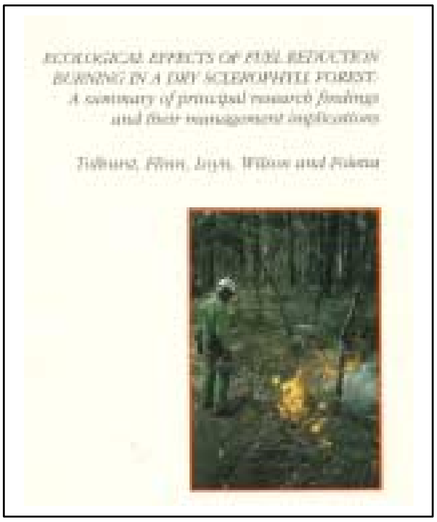
ECOLOGICAL EFFECTS OF FUEL REDUCTION BURNING IN A DRY SCLEROPHYLL FOREST

A Summary of Principal Research Findings and their Management Implications



Kevin G. Tolhurst, David W. Flinn, Richard H. Loyn, Andrew A.G. Wilson, and Ian Foletta

August 1992

Forest Research Centre
Department of Conservation and Environment

This Publication was produced by Forest Research, Department of Conservation and Environment. Published by the Department of Conservation and Environment, Melbourne 1992.
ISBN 0 7306 3076 5

Contents

1 INTRODUCTION

1.1 Background

Prescribed burning has been used extensively for fire protection and silvicultural purposes and in a limited way for environmental management on Victorian public land over the past 30 years. Suppression of unplanned fires in Victoria has been given high priority since the devastating 1939 fires and the subsequent Royal Commission Inquiry conducted by Judge Stretton (Stretton 1939). This human control over fire has been contentious with both emotional and scientific arguments being used to influence management objectives and practices. The practice of fuel reduction burning has been the most controversial.

Research into the ecological effects of fire in forested ecosystems in Victoria has been in progress since the 1920s, but the main effort has been made since the late 1950s. In the wake of the 1983 Ash Wednesday fires, a symposium was held at Monash University in September 1983 to review and compare the effects of fuel reduction burning with the effects of wildfire. This symposium indicated that little progress had been made in understanding the effects of repeated fuel reduction burning in the previous 10 years (Ealey 1984). The main reason for the lack of progress was that no long-term experimental research programs had been established. Many research had been opportunistic and had only looked at the effects of a single fire and therefore were unable to compare fires and their effects because they were not replicated in time or space. Few studies included prefire measurements and fewer still had accurate records of fire behaviour and climatic variables.

Current fire ecology research in Victoria is limited to short-term projects conducted by tertiary institutions and some longer-term research conducted by the Museum of Victoria and the Department of Conservation and Environment. Most Victorian tertiary institutes have somebody working in fire related studies; fauna, flora and soil nutrition are the main areas covered. The Museum of Victoria studies fire in relation to invertebrates, although its work is limited by scarce resources. Currently, the main fire ecology research effort is made by the Department of Conservation and Environment. The Department's studies range from broadscale fauna and flora surveys with some interpretation of the effects of fire history, to longer-term studies in heathland in the Grampians and dry sclerophyll forest in the Wombat State Forest. This summary relates to the Wombat State Forest study.

In January 1984, a multi-disciplinary research program was initiated by the Department to study the ecological effects of repeated low-intensity prescribed burning, for fuel reduction purposes, in dry sclerophyll foothill forests. Permanent study areas were established in the Wombat State Forest, 80 km north-west of Melbourne. The relevance of this work has been reinforced by subsequent Government policy documents such as the Victorian State Conservation Strategy (Victorian Government 1987) and the Victorian Timber Industry Strategy (Victorian Government 1986). This report is a summary of some preliminary results reported in detail by Tolhurst and Flinn (1992).

Broad objectives of the Wombat State Forest program are to assess and describe the effects of repeated (rotational) spring and autumn fuel reduction burning on:

- the flora, fauna and soils;
- the functional processes of dry sclerophyll forest ecosystems; and
- the short-term and long-term stability of such ecosystems.

1.2 Individual Research Projects

The fire effects research program is divided into ten projects. Each project has one or more objectives, as follows:

Fire Behaviour and Fuel Dynamics

- Describe the behaviour of each experimental fire.

- Explore the correlation between climatic, site and fuel variables and fire rate of spread, flame height, scorch height and amount of fuel burnt.
- Study the accumulation rate of litter and other fuels following burning.

Vegetation
- Measure understorey vegetation structure and the effects of repeated spring and autumn burning on this structure.
- Assess species composition before and after repeated spring and autumn burning.
- Observe flowering, seed-set, shoot growth, establishment and mortality of individual species, and determine whether spring or autumn burning and seasonal differences change these patterns.
- Quantify the demographic structure of major understorey species and describe the impacts of climate and burning on these structures.

Invertebrates
- Assess the impact of prescribed low-intensity burning regimes on arthropods and earthworms within litter/upper soil habitats, and recommend ways for ameliorating any short-term or long-term adverse effects on invertebrates.

Bat Fauna
- Determine the species present within the forest.
- Improve techniques to measure bat activities in, and movements between, areas with different burning treatments.

Reptiles
- Identify the species present in each burning treatment and the relative abundance between treatments with time after burning.

Mammals
- Identify the species present in each burning treatment and the relative abundance between treatments with time after burning.
- Determine the home range and movement patterns of each species.
- Determine the habitat requirements for each species.

Birds
- Study the species composition and relative abundance of birds before and after prescribed low-intensity burning and between treatments with time after burning.

Soil Chemistry
- Assess changes in soil nutrient status at three locations (upper-, middle-, and lower-slope) in each burning treatment.
- Assess the effects of fire intensity on surface soil chemistry and the changes in nutrient status with time after burning.
- Investigate the effects of fire intensity on rate of nitrogen mineralisation with time after burning.
- Assess the rate of nitrogen fixation by native legumes after low-intensity burning.

Tree Growth and Defect
- Assess the possible effects of repeated prescribed low-intensity burning on tree growth, bark thickness and stem damage.

Climate
- Determine the length of growing season which is considered to influence the rate and nature of plant recovery after burning.
- Measure the climatic conditions important to fire behaviour and relate these to observed fire behaviour.

1.3 Objectives of this Summary Report

This multi-disciplinary study has been in progress for around seven years, and detailed progress reports have recently been prepared on the ten component projects (Tolhurst and Flinn 1992). While these reports primarily discuss preliminary research findings, and many are confined to the effects of a single low-intensity burn, sufficient information has now been collected to identify some potential ecological effects of a single fuel-reduction burn. This is the first time that the impacts of fuel-reduction burning on a wide range of ecological values have been reported for the one study area. This summary brings together the important information from the individual progress reports and draws conclusions on how fire management procedures can be amended to better achieve the conservation and fire protection objectives of forest management.

2 STUDY AREA AND EXPERIMENTAL DESIGN

2.1 Selection of Study Areas

The more extensive forests commonly experiencing wildfires in Victoria are the Messmate /Gum, Silvertop/Stingybark, Stringybark/Box, and Mallee forest types. The Messmate/Gum forest type was selected for the present research program because of its proximity to the Creswick Research Centre, its economic importance and because it is representative of about 25% of the four million hectares of foothill forest in Victoria. Messmate/Gum forest in the Wombat State Forest is also easily accessible and has a good recorded history of logging and fire. Furthermore, the Messmate/Gum forest contains contrasting eucalypt groups (Symphyomyrtus and Monocalyptus).

The principal eucalypt species present are Messmate Stringybark, Candlebark, and Narrow-leaf Peppermint. Within this forest type, areas that had remained unburnt for the previous 18 years were chosen. We determined that individual treatment areas needed to be at least 10 ha in size to study the effects of fire on birds and small mammals, so an overall area of at least 50 ha was required to incorporate one replication of two spring burning treatments, two autumn burning treatments and an unburnt treatment. Five areas (replications), known as Fire Effects Study Areas (FESAs), were selected to represent the geographic range of this forest type in the Wombat State Forest. An extensive vegetation survey was made in each of the five areas to determine the range of species present (Tolhurst, unpublished data).

2.2 Description of Study Areas

The Wombat State Forest is 80 km north-west of Melbourne. The Messmate/Gum forest straddles the Great Dividing Range and grows on yellow podzolic soils derived from Ordovician sedimentary rocks. The location, elevation, annual rainfall and time of last fire in each FESA are given in Table 2.1 and their relative location shown in Figure 2.1.
Air temperatures are cool in the region, with the average monthly temperature being less than 6^{o}C for three months of the year (June, July and August). The average monthly temperature in summer is about 15^{o}C, although the maximum daily temperature may exceed 40^{o}C. Fifty-five frosts occur on average each year. Frosts occur between May and November and are most frequent in winter when air temperatures can be as low as 6^{o}C. Rainfall occurs in all months, with about 70% falling in winter and spring. On average there are about 160 wet days each year.

Table 2.1
Geographic and fire history attributes of the five study areas.

Fire Effects Study Area(FESA)	Last burnt	Elevation (m)	Rainfall (mm)	Distance from GD(a) (km)	Latitude	Longitude
Blakeville	~1935	625-700	900	10.0 S	37°31'	144°10'
Barkstead	~1931	625-640	925	2.5 S	37°29'	144°05'
Burnt Bridge	~1953	685-730	900	1.5 S	37°25'	144°20'
Musk Ck	1974	625-685	920	5.0 S	37°28'	144°10'
Kangaroo Ck	1944	550-640	780	10.0 N	37°19'	144°18'

(a) GD = Great Divide (within the Great Dividing Range).

A total of 366 ha was set aside for the research program. Individual treatment areas exceeded 10 ha at the Blakeville, Burnt Bridge, Musk Creek and Kangaroo Creek FESAs, and were 3 to 4 ha at the Barkstead FESA.

All areas had full tree stocking. Stands were uneven-aged, with few trees older than 90-100 years. Thinning to remove trees with low commercial potential has occurred periodically since the 1930s although a few non-commercial trees remain at Kangaroo Creek. This has left stands which are very productive from a wood production viewpoint. An assessment of the trees in 1985 showed the average stand height to be 34 m, overwood basal area to be 24 $m^2.ha^{-1}$ and regrowth basal area to be 9 $m^2.ha^{-1}$. (Overwood comprises trees with a diameter overbark at 1.3 m above groundlevel (DBHOB) of > 30.0 cm, and regrowth comprises trees with a DBHOB of < 30 cm).

Messmate Stringybark was the dominant species (54% of total basal area) in the overwood trees and Narrow-leafed Peppermint dominated the regrowth (47% of total basal area). Candlebark was a minor component in both size classes.

Three main plant associations were recognised, two occurred on mid-slopes and a third limited to moist gullies. The characteristic species in the main mid-slope plant associations were Common Raspwort, Bracken, Poa Tussock-grass, Ivy-leaf Violet, Wattle Mat-rush, Trailing Goodenia, Flatweed and Fireweed. All these species are common and widespread. The second mid-slope plant association was characterised by Small Poranthera, Bidgee Widgee, Crane's Bill, Common Lagenifera, Prickly Woodruff and Australian Clematis. The plant association in gullies was characterised by Tall Sword-sedge and Prickly Tea-tree.

Numbers of observed hollows, which were potential nest sites for birds or mammals, were mapped. Burnt Bridge and Barkstead study areas had very few hollows, while hollows were more numerous at Kangaroo Creek due to the presence of a greater number of older trees.
Slope and aspect of each study area were measured on a 50 x 200 m grid. Very few areas are steeper than 15°. Predominant aspects are south-westerly in Blakeville, Barkstead and Musk Creek, northerly at Kangaroo Creek and easterly or westerly at Burnt Bridge.

2.3 Experimental Design

The experiment conforms to a randomised block design, with five blocks located across the geographic range of the forest type within the Wombat State Forest. The following burning treatments were randomly allocated within each block:

- Burning as often as possible in spring (S3)
- Burning as often as possible in autumn (A3)
- Burning on a 10 year rotation in spring (S10)
- Burning on a 10 year rotation in autumn (A10)
- Control, long-unburnt (C)

Permanent plots were established for the study of understorey vegetation, overstorey trees, invertebrates, litter and soils. Mammals and birds are being studied across the whole of each treatment area.

Fauna, flora, soils and litter were assessed in all treatment areas before any burning treatments were applied. Results from these assessments combined with assessments following burning treatments on burnt and control treatment areas, enabled measurements to be made of changes due to seasonal effects and those due to fire effects.

Weather stations were established within three kilometres of each FESA. Monitoring of weather conditions allowed seasonal conditions to be considered in conjunction with burning treatments when determining the causes of changes in the forest ecosystems.

Spring burning treatments were first applied in 1985 or 1986. The second rotation spring burning treatments were applied in 1988. Autumn burning treatments were first applied in 1987.
A more complete description of the FESAs and treatments is given in Tolhurst (1992a).

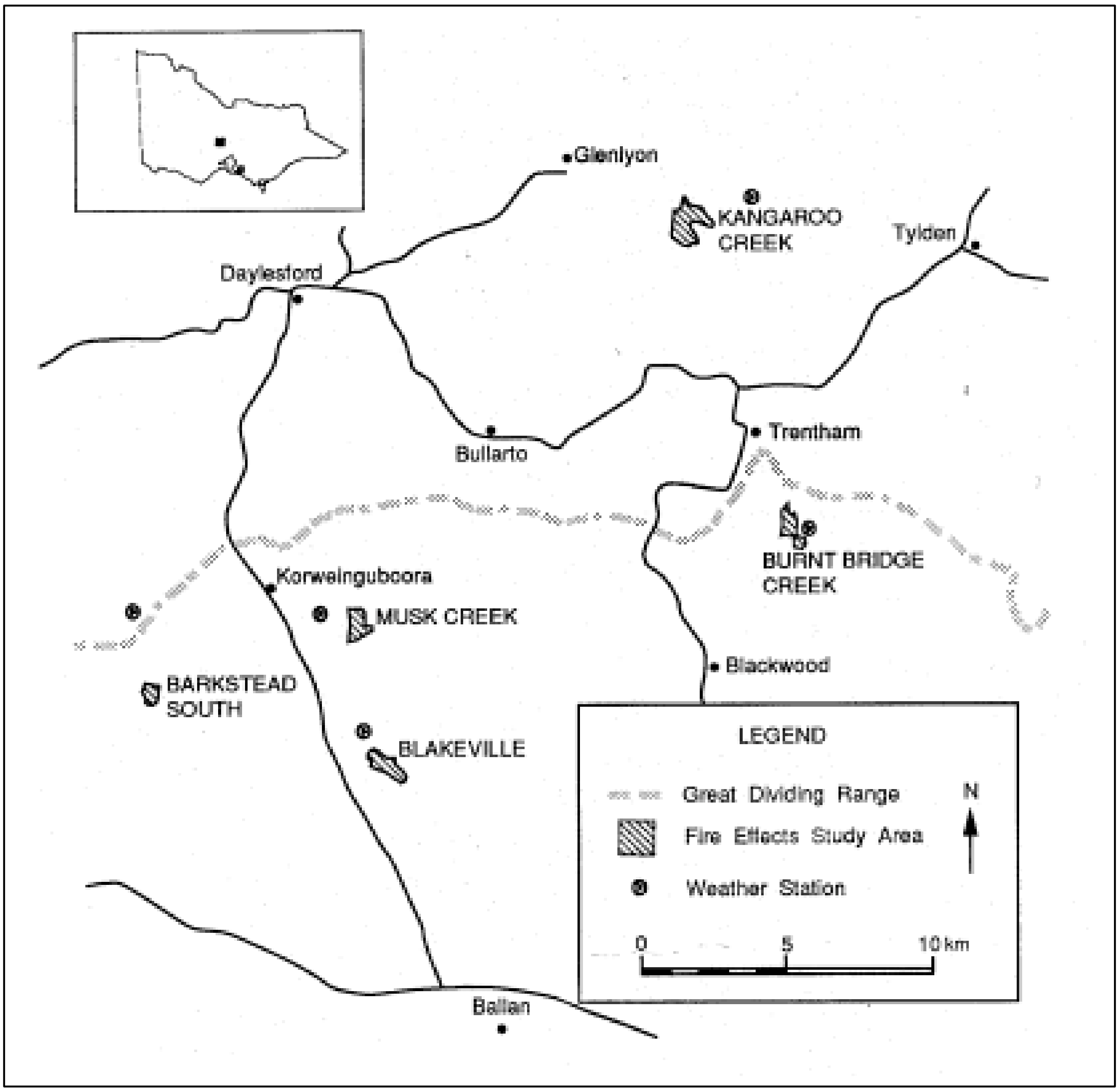


Figure 2.1 Location of the Fire Effects Study Areas, weather stations and the Wombat State Forest.

3 Fire behaviour

3.1 Introduction

1a Fire intensity near the upper limit desired for fuel reduction burning. Average flame height is 0.8 m, rate of spread is 3 m.min^{-1}, and fire intensity, 370 kW.m^{-1}. (Photo: Don Oswin)

Fire behaviour is commonly described in terms of its intensity, flame height and rate of spread. Fires can vary in intensity from less than 100 kW.m^{-1} up to 100 000 kW.m^{-1} (100 kW.m^{-1} is equivalent to the amount of radiant heat given out by 25 single-bar domestic radiators stacked vertically over every metre of fire front). Fires vary according to the prevailing fuel and weather conditions and therefore vary both temporally and spatially within and between areas burnt.

Interpretation of the effects of a fire on the forest ecosystem must be made in conjunction with behaviour of that particular fire. The times taken by plants, animals and soils to recover after a fire are related to the fire's behaviour.

Fire behaviour was closely monitored in all experimental treatments. The fire behaviour measured in this study was similar to the behaviour experienced in most broadscale fuel reduction burning practised throughout the state, but wss much less severe than a high-intensity wildfire.

A full account of the methods and results for fire behaviour studies presented in this summary is given in Tolhurst et al. (1992).

3.2 Results

A summary of the observed fire behaviour is given in Table 3.1. Fires in the plots were ignited using a line of fire approximately 40 m wide and 5 m below the edge of the plot on the downslope/downwind side. Fires in the general treatment area were ignited using a grid of spot ignitions at a spacing of approximately 50 x 50 m although occasionally fire were slow to develop so lines of fire were used instead of spot fires. Fire behaviour observations given here refer to head-fires, therefore much of the areas were burnt with less intense backing and flank fires. Observations were taken at approximately ten minute intervals.

Average forward rate of fire spread (FROS) was not significantly different between treatments. The average FROS was about 0.6 $m.min^{-1}$, but the fastest spread rate was 4.0 $m.min^{-1}$ in one of the second rotation (2R) spring burning treatment areas.

Average fire-line intensities (Byram 1959) were similar in spring (149 $kW.m^{-1}$) and autumn (148 $kW.m^{-1}$). However, maximum fire-line intensities in autumn (2195 kW.m-1) were almost double those observed in spring (1275 $kW.m^{-1}$). Intensity of the 2R fires in the spring treatments were similar to those of the first rotation (1R) (143 $kW.m^{-1}$ and 1922 $kW.m^{-1}$). Thus the overall average intensity of all the fires fell in the optimum fire intensity range for fuel reduction burning of 45-175 $kW.m^{-1}$ recommended by McArthur (1962).

