.4 | 5.5 | 14.0 | 27.5 | 48.1 | 0.3 | 1.2 | 3.943 | 14.8 ± 1.1 |
| 2 | 500.7 | 883 | 0.4 | 2.2 | 8.9 | 20.1 | 67.4 | 0.6 | 0.4 | 0.295 | 5.9 ± 0.9 |
| 3 | 824.1 | 804 | 9.1 | 4.3 | 8.6 | 23.9 | 52.9 | 0.3 | 0.9 | 1.846 | 22.4 ± 3.4 |
| 4 | 722.9 | 855 | 10.7 | 12.7 | 19.7 | 22.8 | 34.0 | 0.1 | - | 2.516 | 34.8 ± 3.3 |
| 5 | 390.5 | 892 | 8.5 | 12.1 | 20.7 | 25.4 | 33.2 | 0.1 | - | 1.222 | 31.3 ± 3.3 |
| 6 | 226.3 | 074 | 52.6 | 16.6 | 12.1 | 11.8 | 6.9 | - | - | 2.720 | 120.2 ± 10.8 |
| 7 | 114.1 | 1204 | 11.0 | 11.5 | 23.2 | 24.8 | 27.0 | 2.4 | 0.1 | 0.476 | 41.7 ± 1.1 |
| 8 | 764.0 | 768 | 2.4 | 7.0 | 17.5 | 30.9 | 42.0 | 0.2 | - | 1.123 | 14.7 ± 1.6 |
| 9 | 1558.0 | 773 | 3.5 | 8.1 | 20.4 | 34.3 | 33.4 | 0.2 | 0.1 | 2.898 | 18.6 ± 1.6 |
| 10 | 2266.0 | 785 | 13.8 | 16.4 | 22.5 | 25.7 | 21.4 | 0.1 | 0.1 | 9.472 | 41.8 ± 2.1 |
| 11 | 324.4 | 775 | 16.9 | 16.9 | 30.4 | 25.5 | 10.3 | 0.0 | - | 1.515 | 46.7 ± 4.1 |
| 12 | 867.1 | 864 | 9.5 | 10.6 | 20.0 | 27.3 | 32.5 | 0.1 | - | 2.775 | 32.0 ± 3.2 |
| gorge | 377.4 | 909 | not data available | | | | | | | | |
| Tot [2] | 11 222.6 | 814 | 8.6 | 9.8 | 18.1 | 26.9 | 36.0 | 0.2 | 0.4 | 30.801 | 27.4 ± 0.8 |

1. Cl.For. = closed forest; Op.For. = open forest; Woodl. = woodland; Scatt. = scattered trees; Isol. = isolated trees; OW = open water
2. excluding the eastern gorge system

standing timber is extracted each year, and that the present quantity would sustain Armidale residents beyond the year 3000! However, a tree-rich landscape does not necessarily imply adequate access to forest products. A more realistic investigation of resource availability and suitability accounts for timber species requirements, land tenure, accessibility, road distance and ecological constraints. These factors are presently discussed.

***Accessibility and land tenure***

Figure 5.5 shows the quantity of standing fuelwood in the study region according to land tenure, cover class and accessibility. Of the total estimated 31.720 Mt in the study region, 14.652 Mt (46.2%) is inaccessible to fuelwood logging, including 11.086 Mt (75.7%) in closed and open forest on private land and 2.085 Mt (14.2%) in closed forest in nature conservation areas and state forests. This is associated with relatively steep terrain (mean slope ~ 14°). A total of 6.032 Mt (19.0%) has limited accessibility, of which 5.313 Mt (88.1%) occurs on private land, mostly in closed and open forest, and 0.569 Mt (9.4%) occurs in state forest. Extraction of fuelwood from such areas is considered inappropriate for urban supply in terms of travel and loading time and risk of bogging and soil erosion on steeper slopes. A total of 11.037 Mt of fuelwood biomass (34.8%) is accessible by truck and 2-wheel drive vehicle, including 10.094 Mt (91.5%) on private property and 0.496 Mt (4.5%) and 0.373 Mt (3.4%) on TSR and state forest, respectively. The total area of accessible land in the study region is 6630 $km^2$, with a mean and maximum recorded slope of 3° and 17°, respectively.

