Survival and Recovery of *Eucalyptus obliqua* Regeneration following Wildfire

Graham Wilkinson and Sue Jennings
Forestry Commission, Tasmania

Abstract

The survival and recovery of young Eucalyptus obliqua *regeneration following wildfire was related to the age of the regeneration and the intensity of fire damage. Seedlings 1.5 years old were completely killed following fires which resulted in total scorching of the foliage. At age 7.5 years, total burning of the foliage had no effect on survival but total burning of the crown (foliage, branches and upper stem) resulted in substantial mortality. At age 9.5 years, most trees were able to recover from total crown-burning.*

Crown-burning of regeneration up to the age of 9.5 years resulted in the death of all above-ground stem tissue, with surviving trees recovering from basal shoots. Trees which survived the total burning or scorching of foliage suffered damage varying from crown dieback to partial stem death, with recovery occurring either from crown epicormics or from stem epicormics immediately below the dead portion of stem. Seven years after the fire, the form of partially killed stems was very poor, with serious stem malformations associated with dead tops and a high incidence of multiple leaders. All fire intensities resulted in a substantial loss of growth.

Areas of burnt regeneration should be re-sown if post-fire assessments indicate a low stocking of survivors. Where survival is adequate, further treatment is generally not justified. However, future wood quality may be downgraded and appropriate adjustments should be made to planned yield estimates.

Introduction

Tasmania contains large, dispersed aggregates of even-aged regeneration resulting from clearfelling operations. Over the last 30 years, the establishment of even-aged regeneration has averaged 5000 ha per year. Total protection of these areas from fire is a high management priority for at least the first 20 years.

Improved fire management practices have minimised the loss of regeneration areas to wildfire (Ingles 1985). Nevertheless, wildfire damage remains a significant management risk, with 4855 ha of regeneration burnt over the last decade. These losses resulted from major wildfires in 1983 (2340 ha), 1988 (930 ha), 1989 (300 ha), 1990 (1065 ha) and 1992 (220 ha).

Major eucalypt species in the wet forest regeneration areas vary from the relatively fire-sensitive *Eucalyptus regnans* to species considered to have higher fire resistance such as *E. obliqua* and *E. delegatensis*. The drier forest types are characterised by very resistant species such as *E. sieberi* and *E. amygdalina*.

Eucalypts are generally well adapted to survive even high intensity fire, with recovery occurring from crown epicormics, stem epicormics or basal shoots, depending upon the intensity of the fire and age of the stand. Although regeneration may recover from wildfire, the stand quality is often downgraded. Forest managers need to know the likely effects of wildfire damage to determine whether remedial treatments should be be undertaken or adjustments made to the future yield estimates.

This paper reviews the survival and recovery of *E. obliqua* regeneration aged

Table 1. Damage classes of regeneration based on colour from aerial photography.

Photo colour	Age of regeneration when burnt (yrs)	Damage
White	1.5, 5.5, 7.5, 9.5	*Total crown burn.* All leaves and most branches and upper stem removed. Ground covered by white ash.
Grey	7.5, 9.5	*Total foliage burn.* All leaves burnt, stems and branches remaining.
Brown	1.5, 9.5	*Total foliage scorch.* Brown leaves remaining on crown.
Brown (plus ground survey)	5.5	*Total crown scorch.* Death of stem at ground level due to peat fire. Brown leaves remaining on crown.

from 1.5 to 9.5 years, following the Holder wildfire of 1983/84. The implications for the future management of such areas are discussed.

Description of the Holder wildfire

The Holder regeneration coupes are located south of the Arthur River in the far north-western corner of Tasmania. This area contains a mosaic of virgin and cut-over wet eucalypt forest, open forest, buttongrass plains and stands of young regeneration. The higher commercial quality forests and regeneration stands are dominated by *E. obliqua*.