1b Wind speed and direction, air temperature and relative humidity are recorded in the forest and in the open during experimental burning. (Photo: Kevin Tolhurst)

Mean flame heights in the 1R spring burning (0.54 m) were not significantly different to those in the autumn (0.42 m), but the flame heights in the 2R spring burning (0.15 m) were less than half of those in the first rotation fires. The maximum average flame height (5 m) occurred in an autumn fire where elevated fine fuels were burnt.

The production of firebrands, causing short-distance spotting, was common in the first rotation burns, but was almost non-existent during the second rotation. Most of the firebrands fell into the burnt area and those which fell ahead developed only small spot fires which were soon overrun by the main fire. Spotting distance was found to be a function of wind speed in the open and the fire danger index.

Table 3.1
Fire behaviour observation summary. Means are calculated from treatment means, and maximum values are based on individual observations. Standard errors of means are shown in parentheses.

Parameter		Spring 1R		Autumn		Spring 2R	
		Plots	Various	Plots	Various	Plots	Various
Flame Ht(m)	Mean	0.54 (0.07)	0.67 (0.06)	0.42 (0.03)	0.72 (0.08)	0.15 (0.03)	0.28 (0.05)
	Max	2.00	2.50	1.40	5.00	0.50	1.00
FROS ($m.min^{-1}$)	Mean	0.63 (0.09)	0.57 (0.12)	0.43 (0.07)	0.58 (0.10)	0.69 (0.45)	0.43 (0.06)
	Max	2.17	3.12	2.00	3.35	4.00	2.07
Intensity ($kW.m^{-1}$)	Mean	149 (33)	151 (43)	148 (27)	186 (37)	143 (104)	90 (19)
	Max	1140	1275	1736	2195	1922	773
Soil Temp (^{o}C)	Mean	161 (30)		367 (39)		403 (14)	
	Max Min	$\geq$600 0		$\geq$600 <65		$\geq$600 65	
% Area Burnt		90 (4)	73 (6)	94 (3)	90 (3)	87 (4)	78 (5)
Scorch Ht. (m)	Mean	5.8 (1.0)	5.0 (1.0)	7.4 (1.1)	11.9 (1.6)	3.8 (1.6)	4.2 (0.9)

Notes: Spring = spring fire treatments.
Autumn = autumn burning treatments.
Spring 2R = second rotation spring burning treatments.
Plots = permanent vegetation plots (30 x 30 m) on which fire behaviour was observed in detail.
Various = various sites throughout the treated area (generally > 10 ha).
Flame Ht = average flame height as observed across the flame front.
FROS = forward rate of spread of fire.
Intensity = Byram fire-line intensity.
Soil Temp = surface soil temperature measured by heat sensitive crayons on aluminium plates between the litter and soil surface.
% Area Burnt = areal coverage of fire determined by line intercept technique.

3.3 Conclusions

Fire behaviour in all treatments was within the acceptable limits for fuel reduction burning. Maximum values of any fire behaviour parameter were often up to ten times greater than the average value, showing the inherent spatial variability of fire. The fire intensities observed in this study are two to three orders of magnitude less than might be expected in a high-intensity wildfire and so the ecological effects are likely to be different between the two types of fire.

4 Fuel Dynamics

4.1 Introduction

Low-intensity burning is used in Victoria as a fire protection measure and as a tool to conserve fauna and flora. Approximately 150 000 ha of native vegetation on public land are burnt annually for these purposes, with most of that area being burnt as a fire protection measure. The main objective of burning for fire protection is to reduce fuel levels during mild weather conditions and thereby reduce the intensity and damage of any subsequent wildfire burning under hot, windy conditions.

The amount of fuel reduced, and its rate of recovery to pre-fire levels, is of particular relevance to management because the basis of a fire protection strategy is to keep fuels below specified levels. In spite of the importance of fuel loads to fire protection operations, there is a paucity of fuel load or fuel accumulation information for Victoria.

In this study we are measuring fuel loads in burnt and unburnt forest and quantifying the accumulation rates after fires. Humus, litter, twigs, branches, fallen trees, shrubs and bark on trees are being assessed in spring and autumn. A complete account of the methods and results presented in this summary is given in Tolhurst et al. (1992).

4.2 Results

Surface fuel loads at the beginning of the study are shown in Table 4.1.

Table 4.1
Average surface fuel quantity, subdivided by particle size, within treatment areas before the application of burning. Ninety-five percent confidence interval ($\pm$) shown in parentheses.

Treatment	Humus (< 5mm) ($t.ha^{-1}$)	Litter (< 6mm) ($t.ha^{-1}$)	Twigs (6 to 25mm) ($t.ha^{-1}$)	Branches/ Logs (>25 mm) ($t.ha^{-1}$)
Control	2.9 (0.6)	10.3 (1.1)	2.2 (0.5)	77.8 (31.8)
Autumn	3.0 (0.4)	10.8 (2.0)	1.9 (0.7)	73.5 (28.8)
Spring	3.4 (0.5)	11.1 (1.9)	3.1 (0.9)	62.1 (22.3)
Average	3.1 (0.3)	10.8 (0.8)	2.4 (0.4)	71.1 (11.5)

Note: Total fine fuel is the combined weight of humus and litter.

The low-intensity fires used in this experiment reduced the amount of litter, twigs, shrubs and Wire-grass by about 60% and bark on trees by about 30%, but had no significant effect on the amount of humus or coarse fuel components. This was attributed to the difference in drying patterns of the various fuel components; during the mild spring and autumn conditions, only the elevated and loosely compacted litter fuels were dry enough to burn.

Coarse fuels (twigs, branches and fallen trees) are not important to the rate of spread of a fire. However, they are important in the mop-up stage of fire control, they influence the degree of stem damage to trees, and they provide habitat for reptiles, small mammals and invertebrates. Coarse fuels which remain unburnt provide islands of remnant fauna and micro-flora which can recolonise the surrounding area after burning. Coarse fuels that burn near the base of trees can sustain a heat load long enough to cause stem damage (Cheney et al. 1990; Buckley and Corkish 1991). By leaving coarse fuels unburnt, adverse biological effects have been minimised, but it has not reduced the difficulty to fire fighters of mopping-up wildfires.

Humus is in an advanced stage of decomposition and therefore contains many decomposing organisms. The drying of the humus layer, brought about by the removal by burning of the overlying litter, the subsequent increased exposure to sun and wind, and redistribution by rain splash following burning, can be expected to reduce the levels and activity of decomposing organisms, and hence the rate of decomposition, until the litter layer is re-established (Baker and Attiwill 1985).

In this study, the rapid accumulation of litter after burning (Figure 4.1) can be attributed to the non-combustion of 35% of the pre-burning litter load, the additions from annual litterfall, and the interruption to invertebrate and fungal decomposition of litter for one to two years after the fires (Neumann and Tolhurst 1991). This rapid rate of litter accumulation after burning has been reported in other forest types (e.g. Raison et al. 1983) and is related to the forest age, productivity, amount of scorching, effects of burning on decomposing microbes, and seasonal patterns. The interplay of these various factors has not been described adequately enough to enable accurate prediction of fuel accumulation rates in most forest stands (Walker 1979). Attiwill et al. (1978), working in the Wombat State Forest, found that litterfall, including twigs up to 2 cm diameter, varied between 4.4 and 6.1 $t.ha^{-1}.yr^{-1}$ over a three year period; and that in the Mt Disappointment forest, litterfall averaged 3.6 $t.ha^{-1}.yr^{-1}$ over a two year period with approximately 30% of this litter being twigs. Similar rates of litterfall could be expected in the present study which would indicate that very little of the residual or new litter decomposed during the two years after burning.

This rapid rate of litter accumulation means that the "trigger levels" for fine fuel of 8 $t.ha^{-1}$ (Protection Priority 1[2] Zones) and 12 $t.ha^{-1}$ (Protection Priority 2[2] Zones) used in public land fire management plans in Victoria (O'Bryan 1988) will be exceeded in about two and four years respectively, after a fuel reduction burn. These plans specify the areas in which these trigger levels are to apply, and require that these areas be repeatedly burnt to keep fine fuel loads below the trigger levels. Emphasis on the litter fuel component of the fuel complex in the plans, however, may be over-emphasised when it is considered that the two major objectives of fuel reduction burning are to make fire control easier and to minimise fire severity should a wildfire occur. Other fuels that affect the severity of the fire and the ability of fire fighters to control it are Wire-grass, shrubs and bark on trees. These other fuel components accumulate much more slowly after a fire, and so the effectiveness of fuel reduction burning from a fire protection point of view may be underestimated if only litter fuels are considered.

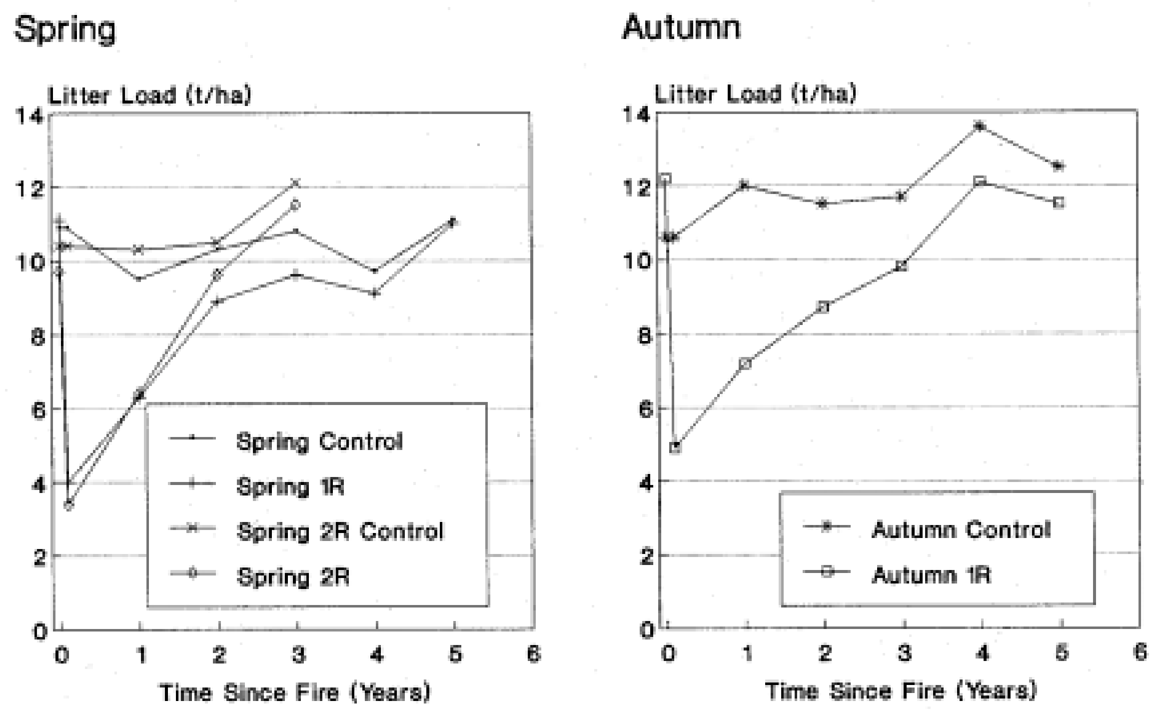


Figure 4.1 Variation in litter fuel on the forest floor with time since burning compared with the unburnt control. Spring burning treatment was measured in spring and autumn burning treatment was measured in autumn.

1c In long unburnt forests, fires quickly climbed Messmate Stringybark trees and caused a great deal of short-distance spotting, but did not do so up to five years later in the second rotation fires. (Photo: Kevin Tolhurst)

Elevated fine fuels such as Wire-grass and shrubs take much longer to return to pre-burn cover and height. Based on the initial recovery rates for elevated fine fuels measured in the present study, shrub height may take at least ten years to return to pre-burning conditions and Wire-grass height may take at least four years. Cover can be expected to return to pre-burn levels much faster than height, but overall the structure of both of these elevated fuels can be expected to remain significantly altered for at least ten years. This expectation is consistent with Fox et al. (1979), who found that the height of understorey shrubs increased at a constant rate for at least ten years after burning, and with Van Loon (1977), who found that shrub height increased for at least 25 years.

The bark of the Messmate Stringybark trees burnt readily because of its fibrous nature, vertical arrangement and deep fissures. In isolated instances, the bark did not burn, especially in mild conditions, because there was insufficient surface fuel to carry the fire to the base of the tree. As most of the study areas had not been burnt for 30 to 50 years, the bark on the trees was quite thick (up to 10 cm). Burning significantly reduced both the amount of bark and the fissure depth on the trees in the first rotation fires. As a result of this and the slow growth rate of the bark, most trees from which bark was burnt in the first fire did not burn again in the second rotation fires. The estimated 7 t.ha-1 of bark that was burnt from the trees in the first rotation fires added significantly to the amount of short-distance spotting, which increased the difficulty of keeping these fires controlled. No such problems were experienced with the second rotation fires, demonstrating that the fuel reduction burn had given good protection from short-distance spotting for the three years studied, and probably for several more years to come. Under drier and windier conditions, bark, via spotting, may be more important to the forward rate of spread of the fire than was found under the mild conditions during this study and is certainly a key limitation to fire control under most weather conditions. At the present growth rate of 1.26 $mm.yr^{-1}$, bark thickness would take 15 to 25 years to return to pre-burning conditions on the overstorey trees (> 30 cm DBHOB). Given the significant bark reduction by low-intensity burning, there is likely to be a period of about ten years during which short-distance spotting will be reduced and fire control made easier should another high- or low-intensity fire occur.

Fine fuel quantities on the control (unburnt) treatments tended to be greater in autumn than in spring. This was to be expected because the greatest period of litterfall is in summer and autumn because this is the driest part of the year when the trees are subject to moisture stress (e.g. Attiwill et al. 1978). Being dry, there is also unlikely to be much litter decomposition at this time. This seasonal difference is exaggerated during extended droughts as found by Simmons and Adams (1986) in 1982/83, when fuel loads were 4.5 $t.ha^{-1}$ above the levels observed in a normal season. Pook (1985) also found that a severe drought caused the levels of leaf shedding in a eucalypt forest to be 3.5 times greater than average, with up to 97% of the total tree leaf area being shed.

4.3 Conclusions

Low-intensity fires in this study reduced the litter, twig, elevated fuels and bark on trees. A single fire did not significantly affect the coarse fuels or the fragmented humus fuels. Both spring and autumn burning were similar in this regard.

Leaf and twig litter accumulated quickly after burning, and the levels were not significantly different from those in the unburnt areas within a 2-4 year period of the fires. Elevated fuels, such as the shrubs and Wire-grass, were much slower to recover, and may take ten years or more to return to unburnt conditions. Bark on trees will take an estimated 15-25 years to recover to pre-burn conditions, and it was found that almost no burnt trees had enough bark to support a second fire within three years. The effectiveness of the low-intensity fires in reducing the fire hazard therefore persists for longer than the effect on litter fuels alone would indicate. Indeed, litter fuel load underestimates the fire hazard by ignoring elevated fuels and bark on standing trees. The current trigger levels used in Priority 1 and Priority 2 areas should therefore be replaced with a measure of fire hazard which includes litter fuel, shrub fuels, bark on standing trees and other elevated fuels.

Litter loads in autumn were generally greater than those in spring. Fire intensities in late summer and autumn could therefore be expected to be marginally greater than they are in late spring and early summer in any given area under a given set of weather conditions. This difference would be more marked in drought years.

1d Fire intensity at the lower end of that desired for effective fuel reduction. Average flame height is 0.2 m, rate of spread 0.4 $m.min^{-1}$, and fire intensity 92 $kW.m^{-1}$. (Photo: Don Oswin)

5 Flora

5.1 Introduction

The understorey strata in open forest usually include a combination of shrubs, grasses, sedges and heath species, most of them with fire adaptive traits (Gill 1981). However, many species decrease in abundance after burning and so are disadvantaged by frequent fires, while a few shrubs and graminoids increase (Purdie and Slatyer 1976). Changes in a fire regime, particularly fire frequency, can therefore change the proportion of each species within a community, even though the species complement may remain the same.

The flora project aimed to describe the effects of burning on growth and development of individual species and plants with similar lifeforms within the understorey community. Plant community structure, demographics of selected species, and growing cycles of individual species are being studied in relation to repeated spring and autumn burning treatments and climatic variables. A full account of the methods and results is given in Tolhurst and Oswin (1992).

3a Understorey vegetation structure is measured on permanent plots using the line intercept technique. (Photo: Kevin Tolhurst)

5.2 Species Composition

No plant species was gained or lost from any treatment. This was also the finding of other studies in similar vegetation (Christensen and Kimber 1975; Wark et al. 1987; Purdie and

Slatyer 1976; Bell and Koch 1980). No sclerophyllous plant has ever been reported as having been made extinct as a direct result of burning, but some species have been eliminated from local areas as a result of frequent fires (e.g. Mountain Ash and Alpine Ash were eliminated in some areas of the Central Highlands of Victoria when burnt in 1926 and again in 1939). The relative abundance of different species varied with time since burning depending on the rate of development and the method of persistence.

5.3 Plant Community Structure

Plant structure is described for common species or groups of species with similar growth habit. The groups and species used, and their relative dominance, are given in Table 5.1. A total of 218 species have been recorded across the five FESAs.

3b Weather station near Blakeville FESA. Weather data are used to help explain differences in: the recovery rates of vegetation after fire; reptile, bat and invertebrate activity between treatments, and fire behaviour. (Photo: Kevin Tolhurst)

The cover, density and height of the eleven plant groups and the total plant cover are considered below.

Total Plant Cover (Understorey)

Total plant cover in the understorey on unburnt plots increased significantly from 27% in 1985 to 44% in 1989, and then appeared to plateau. This increase was predominantly attributable to Wire-grass, Bracken and Tussocks. Herb cover declined over the same period, and most other plant groups remained about the same. This overall increase may be due to a long-term recovery in leaf area following the decade of below average rainfall culminating in the 1982/3 drought. Specht (1983) has shown that projective foliage cover is related to the climatic moisture regime and therefore such an increase in total plant cover could be expected.

Because of the variation in the control treatment with seasonal factors, the changes in the burnt treatments have been compared with the changes in the control. This approach shows the changes due to the fire treatment alone.

Total plant cover returned to pre-burn conditions 2-3 years after the first rotation spring burning, but there was little recovery within 50 months of first rotation autumn burning. Recovery was also slow within 27 months of the second rotation spring burning.

Table 5.1
Average cover, density and height of major plant groups in the understorey for control treatments across all study areas (1985-1991).

Plant Group[a]	Cover[b] (%)	Density[c] (plants m^{-2})	Height (cm)
Wire-grass	12.4	37.0	52.3
Bracken	9.9	1.2	75.5
Herbs	4.0	140.5	5.0
Tussocks	2.9	2.3	22.2
Poa Tussock-grass	2.4	14.1	11.3
Shrubs (0.5 - 4m)	1.8	0.2	79.9
Trees (> 15m)	1.3	0.3	146.4
Small-shrubs (<0.5m)	0.8	2.3	17.2
Climbers	0.2	0.7	22.5
Geophytes	0.1	0.5	27.4
Small-trees (4-15m)	0.1	0.2	26.2
Other	0.8	-	-

(a) Plant groups based on anticipated mature growth form.
(b) Cover is a measure of projected crowns.
(c) Density is the number of plants per square metre.