Land tenure is an important criterion for selecting fuelwood stands in native forest. National parks and nature reserves are designated for protection of flora and fauna and other natural features and timber removal is strictly prohibited. Of the 11 223 $km^2$ of non-gorge country in the study region, an estimated 116 $km^2$ (1.0%) comprises national park or nature reserve, harbouring a total 1.634 Mt of fuelwood timber (Tables 5.6 and 5.7). Of this, only 0.073 Mt within about 5 $km^2$ is accessible.

The paucity of protected land in the study region emphasises the importance of other public reserves for complementing nature conservation (Morgan and Terrey 1990). TSR land comprises numerous patches and strips of open forest, woodland and scattered trees located at regular intervals in the landscape (Figure 2.4). It constitutes a combined 132 $km^2$ or 1.2% of the study region (Table 5.6). Extraction of timber from TSR is permitted under license (a procedure which is largely ignored by the local community) and a significant proportion is taken from such lands (Wall and Reid 1993). Williams and Metcalfe (1991) have identified significant conservation values of TSRs in the Armidale region, recommending that they not be alienated and that illegal felling of trees for firewood and fencewood be controlled by introduction of farm plantation programs. These ideals are endorsed in this thesis and no further consideration is given to the production of fuelwood from the 0.496 Mt of accessible timber in local TSRs, and the small quantity of timber contained along roadsides.

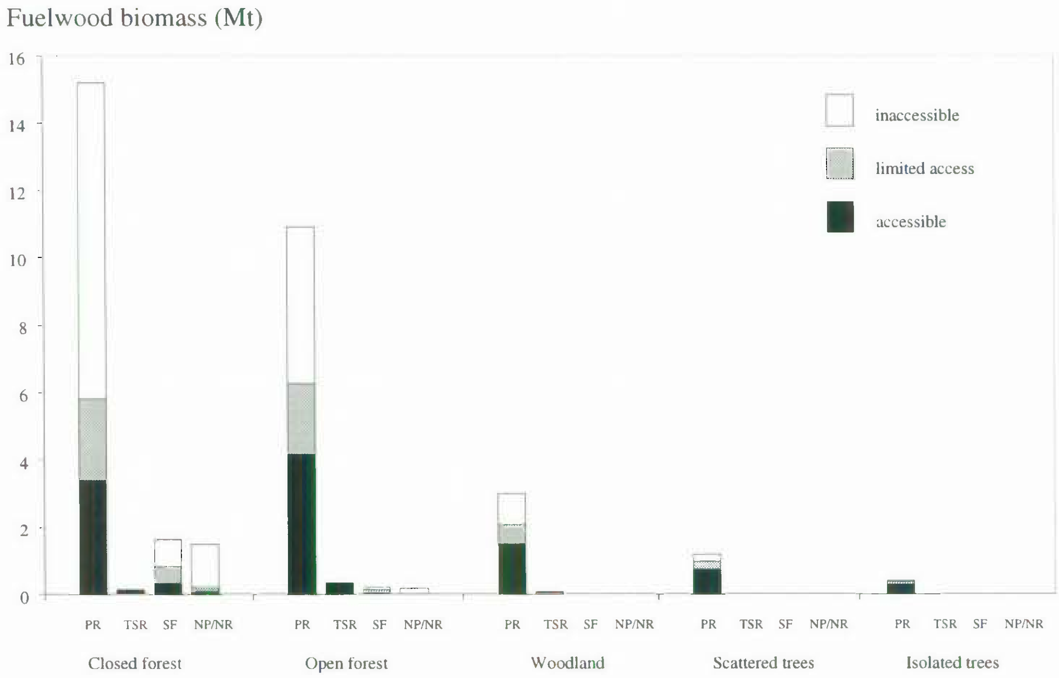


Figure 5.5. Accessibility of fuelwood biomass in stands of varying cover and land tenure in the study region.

