Floristics and vegetation biomass of a forest catchment, Kioloa, south coastal New South Wales

J. Ash and C. Helman

Abstract

Ash, J. & Helman, C. (The Edith and Joy London Foundation, Australian National University, Kioloa, Australia 2539) 1990. Floristics and vegetation biomass of a forest catchment, Kioloa, south coastal New South Wales. Cunninghamia 2(2): 167–182.* Butlers Creek near Kioloa (35°33'S 150°22'E) is a monitored forest catchment of 33.2 ha, 1 to 2 km inland and at 17 to 172 m altitude on sandstones of the Murramarang Range.

A polythetic agglomerative classification of trees >5 cm diameter at breast height (d.b.h.) at 285 point-centred quarter sites revealed five vegetation types: 1 – notophyll rainforest associated with south-facing gullies typified by abundant *Acmena smithii, Ceratopetalum apetalum* and *Doryphora sassafras;* 2 – notophyll species around gullies with abundant *Cryptocarya microneura, Doryphora sassafras* and *Callicoma serratifolia;* 3 – *Acacia mabelliae* on slopes above the rainforest gullies together with both notophyll and sclerophyll species; 4 – sclerophyll forest on mid-slopes with abundant *Eucalyptus maculata*, merging with; 5 – sclerophyll forest on steep upper slopes with abundant *E. botryoides* on eastern facing slopes and *E. pilularis* on southern slopes. Fires periodically burn the sclerophyll and *Acacia mabelliae* forest but rarely enter the rainforest gullies.

Biomass of trees and shrubs was estimated from regression equations relating $\log_{10}$ d.b.h. with $\log_{10}$ wood volume, $\log_{10}$ bark volume, wood and bark density, the number and average volume of 2 cm diameter branches, and leaf weight on these branches. Separate equations were derived for *Eucalyptus* species and notophyll species, and applied to the measurements of d.b.h. from the point-centred quarter survey. Tree biomass averaged 510 t ha^{-1}, of which 86% was *Eucalyptus*, and comprised 97% of total biomass for the catchment. Root biomass declined from 18% in saplings to 12% in the largest trees, and overall, 14% of biomass was below ground. *Eucalyptus* net wood and bark production in the sclerophyll forest was estimated as 12.8 t ha^{-1}yr^{-1} and 2.9 t ha^{-1}yr^{-1} in the intermediate and notophyll forest, excluding notophyll species. Selective logging of *Eucalyptus* >50 cm d.b.h. removed about 2.4 trees ha^{-1}, about 2.7% of the total tree biomass.

The size threshold for inclusion in surveys is discussed in relation to the floristic analysis, and the floristics and biomass of the catchment are considered in their regional context.

Introduction

Some years after the Australian National University was given the property now known as the Edith and Joy London Foundation, a small forested catchment was set aside for long-term monitoring and experimentation. An initial floristic survey was made in 1980, before the catchment was selectively logged and a second survey was made in 1984 (Helman 1981 1984). A forest biomass survey was made at the time of logging (Ash & Southern 1982). This paper presents background information on the catchment and the results of these surveys. The study area is the catchment of a stream-gauging weir on

---

* Present address: Botany Department, Australian National University, GPO Box 4, Canberra, Australia 2601.

Butlers Creek at Kioloa (35°33′S 150°22′E Figure 1), on the south coast of New South Wales; has an area of 33.2 ha, and extends from the weir at 17 m altitude to 100 to 172 m altitude on the divide of the Murramarang Range. The catchment is shaped like a portion of a basin, the lower half having slopes of 10° to 15° and the upper half 25° to 35°, with 2.6 km of drainage channels converging on the weir.

Geology and soils

The substrate is mostly Permian sandstone of the Shoalhaven group (Pogson 1972), which outcrops as boulders and low cliffs along the steep upper slopes of the catchment, and also as pavements on the lower slopes. The ridge forming the north-eastern divide has a capping of essexite, an instrusive alkaline gabbro, and essexite boulders occur downslope (Figure 1).

The soils vary with the nature and depth of the bedrock. On sandstone the profile typically passes from a dark sandy organic 'O' horizon through a grey leached sandy 'A' horizon, to a mottled yellow-grey 'B' horizon with a high clay content, overlying partially weathered sandstone. Quartz pebbles and sandstone fragments occur throughout the profiles. The depth of the profile varies from 30 cm on steep slopes to more than one metre on the gentler lower slopes. Enclosed depressions on the sandstone pavements have highly organic soils and had a water table at a depth of 30 to 50 cm. On essexite the soil forms a matrix between 10 to 50 cm diameter boulders, and the profile passes from a dark organic layer into brown and grey clays within 20 to 30 cm. Downslope of the essexite, on a sandstone substrate, the soil has intermediate characteristics.

Soil water drainage is impeded by clay and iron-rich layers in the 'B' horizon. Three soil water regimes may be identified: sandstone soils on slopes with water available at depth, gullies and depressions in sandstone with a water table near the surface, and the essexite ridge with limited surface water availability.

Climate

Mean daily temperatures range from 9° to 16°C in July and 17° to 23°C in January with extremes of 0° and 40°C. Frosts are infrequent in the near-coastal forests. The mean monthly rainfall is about 100 mm with a uniform distribution through the year, while pan evaporation increases from about 40 mm in July to 120 mm in January. Plant growth is probably limited by low temperatures in winter and by water deficits in most summers. The steep south-facing slopes and gullies in the catchment are more humid throughout the year.

Vegetation

The vegetation comprises both sclerophyll and notophyll-rainforest species and varies in response to substrate, topography, aspect and human interference. Except for tracks, the catchment is forested and has a canopy height of up to 40 m. Sclerophyll species (mostly *Eucalyptus* spp.) occur throughout the catchment but are less abundant in the south-facing gullies. Notophyll trees and shrubs are associated with gullies and adjacent slopes (Figure 1). Large notophyll trees are restricted to the gullies but smaller individuals occur on the slopes. The understorey varies with site conditions. *Gahnia sieberana* is abundant in wetter areas, ferns (e.g. *Culcita dubia* and *Histiopteris incisa*) are abundant in shady conditions and *Pteridium esculentum* and grasses are abundant in