Wire-grass
Wire-grass density remained constant after a single spring fire and increased marginally after autumn burning. The stoloniferous habit of the plant (i.e. the ability to take root at nodes along the stem) meant that density was increased when the plant was fragmented by burning. Seedlings were rarely seen and flowering did not occur in the first four years after burning. Second rotation spring burning reduced density in the following year, possibly due to the death of some of the smaller plants and in the absence of seedling establishment. Height and cover were significantly reduced by burning. Recovery after autumn burning was much slower than after the spring burning.

Bracken
Bracken responded more vigorously to spring than autumn burning, increasing in both frond density and cover (Fig. 5.1). Bracken burnt in autumn increased in frond density, but was smaller and hence only maintained the cover of the pre-burn population. Burning in either season reduced frond height. This is consistent with Boomsma and Karjalainen (1982) who reported a four-fold increase in density of fronds 12 months after spring burning, but is not totally consistent with Hamilton's (1986) reported a four-fold increase in biomass after autumn burning. Ashton (1970) also provided anecdotal evidence of Bracken being favoured by autumn burning, but the results presented here and by Veitch (1990) indicate that spring burning also stimulates Bracken. The maximum average frond height is determined in part by its edaphic and physical environment and in part by the energy stored in the rhizome system. Since the edaphic and overstorey environment of the Bracken was not greatly affected by burning, the reduction in frond height in the first year may have been due to reduced rhizome reserves as a result of the fire and extra demands on those reserves due to the increased density of fronds, as was found by Preest and Cranswick

(1978), and to reduced understorey height. In each subsequent year, as the understorey plants increased in height, the Bracken gradually increased in height until the average maximum pre-burn height was regained.

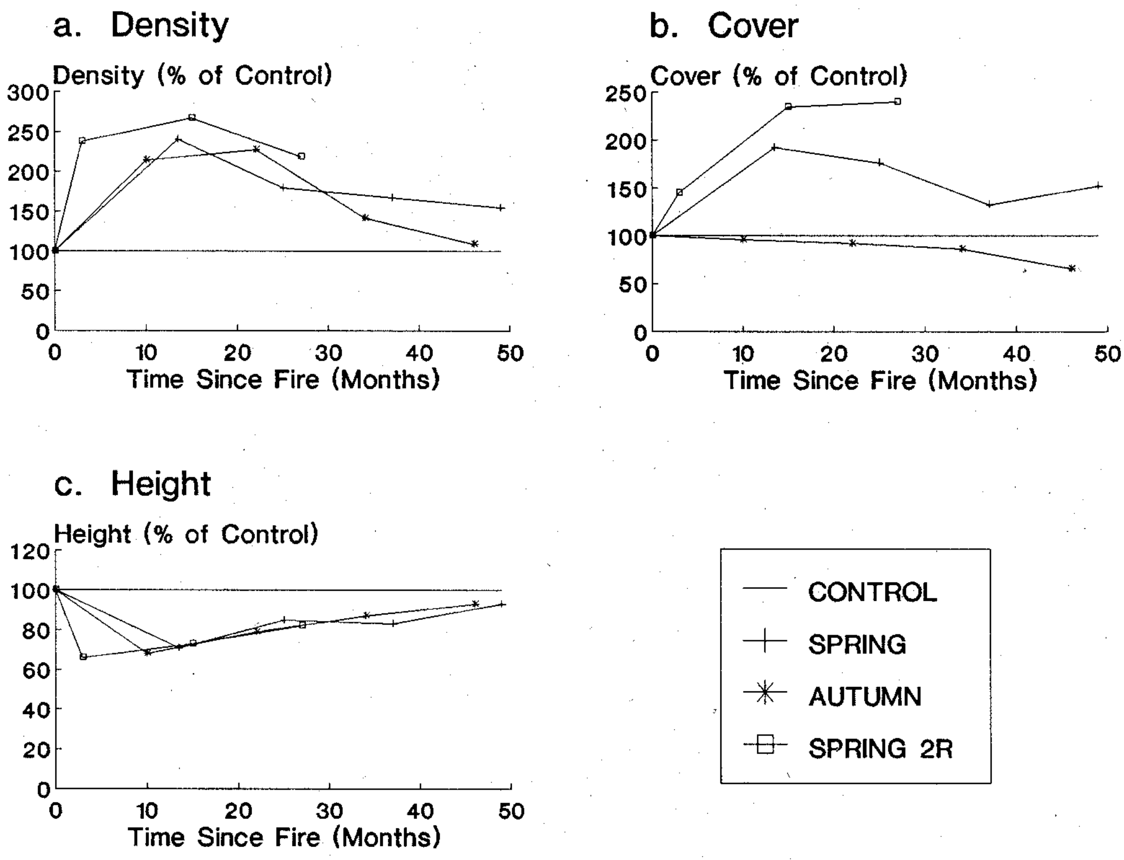


Figure 5.1 Changes in frond density, cover and height of Bracken with time since spring and autumn burning compared with the control treatment.

Herbs

Herb density and cover both consistently declined in the control treatments over the seven years of measurement This trend did not occur on treatments burnt in spring or autumn. Cover of herbs after spring burning took 1-2 years to return to the level of the control treatment and then exceeded it. Density of herbs in the spring treatment was always as great or greater than the control treatment, but the herbs were not set back at all after autumn burning so that 4 years after the burning, herb density and cover were both significantly greater than the control. This increase in herb cover after burning was also reported by Kirkpatrick and Dickinson (1984) and Baird (1984). Herb density and cover increased as a result of seedling establishment, and this was greatest after autumn burning which also has been reported by others such as Purdie (1977a) and Christensen et al. (1981). The response of herbs to second rotation spring burning was a greater decline in the first year and then a recovery to pre-burn conditions in the second and third years after the second burn. There was no indication of herb promotion after the second spring fire.

The decline in herb cover and density on the control treatments may be due to an initial abnormally high herb abundance in 1985 following the drought of 1982/3 when the tree and shrub canopy had been reduced by the dry conditions; Wire-grass, Bracken and Tussocks cover has increased since that time. This decline has been longer than expected and continues to be a strong trend seven years after the drought.

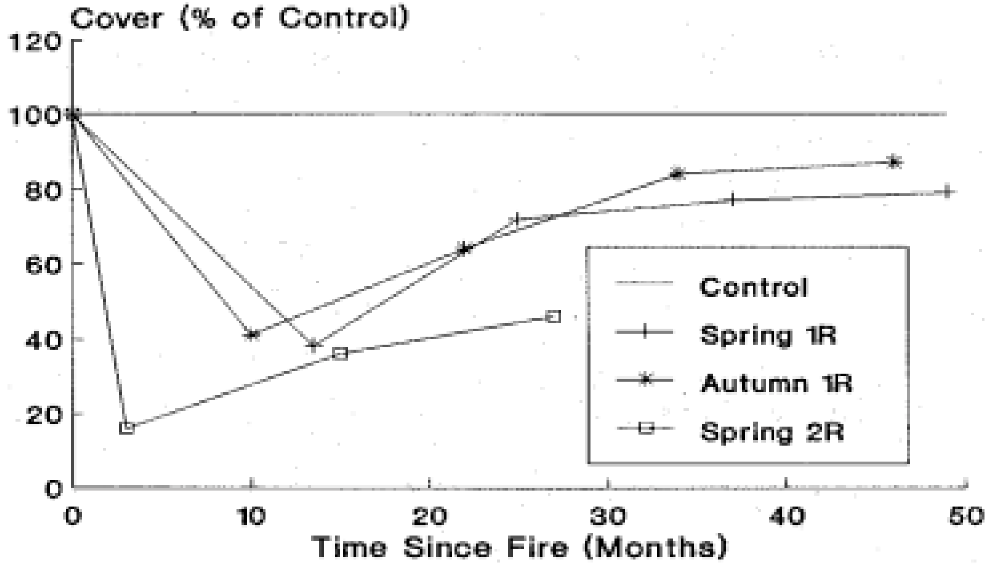


Figure 5.2 Increase in Tussock cover with time since spring and autumn burning compared with the control treatment

Tussock

Tussock density, as measured by the number of emergent tillers at ground level, at least doubled compared with the control after both spring and autumn burning within the first year. Two years after spring burning, and four years after autumn burning, density had returned to pre-burn conditions. The second rotation spring burn did not significantly affect density.

The cover of tussocks was the attribute most dramatically affected by burning (Fig. 5.2). One year after both spring and autumn burning, cover was around 40% of the initial level. After four years, tussock cover had returned to around 80% of pre-burn level. During the first two years after the second rotation spring burning, there seemed to be a slower recovery than after the first rotation fires.

Tussock height was significantly reduced, for 12 months, by both spring and autumn burning and then returned to pre-burn conditions within the second year.

Overall, there was little difference between the effects of a single spring or autumn fire on tussock density, cover and height. Three years after burning, the tussocks had recovered to their original density and height, but cover remained below the pre-burn level four years after burning. The initial impact of a second rotation spring burn was to maintain density without the initial doubling as seen following the first fires. The recovery of height was similar to that following first rotation burning, but cover appeared to be slower to increase.

Poa Tussock-grass

A single spring fire tended to increase Poa tiller density and cover and marginally reduce its height. The second spring fire reduced the plant's tiller density, cover and height indicating that the response to repeated burning was different to a single fire. It is postulated that this was due to a loss of regenerative energy, that is, a decrease in the number of shoot buds and carbohydrate, lasting for at least three years following the first fire.

A single autumn burn dramatically increased the tiller density of Poa, but cover and height were reduced. The stimulation of tillers by burning seemed to be greater under autumn conditions than spring conditions, but the regenerative energy was less in autumn, possibly as a result of moisture and temperature stress during the preceding summer and early autumn period or increased grazing pressure by native animals.

Height reduction was greater following autumn burning than after spring burning. This may also have resulted from the increased grazing pressure in autumn due to the palatability of the new shoots at a time when other green fodder was limited. Grazing of new shoots was observed to be common after autumn burning. Increased grazing pressure brought about by the high palatability of fresh shoots after burning may also reduce the regenerative energy of plants as was shown by Leigh and Holgate (1979) in southern New South Wales.

Small-shrubs
The impact of a single spring fire on small-shrub density, cover and height was minimal four years after burning. The recovery in height and cover after autumn burning will take much longer, but in the longer term, the increased density due to the establishment of new seedlings will probably increase the population provided they are not burnt or disturbed for at least six years. Early indications are that the second rotation spring burning had a greater effect than the first rotation, and that recovery will be much slower.

Shrubs
Recovery of shrub height and cover was faster following spring burning than after the autumn burning, but there was limited recruitment through burning-stimulated seedling establishment and suckering. Autumn burning changed the structure of the shrub layer more dramatically, increasing the number of new plants, but decreasing the height and cover of existing plants. A second rotation spring fire appeared to reduced population levels more than the first rotation spring burning after 27 months, and therefore may have a significant impact in the longer term.

Small-trees
Small-trees have a mature height of between 4 and 15 m, but only young small-trees were measured in this study. The maximum height measured was 4 m.

Small-trees seemed to be slow growing and significantly reduced in size or killed by burning. Seedling establishment after burning replaced those small-trees killed, but the seedlings will take a long time (probably more than 15 years) to grow large enough to survive another fire.

Trees
Trees measured in this part of the study have a potential mature height of more than 15 m, but to be included here must have foliage below 2 m or be no taller than 4 m, i.e. be small regrowth trees. A 4 m height limit was used in measurements.
The main effect of burning on trees was to reduce their cover (up to 4 m above the ground). The second rotation spring burning had a greater effect on reducing tree height and cover, indicating that the trees had not fully recovered from the first rotation of burning two or three years earlier. Tree density remained about the same after burning.

Climbers
Climbers were uncommon in this forest so structural data were unreliable. The evidence that was available indicates that autumn burning did not affect the density of the climbers. A similar conclusion was drawn for the effects of spring burning, until a dramatic drop in density three years after burning. The second rotation spring burn more than doubled the density of climbers within one year of being burnt. More observations are needed before these effects can be confirmed. The height of climbers was reduced for less than three years by spring burning, but was little affected by autumn burning. Second rotation spring burning had a similar effect to the first rotation, but there were indications that the recovery of climbers back to pre-burn height would be slower.

Geophytes
Fluctuations in geophyte density, height, and cover due to seasonal conditions mask the effects of fires. The tendency, if any, was for there to be fewer plants four years after both spring and autumn burning.

5.4 Species Characteristics

Species characteristics have been classified according to the scheme described by Noble and Slatyer (1980). This scheme has three parts: 1) the method of regeneration (persistence) used by a species after a disturbance such as burning, 2) the environmental conditions required to regenerate, and 3) the length of time taken for a plant to go through each life-stage (juvenile, mature, senescent etc.).

Only the method of persistence after low-intensity fire is reported here.

Method of Persistence
Sufficient data were collected to enable the classification of 66 out of 106 plant species into their method of persistence after low-intensity burning. The method of persistence, or regenerative response, applies to plants whose aerial parts were completely scorched or burnt, but with the overstorey tree canopy remaining intact after the fire. Regeneration from seed may have been more common if the tree canopy was also completely scorched or burnt. Purdie (1977b) for example found that all except the geophytic species had some seedling regeneration following a moderate intensity fire (830 to 4200 $kW.m^{-1}$) in dry sclerophyll forest. A summary of the number of plants in each regenerative category is given in Table 5.2.

Table 5.2
Numbers of plant species in the Fire Effects Study Areas using the methods of persistence as defined by Noble and Slatyer (1980).

Method of Persistence		*Number*
Symbol	*Meaning*	
D	seed : dispersed long distances	1
S	seed : stored, maintains viability	2
G	seed : long lived, exhausted after first germination	0
C	seed : short lived, exhausted after first germination	3
V	sprouters : all ages survive	36
U	sprouters : mature remain mature, juvenile remain juvenile	0
W	sprouters : mature remain, juveniles die	13
Y	sprouters : juveniles remain, mature die	0
ó	dispersed seed + mature resprout + juvenile ñ resprout	4
Ó	seed store + mature resprout + juvenile ñ resprout	7
Ã	seed store with one germination + only mature resprout	0

Understorey plants in this study regenerated primarily by resprouting. Sixty out of the 66 plants classified (91%) used vegetative regeneration to some degree after being completely scorched, and only six (9%) relied totally on seed for regeneration ("obligate seed regenerators"). However, 26% of plants regenerated by seed to some degree. The proportion of plants in fire prone environments relying on seed regeneration is usually less than those reproducing vegetatively. For example, the proportion of plants regenerating from seed in some other communities were: 31% in Jarrah forest (Bell and Koch 1980), 27% in heath at Wilsons Promontory (Russell and Parsons 1978), 27% in eucalypt woodland near Canberra (Purdie and Slatyer 1976), and 56% in chaparral in California (Hanes 1971).

While obligate seed reproducers are a small proportion of the total, they are potentially the most vulnerable to burning. Three of the six obligate seed reproducers in this study were potentially vulnerable to a single fire since the seed pool was short-lived and exhausted after the first germination; these were Thin-leaf Wattle, Prickly Moses, and Small Poranthera. However, all three species regenerated well after being burnt.

5.5 Seasonal Growth Cycles of Selected Species

Bracken

In control treatments, Bracken sprouts (croziers) appeared between mid-September and the end of November. Burning in spring stimulated the sprouts so that they appeared right through to the February after the fire. In the second and subsequent years, sprout production was similar to the control treatment. Autumn burning stimulated the sprouts to appear during the winter and spring (from June to October) after the fire. Therefore, killing the standing fronds with burning stimulated resprouting as soon as moisture was available, regardless of the time of year.

Frond growth took place between October and March. The first rotation spring burning was followed by a twelve month growth period and the autumn burning was followed by an early start to the growth period in August rather than October. In the second and subsequent years, the frond growth period was similar in burnt and unburnt areas.

Frond mortality normally took place between August and November. After both spring and autumn burning, fronds died over a longer period (July-March) for the first three years after the fires Many fronds produced after burning were quite small and weak and died at times when normal, healthy fronds did not.

In summary, sprouts were produced within eight weeks of burning if there was sufficient soil moisture. The growing period of fronds was extended for the first year after burning and then returned to normal. Frond death occurred over a longer period for at least three years after burning, probably due to the greater number of weaker fronds and greater frond density.

Narrow-leaf Wattle

Shoot growth of Narrow-leaf Wattle normally occurred over a seven month period between October and April. Burning killed most established shoots so there was no shoot growth after spring or autumn burning until the second year. After the initial dormant period following spring burning, shoot growth occurred almost continuously for the next three years, possibly in response to the additional nutrients made available by the fire or the greater vigour of the new shoots. This extended growing season in the second, third and fourth years after burning did not occur with autumn burning. Second rotation spring burning again did not kill all shoots and so growth on the surviving plants continued normally, after an initial interruption of about ten weeks following the fire.

Sprouts from stem bases or root suckers were not present in the control treatment, but appeared in the first two years after burning. Sprouts seemed to appear sporadically in any season.

Flowering occurred from mid-September to mid-November in the unburnt areas. Autumn burning did not affect the flowering time of surviving mature individuals. No flowering was observed in the spring-burnt areas for at least four years even though some mature plants survived. This may be due to the increased vigour of the shoot growth after spring burning which may limit flowering. Since this increased vigour was not observed after autumn burning, flowering continued as normal.

Narrow-leaf Wattle rarely set seed. Seed-set was observed only in unburnt areas and then in summer after flowering.

Shoot mortality was observed only after sprouts appeared. Some sprouts died shortly after being produced. Some older shoots died as a result of burning.

Overall, not all mature shoots were killed by the spring and autumn fires. Spring burning increased the period of active shoot growth and autumn burning had no effect. Sprouts were produced after both spring and autumn burning, but not on the unburnt areas. Seedling establishment was not observed and seed-set was rare.

Poa Tussock-grass

Poa shoot growth normally occurred in spring from August to November (Fig. 5.3). Spring burning stimulated shoot growth soon after the fire and this growth continued from late spring through the summer. The growth period was longer than normal for two years after the spring and autumn burning, and then returned to normal in the third year.

Sprouts were observed only after the existing plants had been burnt. Sprouts appeared within about four weeks of burning regardless of whether the fires were in spring or autumn.

Flowering occurred between mid-November and January. Burning had little effect on flowering time except after the first rotation spring burning when flowering was delayed for about two months. Seed-set followed flowering in late summer/early autumn.