On 21 December 1983, a fire started from a chainsaw in cull-felling operations within a cut-over coupe. Weather conditions were slightly drier than average (Soil Dryness Index of 74). Strong south-westerly winds fanned the spread of the fire into cut-over forest along the northern side of the Arthur River. Gale force north-easterly winds on 31 December spotted the fire across the Arthur River into the Holder regeneration areas. The main run of the fire occurred over one day when a wind-driven crown fire burnt standing green fuels of 40–60 t/ha. The fire danger rating according to the McArthur meter was 12 (high), with conditions mitigated by a high relative humidity of 60%. Subsequent peat fires remained alight for a further two months until 9 March 1984, by which time 3160 ha had been burnt, comprising 820 ha of mature forest, 1270 ha of wet forest regeneration and 1070 ha of open forest regeneration and plains. Variable weather conditions and fuel types throughout the fire resulted in a range of fire intensities, which included crown fires, ground surface fires and sub-surface peat fires. The first heavy rainfall (70 mm) fell on 24–26 March. The months of April to June were 25% drier than average and the normal heavy winter rainfall of 130 mm per month did not commence until July.

Monitoring of wildfire damage

1. *Aerial photography.* Colour aerial photographs of the fire were taken at a 1:10 000 scale on 1 February 1984. From the photographs, four main categories of damage were identified, based on the degree of crown loss (Table 1, Photos 1–3).

2. *Ground surveys.* Observations were made on line surveys during May to August 1984 to assess the stocking of living stems.

Photo 1. Total crown burn in 7.5-year-old regeneration (mapped as a 'white' area on aerial photographs due to loss of the crown, leaving a white ash layer visible on the ground surface).

Photo 2. Total foliage burn in 9.5-year-old regeneration (mapped as a 'grey' area on aerial photographs due to the grey-black appearance of burnt crowns over the black ground surface).

Photo 3. Total foliage scorch in 9.5-year-old regeneration (mapped as a 'brown' area on aerial photographs due to the brown colour of the retained canopy).

Table 2. Survival and recovery of regeneration in monitoring plots.

Fire damage	Age of regeneration at burning (yrs)	Estimated MDH* of regeneration at burning (m)	Stocking of regeneration at burning (stems/ha)	Survival after 1 year (%)	Survival after 7 years (%)	Height after 7 years (m)	Dbhob† after 7 years (cm)	Recovery after 7 years: Mean no. stems/tree	Recovery after 7 years: Height of surviving original stem (m)	Recovery after 7 years: Origin of shoots
Total foliage scorch	1.5	1	2 400	0	0	0	0	0	0	-
	9.5	12	3 400	97	53	10	11.6	1.2	full height (60% of stems)	crown
									4 (40%of stems)	stem
Total foliage burn	7.5	9	4 500	94	62	8	5.5	1.9	1.4 (50%of stems)	stem
									0 (50% of stems)	basal
	9.5	12	3 200	97	59	12	9.6	1.3	2	stem
Total crown burn	1.5	1	adequately stocked	0	0	0	0	0	0	-
	5.5	7	12 600	18	13	7	3.4	1.4	0	basal
	7.5	9	3 900	26	15	3	3.6	2.5	0	basal
	9.5	12	3 100	77	26	4	2.9	2.0	0	basal
Cambium death due to peat fire	5.5	7	5 000	10	4	5	4.4	2.0	0	basal

* MDH = mean dominant height
† dbhob = diameter at breast height over bark

3. *Survival and growth plots.* A single measurement plot of 10 m x 10 m was established in each age class to monitor the survival and growth of regeneration within each damage category.

Effects of wildfire damage

A summary of observations on survival and recovery is given in Table 2 and Figure 1.

Survival

Survival of 9.5-year-old regeneration was almost 100% one year after total foliage scorch or total foliage burn. Total crown burn reduced initial survival of 9.5-year-old regeneration to 77% and, after seven years, survival was less than 50% of that for the lower intensities of crown damage, indicating a longer term effect on the survival of damaged and weakened stems.

Survival of 7.5-year-old regeneration was 94% one year after total foliage burn. Total crown burn reduced initial survival to 26%, but subsequent mortality after seven years was relatively low.