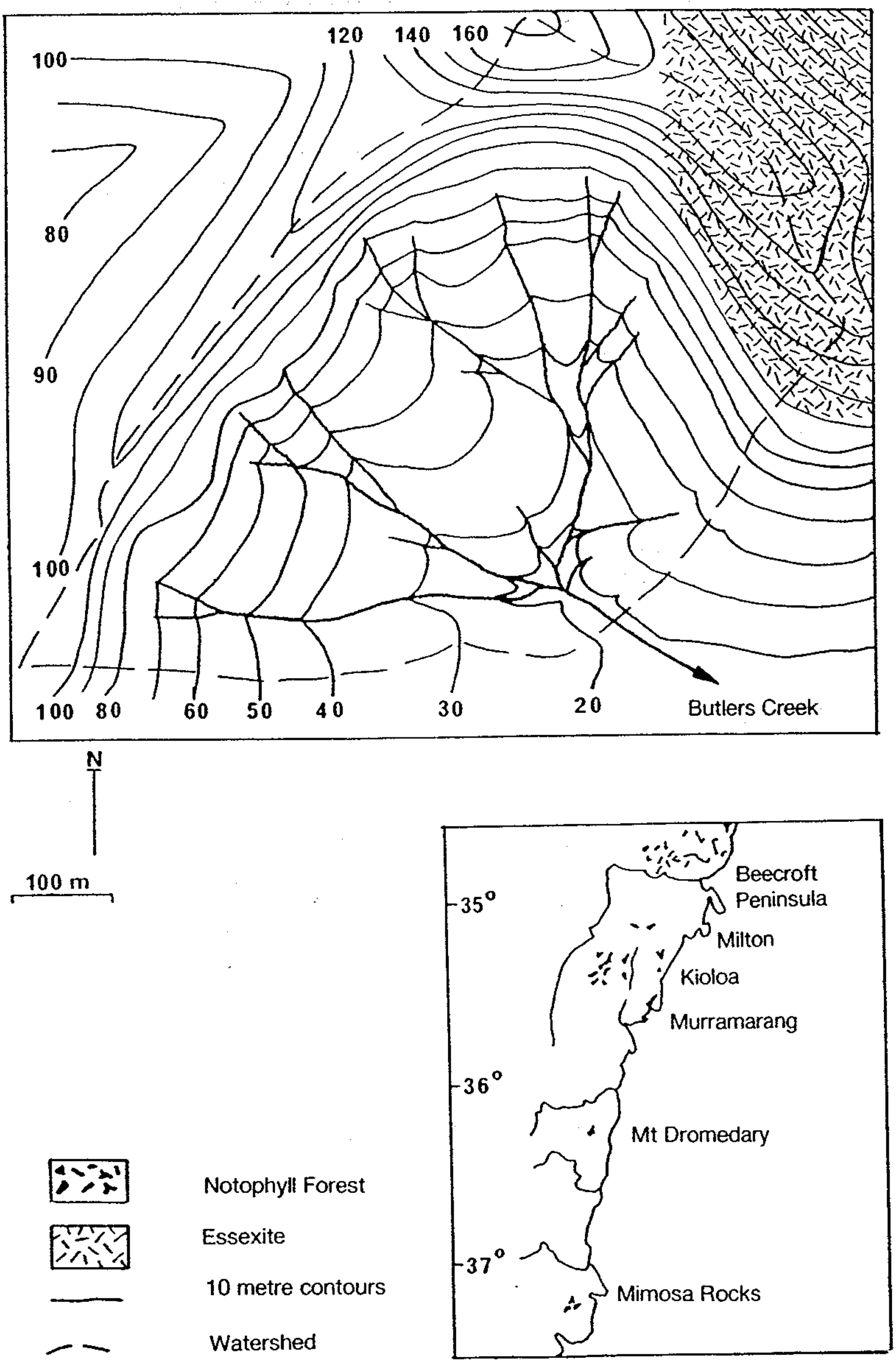

Figure 1. Maps showing the location of Kioloa and other major notophyll forest patches in southern New South Wales (Inset), and the geology and topography of the Butlers Creek catchment.

clearings and open eucalypt forest. *Macrozamia communis* is restricted to sandstone outcrops near the rim of the catchment.

Site history

Timber has been taken from the catchment since the 1880s, most intensively in the period 1910–1926 (pers. comm. J. London). The lower slopes have been most frequently logged. Old tree stumps indicate that the forest used to contain many large trees, of which there are now few living examples. The logging history and regeneration are typical of adjacent forests.

Methods

Floristic classification of woody dicotyledons

The point-centred quarter survey method was used (Curtis 1959, Mueller-Dombois and Ellenberg 1974) with a minimum size of 5 cm diameter at breast height (d.b.h.). At each point, quadrants were defined by the four cardinal points of a magnetic compass. In each quadrant the nearest living tree, and any nearer stumps of felled trees were recorded by their species, and distance from the centre point. Points were chosen at predetermined regular intervals along the catchment contours. In 1981, 132 points were located at 40 m intervals along each 10 m contour between 20 m and 60 m altitudes and at 120 m intervals along each 10 m contour between 70 m and 140 m altitude. Selective logging interfered with sampling the upper part of the catchment in 1981, and a second survey of 153 points was conducted in 1984, at intermediate locations on the contours, extending up to 170 m altitude. Despite logging during 1981–82 only 0.5% of the trees selected during the 1984 survey were felled, so major changes in the forest composition between the surveys were not expected. Tree ferns, *Macrozamia communis* and *Livistona australis* were minor components of the woody vegetation, and were excluded from the survey.

The species abundance at each point was used to classify the vegetation using an agglomerative polythetic algorithm (CLUSTAN) with a Bray-Curtis distance measure (Bray and Curtis 1957) and a space-conserving sorting stratey using group averages (Wishart 1978). The resulting vegetation types were mapped to facilitate interpretation. The results of the two surveys were very similar and they were combined for presentation here.

Estimation of biomass

Various components of the biomass in the catchment were estimated, using several procedures. Total tree biomass (>5 cm d.b.h.) was estimated from the abundance of trees as determined by the floristic survey, their d.b.h. and regression equations linking d.b.h. with biomass. A similar procedure was used for shrubs and saplings (0–5 cm d.b.h.), for which a point-centred quarter survey of 190 points was undertaken at 10 m intervals along the 35 m and 100 m contours.

Tree biomass was estimated in several components: wood and bark volume above and below ground, wood density in relation to d.b.h., bark density, the number of branches of 2 cm wood diameter, their volume, and the number, dry-weight and area of leaves on branches of 2 cm wood diameter. The relationships between these components and non-destructive measurements (d.b.h.) were determined from uprooted, fallen and felled trees in and around the catchment. In many cases one or more biomass components could not be estimated from a tree. Because of its importance for biomass estimation, particular attention was given to measurements of d.b.h. and possible errors in the survey d.b.h. measurements.