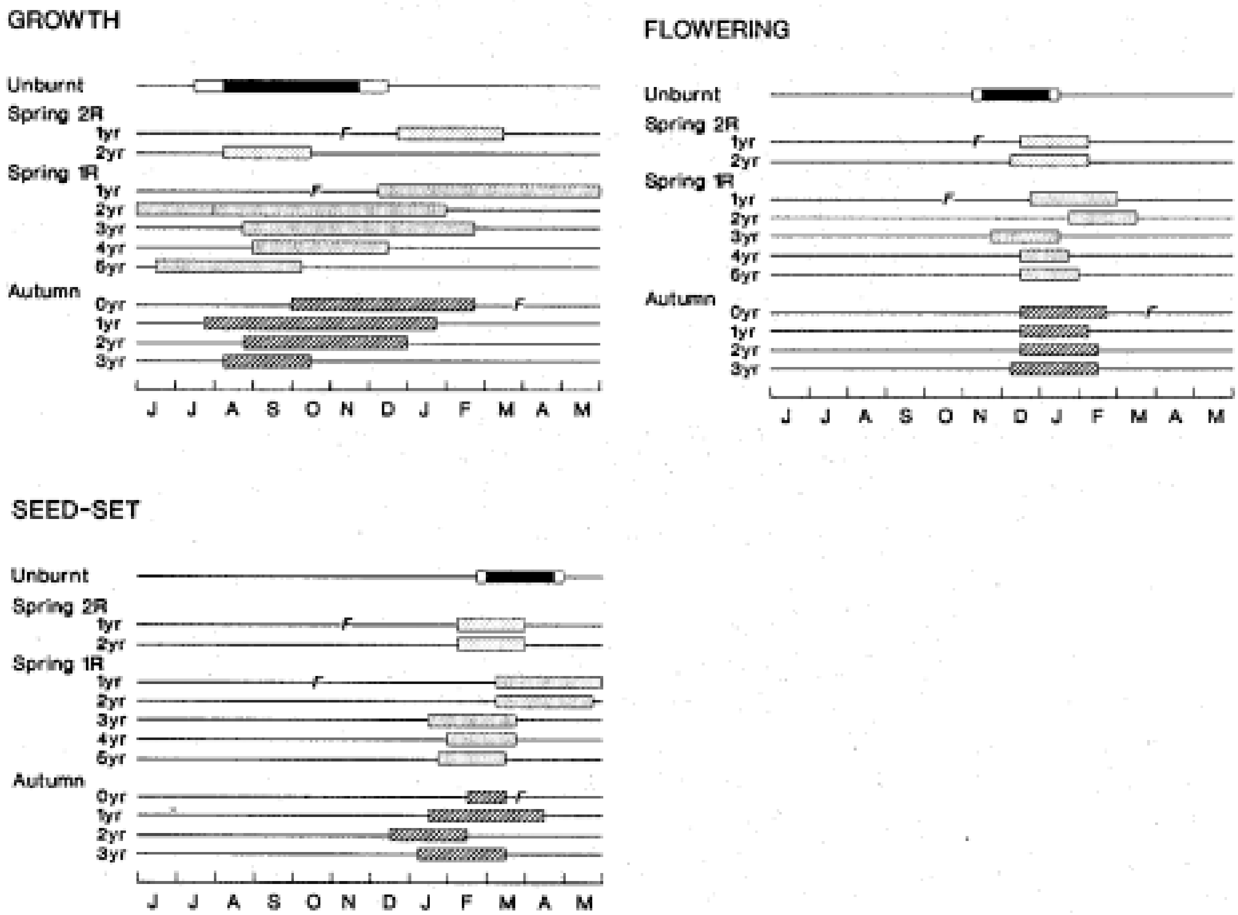


Figure 5.3 Effects of spring and autumn burning on the timing of shoot growth, flowering and seed-setting of Poa Tussock-grass. "F" indicates the time of burning.

Seedling establishment was uncommon and was observed only in late spring soon after the spring burning.

No plants were recorded as having died. However, tillers die each year and new ones replace them nearby, making the recording of the period of mortality very difficult.

Overall, both spring and autumn burning extended the period of shoot growth during the first two years after burning. Sprouts and seedlings grew within two months of all fires. Burning had negligible effect on the timing of flowering and seed-set.

Messmate Stringybark

Mature trees in the overstorey were observed in this part of the study.

Messmate Stringybark grew for most of the year. Growth usually stopped during the winter (June-July) and sometimes during extended dry periods (usually about April). Burning in spring or autumn did not change this pattern. The crowns of Messmate Stringybark and other trees in the overstorey were rarely visibly affected by the experimental fires.

Flowering occurred in March and April regardless of burning treatment, and was exceptionally heavy in 1987. Flowering started in February in the 2R spring burning treatment, two years after burning.

Burning did not significantly affect the observed growth period of Messmate Stringybark.

Ivy-leaf Violet
Ivy-leaf Violet normally grew from August to mid-March. Shoot growth continued through the autumn and into the winter for the first year after spring burning. After autumn burning, shoot growth took place only during the normal spring and summer period.

Establishment of seedlings and sprouts was not observed in the control treatment, but did occur soon after spring and autumn burning.

Flowering and seed-set took place during late spring and summer. Burning in spring or autumn did not affect this pattern except that there was no observed seed-set after the first flowering in the spring burning treatment and no flowering or seed-set in the first year after second rotation spring burning.

Spring burning, therefore, stopped seed-set in the year after burning, but extended the shoot growing period. Periods of sprouting and seedling establishment occurred soon after both spring and autumn fires.

5.6 Population Dynamics
Population age structure has been studied so that computer simulation models can eventually be used to predict the changes likely to occur under different fire and climatic regimes.

Population dynamics of the major understorey species were monitored annually in summer on small plots. Poa Tussock-grass and Wire-grass were monitored on 1 m^2 plots, and Bracken, Silvertop Wallaby-grass, Thin-leaf Wattle, Hop Wattle, and Prickly Moses were monitored on 4 m2 plots. Each plant within a plot was tagged or pinned to identify the stage of development and the year that stage was attained. Stages of development were classified as follows:

- Seed
- Seedling - pre-reproductive stage, originating from seed
- Sprout - pre-reproductive stage, originating from vegetative source such as tuber, rhizome, root sucker, and coppice
- Mature Flowering - of reproductive age, flowering in current year
- Mature - of reproductive age, no sign of flowering in current year
- Senescent Flowering - plant dying back, flowering in current year
- Senescent - plant dying back, no sign of flowering in current year
- Dead

Bracken
In the control treatment, the frond population structure of bracken was relatively constant. Approximately equal numbers of senescent and mature fronds were present at each assessment (in December) and a few sprouts (croziers) were counted. This same trend was evident after the first rotation spring and autumn burning treatments with two variations: first the number of the fronds were two to three times greater and second there was a pronounced peak in mature frond abundance in the first year after autumn burning. Following the second rotation spring burning, there was a peak in immature fronds at the time of assessment, about two months after the

burning. Therefore burning affected the frond population structure only for the first two years. This is discussed in greater detail in Tolhurst (1990).

Silvertop Wallaby-grass

Wallaby-grass populations were dominated by "sprouts" (i.e. plants not known to have flowered) in the unburnt and spring burnt treatments. Flowering of mature and previously designated "sprout" individuals was recorded in the second year after both spring and autumn burning, but was most pronounced after the autumn burning. Only one individual was recorded flowering in the control treatment during six years of observations.

Poa Tussock-grass

Populations of Poa were dominated by sprouts. A small proportion of the population flowered each year regardless of whether or not it was burnt. The proportion of flowering and non-flowering mature plants remained approximately the same. Observations suggested that mature individuals tended to flower every second year so that there was a regular exchange between the status of flowering and non-flowering each year.

Silver Wattle

Unfortunately, only one specimen of Silver Wattle was present in the control treatment and it died after the first year. Only sprouts were present after burning in spring or autumn. Mature, senescent and seedling plants present before burning were either killed or reduced to numerous sprouts which generally arose from roots near the surface.

Narrow-leaf Wattle

In the control treatment, sprout, mature and senescent plants, both flowering and not, were present. During the six years of observation, the populations of Narrow-leaf Wattle had aged until there were no longer any sprouts within the plots and the proportion of senescent plants had increased. In the burnt treatments the populations were predominantly sprouts arising from the roots or the stem base, with a few seedlings present in some areas (Fig. 5.4).

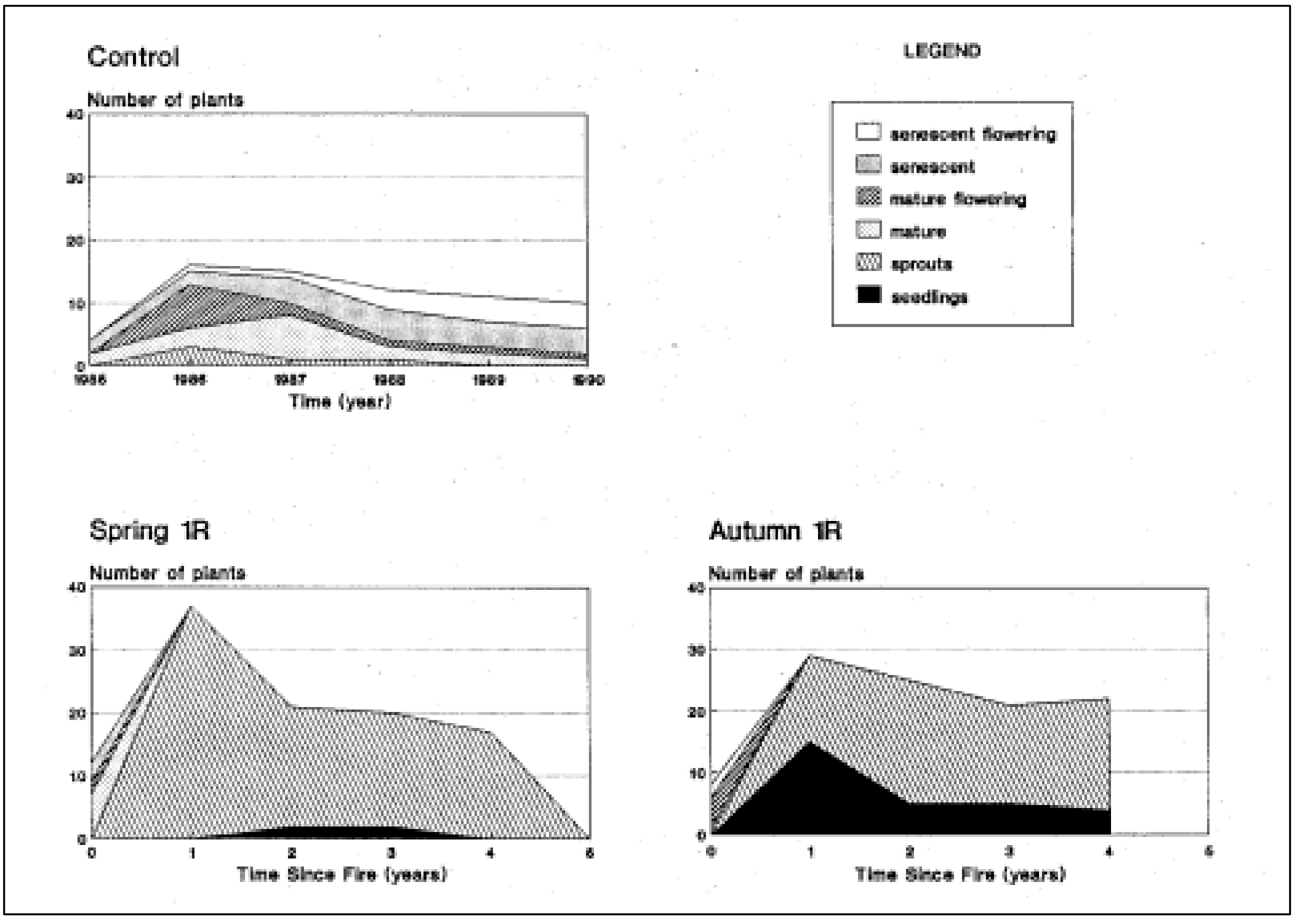


Figure 5.4 Simplification of the age structure of Narrow-leaf Wattle populations after spring and autumn burning treatments compared with the control treatment.

Hop Wattle

As with Narrow-leaf Wattle, Hop Wattle populations aged so that mature plants became senescent in the control treatment. No seedlings established within the plots burnt in spring, even though seedlings were common elsewhere in the same study areas, but large numbers of seedlings did establish after autumn burning. The first rotation spring burning was not intense enough to kill the mature plants being studied. These plants continued to flower and became senescent three years after the fires. All mature and senescent plants were burnt in the second rotation spring burning, but there was still no seedling establishment within the study plot. The population after the second spring burning consisted entirely of sprouts. A few sprouts were also present after the autumn burning, but the population was predominantly seedlings. These seedlings were still dominant four years after burning.

5.7 Conclusions

All species present in the understorey plant community before burning were still present following both spring and autumn burning. Fire has been a part of this ecosystem for thousands of years and all species had regeneration strategies to cope with periodic fire disturbance.

The structure of the understorey was modified by burning for at least four years, predominantly because of the reduced height of the non-herbaceous plants such as small-trees, shrubs and Wire-grass, but also because of reduced cover after autumn and second rotation spring burning.

Recovery from second rotation spring burning was slower than after the first rotation. This effect can be partially attributed to seasonal affects (Tolhurst 1992b), but it is postulated that the main effect was caused by a reduction in the regenerative reserves of the plants following the first fires, and that these reserves take more than three years to be replenished. Repeated burning may therefore significantly deplete regenerative reserves and result in species loss if fires are more frequent than the time needed for plants to fully recover from the effects of being burnt.

Populations of wattles and perennial grasses were of mixed age before burning, but were dominated by sprouts or seedlings after burning. Thus burning simplified the age structure of these populations. However, the population age structure of Bracken fronds was little affected because of the relatively short life-span of individual fronds.

Seedling establishment, when it occurred, was more pronounced after autumn burning than spring burning. No species relied totally on seedling establishment for survival. Seedling regeneration was often supplemented by resprouting plants or a small proportion of the pre-burn population that remained unburnt.

Resprouting was most vigorous after first rotation spring burning. The period of shoot growth was extended after spring burning, but not affected by autumn burning. Total plant cover returned to pre-burn levels within three years of a single spring fire.

While there were qualitative and quantitative differences between the effects of single spring and autumn low-intensity fires, neither had any irreversible effect on the understorey plants. However, frequent repeated fires are likely to alter significantly the species diversity and structure of plant communities studied here; and this may be a legitimate management objective in some cases. This is the subject of continuing research in the Wombat State Forest where short and long rotational burning in both spring and autumn is under investigation. The findings also highlight the need for long term studies of repeated burning at varying frequencies if the true effects of repeated fuel reduction burning are to be identified.

2a Foothill mixed eucalypt forest last burnt 34 years previously. (Photo: Kevin Tolhurst)

2b Immediately after burning in autumn. Scorch height was 0.8 m, 98% of the area was burnt and 11.4 $t.ha^{-1}$ of fine fuel was consumed. Fire intensity was 153 $kW.m^{-1}$. (Photo: Kevin Tolhurst)

2c One year after burning. (Photo: Don Oswin)

2d Two years after burning. Note the separation between the understorey and overstorey compared with 2a. (Photo: Don Oswin)

2e Immediately after the second rotation burning, four years after the first fire. Note the disintegration of the old log in the foreground compared with 2b. Scorch height of the second fire was 5.5 m, 98% of the area was burnt and 7.5 $t.ha^{-1}$ of fine fuel was burnt. Fire intensity was 199 $kW.m^{-1}$. (Photo: Don Oswin)

2f One year after the second rotation burn. Note the rapid recovery of litter, Bracken and other understorey plants. (Photo: Don Oswin)

6 FAUNA

6.1 Introduction
Fire ecology literature is largely based on observations of different ecosystems following burning. Very few studies have included pre-burning observations, so there has been a heavy reliance on the study of fire effects by comparing areas with different burning histories (mainly comparing recently burnt areas with nearby unburnt areas). The inherent problem with this approach is accounting for the natural variation in population densities between areas.

Effects of fire on forest vertebrates have been studied mainly in relation to single events (wildfires or fuel reduction burns), and mammals have been the main animals studied (e.g. Catling and Newsome 1981; Christensen et al. 1981; Heislers 1974; Newsome et al. 1975; Recher et al. 1974; Suckling and Macfarlane 1984).

Small ground mammals are the best studied faunal group in relation to fire responses. Very little is known about arboreal mammals, macropods, large ground mammals and invertebrates. Virtually no data exist on the effects of burning on reptiles, amphibians or bats, even though these species may be quite common. More is known about the effects of fire on birds, and this has shown that bird populations change with changes in habitat.

The results presented here relate to the fauna of Wombat State forest, which is less diverse than some other forest types such as the box/ironbark forests in dryer country north of the divide. The forest has been previously disturbed by extensive wood harvesting activities associated with gold mining in the late 19th century and a long history of previous fires.

This study aimed to improve the knowledge of the response of all faunal groups to low-intensity burning. To achieve this, techniques were developed or refined to determine the population size, community composition, and seasonal and site variation of each faunal group. Further development is needed, particularly for reptiles, bats and invertebrates.

6.2 Birds

Introduction
Birds are a conspicuous and important element of Victoria's forest fauna and a major predator of forest insects. Their response to different burning regimes needs to be understood and managed.

The effects of fuel reduction burning on forest birds have been studied in south-west Western Australia by Kimber (1974) and Christensen and Kimber (1975), and in Victoria (Wombat Forest) by Cowley (1974). The approach of looking at areas burnt under various regimes in the past (retrospective studies) has been used by Woinarski (1990) in tropical woodlands of northern Australia.

The present study offered an opportunity to collect information on the responses of bird populations to low-intensity prescribed burning in a particular forest type, using a properly replicated design using unburnt treatments as controls. An important advantage over previous studies was that detailed information would be collected simultaneously on vegetation, fire behaviour and other animals including invertebrates. Another advantage was that burns were planned to be repeated over time, at two different frequencies.

This summary reports selected results after a single prescribed fire. Further analysis is needed to relate these results to changes in other parameters, although preliminary observations are offered. The results deal with just three of the study areas (Blakeville, Kangaroo Creek and Burnt Bridge) as only baseline data have been collected from the other two (Barkstead and Musk Creek). A complete account of methods and results presented here is given in Loyn et al. (1992). Data collection will continue and future results will provide information on the effects of repeated prescribed fires in spring and autumn.

Results and Discussion

Bird abundance and species composition remained remarkably stable on burnt and unburnt areas. The main changes observed after burning were influxes of some species which fed from recently exposed soil, small decreases in some species inhabiting understorey, and influxes of some species (e.g. Scarlet Robin, Flame Robin) which fed on eucalypt nectar. The latter is of interest, as such influxes have not been reported in previous studies of prescribed burning. Quantitative observations show that the flowering of Messmate Stingybark in 1987 was quite exceptional, and lasted from late March to early May throughout the study areas. Yet the main concentrations of nectar feeding birds were much more localised. The areas where concentrations were found coincided with areas that had been burnt the previous spring (Burnt Bridge) or more recently (a fortnight before the counts at Kangaroo Creek). This suggests that the burns may have affected the quality of flowering (e.g. nectar flow or nutritional value) and birds responded to that rather than simply to the amount of flowering. More data are needed to establish that this apparent link with burning is not coincidental and to determine whether any effects persist in the long term.