***Travel distance***

The maximum road distance from Armidale to the perimeter of the study region is about 150 km. A total round distance of 300 km would thus be required to cart a single load of firewood into town from the furthest point. While this may not be economically feasible using a utility and trailer, trucks can carry large loads at relatively low cost. Distance from Armidale is not considered a constraint to timber availability within Armidale's fuelwood catchment.

***Species suitability***

Various stands within the 6481 km$^2$ of accessible private property and state forest in the study region are dominated by inferior eucalypt species considered unsuitable for production of domestic fuelwood (section 2.2.5). Table 5.13 lists the factors associated with distribution of inferior stands as adapted from land province descriptions by Morgan and Terrey (1990). The factors have been used in conjunction with the forest inventory database to estimate the area of land dominated by 'light' species and the biomass contained therein. These are also shown in Table 5.13.

Of a total 10.467 Mt of fuelwood timber contained within 6481 km$^2$ of accessible private land and state forest, some 3.050 Mt (29.1%) occurs as inferior species across 2416 km$^2$ (Figure 5.6). An estimated 3.027 Mt occurs on private land, representing 30% of all accessible biomass on private land, while 0.023 Mt occurs in state forest, representing just 6.2% of all accessible biomass in state forest. A total of 2.688 Mt of inferior timber (88.1%) occurs in private forest and woodland.

Table 5.13. Occurrence of inferior species in accessible stands on private property and state forest in the study region (percentages in parentheses).

| Land Province | Location of 'light' species | Biomass (Mt) | Area ($km^2$) |
|---|---|---|---|
| Armidale plateau : | *E. viminalis*, *E. pauciflora*, *E. stellutata* and *E. nova-anglica* dominant on lower slopes and poorly drained valley floors. | 0.433 [11.0] | 738.9 [27.7] |
| Guyra-Glen Innes basalts: | *E. pauciflora*, *E. stellulata*, *E. viminalis* on midslopes *with E. nova-anglica* on lower slopes and valleys. | 0.075 [25.6] | 201.8 [40.3] |
| Walcha plateau: | *E. viminalis* and *E. dalrympleana* on midslopes and *E. nova-anglica* on valley floors in Sandon Beds. | 0.176 [9.5] | 342.6 [41.6] |
| Wongwibinda plateau: | *E. stellulata*, *E. pauciflora* and *E. acaciiformis* on mid-lower slopes and *E. nova-anglica* in valleys 1100 - 1300 m a.s.l. *E. pauciflora*. *E. stellulata* and *E. viminalis* dominant >1300 m a.s.l. | 0.477 [18.9] | 217.7 [30.1] |
| Nightcap | *E. acaciiformis*, *E. radiata* and *E. viminalis* on midslopes *with E. nova-anglica*, *E. stellulata* and *E. pauciflora* on lower slopes and valleys. | 0.158 [13.0] | 103.7 [26.6] |
| Round Mountain: | *E. acaciiformis*, *E. radiata* and *E. dalrympleana* on lower slopes and valley floors > 1200 m a.s.l. and *E. dalrympleana*, *E. bridgesiana*, *E. nova-anglica*, *E. acaciiformis* and *E. pauciflora* on midslopes to valley floors < 1200 m a.s.l. | 0.179 [6.6] | 41.3 [18.3] |
| Ebor basalts | *E. pauciflora*, *E. stellulata* and *E. nova-anglica* in lower slopes and valleys. | 0.082 [17.2] | 26.5 [23.2] |
| Yarrowyck-Kentucky Downs: | *E. nova-anglica* and *E. dalrympleana* woodland dominant on mid to lower slopes and valleys south west of Armidale >1000 m a.s.l. | 0.025 [2.3] | 95.5 [12.5] |
| Bundarra Downs: | - | - | - |
| Nandewaars | *E. viminalis*, *E. pauciflora* and *E. nova-anglica* on lower slopes and valley floors in south-east. | 1.129 [10.3] | 490.3 [18.9] |
| Moredun volcanics | *E. pauciflora*, *E. stellulata*, *E. viminalis* and *E. nova-anglica* from midslopes to valley floors on basalts and adamellites. | 0.316 [11.4] | 157.2 [18.2] |
| | | 3.050 | 2415.5 |

note : percentages are relative to all land and biomass contained within land provinces, including inaccessible land, TSR and conservation areas (not including urban land and gorges)

