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Attributes of logs on the floor of Australian Mountain Ash (*Eucalyptus regnans*) forests of different ages

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Abstract

We describe the results of a study of the characteristics of 984 logs measured on 60 sites located in four distinct age classes of Mountain Ash (*Eucalyptus regnans* F. Muell) forest in the Central Highlands of Victoria, south-eastern Australia. The age classes were young regrowth (approximately 20 years old), 59 year old forest (dating from the 1939 wildfires), mature stands (dating from fires in the 1820s) and old growth stands (>250–350+ years old). Statistical relationships were established between log attributes (number, diameter, length, and moss cover) and site attributes or covariates (stand age, slope, aspect, topographic position).

Our data showed that the diameter of logs and the cover of mosses on logs was significantly greater in mature and old growth stands than forests in younger cohorts ($p=0.03$ and $p=0.002$, respectively). No relationships were found between log length and any of the measured site-based covariates.

Estimated log volumes did not vary significantly between stands of different ages. Other site attributes (slope, aspect, topographic position) also showed no significant effects. Estimated log volumes for each age class were high and the mean estimate for all sites was approximately 350 m³/ha. At some sites, log volumes exceeded 1000 m³/ha; an estimate higher than calculated for many other temperate forest types around the world. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Logs; Mountain Ash forest; South-eastern Australia; Forest floor architecture; Age classes

1. Introduction

Logs are a key components of stand structure in temperate forests throughout the world (Maser and Trappe, 1984; Harmon et al., 1986; Sollins et al., 1987; Niemela et al., 1993; Recher, 1996; Kaila et al., 1997; Lee et al., 1997). Logs have many functions including

playing a key role in nutrient cycling (Harmon et al., 1986), providing a source of fuel for forest fires (Luke and McArthur, 1978), influencing stream hydrodynamics (Gippel et al., 1996), acting as nursery sites for plants (Howard, 1973; Ough and Ross, 1992; Barker and Kirkpatrick, 1994), providing runways to assist the movement of terrestrial animals (Maser et al., 1977), serving as basking sites for reptiles (Webb, 1985; Cogger, 1995), providing nesting and shelter sites for forest-dependent animals (Tallmon

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and Mills, 1994; Wilkinson et al., 1998) and fish (Koehn, 1993), and acting as foraging substrates for wildlife (Smith et al., 1989) including species-rich assemblages of invertebrates (Taylor, 1990; New, 1995).

There have been numerous studies of logs in temperate forests from many parts of the world (e.g. Grier, 1978; Spies et al., 1988; Tyrell and Crow, 1994; Brown et al., 1996; Lee et al., 1997; Sturtevant et al., 1997; Williams and Faunt, 1997; Kirby et al., 1998, reviewed by Harmon et al. (1986)). Investigations of changes in the abundance and condition of large logs in forests of different ages and subject to different disturbance regimes (like logging) are fundamental to attempts to conserve populations of organisms dependent on logs (e.g. see Andersson and Hyttenborn, 1991; Kaila et al., 1997). In this study, we present the results of a study in which extensive data were gathered on the attributes of logs measured in stands of four distinct age classes of Mountain Ash (*Eucalyptus regnans*)

forest in the Central Highlands of Victoria, south-eastern Australia. Our primary aim was to present new information on the features of logs in stands of markedly different age. We did this by exploring relationships between log characteristics such as the number of logs, log diameter, log length, and the percentage cover of mosses, ferns and liverworts and site attributes or covariates (stand age, slope, aspect, topographic position). Some implications of the results from this preliminary study for forest management are briefly outlined.

2. Methods

2.1. Study area and field surveys

The area studied covers approximately one degree of latitude and one degree of longitude and is located about 120 km north-east of the city of Melbourne in south-eastern Australia (Fig. 1).