4c Flame Robins increased after fire in this study. Generally, bird species composition showed little change because no habitat was completely removed or created. (Photo: Andrew Corrick)

The other changes recorded on the three study areas are similar to those observed by Cowley (1974), in a swampier, shrubbier part of this same forest, and by Kimber (1974) and Christensen and Kimber (1975) in Western Australia. Cowley (1974) studied survival of banded birds and his observations relate mainly to nine species inhabiting the understorey. Numbers of understorey birds declined initially in all studies, although Kimber (1974) found that they exceeded previous levels after two years and were then higher than in adjacent forest that had been unburnt for 40 years. These results all relate to the structure of the forest understorey.

Some important caveats must be made if results are to be extrapolated elsewhere. Firstly, the study areas were small (approximately 10 ha/site) and no part of any burnt site was more than 300 m from unburnt forest. The burns were well conducted and some shrubs remained intact (albeit often scorched or killed), as did the eucalypt canopy. Hence birds were easily able to survive the burning and move back into habitat as it suited them. It is not known whether adjacent unburnt forest was a necessary part of the habitat for any species. This should not be seen as a design defect of the study, because it may reflect a common situation where prescribed burns are carried out on a small-scale mosaic pattern. But it does not reflect the equally real situation where prescribed burns are carried out on a large-scale, with greater variation in fire intensity due to site and weather conditions over the period of the burn. Cowley (1974) considered that most prescribed fires in the Wombat State Forest were so patchy that they would have little effect on birds, and he designed his experimental burn to be more complete than usual. Nevertheless, at least two-thirds of his banded birds survived and remained on the burnt study areas.

Another qualification arises from the nature of Wombat State Forest. Before treatment, the areas contained scattered shrubs (which were less numerous after burning) and areas of bare ground (which were larger and more numerous after burning). Hence there were no dramatic changes in habitat as a result of burning; no obvious habitats were lost or created. In shrubbier forest, birds such as Scarlet Robins and Buff-rumped Thornbills would usually be absent and enter only after burning (Loyn 1985; Christensen 1974), whereas here they remained present throughout. Flame Robins have been observed elsewhere to increase after wildfire (Stokes 1975; Reilly 1991). The birds that did appear to enter the study areas after burning (e.g. White-winged Chough) were also present initially in nearby forest, and were just responding to burning on a different spatial scale to the smaller birds. The results of this study must therefore be viewed in the context of the initial vegetation structure, the relatively short-term period of study and the size of the burnt areas.

6.3 Bats

Introduction

In Australia, less is known about bats than any other order of mammals, though there have been great advances in the last decade. They were overlooked in mammal surveys, despite the fact they often occur in large numbers and may be more diverse than other mammal groups present. The major reason for this lack of knowledge is that bats are generally difficult to catch or observe. The techniques for catching bats in flight have particular limitations, and researchers can put in much effort for few results. These limitations are due to the variety of foraging behaviour exhibited by different bat species, with some species foraging above the canopy, some below and some even taking insects from the ground (McKenzie 1983). Because of these limitations, early research on Australian bats was mainly restricted to the study of colonial or cave dwelling species with easily accessible roosts (Hall 1981). Bats are included in most current studies of forest wildlife in Victoria (e.g. Squire 1990; Earl and Lunt 1989), but there is still a dearth of basic knowledge about their ecology.

The aim of studies over the past three years has been to provide information on the bats of the Wombat State Forest to understand more readily the possible impact of particular fire regimes if widely applied. Comparisons are difficult to make for bats as their home range may cover several treatment areas. This work is covered more fully in Kemp et al. (1992).

Results and Discussion

Seven bat species were identified (Table 6.1), making bats the most diverse group of mammals in the study area. These species represented seven out of the ten species of the Microchiroptera that were recorded within a sixty kilometre radius of Ballarat (Gilmore et al. 1979; Parnaby 1977).

All species identified were aerial insectivores, with the Lesser and Gould's Long-eared Bats being foliage gleaners as well. The abundance of these bats was therefore likely to depend on the insect population in the forest understorey and tree canopy as well as availability of sites for roosting and breeding.

4a Gould's Wattled Bat is one of seven bat species found to inhabit the study areas. Very little is known about the possible effects of fire on bats. (Photo: Ed McNabb)

Table 6.1
Bat species recorded from the Blakeville, Barkstead and Musk Creek FESAs.

Scientific Name [(a)]	Common Name
Tadarida australis	White-striped Mastiff-bat
Nyctophilus gouldi	Gould's Long-eared Bat
Nyctophilus geoffroyii	Lesser Long-eared Bat
Chalinolobus gouldii	Gould's Wattled Bat
Chalinolobus morio	Chocolate Wattled Bat
Eptesicus darlingtonii	Large forest Eptesicus
Falsitrellus tasmaniensis	Great Pipistrelle

[(a)] Nomenclature follows Menkhorst (1987)

Data on the comparative abundance of bat species were not conclusive as the trapping methods were selective and air temperature at the time of assessment was critical to the results (Fig. 6.1).

Insufficient data were collected to comment on the effects of fuel reduction burning on bats. Research into the effects of burning on bats is difficult and will require improvements in assessment methodologies and careful experimental design before any conclusions about population changes can be drawn.

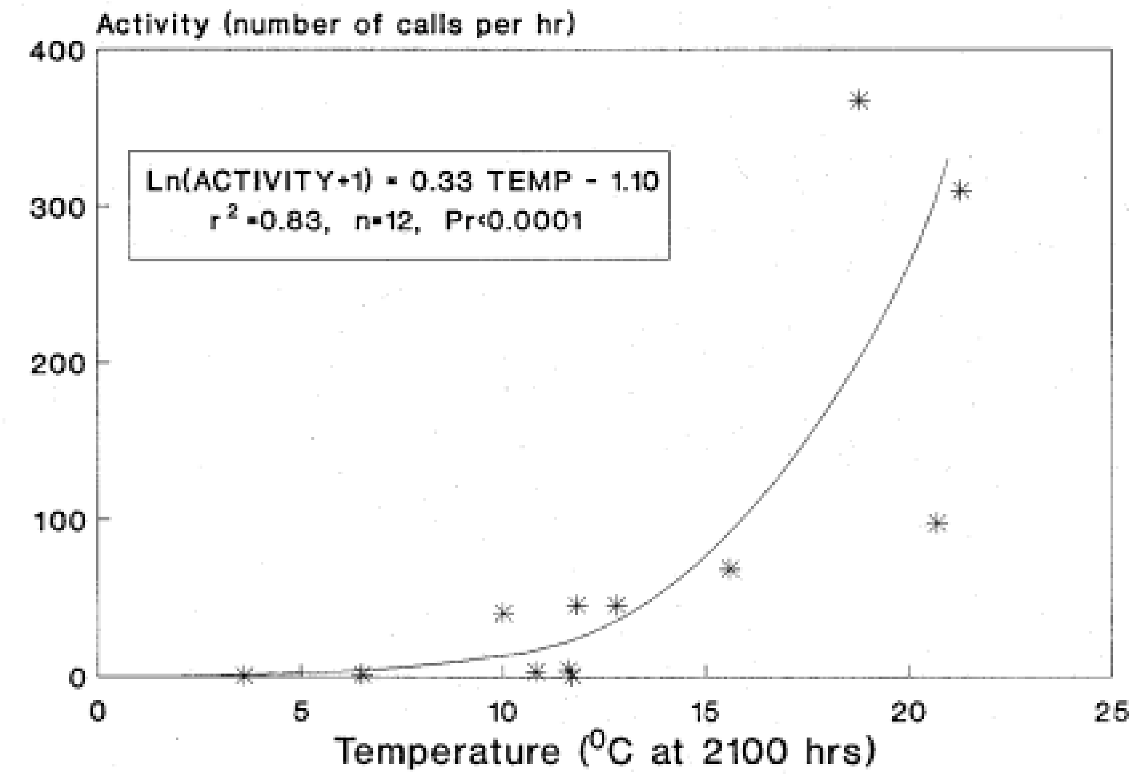


Figure 6.1 Relationship between bat activity and air temperature showing the importance of monitoring temperature during all bat surveys.

6.4 Small Mammals

Introduction

The effects of fire on fauna have been reviewed by Suckling and Macfarlane (1984) who found that little attention has been paid to the effects of repeated burning and the season of burning on fauna. These factors may have a significant effect due to the seasonal fluctuations in small mammal populations and their usually well-defined breeding periods. Many studies of

3d Feathertail Gliders inhabit tree hollows. Artificial hollows are being used to help understand the effects of fuel reduction burning on these possums. (Photo: Ballarat prescribed burning have looked at differences between sites with different time since fire rather than changes on the same sites subjected to different fire regimes. The conclusions drawn from these studies need to be considered with caution as differences in fauna may be due to climatic differences following burning, site differences, pre-burning differences or the effect of the burning being studied, any of which may significantly influence plant regeneration and therefore faunal habitat.

This summary describes the effects of single spring and single autumn prescribed fire on Brown Antechinus and Bush Rats at three of the FESAs. A detailed account of the study is given in Humphries and Tolhurst (1992). Data collection and analysis is continuing and future results will provide information on the effects of repeated prescribed fires in spring and autumn.

Results and Discussion
A single prescribed fire in either spring or autumn had little effect on Brown Antechinus populations. Populations were initially reduced as a result of direct mortality in the fire, probable predation and some emigration from the burnt areas in the first few months after treatment. The high breeding potential of Brown Antechinus, and an adequate availability of nesting sites, combined to allow populations to recover to pre-burning levels within two breeding periods after spring burning, but they had not recovered after a single breeding period following autumn burning.

Populations of Bush Rats took three breeding seasons to recover when between 50% and 80% of their habitat in gullies was burnt in spring or autumn, but there was no recovery in the same period when all the habitat was burnt. When less than 50% of Bush Rat habitat was burnt, populations recovered after a single breeding season. The variability in fires, as indicated in this study, highlights the importance of both the large and small scale burning mosaic as limiting factors for the short term survival and subsequent recovery of some species.


3c : Bush Rats are common in moist gullies with sedges and rushes. Usually, these gullies do not get completely burnt in fuel reduction burns. (Photo: Robert Humphries)

Recovery of both species occurred within a two year period of spring or autumn burning when about 40% of gully vegetation and about 10% of the mid-slope ground cover was left unburnt. This rapid recovery was attributed to the successful survival and breeding of individuals during this period in unburnt patches. Because the animals remain within defined ranges except when dispersing, recolonisation of areas totally burnt by fire would occur only when their habitat had recovered sufficiently to provide adequate food, shelter and breeding sites. The results suggest that fire management prescriptions should aim to minimise the burning of gully vegetation and burn no more than 70-80% of an area overall if rapid recovery (within 3 years) of Bush Rats and Brown Antechinus is a management objective.

6.5 Reptiles

Introduction
Less is known about the response of Australian reptiles to wildfire or prescribed burning than is known about the response of birds or small mammals. The few studies reported in the literature compare species assemblages in areas of known burning history, but without knowledge of species complements before the fire event. These studies have concentrated on the reptilian fauna of central Australia (Cogger 1969; Fyfe 1980; Caughley 1985) and northern Australia (Braithwaite 1987), areas noted for their reptilian diversity. Few studies have been conducted in the southern temperate regions of south-eastern Australia where prescribed burning is a common and frequently used management tool in forest ecosystems. These environments have low reptilian species richness (Rawlinson 1971). The fine and heavy fuels temporarily removed by prescribed burning are parts of reptile habitat required for thermoregulation sites, shelter, food; and as oviposition sites for oviparous species (Rawlinson 1971).

This summary documents the short term responses of eight common scincid lizards to single spring and autumn low-intensity prescribed fires. Full details of the methods and results are given in Humphries (1992). Data collection will continue and future results will provide information on the effects of repeated prescribed fires in spring and autumn.

Results and Discussion

The abundance of Southern Water Skinks remained relatively stable following both spring and autumn burning because their primary habitat, fallen logs and branches, had not been significantly affected in terms of abundance or condition. Coventry's Skinks and McCoy's Skinks forage on and in the ground/litter layer, the microhabitat most affected by burning. The relatively high recorded abundances of these species after burning were probably due to the increased ease of detecting them as a result of reduced cover. The abundances of skinks at different times since fire are shown in Figure 6.2.

4b Coventry's Skink is one of eight species found in the study areas. Although the skinks usually survive a fire, little is known about the longer term effects of fire on their populations. (Photo: Robert Humphries)

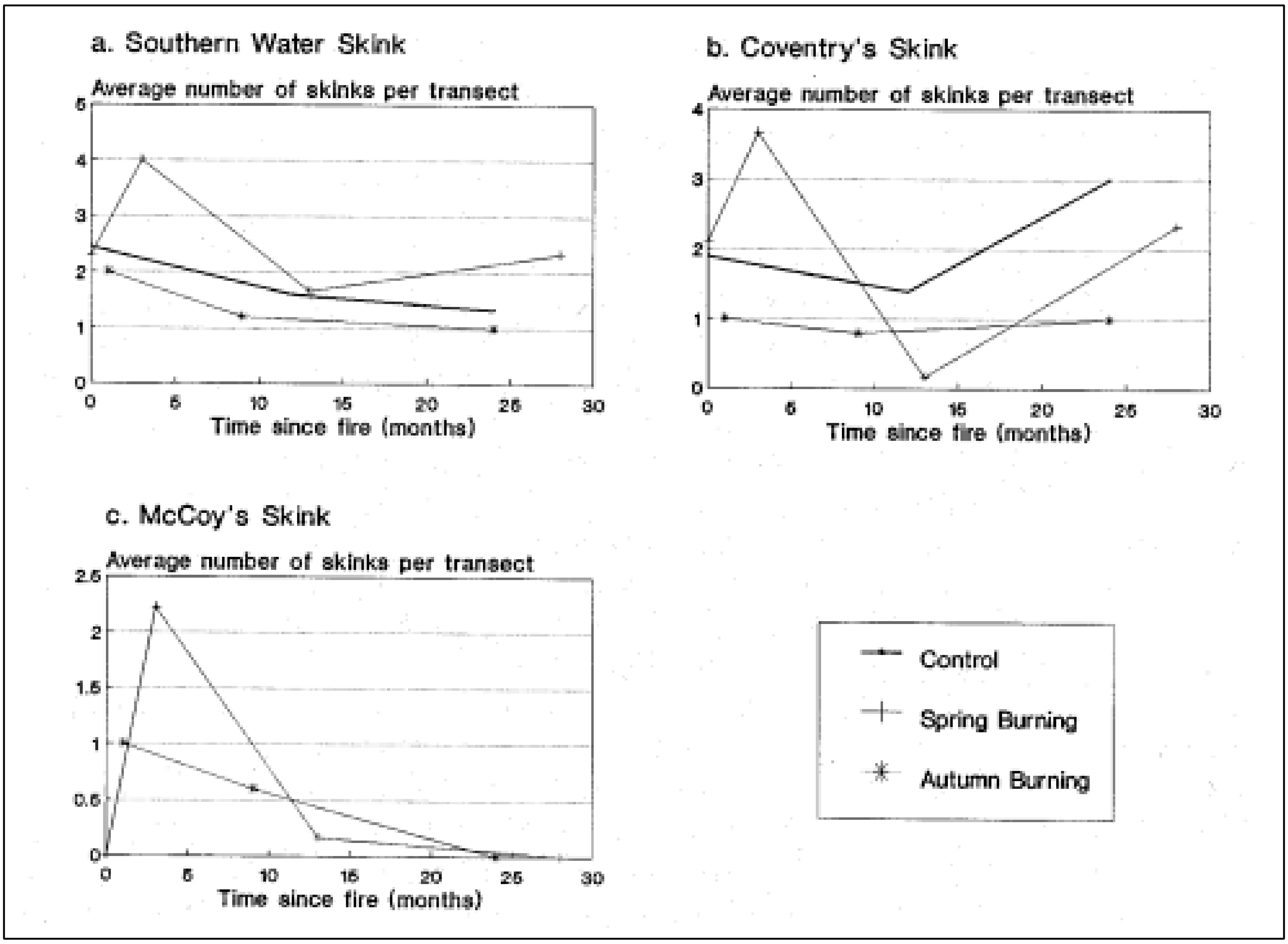


Figure 6.2 Skink abundance at the Musk Creek FESA at different times since fire in the spring, autumn and control treatments. No McCoy's Skinks were observed in the control treatment.

The few studies of the effects of burning on reptiles in southern Australia have dealt with the survival of particular species after high-intensity wildfire (e.g. Lunney et al. 1991; Newsome et al. 1975). In the present study observations were made of species surviving or being killed by low-intensity fire. During the autumn burn at the Barkstead FESA in April 1987, the comparatively strong-limbed species, Southern Water Skink, was observed moving ahead of the fire front, which had a forward rate of spread calculated at a maximum of 1.2 $m.min^{-1}$, and taking refuge in hollow logs and stumps. The security of these refuges depended on a number of factors including: size, degree of decomposition, seasonal dryness and fire intensity. Individual Southern Water Skinks were also occasionally observed crossing a two metre wide bulldozed mineral earth break separating the treatment areas from unburnt sites. At the Musk Creek FESA, the day after both spring and autumn burns, numerous individuals of McCoy's Skink were observed under large logs. These specimens of McCoy's Skink, a short limbed and slow moving species, often showed signs of being burnt in the fire with scales and limbs melted and fused together. Many individuals probably died as a direct result of the burning. At the Barkstead FESA before the burning, a group of eight Grass Skinks were sheltering in a small pile of decaying timber. The day after the autumn burning, the wood was blackened all over but not totally burnt, but the skinks were no longer present. It was assumed the skinks would have survived, but this was not verified.

The effects of single spring and autumn prescribed fires in this study were similar. Four of the five species studied either depend on or largely rely on the litter layer for food and shelter. These species showed the greatest fluctuations in abundance. Litter loads reached pre-burn levels two to four years after burning. The importance of this rapid recovery of a major habitat component is shown by the increase in the relative abundances of Coventry's Skink 28 months after spring burning. McCoy's Skink, a species dependent on deep litter, is likely to be the most vulnerable to high-frequency and moderate- to high-intensity burning regimes. The only species that has a preferred semi-arboreal (fallen logs) microhabitat preference, Southern Water Skink, showed little variation in abundance. It has been suggested that this species may actually benefit, in the short term, from infrequent fires and some forestry practices through to a reduction in the shrub and ground cover and an increase in available basking sites (Rawlinson 1971; Mather 1978).

In a fuel reduction burn, the result, and indeed the aim, is not the complete consumption of all litter. Fires generally achieve 60 to 80 percent of the area being burnt to some degree (Hodgson and Heislers 1972). The small-scale mosaic of burnt and unburnt areas that follow a fuel reduction burn are crucial to the local survival of many litter invertebrates and can act as the source of future recolonisation by invertebrates and small mammals (Leonard 1972; Heislers 1980; Humphries and Tolhurst 1992). These unburnt patches are also likely to act as refuges for small skinks. Most lizard species studied have definite home ranges (Heatwole and Taylor 1987). These permit lizards to familiarise themselves with their immediate environment and thus the nearest point of shelter in case of attacks from predators. The size of home ranges for some lizards is very small. Mather (1978) determined the mean home range of Southern Water Skink to be 7.6 m^2 in open-forest at Toolangi, central Victoria. It is conceivable that in a low-intensity prescribed fire, entire or large proportions of existing home ranges of Southern Water Skink and other small skinks would be left relatively intact.