Survival of 5.5-year-old regeneration subjected to total crown burn was only 18%, although after seven years the stand was still relatively well stocked with 2000 stems/ha. However, a large proportion of the remaining stand consisted of *E. nitida* which recovers better from fire than *E. obliqua*. Survival in areas damaged by peat fires was very low, with only 10% survival after one year and only 4% survival seven years later.

Regeneration aged 1.5 years was totally killed by even a relatively low intensity fire which caused total foliage scorch.

Recovery

Total crown burn caused the above-ground stem death of all regeneration up to 9.5 years in age. Regeneration 5.5 years or older recovered from basal shoots which appeared within seven weeks of the fire. Heavy browsing of these shoots by native animals occurred during the first autumn and continued until the following summer. Shoot loss due to browsing may have contributed to the poor survival of many stems. The multi-stemmed basal shoots were growing vigorously from surviving rootstocks one year after the fire. The number of stems per tree has subsequently decreased but still averaged approximately two after seven years (Photo 4).

Total foliage burn in 7.5-year-old regeneration resulted in stem death at ground level for 50% of survivors and stem death at 1.4 m above ground level for the remainder. In 9.5-year-old regeneration, stem death occurred at a mean height of 2.0 m above ground level. Recovery of 7.5-year-old regeneration occurred from basal

Photo 4. Multi-stemmed basal shoots seven years after stem death of 7.5-year-old regeneration.

Fire damage	Recovery of regeneration	Results
Total foliage scorch or foliage burn in 7.5- to 9.5-year-old regeneration.		**Survival:** High. **Form:** High proportions of defect due to dead tops, multiple leaders and stem malformation. **Recommended treatment:** None, except on suitable high quality sites where clearing followed by sowing or planting are options. **Future management:** Short-rotation pulp crop or normal rotation with reduced sawlog yield.
Total crown burn in 5.5- to 9.5-year-old regeneration.		**Survival:** Very low for trees younger than 9.5 years. **Form:** Multiple leaders with poor form. **Recommended treatment:** Sow areas of low survival. **Future management:** Short-rotation pulp crop or normal rotation with reduced sawlog yield.
Total foliage scorch or foliage burn in 1.5-year-old regeneration.		**Survival:** Negligible. **Recommended treatment:** Sow areas in following autumn. **Future management:** Normal rotation and yields.

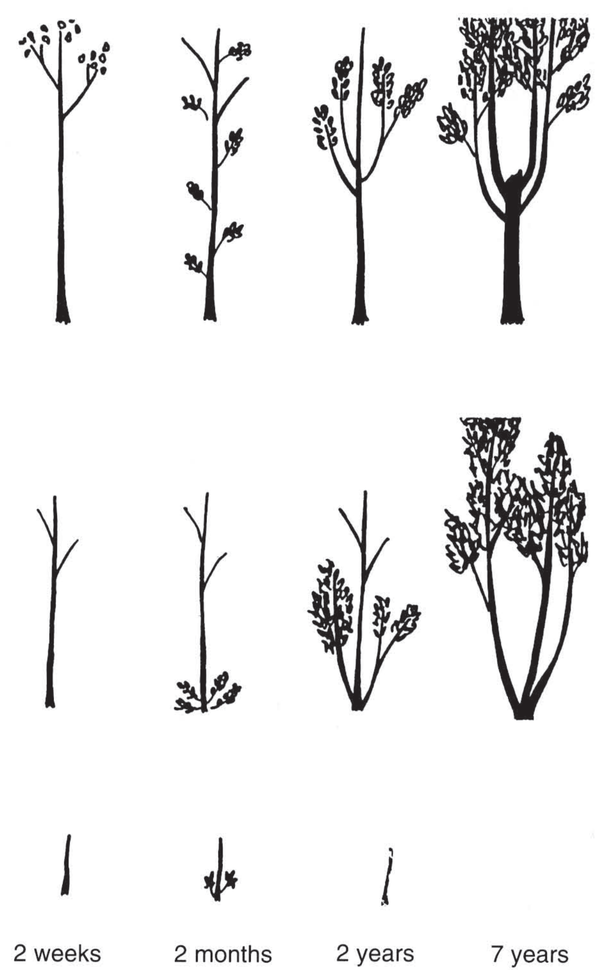

Figure 1. Summary of recovery of regeneration from wildfire and future management options.

shoots and stem epicormics. The 9.5-year-old regeneration recovered predominantly from stem epicormics.