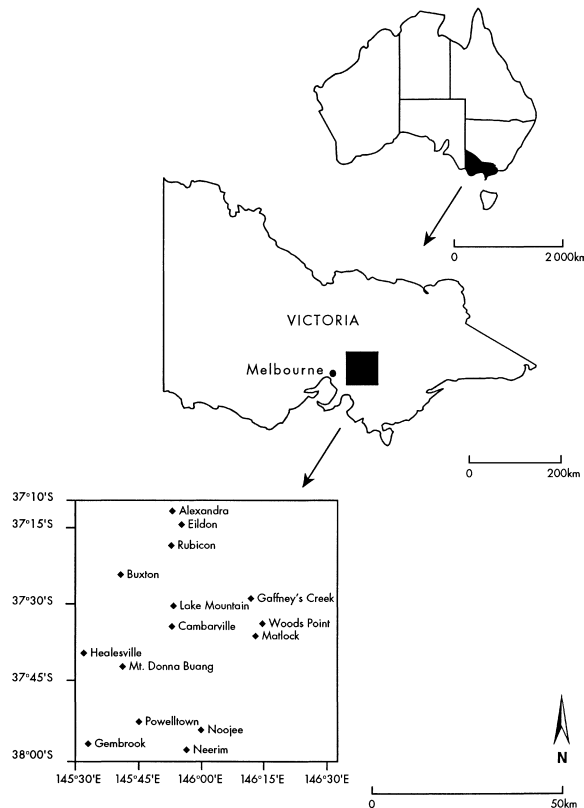


Fig. 1. The general location of the study area in the Central Highlands of Victoria.

Table 1
Measurements of sites and logs surveyed in the Mountain Ash forests of the Central Highlands of Victoria

Variable	Description
<i>Site variables</i>	
Forest age	<i>Ageclass 1</i> : 1970s logging regeneration <i>Ageclass 2</i> : 1939 regrowth <i>Ageclass 3</i> : mature forest, dating from 1820s fires <i>Ageclass 4</i> : old forest, 300+years
Slope	<i>Class 1</i> : steep <i>Class 2</i> : steep to intermediate <i>Class 3</i> : intermediate <i>Class 4</i> : intermediate to flat <i>Class 5</i> : flat
Aspect	N, NE, E, SE, S, SW, W, or NW
Topographic position	Ridge, midslope, or flat
<i>Log variables</i>	
Diameter	Measured to the closest cm at the point where the transect crossed the log
Length	Measured to the closest metre
Decay status	<i>Class 1</i> : solid log, bark intact, and recently fallen <i>Class 2</i> : solid log, and no bark <i>Class 3</i> : some decomposition of log, soft sapwood, and soil heart wood <i>Class 4</i> : intermediate decomposition, soft sapwood or sapwood not present soft heartwood, and log “breaking-up” <i>Class 5</i> : advanced decomposition of log, soft sapwood and heartwood (if identifiable), and log fragmented
% Moss cover	Proportion of log covered by moss, the moss must be rooted or grow in/on the log
% Cover by other plant species	Proportion of the log covered by other plant or fungi, the species must be rooted or grow in/on the log

A major form of heterogeneity in Mountain Ash landscapes is the age of stands. Mountain Ash is considered to be a fire-sensitive type of eucalypt forest and tree mortality is high after fire (Noble and Slatyer, 1980). As a result, wildfires are often stand-replacing events which result in distinct cohorts of trees belonging to a single age class regenerating after a fire event (Ashton and Attiwill, 1994). Four age classes which represent the most prevalent range of age classes found in the Central Highlands were selected for study (Table 1). Other age classes exist, but are restricted or isolated, making them difficult to study because of limited opportunities for site replication.

Sixty sites were surveyed. All old growth and mature sites were located in closed water catchments administered by the Melbourne Water Corporation and where there have been no significant timber harvesting activities (Land Conservation Council, 1994). The 1939 regrowth sites were established both in closed water catchment areas and State Forests

where timber harvesting has occurred since the late 1800s (Houghton, 1986). The 1939 regrowth, mature, and old growth sites represent forests that germinated after disturbance by a major fire. In contrast, all sites dating from the 1970s were located in State Forest and have regenerated after clearfell logging operations. In State Forest, stand age was determined at each site using assessment maps produced by the Victorian Department of Natural Resources and Environment. The Melbourne Water Corporation provided maps of the ages of forests in water catchment areas. The number of sites in each age class was: 1970s regeneration (12 sites), 1939 regrowth (16 sites), mature (13 sites), and, old growth (19 sites).