Trunk d.b.h. calculated from a circumference tape overestimates the mean diameter if the trunk is not circular. An examination of 50 *Eucalyptus maculata* stumps showed that the ratio of the longest to the shortest diameter ranged from 1.0 to 1.35 with a mean of about 1.15. In small trees the sections are usually elliptical, but as buttresses develop the shape is convoluted and the circumference tape passes across the buttresses, enclosing spaces. Relative to a circular trunk of the same cross-sectional area, the tape measurement increases from 1.0 to about 1.5 for highly buttressed trees. Buttressing becomes significant on eucalypts larger than about 120 cm d.b.h. Survey d.b.h. values (D) were, therefore, adjusted (d) by the formula:

$$d = D - 0.00053D^2$$

Wood volumes were estimated from measurements of corrected (circular) trunk, root and branch diameters at intervals of 2 to 5 m along every stem and branch down to 2 cm diameter and for roots down to 0.5 cm diameter. Branches of 2 cm wood diameter were removed from the upper and lower parts of tree canopies of six species, and the volume of the branches, leaf dry weight and leaf areas were measured. Root volumes were estimated from the proportion of the circumference which was exposed on uprooted trees. Bark volumes were estimated from bark thickness, and correction coefficients were determined for species with fissured bark by estimating the volume of bark in relation to the volume if the tree had a smooth bark.

Wood density generally increased from the sapwood to the heartwood, and a linear increase in density with trunk diameter was assumed, reaching heartwood density at the maximum observed diameter. Both sapwood and heartwood densities were estimated for several common species and supplemented by published densities corrected from 12% to 0% moisture content (Cause et al. 1974). Bark density did not show obvious variation with tree size so a single value was used for each species.

Total volume of the floristic survey trees was calculated from corrected trunk diameter (d) by substitution into the regression equations for each component of wood and bark volume and then converted to biomass by multiplication by the appropriate wood density and the bark density. Regression equations were also derived to determine tree biomass directly from corrected trunk diameter.

In addition to direct measurements of root volume on uprooted trees, an independent estimate of root biomass was made by excavating tree roots of less than 5 cm diameter from thirty 0.1 m^2 pits dug to a depth of 15 cm below the lowest recorded roots, typically 40 to 90 cm below the surface, at the base of the B horizon. Some roots penetrating fissures in the sandstone were probably overlooked by this procedure. Fifteen pits were equally spaced along each of the 30 m and 100 m contours.

Fallen logs (>5 cm diameter) were sampled by recording the cross-sectional area of logs along the 25 m, 50 m and 100 m contours; a total distance of 2.25

km. Logged trees were recorded in the 1984 survey, the next nearest tree being used in the floristic analysis. A second estimate of logged trees was made by

Table 1. Percentage frequency of species in forest types (1 to 5) and percentage of total tree biomass. + = present

Species	Sclerophyll		Interm	Notophyll		Biomass
	(1)	(2)	(3)	(4)	(5)	%
Acacia implexa	0.2	0.8				0.11
Acacia maidenii						0.03
Acacia mabelliae	0.4	3.2	19.0	+	4.3	6.59
Acmena smithii	0.5	0.8	0.4	0.8	9.4	2.67
Acronychia oblongifolia			0.6	0.2	0.2	0.02
Alectryon subcinereus				+	+	+
Astrotricha latifolia				+	+	+
Backhousia myrtifolia				0.4	0.4	0.63
Baloghia lucida				+	+	+
Callicoma serratifolia		0.4	0.6	1.2	0.6	0.25
Ceratopetalum apetalum		0.2	+	+	1.6	0.66
Claoxylon australe				+	0.2	0.01
Clerodendron tomentosum				+	0.2	0.01
Commersonia fraseri			1.9	0.2	0.2	0.10
Cryptocarya glaucescens				0.4	+	0.05
Cryptocarya microneura	0.4	0.2	2.0	2.3	1.3	1.59
Diospyros australis				+	+	0.02
Doryphora sassafras			0.2	3.0	0.9	0.49
Elaeocarpus reticulatus			0.2	0.2	+	0.04
Endiandra sieberi				+	0.2	0.01
Eucalyptus agglomerata	+					+
Eucalyptus botryoides	4.3	0.9	1.7	0.6	0.2	13.64
Eucalyptus globoidea	+		0.2			0.41
Eucalyptus gummifera	+					0.69
Eucalyptus maculata	0.2	13.5	2.8	+	0.6	59.46
Eucalyptus pilularis	2.3	3.9	3.0			11.55
Eucalyptus tereticornis		0.2	0.2			0.76
Eupomatia laurina			0.2			0.01
Exocarpus cupressiformis						0.01
Ficus coronata		0.2	0.2	1.1	0.6	0.13
Glochidion ferdinandi				+	0.2	0.14
Guioa semiglauca				+	+	+
Hedycarya angustifolia			0.2	0.2		0.01
Notolaea longifolia				+	+	+
Palmeria scandens				+	+	+
Pittosporum revolutum				+	+	0.02
Pittosporum undulatum				+	+	0.01
Pomaderris aspera				+	+	+
Prostanthera lasianthos				+	+	0.02
Psychotria loniceroides				+	+	+
Rapanea howittiana				0.2	+	0.01
Rhodamnia rubescens			0.2	+	0.4	0.08
Synoum glandulosum			1.1	0.6	0.2	0.03
Trema aspera				+	0.2	0.01
Tristianiopsis collina				0.2	+	0.02
Total	8.3	24.1	34.6	21.8	1.3	100

recording stumps in a 10 m wide transect along contours at 10 m altitude intervals.

Distinct regular growth rings were apparent in logged *Eucalyptus* and were interpreted as annual growth increments. Observations on 67 trees were used to derive a relationship between trunk diameter and annual increment from which annual production could be estimated.

Herbaceous vegetation (stems <1.3 m high) and litter (<5 cm diameter) were removed, dried and weighed from 33 quadrats each 1m^2 equally spaced on the 25 m, 50 m and 100 m contours.

Results

Floristic classification of woody dicotyledons

The distribution of selected abundant species at the sampling points is shown in Figure 2. Species such as *Acacia mabelliae* are widespread, while *Acmena smithii, Cryptocarya microneura* and *Doryphora sassafras* occur in gullies and at lower altitudes, with *Eucalyptus* spp. extending onto the upper slopes.

The classification procedure defined seven classes at the 0.75 dissimilarity level which may be combined as five major vegetation types, two of which are sclerophyll dominated, two are notophyll dominated and one is intermediate. The composition of these types is shown in Table 1 and their distribution is shown in Figure 3. The characteristics of these types are as follows

1. *Eucalyptus botryoides* (52% of trunks) and *E. pilularis* (27%) characterise two classes which form a sclerophyll vegetation type that occurs on the higher and steeper slopes in the catchment. *E. botryoides* dominated communities occurred more commonly on the east-facing slopes in the southwest corner of the catchment, while *E. pilularis* dominated the southwest-facing communities of the eastern section.