Total foliage scorch did not cause stem death in 60% of 9.5-year-old regeneration but killed remaining stems above a height of 4 m. Trees recovered from crown and stem epicormics.

After seven years, there were serious form problems associated with the trees which recovered from partial stem death. Most were characterised by one to three stems arising from below the dead portion of original stem. Tree form was very poor, with defect due to the dead top of the original stem and severe kinking of secondary stems (Photo 5). However, defect due to decay was largely confined to the dead portion of stems. Compartmentalisation of decay was very good seven years after the fire and adjoining living tissue was very healthy (T. Wardlaw, pers. comm.).

All damage intensities resulted in substantial loss of height growth. Mean dominant height of 7.5- and 9.5-year-old regeneration following the total scorching or burning of foliage was only approaching pre-burn levels after seven years. Height increment was markedly reduced following total crown burn, with 7.5- and 9.5-year-old regeneration only recovering to 33% of original height after seven years.

Photo 5. Poor form of regeneration seven years after partial stem death of 9.5-year-old regeneration.

Discussion

The thermal death point of living tissue is a function of temperature and duration of exposure. Death is almost instantaneous at 64°C and will occur within minutes at 54°C (Hare 1961; McArthur 1968). Lethal temperatures occur during wildfires as a result of direct combustion, heat radiation and convection. When leaves are burnt or scorched, recovery typically takes place by copious epicormic shoots, most of which die when the canopy is fully established (Gill and Ashton 1968). The death of branch and stem material occurs when the phloem and cambium are killed with increasing fire intensity.

Lignotubers and buds below the ground are well protected from surface fires since 95% of a fire's heat rises and the soil provides effective insulation against the remaining 5% (Gill 1981). However, humus or peat fires are very damaging and result in death of the cambium at and below the soil surface (Cremer 1962) as indicated by the death of 5.5-year-old regeneration following the peat fire in the current study.

The relative ability of a young eucalypt to survive a surface fire depends upon its ability to respond from above-ground epicormics or below-ground lignotubers. For all species, bark thickness has been clearly identified as the most important factor contributing to the protection of stem cambium (McArthur 1968;

Gill and Ashton 1968; Vines 1968). For *E. obliqua*, there is a linear relationship between bark thickness and time taken for the cambium temperature to rise 40°C to the critical cell death point (Gill and Ashton 1968). Typically, when bark is alight, surface temperatures can reach 1000°C resulting in cambium death after two minutes if bark is 10 mm thick or after 14 minutes if bark is 40 mm thick (Luke and McArthur 1978). Bark thickness varies with species, age and diameter of individual trees. McArthur (1968) found no differences in bark thickness between *E. rossii* and *E. macrorhyncha* saplings up to 7.5 cm dbhob (diameter at breast height over bark) but, for stems 35.5 cm dbhob, the *E. macrorhyncha* bark was twice the thickness of *E. rossii* bark. The relatively thin bark of *E. regnans* has been implicated as one reason for that species having a lower fire resistance than the thicker barked *E. obliqua* (Gill 1981).

Since bark thickness increases with age and diameter growth, the relative resistance of a young tree to fire damage will depend upon its age, growth rate and the height above ground of fire-susceptible thin-barked stems or branches. Peet and McCormick (1971) found that karri saplings less than 5.8 m tall were killed by low intensity, fuel reduction burns of 69 to 104 kW/m. In contrast, 5–7 m tall *E. dives* trees showed 100% survival after total crown burn although 50% of the height of the stem was killed (Gill 1978). Small lignotuberous seedlings of *E. dives*, *E. pauciflora* and *E. dalrympleana* all had 60% survival following an intense fire (Noble 1984). In the current study, significant mortality of *E. obliqua* saplings up to 9 m in height occurred following complete crown burn. For all saplings up to 12 m in height, total crown burn resulted in the death of all stem tissue. Total foliage burn caused the death of all stem tissue higher than 2 m above ground level and total foliage scorch resulted in the death of some stem tissue above 4 m in height.