2.2. Log measurements

For the purposes of this study, a log was defined as any piece of woody debris on the forest floor that was 10 cm or more in diameter and 1 m or more in length. Logs of non-angiosperm origin (e.g., tree fern trunks)

were excluded from our study. A 100 m long transect was established at each site by walking 110 m into the forest from a road on a constant compass bearing and using a cotton string from a hip chain to estimate distance. The string was re-traced to locate logs that intersected the transect. No measurements were made in the first 10 m of each transect to avoid logs that may have accumulated during timber harvesting or roading operations. The length and diameter of each log was measured with a tape. Each log was assigned to a decay class that best represented its decomposition status. The variables collected at the site and log level are presented in Table 1.

2.3. Estimates of log volume

The line intersect method (Warren and Olsen, 1964, Van Wagner, 1976) was used to estimate the volume of logs per ha of forest for each survey sites. Values for log volume (V) (m^3/ha) were calculated using the following equation:

$$V = \frac{\pi^2 \sum d^2}{8L},$$

where d =diameter (cm) at right angles to the length of the log and L =length (m) of the transect.

2.4. Statistical analysis

Ordinary least squares regression analysis was used to model the number of logs as a function of site attributes. For other variables (e.g., log diameter, log length and moss cover), the variation in log measurements occurred at two levels; the site-level and the log-level and restricted maximum likelihood estimation (REML) for mixed models (Robinson, 1991) was used for model estimation.

3. Results

3.1. General findings

A total of 984 logs was measured on the 60 survey sites. Some very large logs were measured – the longest was 68.6 m and the greatest diameter recorded was 2.7 m. Box plots showing variations in the key measured attributes of logs are shown in Fig. 2.

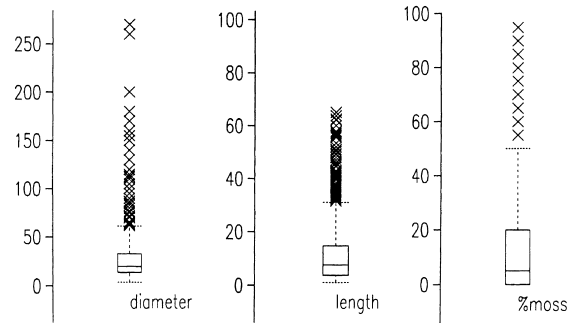


Fig. 2. Box plots showing the distribution of logs attributes measured in Mountain Ash forests. Values for diameter are in centimetres and metres for length.

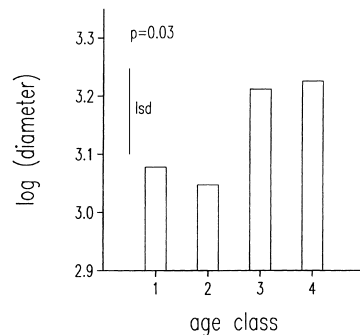


Fig. 3. Log diameter and age class effects ($p=0.03$). Categories 1 and 2 correspond to 20–25 year old and 59 year old forest, respectively. Mature and old growth forest are classes 3 and 4 in the figure.

3.2. Number, length and diameter of logs

No significant relationships were found between the number of logs per site and site attributes (stand age, slope, aspect, topographic position).

Data for log length were analyzed on a logarithm scale. No significant relationships between log length and age class, slope, aspect or topographic position were identified. The diameter of logs was significantly greater ($p=0.03$) in mature and old growth stands than younger age cohorts (Fig. 3). No other measured site covariates had a statistically significant effect.

3.3. Cover of mosses, ferns and liverworts

Moss cover on logs was significantly higher ($p=0.002$) in the older stands (mature and old growth

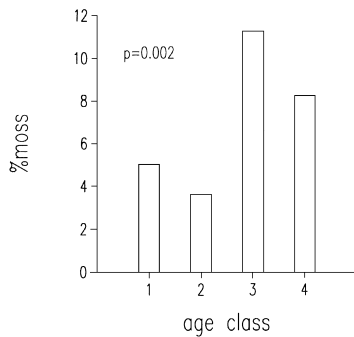


Fig. 4. Moss cover on logs and age class effects ($p=0.002$). Categories 1 and 2 correspond to 20–25 year old and 59 year old forest, respectively. Mature and old growth forest are classes 3 and 4 in the figure.

forests) than young regrowth and 1939-aged regrowth stands (Fig. 4). No other measured covariates had a statistically significant effect. More than 92% of logs supported no lichen or fern cover.