### 5.4.3. Ecological constraints to biomass availability

***Preamble***

Given the large number of dead trees in the study region (section 5.3.2), it is reasonable to assume that several hundred thousand tonnes of dead wood are available for harvesting, although the proportion suitable as fuelwood is unknown. While the industry is presently reliant on dead timber, it might be necessary to retain some dead trees and dead fallen timber in rural forest systems to maintain structural heterogeneity and ecosystem complexity (e.g. section 2.5.2). Harvesting green-felled trees for fuelwood could reduce the environmental impact of dead wood removal.

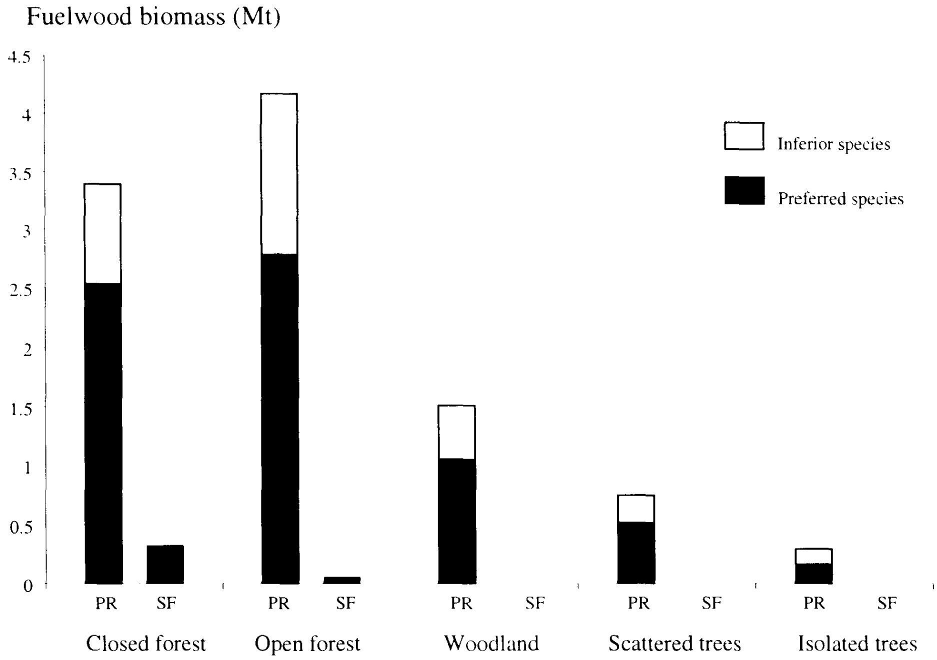


Figure 5.6. Relative contribution to fuelwood biomass of inferior and preferred fuelwood species in accessible stands of varying cover on private land and state forest.

A total of 7.417 Mt of premium quality fuelwood occurs within a combined 4066 $km^2$ of accessible private forest and state forest in the study region (section 5.4.2), and is potentially available for production of domestic fuelwood on a green-felled basis. However, a large proportion of this resource might eventually be withdrawn from consideration on the grounds that fuelwood harvesting may adversely affect nature and resource conservation values. While the evidence is presently inconclusive, ecological and natural resource arguments are reviewed briefly below that could ultimately lead to a reduction in the area of forest considered suitable for fuelwood harvesting as a result of changing community values.

***Cover***

The impact of tree removal on survival of fauna species is often dependent on the availability of suitable alternative habitat. It follows that habitat destruction and subsequent loss of niche opportunity for a given harvest intensity would be relatively greater in woodland and stands of scattered and isolated trees than in eucalypt forest. Removal of 10 trees.$ha^{-1}$ may result in a loss of 50% of standing timber in a woodland community compared with 5% in a closed forest community.