The effect of wildfire damage on growth and form is directly related to the loss of foliage and sapwood. Trees which have less than 50% of their foliage scorched are not likely to produce epicormics or lose diameter or volume increment (Luke and McArthur 1978).

Low intensity fires which do not kill the cambium may still damage the phloem and cause the formation of gum veins (Jacobs 1955). However, a single low intensity fire which does not cause cambium death or stem scars is unlikely to result in significant defect (Greaves *et al.* 1965). If all the foliage is scorched, a significant growth loss is incurred whilst epicormic growth re-establishes the canopy. Hodgson and Heislers (1972) found that young *E. sieberi* regrowth suffered growth losses only when the leading shoots were killed. In completely scorched crowns, the growth of dominants was 33% of that on unburnt trees after 12 months whilst completely defoliated crowns grew at a rate of 13% of that for unburnt trees. Gill (1978) found that the leaf weight of 5–7 m tall *E. dives* was restored within eight months for both crown-scorched and crown-burnt canopies. Normal branching habit was restored in less than three years for *E. dives* but took longer than six years for *E. dalrympleana*.

The current study indicates growth losses of at least seven years before mean dominant height recovers to pre-burn levels in 7.5- to 9.5-year-old regeneration following total burning or scorching of the foliage. Growth losses after total crown burn were much greater since all previous stem growth was lost and recovery was from new (basal) shoots. For 7.5- to 9.5-year-old regeneration, the basal shoots were only about 50% of the height normally expected for new seedlings, indicating a total loss of at least 11–13 years' growth. The slow recovery of growth may be related both to physiological response following fire damage and to loss of site productivity due to nutrient losses on this low fertility site.

Whilst growth losses may be relatively short term, effects on stem form and quality can be more long lasting. In small saplings, the total death of the above-ground stem followed by basal sprouting is preferable to the maintenance of a defective stem.

Generally, the current study indicates that multi-stemmed basal shoots will thin to between one and three stems after seven years and further thinning can be expected as the stand ages. It is not expected that there will be any major long-term effects on wood quality.

Death of the stem at a height above ground results in a serious stem malformation where one or more epicormic stems replace the dead leader. The height of this malformation will affect the length of merchantable bole and result in lower future sawlog value (Wright and Grose 1970). In addition to physical damage, burning indirectly increases defect by providing an entry point for decay and insects. Greaves *et al.* (1965) found that fire damage directly accounted for only 5% of defect but was the primary cause of most scars through which decay and termites entered. The compartmentalisation of fire-defect in *E. obliqua* stems seven years after the Holder wildfire was very good, with no evidence of decay or insect attack to live sections of stem. However, the breakdown of decay barriers followed by rapid spread of decay has been reported to occur in young trees approximately 15 years after the initial entry of decay organisms into wounds (White and Kile 1991). The future long-term value of stem-damaged regeneration is therefore not known but some reduction in sawlog yield appears likely.

Recommendations for the future management of fire-damaged regeneration

A guide to the likely survival and recovery of young regeneration following wildfire is presented as Figure 2. The recommended treatments for fire-damaged regeneration are detailed below.

1. Post-fire assessment

(a) *Colour aerial photography* of the wildfire area at a scale of 1:10 000 should be taken as soon as possible after the fire when smoke has dissipated and whilst dead leaves remain on trees. Colour photography at a scale of 1:24 000 has also been used successfully to delineate up to seven damage classes in mature eucalypt forest (Smith and Woodgate 1985).

(b) *Ground inspections* should be conducted to verify damage classes mapped on photographs.

(c) *Ground assessments* should be undertaken after shoot recovery (6–8 weeks after the fire) to confirm the correlation between damage level and expected recovery (Figure 2).

2. Future management

The remedial treatment of young regeneration to increase future productivity is not economically justified unless large increases in productivity or value can be assured (Forestry Commission 1992).