Clearly no one fire regime is favourable to all species. There are no data on the optimum frequency of burning for conserving any reptile species. However, a fire regime that allows the build-up of litter and other sheltering and basking sites (e.g. logs), and thereby an adequate food supply (litter invertebrates), should enable most reptiles to thrive (Suckling and Macfarlane 1984). Future observations during this study will test this hypothesis.

6.6 Invertebrates

Introduction

Arthropods of the Phyla Chelicerata, Crustacea and Uniramia (Manton 1977) constitute by far the largest and most diverse components of the mesofauna (>100 ìm to <1 cm length) within litter and upper soil horizons of forests. These small animals, together with earthworms (Phylum: Annelida) and microbes (<100 ìm), are essential in (1) regulating the decomposition of organic matter, (2) aerating soils, (3) recycling nutrients, and (4) serving as prey or acting as predators, parasites or parasitoids in food chains (Crossley 1970, 1977; Cromack et al. 1977; Greenslade and Greenslade 1983).

4d Invertebrates in the litter and soil are abundant in these forests, but very little is known about their ecology. Test-tubes inserted in the ground are used as pitfall traps for mobile litter invertebrates. (Photo: Kevin Tolhurst)

Litter-surface frequenting (epigeal) arthropods are especially vulnerable to surface fires, which destroy their habitats and desiccate upper soil layers. Earthworms are also highly fire-sensitive, because of their intolerance to ambient temperatures above 25^{o}C (Reynolds 1973) and low moisture levels in the litter/upper soil horizons (Fig. 6.3). These characteristics of earthworms are due to their essential requirement of a continuous film of moisture within the permeable outer skin (cuticle) for respiratory exchange (Lee 1983).

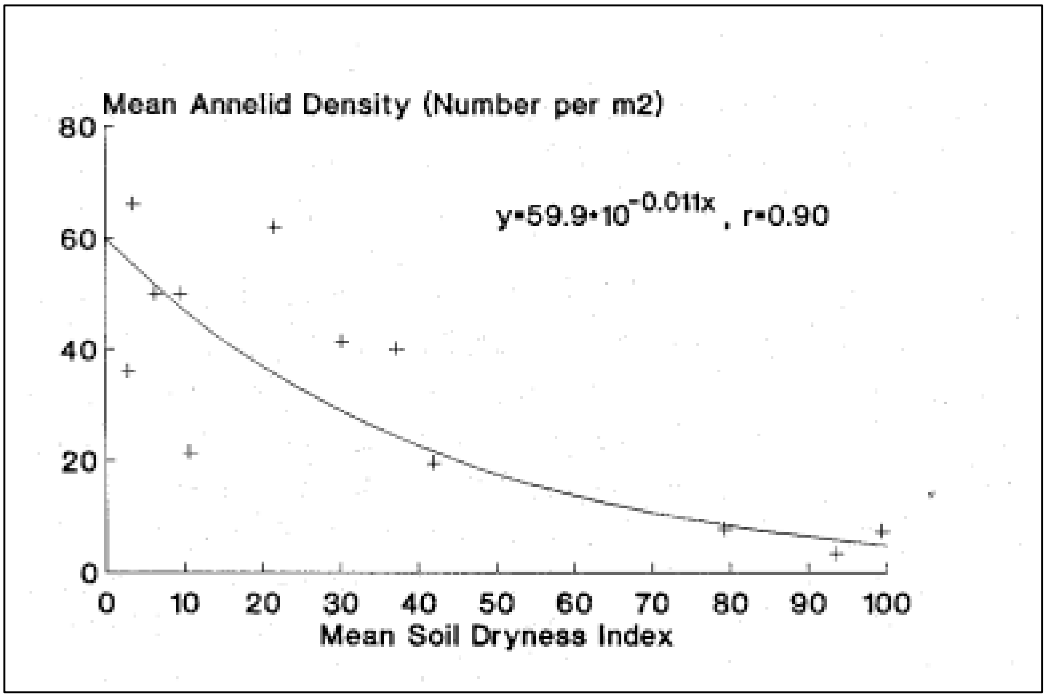


Figure 6.3 Correlation between the annual mean values of earthworm density and soil dryness index, based on 40 composite litter/upper soil samples examined along 100 m transects in the Blakeville control treatment.

The results reported here refer to progress made during the first three years of the study, and specifically relate to impacts of single spring and autumn burns. A complete description of methods and results is given in Neumann (1992).

Results

The study identified 29 arthropod taxa (families) at the litter surface in the Blakeville FESA. Seven of these were trapped frequently at all study sites and 15 taxa were trapped moderately often to occasionally. Only seven taxa - all rare and representing 24.1% of the total number of taxa trapped - were restricted to one or two of the study sites. At the control treatment, the mean number of specimens in composite samples varied little between the sampling years for both non-insect arthropods and insects. This reflected a high degree of stability among the epigeal arthropod fauna in the undisturbed dry sclerophyll forest sampled. It also indicated that pitfall trapping produces consistent results with respect to the activity of epigeal non-insect arthropods and insects, and therefore seems appropriate for this study, which uses sampling over time to assess the effects of low-intensity prescribed burns on litter arthropods.

The spring burn caused short-term reductions in activity among the common "major" taxa Collembola (springtails) and Diptera (flies), and among the rarely trapped "minor" taxa Opilionida (harvestmen), Lepidoptera (moths) and Apocrita (parasitic wasps) for up to one year. These reductions were associated with low litter loads in the first year after the burn. Populations of earthworms also declined substantially, but recovered within 2.9 years of the burn. The autumn burn suppressed the Collembola and the "minor" taxa Blattodea, Polydesmida, Thysanura and Tettigoniidae for up to 10 months. Earthworms were not affected. Very dry soil conditions were associated with depressed Collembolan activity at all study sites irrespective of burning.
Given the importance of Collembola, larval Diptera and earthworms among decomposers in forest litter it appears that the spring burn, and to a lesser extent the autumn burn, may have temporarily

reduced the decomposer cycle. Research at species level is required to substantiate this hypothesis. These results suggest that fuel reduction burning on rotations of three years or less in forest similar to that studied here should be scheduled for autumn rather than spring to minimise adverse impacts on the overall invertebrate fauna inhabiting litter/upper soil.

6.7 Conclusions

Birds were little affected by a single spring or autumn low-intensity burn. Bird abundance and number of species were remarkably stable in burnt and unburnt areas. No new habitats were created and no existing habitats were destroyed, although there was a change in the frequency of each habitat type. These results however, cannot be applied to vegetation types where burning may create or remove particular habitats.

Seven bat species were found in the study areas, making bats the most diverse group of mammals in the area. The data on the comparative abundance of bats associated with fire treatments was inconclusive due to difficulties in the methodology of studying these mammals. Bat activity was significantly related to air temperature and so any bat assessment must take account of the air temperature at the time of assessment.

Recovery of the small mammals, Brown Antechinus and Bush Rats, occurred within a two year period of the burning when at least 50% of gully vegetation and at least 10% of the mid-slope ground cover was left unburnt. This rapid recovery was attributed to the successful survival and breeding of individuals during this period in unburnt patches. Because the animals remain within defined ranges except when dispersing, recolonisation of areas totally burnt by fire would only occur when their habitat had recovered sufficiently to provide adequate food, shelter and breeding sites. If a greater proportion of these animals' habitat was burnt, the recovery time could be expected to be longer. The results suggest that fire management prescriptions should aim to minimise the burning of gully vegetation and burn no more than 70-80% of an area overall if rapid recovery (within 3 years) of Bush Rats and Brown Antechinus is a management objective.

Unburnt patches of litter and fallen logs act as refuges for small skinks and provide food, shelter and breeding sites after a fire. A fire regime that allows the periodic build-up of litter and other sheltering and basking sites (e.g. logs), and thereby an adequate food supply (litter invertebrates), should enable most reptiles to persist.

The spring burn caused short-term reductions in activity among the common invertebrate taxa Collembola (springtails) and Diptera (flies), and among the rarely trapped taxa Opilionida (harvestmen), Lepidoptera (moths) and Apocrita (parasitic wasps) for up to one year. These reductions were associated with low fine fuel loads in the first year after the burn. Populations of earthworms also declined substantially, but recovered within three years of the burn. The autumn burn suppressed the Collembola and the "minor" taxa Blattodea, Polydesmida, Thysanura and Tettigoniidae for up to 10 months. Earthworms were not affected. Very dry soil conditions were associated with depressed Collembolan activity at all study sites irrespective of burning. Autumn burning is favoured to minimise effects on invertebrates.

7 SOIL

7.1 Introduction

An important consideration in fire management is the effect a particular fire regime on nutrient cycling within a forest system and hence the long-term productivity of the managed area. Nutrients such as nitrogen are readily lost from a site in the process of combustion, but nutrients are also released and made available for plant growth when dead plant material is burnt and reduced to mineral ash. Fires can also promote the growth of legumes which are involved in fixing nitrogen from the atmosphere and converting it into a form available to plants.

Fire also affects the physical condition of the soil. The rate of sediment movement on slopes, infiltration, bulk density and soil structure are all potentially affected by fire.

This project has mainly concentrated on soil nutrient properties, since they are the factors most likely to be affected by repeated low-intensity burning. Three separate studies are reported here: (i) changes in surface soil chemistry with different fire intensities including slash burning, (ii) nitrogen fixation rates and (iii) nitrogen mineralisation rates.

7.2 Surface Soil Chemistry

Introduction

There have been several studies of changes in the chemistry of soil and soil solutions after burning in eucalypt forests (e.g. Raison 1979; O'Connell et al. 1981; Raison et al. 1985; Stewart and Flinn 1985). However, these studies have not followed changes in soil chemical parameters with a high frequency of measurement in relation to rainfall, and thus give only a broad indication of the temporal patterns of change.

Generally, burning increases soil pH (i.e. less acidic), exchangeable calcium (Ca2+), organic carbon (C), extractable phosphorus (P) and other nutrients in the surface 3 cm following their release from slash and debris. These increases occur rapidly and elevated concentrations may persist for up to a year. The changes at depth in the soil profile are less and occur more slowly as the nutrients are leached downwards (e.g. Ellis et al. 1982; Khanna and Raison 1986; Grove et al. 1986; Stewart and Flinn 1985). Direct measurement of nutrient content of slash and ash establishes upper limits for potential nutrient input, but loss of nutrient occurs during burning (smoke and ash, volatilisation), and can occur afterwards (wind, leaching and water runoff).

This project examined the patterns of changes in the surface soil chemistry in relation to rainfall, following the burning of 0, 15, 50, 150 and 300 t.ha-1 fuel loads, with an emphasis on the upper 10 cm of soil because changes in this layer are most likely to affect plant regeneration. The highest fuel loads used in this study represent the conditions of slash burning after logging. In particular, the study sought to examine trends and magnitude of nutrient inputs for specified fuel loads and composition at specific cumulative rainfall following burning, and possible relationships between soil nutrient concentrations and fuel loads within the period of the study. This study was a separate plot study in forest similar to the FESAs. A full account of the study is given in Tomkins et al. (1992).

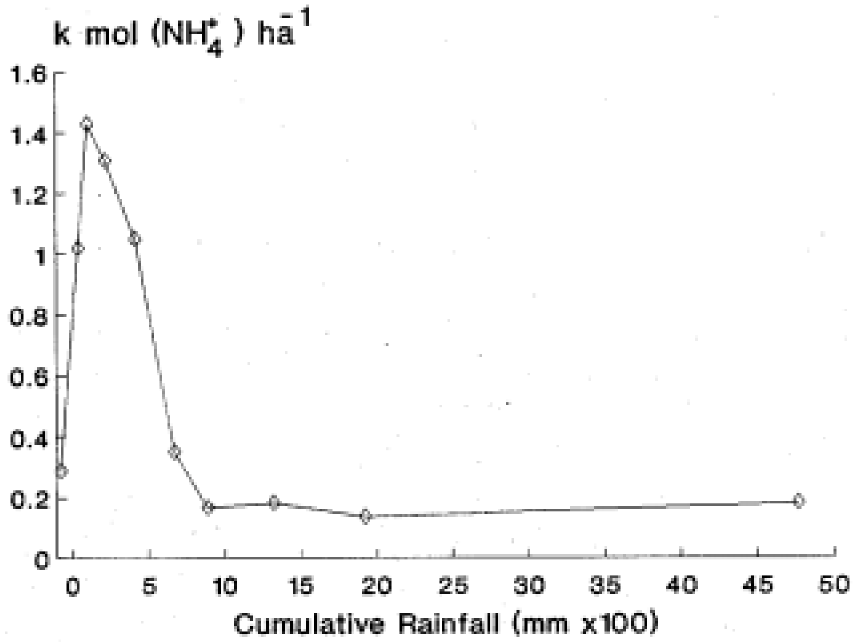


Figure 7.1 Exchangeable ammonium with cumulative rainfall on the 300 t.ha^{-1} plot. Easily leached nutrients such as ammonium reached peak concentrations in the soil after about 100 mm of rain and declined rapidly to pre-burn levels after about 675 mm of rainfall.

Results

Chemical Changes
The more easily leached nutrients declined from the peak value quite rapidly, i.e. exchangeable potassium (K+), magnesium (Mg2+), ammonium (NH4+) in particular, and returned to the levels before burning or lower, within 8 months (December 1986, 675 mm rainfall) (Fig. 7.1). For the high fuel load plots (150 and 300 t.ha-1), pH, exchangeable Ca2+ and available P were, in general, still at elevated levels after two years (1923 mm rainfall). After five years (4770 mm rainfall) the levels at soil depth of 0-2 cm for these plots had fallen further, but were still above those for the control plot.

The pattern of nutrient changes in the soil on low fuel load plots behaved in a similar way to high fuel load plots. The difference was in magnitude rather than in nature. While it was not possible to show this statistically, the increase in soil nutrient concentrations on the low fuel load plots was consistent with the high fuel load plots when the amount of fuel burnt is considered. Calculations of the potential nutrient inputs from the amount of fuel burnt showed that at least 80% of the nutrients, with the possible exception of nitrogen which was not studied, were washed into the soil (Tomkins et al. 1991).

Nutrient Relationships
The relationships between pH, exchangeable Ca2+ and Mg2+, and available P show strong correlation and therefore the measurement of one property could be used to predict any of the other three. Similar correlations between Ca2+ and Mg2+ in soil subject to burning can be seen in other studies (Humphreys and Lambert 1965; Grove et al. 1986).

In this study, increases in pH in excess of 1 pH unit (that is, a 10-fold decrease in H+ concentration) for the high fuel load treatments at 0-2 cm soil depth are maintained up to two years after burning. This increase in pH is due to Ca2+ released from the fuel when burnt, which has the same effect as liming the soil in agricultural systems (Bromfield et al. 1987).

Nutrient relationships reported by Tomkins et al. (1991) using data from the first two years after burning were still valid five years after burning. These relationships are expected to remain constant and characteristic of this soil.

Measurement of changes in soil pH may be a useful indicator for estimating inputs of exchangeable Ca2+ and Mg2+, and available P to the soil, provided accurate estimates of the nutrient content of fuel to be burnt are available, and the soil pH buffering capacity is not limiting.

The correlations involving available P are unlikely to be found in soils with high aluminium (Al3+) or ferric iron (Fe3+), and so could be soil-type specific.

Conclusions

The results obtained provide an accurate guide to the changes in soil chemistry with rainfall in the top 10 cm of soil following burning of various fuel quantities. Earlier studies have involved less accurate estimates of fuel load and less frequent sampling after burning, but in general responses are similar to those reported here.

The effect of burning large amounts of slash fuel (e.g. >50 $t.ha^{-1}$) can be compared with the effect of adding lime to the soil. The release of Ca2+ from fuel on burning is primarily responsible for soil chemistry changes, particularly in the top 2 cm of soil. Provided an accurate estimate of fuel load and its composition can be made, the data provided by this work and other published nutrient data, should allow reasonable predictions of the effects of burning on surface soil chemistry for soils similar to that in this study.

Monitoring surface-soil pH following slash burning may be a useful indicator of the likely release of cations, particularly Ca2+ and Mg2+. If preliminary analyses are carried out, estimates after burning could be made which require minimal chemical analyses of bulked samples for reasonable confirmation of input of P within a two year time-span.

Some of the changes, particularly at a soil depth of 0-2 cm, are relatively long-lived; pH, exchangeable Ca2+ and available P were still at elevated levels for the high fuel-load treatments after five years and approximately 4800 mm of rain, whereas more easily leached or utilised cations, such as sodium (Na+) and NH4+, fall below the pre-burning levels before recovering over a two year period.

This study has shown that rapid seedling growth due to high levels of soil nutrients is most likely during the first year after slash burning. The main benefit to seedlings comes with the first 100 mm of rainfall, which washes ash from the burn into the surface soil. Further rain leaches the more mobile nutrients deeper into the soil profile. Most of the initial nutrient pulse has passed through the surface soil after 900 mm of rainfall (i.e. one year after the burn). However, plant regeneration after a slash-burn will benefit from the nutrients released from the slash for at least two years on podzolic soils.

The effects of the low-intensity fires were similar in nature, but smaller in magnitude to the effects of the high-intensity fires. Nutrients released from the fuel by low-intensity fires were available to plants for a period of about one year. With the possible exception of nitrogen, there was little evidence of nutrient loss from the site due to burning.

7.3 Nitrogen fixation after low-intensity burning

Introduction

Biological fixation of atmospheric nitrogen (N2) by forest legumes is an important process for replenishing some of the N lost from Australian eucalypt ecosystems through prescribed burns or wildfires. Estimates of N2 fixation by forest legumes have generally been based on acetylene reduction techniques (e.g. Hopmans et al. 1983). Estimated inputs of N have varied greatly, ranging from 0.1 $kg.ha^{-1}.yr^{-1}$ in dry, open woodlands to 32 $kg.ha^{-1}.yr^{-1}$ in wet, tall montane forests. There is doubt about the accuracy of these estimates because of limitations of the acetylene reduction technique (Witty and Minchin 1988). The forest environment presents some unique difficulties in the calibration of the acetylene reduction method to quantify N2 fixation in the field (Hansen et al. 1987a, b). Because of this, there is interest in radioactive nitrogen (15N) isotope dilution techniques to estimate N2 fixation, both in woody legumes (e.g. Cornet et al. 1985) and actinorhizal plants (e.g. Chalk 1991).

The 15N isotope dilution technique depends on differences in isotopic composition between the sources of N available to the plant (natural soil N, enriched fertilizer N and atmospheric N2) (McAuliffe et al. 1958) and generally involves addition of 15N-enriched fertilizer to the soil. 15N assimilated from the soil by the legume is isotopically diluted with biologically-fixed atmospheric N2. This dilution is used to determine the proportion of N in the legume derived by N2 fixation. The 15N enrichment of a non-fixing plant provides an estimate of the proportion of N derived from the soil.