2. A more abundant sclerophyll type is characterised by *E. maculata* (56% of trunks), often forming a single-dominant community on the lower, gentle ridges in the centre and southeast of the catchment, but also occuring with *E. botryoides* (5%) or *E. pilularis* (9%) on higher and steeper slopes.

3. An intermediate vegetation type is characterised by *Acacia mabelliae* (55% of trunks), forming a low-canopied community (5 to 15 m high) between large, widely-spaced eucalypts, but the outliers of this group include notophyll species e.g. *Cryptocarya microneura* (6%), *Commersonia fraseri* (5%), *Callicoma serratifolia* (2%) and *Synoum glandulosum* (3%), linking it floristically with rainforest. This intermediate type occurs in various locations including above rainforest gully edges, in gaps in the rainforest, and above rainforest on steep fire-protected east- and south-facing small ridges.

4. A notophyll rainforest type on well drained sites, dominated by *Cryptocarya microneura* (20% of trunks), *Doryphora sassafras* (27%), or *Callicoma serratifolia* (10%) with variable combinations of subordinate notophyll species, including *Ficus coronata* (10%), *Backhousia myrtifolia* (3%) and *Acmena smithii* (7%). This rainforest type occurs around the edge of the main rainforest, higher in gullies, and in places where it is more vulnerable to desiccation from hot winds and to disturbance from fire, logging and windthrow. This group corresponds to disturbed and successional forest of types described as the

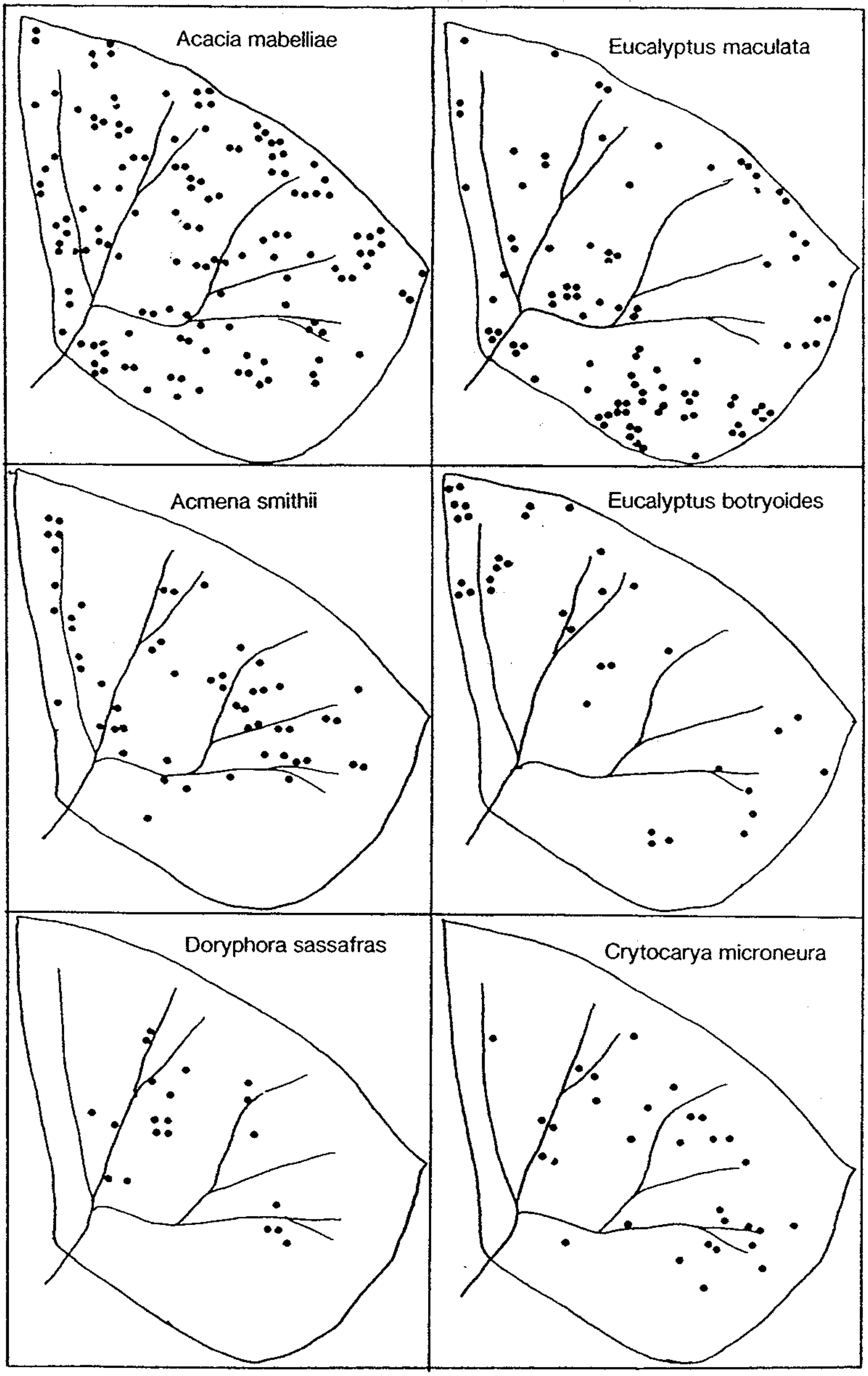

Figure 2. Maps showing trees of selected species at sampling points in the Butlers Creek catchment.

Ceratopetalum/Doryphora association (Baur 1957), notophyll vine forest (Webb 1959), and the warm temperature community (type 8) of Helman (1983).

5. Notophyll rainforest characterised by *Acmena smithii* (43% of trunks) which is abundant on wetter sites and the fire-protected south- and southeast-facing gullies. In the most protected places other species include *Doryphora sassafrass* (4%) and *Ceratopetalum apetalum* (7%). More commonly, away from the gully centres, a variety of other species occur including *Cryptocarya microneura* (6%), *Ficus coronata* (3%), *Backhousia myrtifolia* (2%) and *Acacia mabelliae* (20%). The latter vegetation type merges with the type 4 vegetation.

Tree biomass

Observations were made on the dimensions of 85 *Eucalyptus*, 16 *Acacia mabelliae* and 52 notophyll rainforest trees. It was found that d.b.h. and tree volume regressions were similar in all species (Table 2) but that wood densities varied significantly (Table 3) and for calculating tree biomass the following equations were used to relate density (g) to d.b.h. (d):

in *Eucalyptus*, $g = 0.5 + 0.005\ d$,

in *Commersonia* and *Trema*, $g = 0.25 + 0.0015\ d$,

in other notophyll species, $g = 0.5 + 0.003\ d$.