Recommendations for remedial treatments include:

(a) *Fire-killed regeneration*. Re-sow in early autumn whilst a receptive seedbed remains; control animal browsing.

(b) *Stem-killed regeneration with basal shoots*. No further treatment is justified where survival is adequate. Understocked areas should be re-sown in early autumn. Control animal browsing.

(c) *Dead-topped regeneration with stem epicormics*. Treatment may be justified where the following criteria apply:

- high quality site;
- machine clearing can be carried out at a reasonable cost and without environmental damage;
- management priority is for the production of high quality sawlogs and/or priority for pulpwood production is low;
- funds are available for investment in remedial treatment.

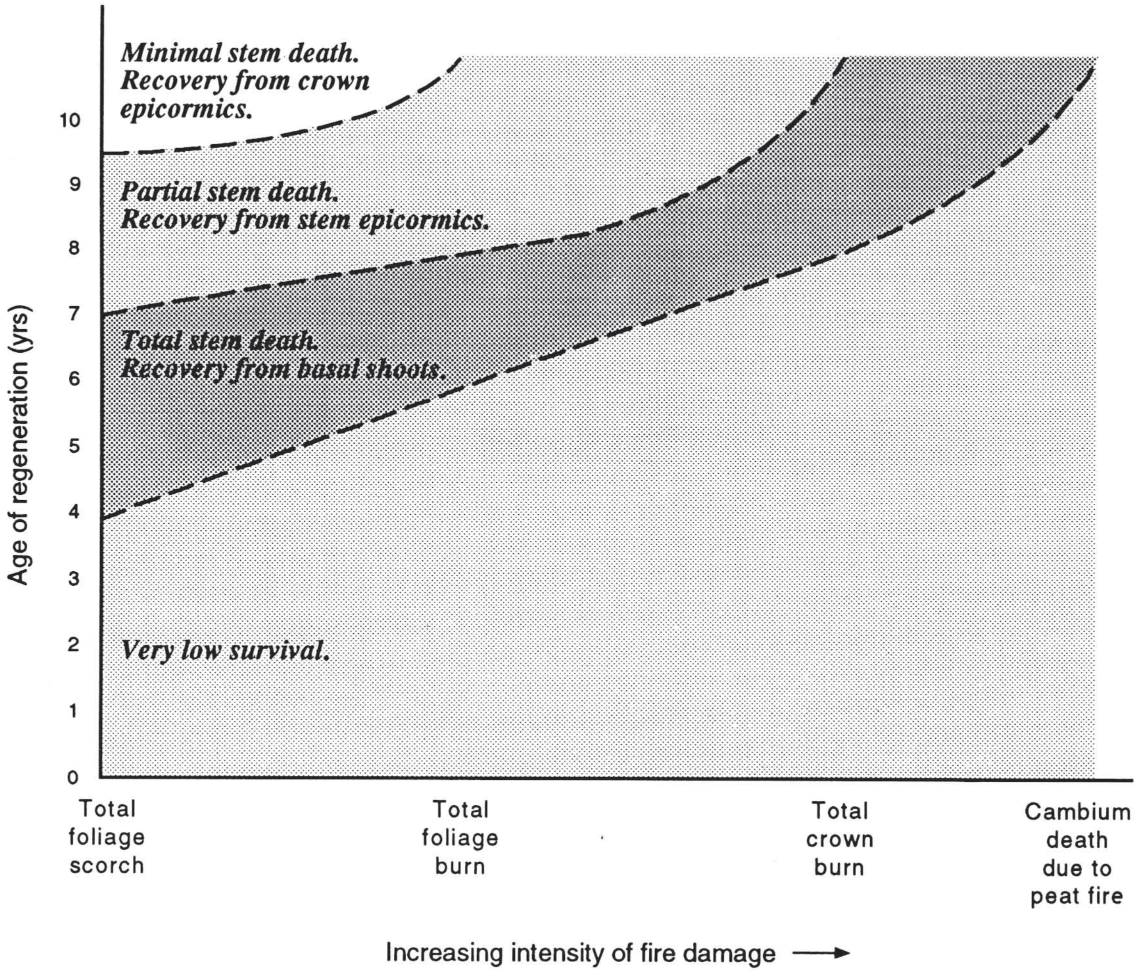

Figure 2. A guide to the likely survival and recovery of young E. obliqua *regeneration following wildfire.*