3.4. Estimates of log volume

Log volumes estimated using the line transect method varied considerably between sites ($13.5 \text{ m}^3/$

ha up to $1026 \text{ m}^3/\text{ha}$). The average value calculated from all sites was $353 \text{ m}^3/\text{ha}$ (see Table 2). No significant age class or other effects (slope, aspect or topographic position) were found for log volume.

4. Discussion

The primary aim of this investigation was to present new information on the features of logs in Mountain Ash stands of markedly different age. Below we briefly summarize some factors that may account for the statistical relationships observed between log-level characteristics and measured site attributes.

4.1. Number of logs

The lack of differences between age classes for the number of logs was surprising and may have occurred because we did not attempt to distinguish between the trunks of collapsed trees and branches or tree crowns that had been shed and fallen to the ground. A significant portion of the logs in younger age classes may have been recruited by processes such as branch

Table 2
Stand age and log volume in various forest types

Forest type and location	Stand age (years)	Ecological age	Minimum size (cm)	Snags included	Volume (m^3/ha)	Source
Aspen, Alberta, Canada	20–30	Young	11	No	61.3	Lee et al., 1997
	50–65	Mature			76.8	
	120+	Old			101.4	
Balsam fir and balsam fir x black spruce, Newfoundland, Canada	36	Second growth	7.6	No	32.3	Sturtevant et al., 1997
	58	Second growth			15.2	
	80	Old			78.1	
Douglas Fir, Oregon/Washington	<80	Young	10	No	248	Spies et al., 1988
	80–199	Mature			148	
	>200	Old			313	
Hemlock-hardwood, Wisconsin/Michigan	<200	n/a	20	Yes	84.5	Tyrell and Crow, 1994
	>200				150–200	
<i>Fagus/Acer/Tilia/Quercus</i> , Kentucky, USA	300	Old growth	20	Yes	54.3	Muller and Liu, 1991
Mountain Ash, south-eastern Australia	20–30	Young	10	No	342	This study
	59	Pole			309	
	170	Mature			393	
	250–300+	Old growth			375	

shedding and natural self-thinning which are prevalent in regenerating stands of Mountain Ash forest (Cunningham, 1960; Ashton, 1975). Small suppressed pole and sapling trees, which add greatly to the density of the vegetation in regrowth forests, die and collapse as the forests mature (Opie et al., 1984). The decline in stem density due to self-thinning is rapid, from up to several million seedlings per hectare soon after fire (Ashton and Attiwill, 1994), to 380 stems/ha at 40 years, and finally 40–80 stems/ha in mature forest (>150 years) (Ashton and Attiwill, 1994). Many understorey shrubs and trees (e.g., wattles [*Acacia* spp.]) also die and collapse as stands of Mountain Ash mature (Adams and Attiwill, 1984).

4.2. Diameter and length of logs

The occurrence of significantly ($p=0.03$) larger logs in mature and old growth stands (Fig. 3) was expected as these aged stands also support the largest diameter trees and largest branches on such trees (Ashton, 1976). We also expected a log length effect prior to commencing our study with longer logs occurring in older forests where taller trees occur. The lack of log length relationships with stand age may have been associated with our decision not to differentiate between fallen branches and collapsed tree trunks during field surveys (see above).