The resulting equations for predicting biomass from d.b.h. are given in Table 2. It was apparent that the percentage of tree volume below ground declined from about 18% at 1 cm d.b.h. to 12% at 150 cm d.b.h. Leaf or phyllode weight on 2

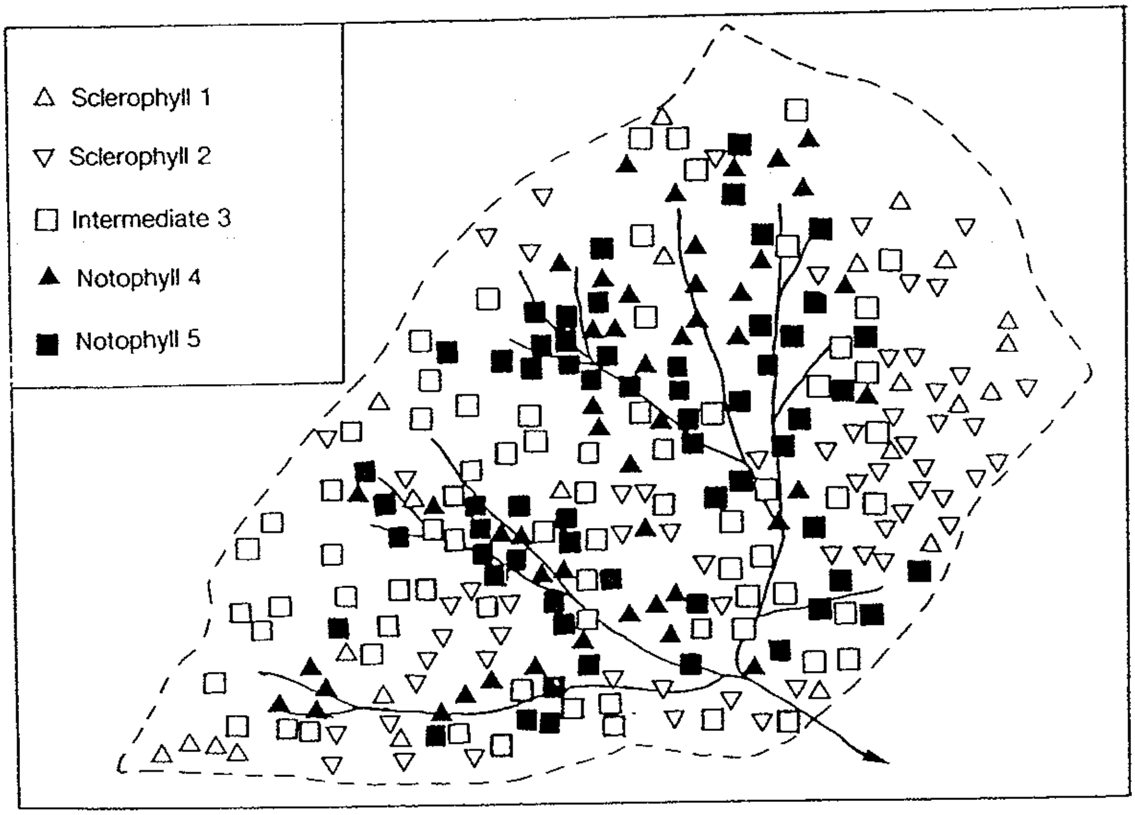

Figure 3. Map showing the distribution of the five vegetation types at sampling points in Butlers Creek catchment.

cm diameter branches varied considerably between species but total areas were similar (Table 4).

Forest biomass

From the survey of trunk diameter it was estimated that individual tree biomass ranged up to 80,000 kg, though the mean was only 898 kg (±111 s.e., n = 1140). This highly skewed distribution was approximated by a Weibull distribution (Candy 1983) in which the expected value (y, kg) was set equal to the mean biomass and the tail was set such that, as observed, seven trees should exceed 15,000 kg, i.e.

$$y = 305.4 \; G \; (1 + 1/0.417)$$

The sampling distribution of the mean of this highly skewed distribution was examined by simulating the survey 100 times, picking 1140 trees at random each time, which yielded normally distributed estimates of the mean (Kolmogorov-Smirnov test, $p = 0.98$) with a standard error of ±89 kg, slightly smaller than the observed standard error (±111 kg). It was also determined by simulation that surveys of 500 trees would have yielded a normally distributed mean but this property would be lost with samples of only 100 trees. These results indicate that despite the highly skewed distribution of tree biomass, the calculated mean biomass is a reliable measure for determining forest biomass.

Table 2. Relationships of $\log^{10}$ tree components (y, number or kg or 0.001 m^3) with $\log_{10}$ trunk diameter (d, cm):
$\log_{10}y = a + b \log_{10}d$ where, n = number of observations, r = Pearson correlation, a = intercept, b = slope, and s.e. = standard error. Above ground components (A.G.) are indicated. 2 cm diameter branch wood volume was estimated as 0.0011 m^3. Biomass and biomass increment were derived from the other equations, density and growth ring width. Underground bark and 2 cm branch bark biomass were estimated as 10% of the wood biomass. The biomass of *Commersonia* and *Trema* is about half that estimated for other notophyll species because of their low wood density. The equations are based on measurements of: *Eucalyptus maculata* (30), *E. pilularis* (47), *E. botryoides* (8), *Acacia mabelliae* (16), *Commersonia fraseri* (12), *Acmena smithii* (26), *Backhousia myrtifolia* (11), *Cryptocarya microneura* (2), *Doryphora sassafras* (1).

Species	Component	n	r	a	b	s.e.
All	Wood Volume (A.G.)	133	.994	−0.69	2.41	.106
"	Number 2 cm branches	78	.951	−0.15	1.29	.151
"	Bark Volume (A.G.)	17	.988	−1.01	2.12	.151
"	Root crown wood Volume	53	.989	−2.42	2.56	.161
"	Root wood Volume	54	.972	−0.96	2.03	.217
Eucalyptus	Wood Volume (A.G.)	66	.996	−0.72	2.43	.109
"	Number 2 cm branches	31	.961	−0.51	1.51	.158
"	Bark Volume (A.G.)	13	.987	−0.83	2.02	.127
"	Root crown wood Volume	40	.991	−2.46	2.59	.165
"	Root wood Volume	41	.977	−0.91	2.01	.206
"	Biomass, kg	–	–	−0.92	2.56	–
"	Biomass increment, kg yr^{-1}	–	–	−0.35	1.37	–
Notophyll	Wood Volume (A.G.)	67	.989	−0.63	2.34	.101
"	Number 2 cm branches	47	.956	−0.03	1.22	.120
"	Bark Volume (A.G.)	4	.992	−1.19	2.21	.085
"	Root crown wood Volume	13	.978	−2.19	2.38	.148
"	Root wood Volume	13	.921	−0.76	1.75	.216
"	Biomass, kg	–	–	−0.72	2.39	–