In a study of the conservation of 137 woodland bird species on the New England Tablelands, Barrett *et al.* (1994) argued the need to maintain species richness by appropriate management outside large blocks of continuous woodland. They suggested that a conservation strategy focused only on habitat specialists in large blocks could result in loss of species that require remnant eucalypt stands and single isolated trees. From an agricultural viewpoint, isolated trees or clumps of trees such as *E. melliodora* are important for the provision of shade and shelter of domestic livestock (Brown and Hall 1968; Reid and Wilson 1985). It is suggested that domestic fuelwood supply might thus be thus confined to stands of closed and open forest, and that areas of woodland and scattered or isolated trees be protected from fuelwood operations as habitat for native fauna, for maintenance of local genetic diversity, and for provision of shade and shelter. This resource represents some 1.730 Mt air-dry timber in accessible private lands (Figures 5.6 and 5.7), covering 3639 km$^2$, or 31.4% of the study region.

***Patch size and isolation***

Although the size of habitat islands is a major determinant of species richness (Suckling 1982; Harris 1984; Bennett 1990; Lindenmayer 1994), habitat size requirements and viable population sizes for fauna and flora are not well understood for even the most common species (Scanlan *et al.* 1991, 1992). The effects of selective fuelwood cutting on the viability of flora and fauna populations have not been studied in Australia. A review of relevant biogeographical literature, however, assists in the choice of minimum patch size for firewood manipulation in the New England area.

If the agricultural landscape is viewed as an holistic system important in the conservation of biological resources rather than a hostile matrix in which remnant stands of native vegetation and associated fauna species struggle to survive (Barrett *et al.* 1994), the characteristics of individual remnant patches assume importance in their allocation to different forms of management. The size, shape, isolation and condition (degree of disturbance) of native forest determines the extent to which it is able to retain self-sustaining populations of individual species. Those species most vulnerable to local extinction are represented by small populations due to factors such as spatial resource limitation, exploitation, and predation or preclusion by feral animals and weeds. As habitat islands become progressively more isolated, fauna are rapidly lost, most notably reptiles and amphibians, followed by mammals, permanent resident birds and migratory birds (Harris 1984). Analogous to the increasing isolation of remnant stands is a reduction in their overall size and an increase in their level of disturbance through the mechanism of edge effects. Harris (1984) cited various studies which refer to the 'three-tree-height' rule of thumb for climatic edge effects (e.g. wind and light will affect the ecology of a patch within 75 m of a pasture-forest interface in a stand of 25 m mean dominant height). Scanlan *et al.* (1992) similarly defined natural habitat as that part of a forest patch greater than 75 m from the nearest boundary.

While it could be argued that fuelwood extraction be confined to small patches in which species richness is relatively low (Bennett 1990), edge effects and disturbance relatively high (Scanlan *et al.* 1992) and conservation status considerably lower (RAC 1992), it is contended that farm forestry be discouraged in small patches to ensure that their regional contribution to the vegetation mosaic is not thwarted. A heterogeneous landscape containing abundant edges and a variety of vegetation types encourages high species diversity (Gepp 1985), although many are 'generalist' species for which conservation is not a major concern (Orians and Millar 1992). In addition, smaller patches assume an importance in excess of their size since they function as corridors between larger reserves, linking areas capable of sustaining viable populations of most plants and animal native to a local region (Hibberd 1978). Some native species can occur in small remnants at densities comparable to or in excess of those in large reserves (Loyn and Suckling 1987).

A minimum forest area of 40 ha, in which effective natural habitat (less edges) provides about 25 ha in a circular clump of diameter 720 m, or 10 ha in a 2000 x 200 m strip (from Scanlan *et al.* 1992), is suggested for fuelwood cutting in the New England region. By eliminating photo-grids from the forest inventory in which accessible closed and open forest collectively account for less than 40% of the total cover (i.e. < 40 ha per 100 ha plot), a further 2.707 Mt of accessible forest covering 235 $km^2$ (2% of the study region) might be excluded from harvesting due to its fragmented and isolated nature (Figure 5.7).

***Representativeness***

A characteristic of forest clearing and exploitation in agricultural regions is depletion of certain tree species. Bahre and Hutchinson (1985) discussed the loss of native juniper and oak to fuelwood cutters in the Arizona mountains and Osei (1993) discussed depletion of the favoured *Celtis* spp. in areas of Ghana. In the New England region, timber cutting has been particularly severe on *E. sideroxylon* and river oak *C. cunninghamiana*. The former was favoured as mining timber, railway sleepers, fencewood and fuelwood. The latter was favoured principally for its burning qualities.