The objectives of this field study were to estimate N2 fixation by two Acacia spp. using the isotope dilution technique with the 15N-enriched (from fertilizer) and natural 15N abundance (in soil) methods, and to evaluate labelling with radioactive sulphur (35S) as a technique for determining the accuracy of reference plants for estimating the ratio of labelled to unlabelled N derived from soil sources by legumes. A full account of this study is given in Hamilton et al. (1992a).

Results

Fuel-reduction burning of the autumn treatment (A3) in Musk Creek FESA promoted regeneration of the non-fixing species Bracken, Poa Tussock-grass and Wire-grass and the N2-fixing legumes Blackwood, Narrow-leaf Wattle and, to a lesser extent, Silver Wattle (Tolhurst and Oswin, 1992). Burning reduced litter biomass on average by 7 t.ha^{-1}, which is similar to litter losses of around 9 t.ha^{-1} reported for low-intensity prescribed fires by Raison et al. (1985) and Hamilton et al. (1992b).

Amounts of N fixed by Blackwood and Narrow-leaf Wattle during 27 months following a prescribed burning were 12 and 25 mg.N.plant^{-1}.yr^{-1}, respectively. These estimates were similar to estimates for Blackwood, Black Wattle and Hedge Wattle of 19, 27, and 30 mg.N.plant^{-1}.yr^{-1} respectively, measured over a 2-year period using the acetylene reduction assay (Lawrie 1981). This latter study was carried out in a similar forest type dominated by Messmate Stringybark, Narrow-leaf Peppermint and Long-leaf Box. In contrast, rates of N2 fixation (also using the acetylene reduction assay) of Silver Wattle in a wet, tall Mountain Ash forest ranged from 28 to 74 mg.N.plant^{-1}.yr^{-1} (Adams and Attiwill 1984); approximately twice to three times the rate of fixation estimated in the present study. These comparisons show that estimates of N2 fixation by forest legumes as determined by the 15N isotope dilution method used in this study were similar to the estimates using acetylene reduction assays in the field despite the limitations in the use and calibration of this latter method (Witty and Minchin 1988; Hansen et al. 1987a).

In this study, the estimated accretion of N to the forest ecosystem from N2 fixation by Blackwood and Narrow-leaf Wattle over 27 months following a prescribed burn was small (0.002 to 0.052 kg.ha^{-1} yr^{-1}) compared with estimates for Acacia spp. ranging from 0.1 to 32 kg.ha^{-1} yr^{-1} (Lawrie 1981; Monk et al. 1981; Hingston et al. 1982; Adams and Attiwill 1984; Hansen et al. 1987a). Apart from some variation in individual rates of N2 fixation between legume species, these differences were mainly due to variation in plant densities. The lower estimates of N accretion were associated with plant densities around 14 000 plants.ha^{-1} (Lawrie 1981), while higher rates were reported for dense regeneration of Silver Wattle with up to 200 000 plants.ha^{-1} (Adams and Attiwill 1984). At the low plant densities in this study (< 5000 plants.ha^{-1}), N accretion to the forest ecosystem from N2 fixation is very small compared with the amount of N lost to the atmosphere during similar prescribed fires, estimated at 74 to 109 kg.ha^{-1} for a subalpine eucalypt forest (Raison et al. 1985) and 100 kg.ha^{-1} for a Messmate Stringybark forest (Hamilton et al. 1992b). To prevent depletion of N from these forest ecosystems, frequency of prescribed fires should allow significant replenishment of N from symbiotic and asymbiotic N2 fixation and other atmospheric sources during the inter-fire period.

Conclusions

The results obtained in the present study with perennial legumes suggest that the isotope dilution technique using reference plants may provide accurate estimates of the ratio of labelled to unlabelled N from soil sources by legume plants when using the natural 15N abundance method but not with the 15N enriched method.

The rate of nitrogen accretion is very slow compared with the amount of nitrogen lost to the atmosphere during low-intensity prescribed fires. Fires should therefore be infrequent if site productivity is to be maintained. The rate of nitrogen accretion can be increased by burning under conditions that encourage dense legume regrowth, since the rate of nitrogen fixation is directly related to the density of legumes.

7.4 Nitrogen Mineralisation

Introduction
The literature describing the effect of burning on soil properties is voluminous (e.g. see Raison et al. 1990). However, in virtually none of the studies conducted to date has there been any effort to measure precisely fuel load prior to burning or the proportion of fuel combusted. Consequently it has been difficult to relate observed changes to the quantity of fuel present. This study describes the effect of increasing fuel load (0-300 $t.ha^{-1}$) on soil mineral nitrogen concentrations and nitrogen mineralisation for 170 days after burning. A full account of the methods and results is given in Carlyle (1992). This study was conducted outside the FESAs as a separate plot experiment, but was in the same forest type. The lower fuel loads (15 and 50 $t.ha^{-1}$) are relevant to fuel reduction burning.

Results
Burning had no effect on net nitrogen mineralisation except at the two highest fuel loads (150 and 300 $t.ha^{-1}$), where rates were increased relative to the other treatments. While burning is known to depress net mineralisation where severe soil heating occurs (Raison et al. 1990) it is more common to find an increase (e.g. Humphreys and Craig 1981) as observed here. Soil mineral nitrogen concentrations were markedly elevated immediately after burning suggesting thermal decomposition of organic matter, death of microbial biomass, and some input from ash. Mineral nitrogen concentrations remained fairly stable until 119 days from burning when they declined. This was coincident with increased rates of nitrification and suggests leaching of the more mobile nitrate ion (NO3-); prior to 119 days mineral nitrogen was dominated by the relatively immobile ammonium form (NH4+).

High mineral nitrogen concentrations and elevated mineralisation rates following burning are likely to favour plant growth. Nitrogen losses through leaching are small so long as ammonium is the dominant form of mineral nitrogen. Nitrification was not significant until 119 days from burning at which time pioneer plants were actively recolonizing the burnt areas. With effective revegetation and the delay in nitrification, it is likely that solution losses of nitrogen following burning will be small. Volatilization loss of nitrogen during burning is more likely to be significant in terms of the soil's long-term nitrogen supplying capacity.

7.5 Conclusions

Surface soil chemistry changes due to burning can be monitored by knowing the amount and type of fuel burnt and by measuring the soil's pH. Inputs to the soil from the ash is akin to liming the soil. The main nutrient benefit to seedlings comes with the first 100 mm of rainfall, which washes ash from the burn into the surface soil, but further rain leaches the more mobile nutrients deeper into the soil profile. Most of the initial nutrient pulse has passed through the surface soil after 900 mm of rainfall (approximately one year after the burn). However, plant regeneration after a slash-burn will benefit from the nutrients released from the slash for at least two years on podzolic soils.

The effects of the low-intensity fires were similar in nature, but smaller in magnitude to the effects of the high-intensity fires. Nutrients released from the fuel by low-intensity fires were available to plants for a period of about one year. With the possible exception of nitrogen, there was little evidence of nutrient loss from the site due to burning.

The rate of nitrogen accretion following low-intensity fire is very slow compared with the amount of nitrogen lost to the atmosphere during burning. Fires should be infrequent if the site's nutrient status is to be maintained. The rate of nitrogen accretion can be increased by burning under conditions that encourage dense legume regrowth, since the rate of nitrogen fixation is directly related to the density of legumes.

High mineral nitrogen concentrations and elevated mineralisation rates following high-intensity fires are likely to favour plant growth. Nitrogen losses through leaching are small so long as ammonium is the dominant form of mineral nitrogen. Nitrification was not significant until 119 days from burning at which time pioneer plants were actively recolonising the burnt areas. With effective revegetation and the delay in nitrification, it is likely that solution losses of nitrogen following burning will be small. Volatilisation loss of nitrogen during burning is more likely to be significant in terms of the soil's long-term nitrogen supplying capacity.

8 MANAGEMENT IMPLICATIONS

8.1 Fire Protection Implications

Reducing fire hazard in order to protect human life and assets, and environmental values is the objective of fuel reduction burning: lower fuel loads reduce the intensity of wildfires and the difficulty and risk of fire control, and hence reduce the area burnt and damage caused. Results from the present research show that, in the particular forest under consideration, there is only a short period of as little as two years (spring burns) and about four years (autumn burns) when the litter fuel load is significantly lower in fuel reduced areas than it is in areas that have not been burnt for 30 to 50 years; but that the structure of shrub and bark fuel is modified for a period estimated to be more than 10 years. Therefore, although a fire burning under conditions of high to extreme fire danger could still burn through an area which had been fuel reduced 4 to 10 years previously, the severity of the fire would be reduced and the ability to control it would be substantially increased. The impact of fuel reduction burning on fire hazard is underestimated by solely assessing the impact on the quantity of litter fuels: assessments should be based on the quantity and arrangement of the total fuel complex. This is an important finding, and an appropriate mechanism for integrated fuel assessment is needed.

Autumn burns appear to provide a longer period of reduced litter fuel loads. This effect can be attributed to the lesser disruption to decomposition following autumn burns compared with spring burns; and it provides support for continuing the current management practice of conducting most fuel reduction burning in autumn. However, burning in spring still significantly reduces the fire hazard and should be kept as a management option.

The fuel results of the present study apply to the Messmate/gum/peppermint forest in the Wombat State Forest where the rainfall ranges between 800 and 1000 mm. Forests of similar type and quality may be found on about 25% of the four million hectares of mixed species foothill forests in Victoria. The specific rate of accumulation of litter fuel at a particular site can be expected to depend on factors such as the site productivity, climate and the number, size and species of trees that are present. Relationships with these variables should be determined and evaluated before the results from this study can be extended reliably to other forest types or parts of Victoria.

8.2 Ecological Effects of a Single Low-intensity Fire

No plant or animal species was lost from any study area and timber growth was not affected after either spring or autumn burning during the first seven years of this study. This is not surprising, given that the forest had been previously disturbed by extensive wood harvesting activities associated with gold mining in the late 19th century and an estimated 50 000 previous fires over the past five million years. However, some fire regimes can change ecosystems gradually. The results of this study provide some insight into the processes of interaction among the various ecological components, which are useful in considering the possible effects of applying repeated fire for longer periods, and the possible effects of fuel reduction burns in other places or situations.

In comparison with understorey vegetation in a forest in which fire had been excluded for 30 to 50 years, the burns in the short-term simplified the physical structure for at least four years, mainly by reducing the height of Wire-grass and non-herbaceous plants such as shrubs, and small-trees; and simplified the age structure of some plant species by replacing a population of immature, mature and senescent plants with a population of predominantly immature ones. This has reduced the diversity of animal habitat and plant population structure in the short-term; but that diversity should increase again with time.

Unburnt patches, even as small as one square metre, can be quite important to the survival and recolonisation of the burnt area by invertebrates, small mammals, reptiles, birds and plants. Patchiness, which concerns the number, size and distribution of unburnt patches, is affected by the abundance of rocky outcrops and fallen timber, the weather conditions which determine the proportion of the fuel that is available for burning, the ignition pattern that is used to burn the area, and the presence of areas of low fuel load which may have resulted from previous fires. Recolonisation from unburnt patches becomes even more important when extensive areas are burnt by either wildfires or fuel reduction burns. The definition and importance of patchiness, and the "home range" of particular animal species, needs further investigation. In the meantime, land managers should, in this forest type, extend their existing prescriptions to leave unburnt at least 50% of gully vegetation in addition to at least 10% of non-gully vegetation, distributed across the burn area.

Invertebrates living in the upper soil and litter substrata are directly exposed to the effects of surface fires. Spring burning, and to a lesser extent autumn burning, induced a short-term decline in the activity of the decomposer cycle because members of the Collembola, larval Diptera and earthworms, which are important and dominant among decomposers in forest litter, were adversely affected. The effects of spring burning, plus the desiccating conditions of the ensuing summer, more adversely affected earthworms than did autumn burning (which usually heats the soil more than spring burning) plus the cool and wet conditions that follow in winter. Further research is needed to determine whether particular species, especially within those three families, are adversely affected for more than three years. In the meantime, prescribed burning on rotations of less than three years in forest similar to that studied here should be scheduled mainly for autumn rather than spring to minimise the possibility of long-term adverse effects on the overall invertebrate fauna inhabiting litter and upper soil.

Levels of forest nutrients must be maintained if the species composition and structural diversity of the forest are to be sustained. Fires play an important role in nutrient cycling, including nutrient loss. In this study, the effect of low-intensity fire on most nutrients in the soil lasted for less than two years, except for nitrogen. Repeated low-intensity burning at frequencies of less than 10 years may reduce the total nitrogen pool in this forest type by about 1%, which is equivalent to about 10% of the nitrogen in the live and dead above-ground biomass, since the rate of nitrogen accretion is very slow compared with the amount of nitrogen lost to the atmosphere during fires. Further research is needed to determine the time taken for nitrogen to reach pre-burn levels after burning. In the meantime, fires in this forest type should be less frequent than every 10 years if nutrient levels are to be maintained. The rate of nitrogen accretion can be increased, if legumes are present, by burning under conditions and at intervals that encourage dense legume regrowth (usually autumn in this study) since the rate of nitrogen fixation is directly related to the density of legumes.

8.3 Ecological Effects of the Fire Regime

The effects of spring burns differ from autumn burns in this forest type in the short-term, but these differences are generally no longer evident three years after burning and the occasional burn in either season would appear to have no lasting effect. However, rotational burning in the same season may eventually result in longer-term changes because:

- Spring burning occurs during a period of active growth for plants and the main breeding time for animals.
- Vegetative recovery after spring burning was more rapid than after autumn burning.
- Autumn burning promoted more seedling regeneration and this is particularly important from a nutrient point of view when legumes, which fix atmospheric nitrogen, form part of the understorey and regenerate from seed.
- Spring burning was usually, but not always, more patchy than autumn burning, leaving unburnt litter and vegetation which assisted in the survival of some invertebrates, small ground dwelling mammals and birds.
- Spring burning also occurred at a time when many animals were breeding and so may have been more vulnerable to loss of habitat i.e. food, shelter and breeding sites.

Therefore, burning in both spring and autumn should continue in this forest type along with research into the functional relationships between season of burning and plant and animal responses.

A second spring burn, three years after the first, appeared to reduce the recovery rate of the vegetation. This effect may be attributed partly to the comparatively rapid recovery of the vegetation after the first spring burns due to an unusually long growth period following the burns, but is attributed mostly to an effect of each burn reducing, for at least three years, the regenerative reserves of the plants. Continuing research is needed to test this hypothesis and to determine the minimum periods between burns for the maintenance of populations of plants and animals, with particular reference to longer lived and slower growing plants such as shrubs, and longer lived and slower breeding animals such as Bush Rats. In the meantime, land managers should avoid repeated burning of this forest type at intervals of three years or less in spring and perhaps also autumn.

Management of most ecosystems in Victoria may require diverse fire regimes rather than regular cyclic burning. These regimes should define the frequency, intensity, season and extent of burning, and may even include fire exclusion. The various fires within a regime may be, or may even need to be, quite different to each other in any of these respects; and the regime should accommodate the possibility of wildfire. Monitoring of climatic, biotic and physical factors and new research results must all be on-going inputs into the prescribing of suitable fire regimes which satisfy management objectives.

Land management in Victoria has to address many needs, including conservation of ecosystems, fire protection, provision of forest produce, and recreation. Needs and priorities must be defined, environmental resources and processes must be understood, and techniques must be applied to achieve desired outcomes. The results of the research reported here are valuable in obtaining a better understanding of fire ecology, and will lead to progressive improvements of fire management in Victoria; but the real value of this research will come when data are available on the effects of repeated burns. Future research should compare repeated fuel reduction burning with the effects of less frequent high-intensity wildfires in addition to the comparison with the effects of fire exclusion made in this report. The work in the Wombat State Forest is therefore continuing and will be given high priority.

Acknowledgements
Acknowledgement is given to the staff of the Forest Research Centre, Creswick, for their unfading support of the project since its inception in 1984. We wish to thank the significant contribution made by the Geelong Region in making the study areas available and for the logistical support in conducting the burning treatments. We also thank Melbourne University and especially the Ballarat University College for their valuable input to the program, and all the authors of unpublished reports which formed the basis of this summary. A special thanks to Phil Cheney, National Bushfire Research Unit, CSIRO for his critical comments on the manuscript of this report. Specific comments were also made by Lindy Lumsden and Malcolm Macfarlane of the Wildlife Section on the fauna section and the Regional Fire Management Officers and officers of Fire Management Branch have provided constructive comments on the Management Implications section.

References

Adams, M.A. and Attiwill, P.M. (1984) Aust. J. Bot. 32: 217-223.

Ashton, D.H. (1970) in Second Fire Ecology Symposium, Monash University, Melbourne, 6pp.

Attiwill, P.M., Guthrie, H.B. and Leuning, R. (1978) Aust. J. Bot. 26: 79-91.

Baird, A. (1984) in Moore, S.A. (ed.) The Management of Small Bush Areas in the Perth Metropolitan Region, Seminar, 20 Sept. 1983, Dept. Fisheries & Wildlife, Perth. Pp. 18-20.

Baker, T.G. and Attiwill, P.M. (1985) Aust. For. Res. 15: 309-319.

Bell, D.T. and Koch, J.M. (1980) Aust. J. Ecol. 5: 9-14.

Boomsma, D.B. and Karjalainen, U. (1982) in Proc. Workshop on Establishment of Coniferous Plantations, Sept. 1982, Mt. Gambier, South Australia.

Braithwaite, R.W. (1987) J. Trop. Ecol. 3: 265-275.

Bromfield, S.M., Cumming, R.W., David, D.J. and Williams, C.H. (1987) Aust. J. Exp. Agric. 27: 533-538.

Buckley, A.J. and Corkish, N.J. (1991) Fire Management Branch, Research Report No. 29. Department of Conservation and Environment, Victoria. 28 pp.

Byram, G.M. (1959) in Davis, K.P. (ed.) Forest Fire, Control and Use McGraw-Hill Book Co., New York.

Carlyle, J.C. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Catling, P.C. and Newsome, A.E. (1981) in Gill, A.M., Groves, R.H. and Noble, I.R. (eds.) Fire and the Australian Biota Aust. Acad. of Sci., Canberra, pp. 273-310.

Caughley, J. (1985) in Grigg, G., Shine, R. and Erman, H. (eds.). Biology of Australian frogs and reptiles. Surrey Beatty, Chipping Norton, NSW. Pp. 31-34.

Chalk, P.M. (1991) Plant and Soil 132: 29-39.

Cheney, N.P., Gould, J.S. and Hutchings, P.T. (1990) Eucalypt Regrowth Management, Technical Report No.12, Dept. Con. & Env., Victoria.

Christensen, P. (1974) in Proc. Fire Ecol. Symposium, Monash Univ., Clayton, pp. 66-73.

Christensen, P., Recher, H. and Hoare, J. (1981) in Gill, A.M. Groves, R.H. and Noble, I.R. (eds.) Fire and the Australian Biota, Aust. Acad. Sci., Canberra. Pp. 367-393.

Christensen, P.E. and Kimber, P.C. (1975) Proc. Ecol. Soc. Aust. 9: 85-106.

Cogger, H.G. (1969) Ph .D. Thesis, Macquarie University.

Cornet, F., Otto, C., Rinaundo, G., Diem, H.G. and Dommergues, Y. (1985) Acta Oecol./Oecol. Plant. 6: 211-218.