The mean point to tree distances (4.20 m ±0.12 s.e., n = 285) and point to shrub distances (2.62 ±0.16 s.e., n = 190) provided estimates of abundance per hectare. There was marked variation between the sclerophyll dominated (78% *Eucalyptus*) upper slopes, with 425 trees ha^{-1} and 1047 shrubs ha^{-1}, and the notophyll dominated (13% *Eucalyptus*) lower slopes with 775 trees ha^{-1} and 3300 shrubs ha^{-1}. The *Eucalyptus* are, however, generally larger trees that the notophyll species and total tree biomass was estimated as 588 t ha^{-1} (± 104 s.e.) on the upper slopes and 347 t ha^{-1} (±62 s.e.) on the lower slopes, with an average of 510 t ha^{-1} for the whole catchment. Tree foliage averaged 6.31 kg (±0.25 s.e.) or 3.58 t ha^{-1} (±0.24 s.e.). Tree roots of less than 5 cm diameter were estimated at 11.6 t ha^{-1} (95% range 9.2 to 18.2 t ha^{-1}). The percentage of biomass contributed by each species is shown in Table 1, from which it is apparent that the *Eucalyptus* species account for 86% of tree biomass, though they only account for 38% of tree trunks.

Mean shrub biomass was similar throughout the catchment (1.58 kg ±0.07 s.e., n = 760 for volume) yielding 1.74 t ha^{-1} (±0.11 s.e.) in the upper catchment and 4.73 t ha^{-1} (±0.40 s.e.) in the lower catchment with an average of 2.31 t ha^{-1} (±0.20 s.e.).

Herbs were estimated to comprise 0.61 t ha^{-1} (95% range 0.57 to 0.75 t ha^{-1}), litter comprised 4.9 t ha^{-1} (95% range 4.3 to 5.6 t ha^{-1}), and fallen logs 8.4 t ha^{-1}. Of the total biomass (530 t ha^{-1} ±73 s.e.) 97% was contained in the trees

Table 3. Wood and bark density (g cm^{-3}) of selected species. Values determined from this study are given with standard deviations (n = 3); other values are from Cause et al. (1974) adjusted to zero moisture content.

Species	Heartwood	Sapwood	Bark
Acacia mabelliae	.55	.35±.09	
Acmena smithii	.81	.65±.08	.44±.01
Acronychia oblongifolia	.81	.56	
Backhousia myrtifolia	.93, .8±.04	.65	.41±.20
Callicoma serratifolia	.51		
Ceratopetalum apetalum	.82	.51	
Commersonia fraseri	.35, .28±.04	.26	.32±.04
Cryptocarya glaucescens	.56		
Cryptocarya microneura	.70		
Diospyros australis	.65 - 1.1		
Doryphora sassafras	.52 - .6		
Elaeocarpus reticulatus	.4 - .65		
Eucalyptus botryoides	1.1		
Eucalyptus globoidea	.85 - 1.12		
Eucalyptus gummifera	.89		
Eucalyptus maculata	.89	.53±.05	.33±.03
Eucalyptus pilularis	.82 - 1.25	.49±.03	.24±.03
Eucalyptus tereticornis	.89		
Exocarpus cupressiformis	.74		
Ficus coronata	.41		
Glochidion ferdinandi	.62 - .75		
Pittosporum undulatum	.76		
Rapanea howittiana	.81		
Rhodamnia rubescens	.68		
Synoum glandulosum	.59		
Trema aspera	.35		
Tristianiopsis collina	.89		

and a further 1.6% was in fallen logs. The very small contribution by herbs (0.1%) and litter (0.9%) partly reflect the burning of the catchment in the previous year. Partly for this reason, 54% of herb biomass was below ground, contrasting with 17% of shrubs, 13% of trees and 14% of total biomass. The number of trees felled in logging operations was estimated as 2.8 ha^{-1} (± 1.7 s.e.) from point-centred quarter records of stumps and as 2.4 ha^{-1} (±0.2 s.e.) from transects. Stump diameters averaged 66.5 cm d.b.h. (± 1.5 s.e., n = 30), corresponding to a tree biomass of 12.5 t ha^{-1}, or about 2.5% of total tree biomass, of which about 60% was removed from the catchment.

Annual net production of *Eucalyptus* was estimated from the growth ring increments shown in Figure 4. *Eucalyptus* production was estimated as 12.8t ha^{-1} yr^{-1} in the upper catchment and 2.9 t ha^{-1} yr^{-1} in the lower catchment.

Table 4. Total oven-dry leaf or phyllode weight, and total leaf area on 2 cm diameter branches from upper and lower parts of the canopy.

Species	Total leaf weight, g mean±s.d.	n	Total leaf area, m^2 mean
Eucalyptus maculata	125±47	(12)	1.25
Eucalyptus pilularis	198±110	(6)	1.91
Acmena smithii	144±56	(9)	1.75
Backhousia myrtifolia	61± 30	(15)	1.12
Acacia mabelliae	203±60	(9)	2.03
Commersonia fraseri	83±25	(7)	1.58