The endangered Regent Honeyeater *Xanthomyza phrygia* has nested and bred 50 km west of Armidale in remnant eucalypt stands dominated by *E. sideroxylon* over the past 10 years (Ley and Williams 1992). The stands are poorly represented in the study region, comprising a discontinuum of small disturbed patches in the west (Figure 2.1). Without the opportunity to conserve large blocks as reserves, these patches should be maintained as a vegetation mosaic (Leach and Recher 1993) for genetic, habitat, ecological and aesthetic reasons (e.g. Franklin *et al.* 1989; Traill 1991; Ley and Williams 1992). Stands of forest oak *C. torulosa* are limited to the eastern escarpment and *C. cunninghamiana* gallery forests are restricted to a few major watercourses, mostly west of Armidale. While casuarinas provide excellent fuelwood, they also provide forage and habitat for fauna with specialised requirements such as the rare and vulnerable glossy black cockatoo *Calyptorhynchus lathami*, as well as the yellow-tailed black cockatoo *C. funereus* and the white-plumed honeyeater *Lichenostomus penicillatus*, all of which are uncommon on the Northern Tablelands (Barrett *et al.* 1994). River oak is host to the mistletoe *Amyema cambagei*, which provides annually a source of nectar and fruit for transitory birds and insects. Only under fuelwood plantations (and naturally regenerating woodlots for *E. sideroxylon*) should these restricted tree species be targeted as a future source of green-felled fuelwood for domestic production. Assuming a total standing area of about 15 $km^2$ of accessible eucalypt forest on private land dominated by ironbark and casuarina, an additional 0.200 Mt of standing timber might be discounted from the area of forest allocated to fuelwood forestry (Figure 5.7).

Stringybarks are probably the most suitable group of naturally occurring eucalypts from which to extract green fuelwood timber for domestic consumption because they are relatively abundant, display superior growth, are easy to harvest and split (especially smaller trees), and provide high quality firewood. Healthy stands of yellow box and red gum might also be utilised, although they are uncommon in the region.

***Water quality and erosion***

Riparian vegetation in agricultural systems can intercept and retain nutrients from surrounding land and maintain water quality (Fail *et al.* 1987; Forman and Gordon 1986; Muscutt *et al.* 1993). The geomorphological and ecological stability of Australian streambeds afforded by native vegetation is reviewed by Riding and Carter (1992), who discussed the role of trees in providing allochthonous input to streams and rivers, stabilising soil banks with roots and litter, and providing an important source of shade and habitat for aquatic and terrestrial fauna. Agricultural practice should include long-term maintenance of natural riparian vegetation (Fail *et al.* 1987) and extraction of riparian tree species such as river she-oak and river red gum for supply of firewood in southern New England is not recommended.

Legislation under the Pollution Control Act 1970 prohibits the felling of native timber in State Forest within 20 m of any watercourse and similar legislation under 1988 amendments of the Soil Conservation Act 1938 restricts the unpermitted cutting of trees in rural land within 20 m of any prescribed stream or lake. About 14% of all photo-points fell within 20 m of watercourses, representing 0.393 Mt of forest biomass (Figure 5.7) in an area of 28.7 $km^2$.