Where treatment is justified, clearing must be completed before suitable conditions for seed germination are lost. Plantation establishment may be an option on approved sites (Neilsen 1990). However, on most sites, remedial treatment will not be justified and the recommended action is:

(a) continue to monitor wood quality as the stand matures;

(b) provisionally plan for sawlog yields to be significantly reduced;

(c) re-schedule burnt areas to short-rotation pulpwood if high defect levels preclude sawlog production.

Acknowledgements

The contribution of Leigh Edwards and the Smithton District staff to the collection of field information is gratefully acknowledged. Peter Bennett and Judi Beck provided valuable comments on the draft manuscript.

References

Cremer, K.W. (1962). The effect of fire on eucalypts reserved for seeding. *Aust. For.* 26: 129–154.

Forestry Commission (1992). *Remedial Treatments.* Native Forest Silviculture Technical Bulletin No. 7. Forestry Commission, Tasmania.

Gill, A.M. (1978). Crown recovery of *Eucalyptus dives* following wildfire. *Aust. For.* 41: 207–214.

Gill, A.M. (1981). Adaptive responses of Australian vascular plant species to fire. In: *Fire and the Australian Biota* (eds A.M. Gill, R.H. Groves and I.R. Noble), pp. 243–272. Australian Academy of Science, Canberra.

Gill, A.M. and Ashton, D.H. (1968). The role of the bark type in relative tolerance to fire in three central Victorian eucalypts. *Aust. J. Bot.* 16: 491–498.

Greaves, T., McInnes, R.S. and Dowse, J.E. (1965). Timber losses caused by termites, decay and fire in alpine forest in NSW. *Aust. For.* 29: 161–173.

Hare, R.C. (1961). *Heat Effects on Living Plants.* Occasional Paper 183. Southern Forest Experiment Station, USDA Forest Service, US Department of Agriculture.

Hodgson, A. and Heislers, A. (1972). *Some Aspects of the Role of Forest Fire in Southeastern Australia.* Bulletin 21. Forests Commission, Victoria.

Ingles, A. (1985). *Fire.* Working Paper 2, Environmental Impact Statement on Tasmanian Woodchip Exports beyond 1988. Forestry Commission, Tasmania.

Jacobs, M.R. (1955). *Growth Habits of the Eucalypts.* Forestry and Timber Bureau, Canberra.

Luke, R.H. and McArthur, A.G. (1978). *Bushfires in Australia.* Australian Government Publishing Service, Canberra.

McArthur, A.G. (1968). The fire resistance of eucalypts. *Proc. Ecol. Soc. Aust.* 37: 83–90.

Neilsen, W.A. (ed.) (1990). *Plantation Handbook.* Forestry Commission, Tasmania.

Noble, I.R. (1984). Mortality of lignotuberous seedlings of *Eucalyptus* species after an intense fire in montane forest. *Aust. J. Ecol.* 9(1): 47–50.

Peet, G.B. and McCormick, J. (1971). *Short-term Responses from Controlled Burning and Intense Fires in the Forests of Western Australia.* Bulletin No. 79. Forests Department, Western Australia.

Smith, R.B. and Woodgate, P.W. (1985). Appraisal of fire damage and inventory for timber salvage by remote sensing in mountain ash forests in Victoria. *Aust. For.* 48: 252–263.

Vines, R.G. (1968). Heat transfer through bark and the resistance of trees to fire. *Aust. J. Bot.* 16: 499–514.

White, D.A. and Kile, G.A. (1991). Thinning damage and defect in regrowth eucalypts. In: *The Young Eucalypt Report* (eds C.M. Kerruish and W.H.M. Rawlins), pp. 152–177. CSIRO, Australia.

Wright, J.P. and Grose, R.J. (1970). Wood degrade due to fire. *Aust. For.* 34: 149–166.

Tasforests