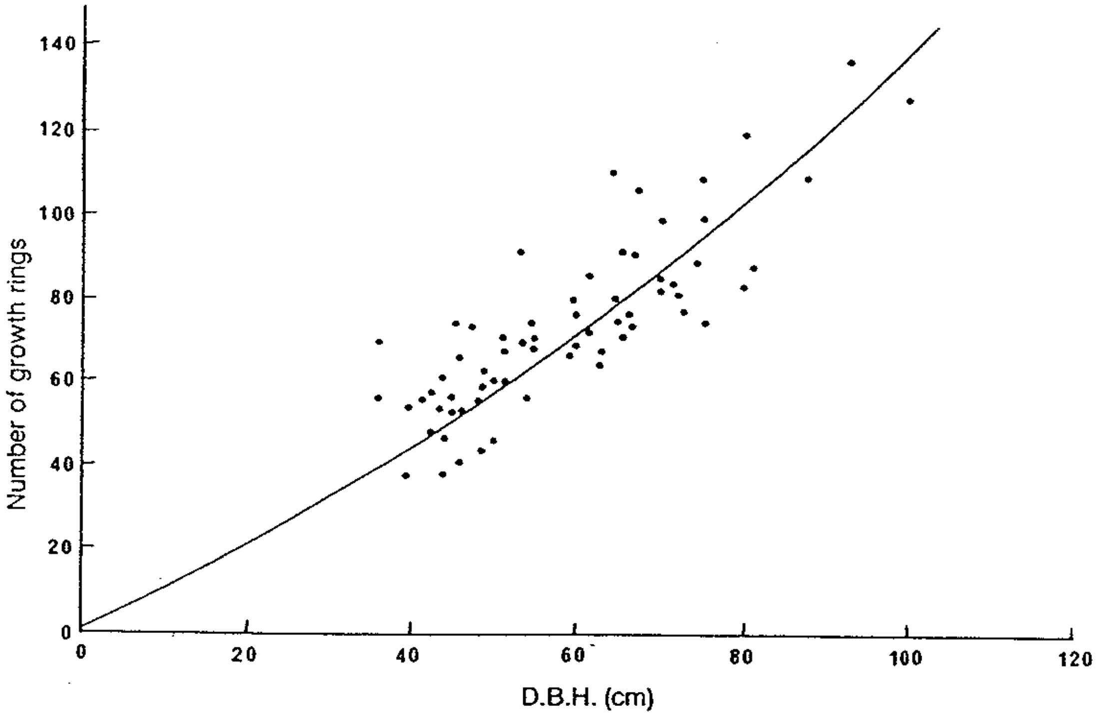

Figure 4. Scatter diagram showing the number of growth rings and trunk wood diameter of *Eucalyptus* spp. at Butlers Creek. The relationship is summarised by a hand-drawn curve passing through the origin.

Assuming similar ratios of production to biomass in the other tree species the net production in the whole catchment would be about 10.3 t ha^{-1} yr^{-1}.

Discussion

The point-centred quarter survey method proved to be suitable both for recording quantitative floristic information on woody species and for recording information suitable for estimating forest biomass. Since then Diggle (1983) has suggested that the 'T-square' sampling procedure yields superior spatial statistics though it only records two trees at each locality. Whichever procedure is used, however, a critical parameter which may not receive sufficient attention is the minimum trunk diameter for inclusion in a survey. Because there is typically an inverse relationship between the tree size and frequency, a survey samples most information about trees slightly larger than the minimum size. This has several implications, firstly, since some species reach larger sizes than others their relative abundance will depend on the size limit. In the present survey *Acacia mabelliae*, exceeding 5 cm d.b.h., were recorded at 47% of the survey points but if a 25 cm d.b.h. limit had been selected instead then they might only have been recorded at 28% of the survey points, the latter mostly restricted to the lower slopes. Evidently changing the d.b.h. threshold could change the definition of vegetation types and would have significantly changed the abundance and boundaries of these types. These thresholds may be of particular signficance in fire-prone vegetation where small trees may be killed by fire.

The vegetation types defined by the cluster analysis had a high spatial contiguity when mapped (Figure 3) and can be interpreted as a catena from ridges to gullies modified by aspect. In part this interpretation reflects soil moisture availability and humidity but it is also a consequence of associated differences in vegetation flammability, resulting from the interaction between the microclimate and vegetation type. A fire in September 1980 burned virtually all the sclerophyll forest, much of the intermediate forest but only the margins of the notophyll forest, leaving the deeper gullies unburned. The vegetation in the middle parts of the catena is evidently relatively variable, being colonised by *Acacia mabelliae* and notophyll species after fires but saplings of these species are likely to die in subsequent fires. In the absence of fires for many years it is possible that notophyll forest could extend upslope.

The notophyll rainforest in the catchment is typical of many other small patches in the region and is close to the southern limit of about eleven species (*Callicoma serratifolia, Ceratopetalum apetalum, Clerodendrum tomentosum, Cryptocarya microneura, Diospyros australis, Endiandra sieberi, Glochidion ferdinandii, Guioa semiglauca, Rhodamnia rubescens*, and *Palmeria scandens)*. The catchment is close to the southern limit of the massive sandstones of the Sydney basin, which may limit the southerly range of some species while other species may be associated with the monzonite and essexite outcrops at Milton, Kioloa and Mt Dromedary (Pogson 1972). It is not clear whether the general southerly decline in numbers of rainforest species represents a stable pattern in equilibrium with the climate, a continuing post-glacial range extension to the south, or even an extinction of southern populations. Evidently several of the rainforest species which are close to their southern limits are reasonably abundant and grow successfully in the catchment, suggesting that the species are not at their climatic limits.

The sclerophyll component of the vegetation is more widespread along the southern coast of New South Wales and these species dominate most of the surrounding forest areas. The balance between *Eucalyptus* and notophyll rainforest species appears to be controlled by fire and is likely to be a consequence of human activity in addition to substrate and climatic factors.

The procedures for estimating forest biomass used in this study follow the usual practice of defining a relationship between an index of tree size, e.g. d.b.h., and tree volume, which is then converted to biomass by measuring wood and bark density (e.g. Whittaker and Woodwell 1968, Westman and Rogers 1980, Feller 1980). This study differs in several aspects, firstly, the entire tree volume was measured down to 2 cm diameter 'standard' branches in contrast to the usual practice of measuring the trunk and a few large representative branches. Secondly, wood density values were adjusted for tree size rather than given as a constant for each species. Thirdly, a broad range of tree sizes were selected to establish reliable slopes for regression equations, and a large number of trees were measured to give confidence to the results. Fourthly, in contrast to most studies, the forest biomass was not measured or calculated for a small plot of trees but for a whole catchment on the basis of an unbiased sample of more than 1100 trees. The biomass estimates can therefore give some measure of the probable variation in forest biomass: a 95% range of 384 to 676 t ha^{-1}. In reality trees are not drawn at random from the forest population but form floristically distinct communities, and the 95% range of tree biomass is likely to be between 220 t ha^{-1} in the notophyll dominated types to 800 t ha^{-1} in the *Eucalyptus* dominated types. This range of values spans virtually all biomass estimates made for humid temperate *Eucalyptus* dominated forests (Ashton 1976, Westman and Rogers 1977, Attiwill 1979, Harrington 1979, Hingston, Turton and Dimmock 1979, Steward, Finn and Aeberli 1979, Feller 1980, Bradstock 1981, Hingston, Dimmock and Turton 1981, Rogers and Westman 1981, Grove and Malajczuk 1985). Local site and floristic variation, in addition to fire and logging history, may partly explain why these published estimates are so variable. The estimate of leaf biomass (3.6 t ha^{-1}) also falls within the same broad range of published values (2.6 to 8.9 t ha^{-1}) for these forests. The percentage of *Eucalyptus* biomass below ground level was estimated as 13% in this study, about 10% in *E. obliqua* and *E. regnans* (Feller 1980) but about 40% in *E. signata* (Westman and Rogers 1971). These results may be compared with other forests (Cannell 1982), from which it is apparent that underground tree biomass (U, %) varies with total tree biomass (B, t ha^{-1}) as

$$U = 47 - 11.9 \log_{10}B, \pm 0.25U \text{ s.e.}$$

giving expected values of about 15% for the forest in this study and those examined by Feller (1980) and 21% for the forest studied by Westman and Rogers (1977). The value for this study is close to that which would be expected.