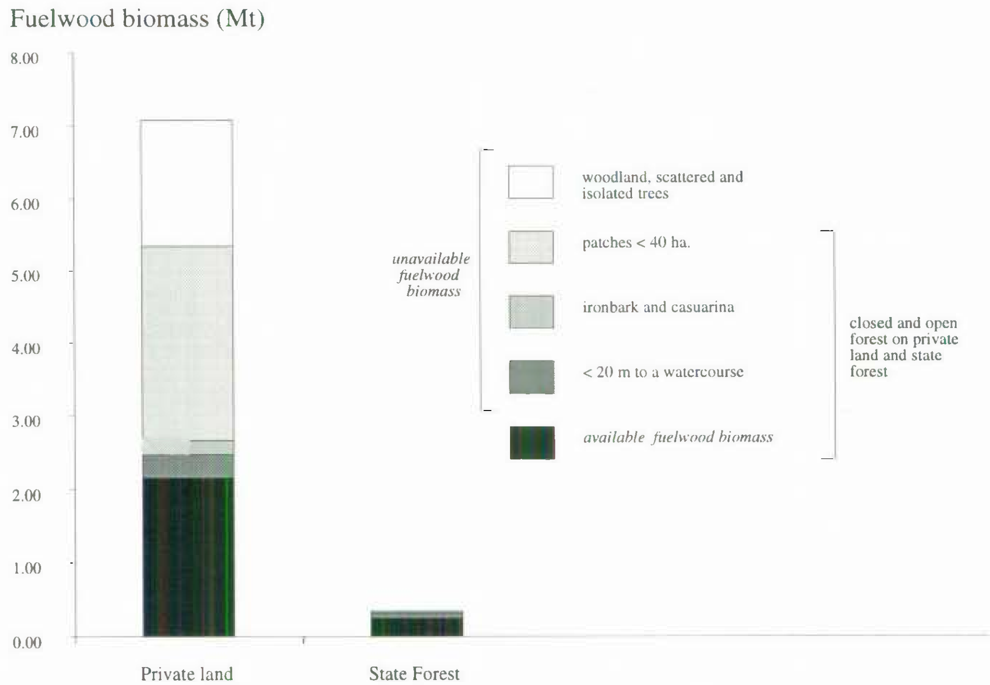


Figure 5.7. Exemption of fuelwood biomass on the basis of cover class, patch size, proximity to watercourses and tree species.

### 5.4.4. Overview

Of the 31.720 Mt of fuelwood biomass in the study region, some 20.684 Mt (65.2%) is inaccessible or has limited accessibility, 0.569 Mt (1.8%) occurs in TSRs or conservation reserves, and 3.050 Mt (9.6%) comprises inferior eucalypt species. Of the remaining 7.417 Mt of good-quality fuelwood on accessible private land and state forest, it is suggested that 5.030 Mt (67.8%) might be reserved against urban fuelwood production on ecological grounds, including 1.730 Mt (23.3%) in woodland and stands of scattered and isolated trees, 2.707 Mt (36.5%) in remnant patches less than 40 ha, 0.200 Mt (2.7%) of ironbark and casuarina, and 0.393 Mt (5.3%) within 20 m of riparian zones. An estimated 29.333 Mt (92.5%) of total fuelwood biomass in the study region could thus be deemed inappropriate for harvesting for urban supply. The remaining 2.387 Mt of fuelwood is concentrated in forest stands dominated by stringybark, including 2.156 Mt on private land (157 $km^2$) and 0.231 Mt in state forest (15 $km^2$). This represents $2.984 \times 10^{10}$ MJ of useable energy, about 60 times the amount of wood energy consumed in the study region each year. The mean land-slope of target stands is 6.8 ± 0.5%, the mean distance from Armidale is 69.7 ± 3.1 km, and the mean fuelwood biomass is 137.2 ± 3.1 $t.ha^{-1}$ on private land and 158.2 ± 14.5 $t.ha^{-1}$ in state forest.

## 5.5. Conclusions

Aerial photographic interpretation was used to estimate the area of five eucalypt cover classes in Armidale's fuelwood catchment: closed forest; open forest; woodland; scattered trees; and isolated trees. This information was used with tree mensuration and forest sampling data (Chapters 3 and 4) to generate an estimate of 31.720 Mt of standing fuelwood biomass over an area of 11 222 $km^2$. Accessibility, land tenure, species, and ecological constraints were subsequently used to eliminate 11 050 $km^2$ of land from consideration for fuelwood supply. The total quantity of fuelwood biomass considered suitable for harvesting in the study region was refined to 2.387 Mt, contained within 172 $km^2$ of stringybark-dominated eucalypt forest. The regional consumption of 30 780 $t.yr^{-1}$ (section 2.4.2) thus represents 1.3% of the harvestable fuelwood resource.