4.3. Moss cover

Moss cover was significantly greater on logs in mature and old forests than those in younger age classes (Fig. 4). Ashton (1986) made a detailed study of the bryophytic communities of Mountain Ash forests and found that some types of mosses such as those which form deep mats are best developed on logs within mature and old growth stands. The dominant moss species found on Mountain Ash logs are *Wijkia extenuata* and *Lepidozia ulothrix* (Ashton, 1986). Ashton estimated that it took 15–30 years for thick mats of moss to develop over 80–100% of logs. These age estimates may account for the lower amount of moss found on logs in the younger age classes, particularly those dating from the 1970s. There also may be delayed establishment of luxuriant moss cover in stands of 1970s regeneration due to changes in solar radiation and temperature regimes in

recently cutover areas (Parry, 1997). Moreover, Ashton (1986) described different niches on logs for different assemblages of bryophytes. Larger diameter logs which were found in this study to be significantly ($p=0.003$) more likely to occur in mature and old growth forests (Fig. 3), may provide a greater range of suitable substrates for moss development and, in turn, facilitate the development of more luxuriant moss cover. Studies from forests in other parts of the world have shown that species richness and cover of bryophytes increases with increasing log diameter (Andersson and Hyttenborn, 1991).

4.4. Log volume comparisons with other forest types

No significant age class or other site attribute effects on the volume of logs were identified in our study. This result contrasts with those by other workers in temperate forests elsewhere in the world have found significant age class differences in log volume (e.g., Spies et al., 1988). The reasons for the paucity of stand age differences in log volume in Mountain Ash forests are not clear. It is possible that different processes such as extensive self-thinning and branch-shedding among the numerous small trees in young stands produces similar quantities of debris on the forest floor as the collapse of a smaller number of more widely-spaced large trees (coupled less frequent abscission of fewer larger branches) in older Mountain Ash forests. However, more work is required to establish if these (or other) processes underpin the patterns we observed.

Our estimates for the volume of logs in Mountain Ash forest were large – approximately 350 m³/ha averaged across all age classes. Meggs (1996) calculated mean levels of decaying wood in young (5 and 20 year old) Messmate (*Eucalyptus obliqua*) forests in Tasmania and also found large log volumes (174–455 m³/ha). Values from this investigation and that by Meggs (1996) are somewhat higher than many other forest types (Table 2). For example, values for Aspen-dominated boreal forests in Canada were estimated to be 108–124 m³/ha (Lee et al., 1997). Our estimates are similar to old growth stands of Douglas Fir forest (313 m³/ha) (Spies et al., 1988). Notably, our estimates for log volume were highly congruent with those from the STANDSIM model that has been used widely in simulations of the growth of Mountain Ash forests of Victoria.

One explanation for the high volume of logs measured in Mountain Ash forests, regardless of age class, is the influence of legacies. Structural legacies such as dead standing trees and logs can remain following disturbance events like fire and wind storms (Franklin, 1990). Therefore, an important consideration in studies of the characteristics of logs in forest environments such as those in Mountain Ash where stand-replacing fires can occur, is the condition of a stand when it was previously disturbed. At our 1970s and 1939 regrowth sites, logs larger than the average present stand DBH were often recorded. At sites dating from the 1970s, large logs would have been left following timber harvesting. Large logs at the 1939 regrowth sites were likely to be legacies from the pre-existing forest burnt in the 1939 fires. Unfortunately, data were not available on stand condition at the time of the last major disturbance in our study sites, particularly for the origin of mature and old growth stands which pre-date European colonization.

4.5. Implications for forest management

Intensive human disturbance in Mountain Ash forest by planned recurrent clearfell logging on a 50–80 year rotation (Squire et al., 1991) will substantially limit the recruitment of large diameter logs to the forest floor. This is because under such silvicultural systems, the frequency and intensity of repeated harvesting events prevents large diameter standing trees from developing. The retention of trees in logged forest may partially alleviate these changes. However, at current rates of retention (typically <5 per ha), these trees would contribute only a small fraction of the stems that would be recruited to the forest floor in an unharvested forest. Although these are potentially important changes, in comparison with forests elsewhere in the world, there have been comparatively few studies of logs in Australian temperate forest ecosystems. Those that have been done are, like the one reported here, of a generally preliminary nature (Taylor, 1990; Brown et al., 1996; Meggs, 1996; Williams and Faunt, 1997). Further work is needed in eucalypt forests, e.g., we did not examine wood density or log biomass on our sites although they can be important features of stands of different ages (Harmon et al., 1986). In addition, it will be important to contrast the abundance and characteristics of logs

in managed and unmanaged eucalypt forests and to determine whether such differences (if there are any) have implications for nature conservation (see Andersson and Hyttenborn, 1991; Kaila et al., 1997).

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