The estimate of *Eucalyptus* net production in the sclerophyll forest, 12.8 t ha^{-1} yr^{-1}, falls within the range of 4 to 16 t ha^{-1} yr^{-1} estimated in other *Eucalyptus* forests (Attiwill 1979, Hingston et al. 1979, Feller 1980, Bradstock 1981, Hingston et al. 1981, Rogers and Westman 1981, Grove and Malajczuk 1985) but significantly below values for *E. regnans* (> 29 t ha^{-1} yr^{-1}) and *E. sieberi* (> 32 t ha^{-1} yr^{-1}) determined by Ashton (1976).

Neither leaf nor fine root production were included in this study and by comparison with other forests, leaf production of about 2.6 t ha^{-1} yr^{-1} might be expected (Attiwill 1979, Rogers and Westman 1981, Grove and Malajczuk

1985) and fine root production might be of a similar magnitude (Fabiao, Persson and Steen 1985).

It was evident that the *Eucalyptus* reached a much larger size than the notophyll rainforest species, often occurring as emergents above the intermediate and marginal notophyll forest types, and *Eucalyptus* comprised the bulk of the forest biomass. The abundance of notophyll species on the lower slopes was, however, much greater, with a more continuous leaf canopy, and production may be similar. There is a lack of comparative information on the biomass and production of these southern rainforests.

Acknowledgements

We thank the following for assistance with collecting information in the forest and subsequent analysis John Burton, Rob Buttrose, Yvonne Pittelkow and Wendy Southern. Joanne Perks typed the manuscript. Professor D. Walker instigated these studies and contributed substantially to their progress and to this paper, which is the outcome of two surveys funded by the Edith and Joy London Foundation.

References

Ash, J. & Southern, W. (1982). *Forest Biomass at Butlers Creek*. Unpublished report to Edith and Joy London Foundation, Kioloa, New South Wales.

Ashton, D.H. (1976). Phosphorus in forest ecosystems at Beenak, Victoria. *J. Ecol.*, 64: 171–86.

Attiwill, P.M. (1979). Nutrient cycling in a *Eucalyptus obliqua* (L'Herit.) forest. III. Growth, biomass, and net primary production. *Aust. J. Bot.*, 27: 439–58.

Baur, G.N. (1957). Nature and distribution of rain-forest in New South Wales. *Aust. J. Bot.*, 5: 190–222.

Bradstock, R. (1981). Biomass in an age series of *Eucalyptus grandis plantations*. *Aust. For. Res.*, 11: 111–27.

Bray, J.R. & Curtis, J.T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecol. Monogr.*, 27: 325–49.

Candy, S. (1983). Fitting a model with identity link and Weibull errors. *GLIM Newsletter*, 7. Roy. Stat. Soc. Num. Algor. Group, Oxford.

Cannell, M.G.R. (1982). *World forest biomass and primary production data*. Academic Press.

Cause, M.L., Weatherhead, T.F. and Kynaston, W.T. (1974). *The nomenclature, density and Lyctus-susceptibility of Queensland timbers*. Pamphlet 13, Queensland Dept. Forests, Brisbane.

Curtis, J.T. (1959). *The vegetation of Wisconsin. An ordination of plant communities*. Univ. Wisconsin Press, Madison.

Diggle, P.J. (1983). *Statistical analysis of spatial point patterns*. Academic Press, London.

Fabiao, A., Persson, H.A. & Steen, E. (1985). Growth dynamics of superficial roots in Portugese plantations of *Eucalyptus globulus* Labill. studied with a mesh bag technique. *Plant and Soil*, 83: 233–42.

Feller, M.C. (1980). Biomass and nutrient distribution in two eucalypt forest ecosystems. *Aust. J. Ecol.*, 5: 309–33.

Grove, T.S. & Malajczuk, N. (1985). Biomass production by trees and understorey shrubs in an age-series of *Eucalyptus diversicolor* F. Muell. stands. *For. Ecol. Manage.*, 11: 59–74.

Harrington, G. (1979). Estimation of above-ground biomass of trees and shrubs in a

Eucalyptus populnea F. Muell. woodland by regression of mass on trunk diameter and plant height. *Aust. J. Bot.*, 27: 135–43.

Helman, C. (1979). *A study of the rainforest vegetation of Beecroft Peninsula, N.S.W.* B. Litt. thesis, University of New England, Armidale.

Helman, C. (1981). *Plant Sociological Survey of an experimental catchment at the Edith and Joy London Foundation, Kioloa, N.S.W.* Unpublished report to Edith and Joy London Foundation, Kioloa, New South Wales.

Helman, C. (1983). *Inventory analysis of southern New South Wales rainforest vegetation.* Unpublished M.Sc. thesis, University of New England, Armidale.

Helman, C. (1984). *Plant Sociological survey of Butlers Creek, N.S.W.* Unpublished report to Edith and Joy London Foundation, Kioloa, New South Wales.

Hingston, F.J., Turton, A.G. & Dimmock, G.M. (1979). Nutrient distribution in karri (*Eucalytpus diversicolor* F. Muell.) ecosystems in south-west Western Australia. *For. Ecol. Manage.*, 2: 133–58.

Hingston, F.J., Dimmock, G.M. & Turton, A.G. (1981). Nutrient distribution in a jarrah (*Eucalyptus marginata* Donn ex Sm.) ecosystem in south-west Western Australia. *For. Ecol. Manage.*, 3: 183–207.

Mueller-Dombois, D. & Ellenberg, H. (1974). *Aims and methods of vegetation Ecology.* J. Wiley, New York.

Pogson, D.J. (1972). Geological map of New South Wales, scale 1:1 000 000, Geol. Surv. N.S.W., Sydney.

Rogers, R.W. & Westman, W.E. (1981). Growth rhythms and productivity of a coastal subtropical eucalypt forest. *Aust. J. Ecol.*, 6: 85–98.

Stewart, H.T.L., Finn, D.W. and Aeberli, B.C. (1979). Above-ground biomass of a mixed eucalypt forest in eastern Victoria. *Aust. J. Bot.*, 27: 725–40.

Webb, L.J. (1959). A physiognomic classification of Australian rainforest. *J. Ecol.*, 47: 551–70.

Westman, W.E. & Rogers, R.W. (1977). Biomass and structure of a subtropical eucalypt forest, North Stradbroke Island. *Aust. J. Bot.*, 25: 171–91.

Whittaker, R.H. & Woodwell, G.M. (1968). Dimension and production relations of trees and shrubs in the Brookhaven forest, New York. *J. Ecol.*, 56: 1–25.

Wishart, D. (1978). *CLUSTAN User manual, 3rd ed. Program Library Unit,* Edingburgh University.

Manuscript received 20 July 1987

Manuscript accepted 18 January 1989