Cowley, R.D. (1974) in Proc. Third Fire Ecol. Symposium, Monash Univ., Clayton, pp. 58-65.

Cromack, K., Sollins, P., Todd, R.L., Crossley, D.A., Fender, W.M., Fogel, R. and Todd, A.W. (1977) in Mattson, W.J. (ed.) The role of arthropods in forest ecosystems, Springer-Verlag, New York, Heidelberg, Berlin, pp. 78-84.

Crossley, D.A. (1970) in Pesticides in the soil: ecology, degradation and movement, Michigan State Univ., East Lansing, MI, pp. 30-35.

Crossley, D.A. (1977) in Mattson, W.J. (ed.) The role of arthropods in forest ecosystems, Springer-Verlag, New York, Heidelberg, Berlin, pp. 49-56.

Ealey, E.H.M. (ed.) (1984) Fighting Fire With Fire, Proc. Symp. on fuel reduction burning, Sept. 17-18, Monash Univ., Melbourne, 215pp.

Earl, G. and Lunt, I. (1989) Vic. Nat. 106: 205-207.

Ellis, R.C., Lowry, R.K. and Davies, S.K. (1982) Plant and Soil 65: 171-86.

Fox, B.J., Fox, M.D. and McKay, G.M. (1979) Aust. J. Bot. 27: 157-65.

Fyfe, G. (1980) Herpetofauna 12: 1-9.

Gill, A.M. (1981) in Gill, A.M. Groves, R.H. and Noble, I.R. (eds.) Fire and the Australian Biota, Aust. Acad. Sci., Canberra. Pp. 243-72.

Gilmore, A.M., Emison, W.B. and Wheeler, J.R. (1979) in Memoirs of the National Museum of Victoria, No. 40.

Greenslade, P.J.M. and Greenslade, P. (1983) in Soils , An Australian Viewpoint. CSIRO, Melbourne, pp. 645-69.

Grove, T.S., O'Connell, A.M. and Dimmock, G.M. (1986) Aust. J. Ecol. 11: 303-17.

Hall, I.S. (1981) in A. Keast (ed.) The Ecological Biogeography of Australia. Dr. W. Junk Publishers, London.

Hamilton, S.D. (1986) M. Appl. Sc., Thesis, Royal Melb. Inst. Tech., Melbourne.

Hamilton, S.D., Hopmans, P., Chalk, P.M. and Smith, C.J. (1992a) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Hamilton, S.D., Smith, C.J., Chalk, P.M. and Hopmans, P. (1992b) Soil Biol. Biochem. 24: 71-78.
Hanes, T.L. (1971) Ecol. Monogr. 41: 27-52.

Hansen, A.P., Pate, J.S. and Atkins, C.A. (1987a) J. Expt. Bot. 38: 1-12.

Hansen, A.P., Pate, J.S., Hansen, A. and Bell, D.T. (1987b) J. Expt. Bot. 38: 26-41.

Heatwole, H.F. and Taylor, J. (1987) Ecology of reptiles. Surrey Beatty & Sons, Chipping Norton, NSW, 325pp.

Heislers, A. (1974) in Proc. Third Fire Ecol. Symposium, Monash Univ., Clayton, pp. 37-42.

Heislers, A. (1980) M.Sc. Thesis, Monash University, Clayton, Victoria.

Hingston, F.J., Malajczuk, N. and Grove, T.S. (1982) J. Appl. Ecol. 19: 631-45.

Hodgson, A. and Heislers, A. (1972) For. Comm. Vic., Bull. 21, 40pp.

Hopmans, P., Douglas, L.A. and Chalk, P.M. (1983) Aust. J. Bot. 31: 331-39.

Humphreys, F.R. and Craig, F.G. (1981) in Gill, A.M, Groves, R.H. and Noble, I.R. (eds.), Fire and the Australian Biota, Australian Academy of Science, Canberra. Pp. 177-200.

Humphreys, F.R. and Lambert, M.J. (1965) Aust. J. Soil Res. 3: 81-94.

Humphries, R.K. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Humphries, R.K. and Tolhurst, K.G. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Kemp, J., Westbrooke, M., van Gaans, G. and Fowler, A. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Khanna, P.K. and Raison, R.J. (1986) Aust. J Soil Res. 24: 423-34.

Kimber, P. (1974) in Proc. Third Fire Ecol. Symposium., Monash Univ., Clayton, pp. 49-57.

Kirkpatrick, J.B. and Dickinson, K.J.M. (1984) Aust. J. Bot. 32: 613-29.

Lawrie, A.C. (1981) Aust. J. Bot. 30: 447-460.

Lee, K. E. (1983) in Soils An Australian Viewpoint. CSIRO, Melbourne, pp 629-44.
Leigh, J.H. and Holgate, M.D. (1979) Aust. J. Ecol. 4: 25-45.

Leonard, B.V. (1972) Unpublished M.Sc. Thesis, Monash Univ.

Loyn, R.H. (1985) in Keast, A., Ford, H., Recher, H. and Saunders, D. (eds.), Birds of eucalypt forests and woodlands: ecology, distribution, conservation and management, Surrey-Beatty and Sons, Sydney, Chapter 5

Loyn, R.H., Hewish, M.J. and Considine, M. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Lunney, D., Eby, P. and O'Connell, M. (1991) Aust. J. Ecol. 16: 33-46.

Manton, S. M. (1977) The Arthropoda. Oxford University Press, Oxford.

Mather, P.B. (1978) M.Sc. Thesis, La Trobe University, Bundoora. Victoria.

McArthur, A.G. (1962) Forestry and Timber Bureau, Aust., Leaflet No. 80.

McAuliffe, C., Chamblee, D.S., Uribe-Arango, H. and Woodhouse, W.W., Jr. (1958) Agron. J. 50: 334-37.

McKenzie, N.L. (1983) in Swans, Vol. 13 No. 3.

Menkhorst, P.W. (1987) A.R.I. Tech. Rept. No. 50.

Monk, D., Pate, J.S. and Loneragan, W.A. (1981) Aust. J. Bot. 29: 579-92.

Neumann, F.G. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Neumann, F.G. and Tolhurst, K.G. (1991) Aust. J. Ecol. 16: 315-30.

Newsome, A., McIlroy, J. and Catling, P. (1975) Proc. Ecol. Soc. Aust. 9: 107-23.

Noble, I.R. and Slatyer, R.O. (1980) Vegetatio 43: 5-21.

O'Bryan, D. (1988) Dept. Con., For. & Lands, File 85/627, 5pp. (unpublished).

O'Connell, A.M., Grove, T.S. and Lamb, D. (1981) in Proceedings Australian Forest Nutrition Workshop, Productivity in Perpetuity, Canberra, CSIRO, Melbourne, pp. 277-289.

Parnaby, H. (1977) Vic. Nat. 94: 191-97.

Pook, E.W. (1985) Aust. J. Bot. 33: 65-79.

Preest, D.S. and Cranswick, A.M. (1978) Proc. 31st N.Z. Weed and Pest Control Conf., New Plymouth, N.Z. Pp. 69-73.

Purdie, R.W. (1977a) Aust. J. Bot. 25: 21-34.

Purdie, R.W. (1977b) Aust. J. Bot. 25: 35-46.

Purdie, R.W. and Slatyer, R.O. (1976) Aust. J. Ecol. 1: 223-36.

Raison, R.J. (1979) Plant and Soil 51: 73-108.

Raison, R.J., Keith, H. and Khanna, P.K. (1990) in Dyck, W.J. and Mees, C.A. (eds.) Impact of Intensive Harvesting on Forest Site Productivity. Forest Research Institute, Rotorua, New Zealand, Bulletin No. 159, pp.39-54.

Raison, R.J., Khanna, P.K. and Woods, P.V. (1985) Can. J. For. Res. 15: 657-64.

Raison, R.J., Woods, P.V. and Khanna, P.K. (1983) Inst. Foresters Aust., 10th Triennial Conf., Melb. pp.59-64.

Rawlinson, P.A. (1971) in Arnold, V.H. (ed.) Victorian Year Book. No.85. Vic. Govt. Printer, Melbourne. Pp 11-36.

Recher, H.F., Lunney, D. and Posamentier, H. (1974) in Proc. Third Fire Ecol. Symposium, Monash Univ., Clayton, pp. 30-36.

Reilly, P. (1991) Emu 91: 100-106.

Reynolds, J. W. (1973) Proc. 1st Soil Microcommunities Conf., Syracuse, N.Y. 1971 (ed. D. Dindal), pp. 95-120 (USAEC, Office of Information Services).

Russell, R.P. and Parsons, R.F. (1978) Aust. J. Bot. 26: 53-61.

Simmons, D. and Adams, R. (1986) Aust. For. 49: 149-54.

Specht, R.L. (1983) Aust. J. Ecol. 8: 433-439.

Squire, R.O. (1990) Report on the progress of the Silvicultural Systems Project, Dept. Con. & Env., Victoria.

Stewart, H.T.L. and Flinn, D.W. (1985) Aust. For. Res. 15: 321-32.

Stokes, T. (1975) Aust. Bird Bander 13: 75-76.

Stretton, L.E.B. (1939) Report of the Royal Commission (Bushfires of 1939). Govt. Printer, Melbourne.

Suckling, G.A. and Macfarlane, M.A. (1984) in Ealey, E.H.M. (ed.) Proc. Symp. on Fuel Reduction Burning. Grad. School. Env. Sci., Monash University, Melbourne, pp.107-128

Tolhurst, K.G. (1990) in Thomson, J.A. and Smith, R.T. (eds.) Bracken Biology and Management, Aust. Inst. Ag. Science, Sydney. Pp. 53-62.

Tolhurst, K.G. (1992a) in Forest Research Report No. 349, Dept. Con. & Env., Victoria, Chap. 1.

Tolhurst, K.G. (1992b) in Forest Research Report No. 349, Dept. Con. & Env., Victoria, Chap. 13.

Tolhurst, K.G. and Flinn, D.W. (eds.) (1992) Ecological impacts of fuel reduction burning in dry sclerophyll forest: First progress report. Forest Research Report No. 349, Dept. Con. & Env., Victoria., 384 pp.

Tolhurst, K.G. and Oswin, D.A. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Tolhurst, K.G., Kellas, J.D. and Wilson, A.A. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Tomkins, I.B., Kellas, J.D., Tolhurst, K.G. and Oswin, D.A. (1991) Aust. J. Soil Res. 29: 25-47.

Tomkins, I.B., Kellas, J.D., Tolhurst, K.G. and Oswin, D.A. (1992) in Forest Research Report No. 349, Dept. Con. & Env., Victoria.

Van Loon, A.P. (1977) N.S.W. For. Comm., Res. Note 33, 22 pp.

Veitch, B. (1990) in Thomson, J.A. and Smith, R.T. (eds.) Bracken Biology and Management, Aust. Inst. Ag. Science, Sydney. Pp. 215-26.

Victorian Government (1986) Victoria Timber Industry Strategy - Government Statement. VGPO, Melb., 104pp.

Victorian Government (1987) Protecting the Environment - A Conservation Strategy for Victoria. VGPO, Melb., 106 pp.

Walker, J. (1979) CSIRO, Inst. Earth Resources, Div. Land Use Res., Tech.Memo. 79/7, 26 pp.

Wark, M.C., White, M.D., Robertson, D.J. and Marriott, P.F. (1987) Proc. Roy. Soc. Vict. 99: 51-88.

Witty, J.F. and Minchin, F.R. (1988) in Beck, D.P. and Materon, L.A. (eds.), Nitrogen Fixation by Legumes in Mediterranean Agriculture. Martinus Nijhoff Publishers, Dordrecht, pp. 331-44.

Woinarski, J.C.Z. (1990) Aust. J. Ecol. 15: 1-22.

Appendix I : Common and Scientific Names of species mentioned in this summary report

Species in brackets are mentioned in the report, but do not occur in the study areas.
Many additional species occur in the study areas, but are not mentioned in this summary report.

Plants	
[Alpine Ash]	*Eucalyptus delegatensis* R. Baker
Australian Clematis	*Clematis aristata* R.Br. ex DC.
Bidgee Widgee	*Acaena anserinifolia* (J.R. & G. Forster) Druce
Black Wattle	*Acacia mearnsii* De Wild.
Blackwood	*Acacia melanoxylon* R.Br.
Bracken	*Pteridium esculentum* (G.Forster) Cockayne
Candlebark	*Eucalyptus rubida* Deane & Maiden
Common Lagenifera	*Lagenifera stipitata* (Labill.) Druce
Common Raspwort	*Gonocarpus tetragynus* Labill.
Crane's Bill	*Geranium potentilloides* L'Herit.
Fireweed	*Senecio minimus* Poiret
Flatweed	*Hypochoeris radicata* L.
Hedge Wattle	*Acacia paradoxa* DC.
Hop Wattle	*Acacia stricta* (Andrews) Willd.
Ivy-leaf Violet	*Viola hederacea* Labill.
Long-leaf Box	*Eucalyptus goniocalyx* F.Muell ex Miq.
Messmate Stringybark	*Eucalyptus obliqua* L'Herit
[Mountain Ash]	*Eucalyptus regnans* F.Muell.
Narrow-leaf Peppermint	*Eucalyptus radiata* Sieber ex DC.
Narrow-leaf Wattle	*Acacia mucronata* Willd. ex H.H. Wendl.
Poa Tussock-grass	*Poa sieberiana* Sprengel
Prickly Moses	*Acacia verticillata* (L'Herit) Willd.
Prickly Tea-tree	*Leptospermum juniperinum* Smith
Prickly Woodruff	*Stellaria pungens* Brongn.
Silver Wattle	*Acacia dealbata* Link
[Silvertop]	*Eucalyptus sieberi* L. Johnson
Silvertop Wallaby-grass	*Chionochloa pallida* (R.Br.) S.W.L. Jacobs
Small Poranthera	*Poranthera microphylla* Brongn.
Tall Sword-sedge	*Lepidosperma elatius* Labill.
Thin-leaf Wattle	*Acacia aculeatissima* Macbr.
Trailing Goodenia	*Goodenia lanata* R. Br.
Wattle Mat-rush	*Lomandra filiformis* (Thunb.) Britten
Wire-grass	*Tetrarrhena juncea* R.Br.
Birds	
Buff-rumped Thornbill	*Acanthiza reguloides*
Flame Robin	*Petroica phoenicea*
Scarlet Robin	*Petroica multicolor*
White-winged Chough	*Corcorax melanorhamphos*
Mammals	
Brown Antechinus	*Antechinus stuartii*
Bush Rat	*Rattus fuscipes*
(for bats, see Table 6.1)	
Reptiles	
Coventry's Skink	*Leiolopisma conventryi*
Grass Skink	*Leiolopisma entrecasteauxii*
McCoy's Skink	*Nannoscincus maccoyi*
Southern Water Skink	*Spenomorphus tympanum*

Appendix II: Glossary

coarse fuels dead woody material, in contact with the soil surface, greater than 25 mm in diameter (fallen trees and branches).

FESA Fire Effects Study Area comprising a suite of five treatment areas

fine fuels fallen leaf, twig, bark and grass (alive or dead) material less than 6 mm thickness.

Firebrand piece of burning material, commonly bark from eucalypts.

fire management
the planning, conduct, monitoring and review of all aspects of fire prevention, fire suppression and use of prescribed burning in land and natural resource management.

fire presuppression
fire-control activities in advance of fire occurrence to ensure effective fire suppression. Includes over-all planning, the recruitment and training of fire-control personnel, the procurement and maintencace of fire-fighting equipment and supplies, and creating, maintaining and improviing the system of control-lines.

fire prevention
those fire-control activities concerned with the attempt to reduce the number of fires through education, law enforcement and fire-hazard reduction.

fire protection
those activities associated with fire prevention, fire presuppression and fire suppression.

fire regime the combination of fire intensity, season of burning, frequency of fire occurrence and extent of area burnt used to describe the succession of fire affecting a specified area.

fire suppression
all the work and activities connected with fire-extinguishing operations, beginning with detection and continuing until the fire is completely extinguished.

Great Divide
the notional line along the Great Dividing Range that separates water catchments with streams flowing inland from those flowing directly towards the coast.

high-intensity fire
moving fires with an average intensity greater than 3000 kW.m-1 and flame heights greater than 3 m, causing complete crown scorch or possibly crown fires in forests. Uncontrollable by direct attack.

Humus fragmented litter passing through a 5 mm sieve.

invertebrates
animals without back bones such as insects, spiders, crustaceans, worms and mites.

Leaching the natural process of washing nutrients through soil with rain water.

Legume plants whose fruit is a particular form of pod and usually have a symbiotic relationship with nitrogen fixing bacteria growing in nodules on the plant's roots.

Litter dead leaf, twig, bark material less than 6 mm thick but not so decomposed and fragmented as to pass through a 5 mm sieve.

Litterfall the addition of litter to the forest floor as it falls from the vegetation.

low-intensity fire
moving fires with an average intensity of less than 500 kW.m-1 and flame height less than 1.5 m. Usually cause little or no crown scorch and is easily controlled.

mineralisation
breakdown of organic materials in soil to its component inorganic forms ("minerals").

mosaic burning
the application of fire to an area with the intention of leaving unburnt areas within a prescribed area.

nitrification
the biological process of converting nitrogenous compounds into nitrate.

nitrogen fixation
the conversion of gaseous nitrogen into organic forms in plants.

prescribed burning
the planned application of fire under selected weather and fuel conditions so that the fire is confined to a predetermined area and burns with the intensity and rate of spread necessary to achieve the objectives of management.

Rotation the planned number of years between repeated operations or a set stage of a development cycle.

rotational burning
the repeated planned application of fire.

slash burning
the burning of scattered residue resulting from timber harvesting.

Spotting ignition of fuels by wind-blown firebrands.

volatilisation
the process of converting a solid or liquid into a gas using an external heat source such as fire.

Wildfire any unplanned fire. (= bushfire)

Photo Captions:

1a
Fire intensity near the upper limit desired for fuel reduction burning. Average flame height 0.8 m, rate of spread 3 m.min-1, fire intensity 370 kW.m-1. (Photo: Don Oswin).

1b
Wind speed and direction, air temperature and relative humidity are recorded in the forest and in the open during experimental burning. (Photo: Kevin Tolhurst).

1c
In long unburnt forests, fires quickly climbed stringbark trees and caused a great deal of short-distance spotting, but did not do so up to 5 years later in the 2R fires. (Photo: Kevin Tolhurst).

1d
Fire intensity at the lower end of that desired for effective fuel reduction. Average flame height 0.2 m, rate of spread 0.4 m.min-1, fire intensity 92 kW.m-1. (Photo: Don Oswin).

2a,b,c,d,e,f
Photo sequence of the same area before and after burning.

2a
Foothill mixed eucalypt forest last burnt 34 years previously. (Photo: Kevin Tolhurst).

2b
Immediately after burning in autumn. Scorch height 8.0 m, 98% of area burnt, 11.4 t.ha-1 fine fuel burnt, fire intensity 153 kW.m-1. (Photo: Kevin Tolhurst).

2c
One year after burning. (Photo: Don Oswin).

2d
Two years after burning, note the separation between the understorey and overstorey compared with 2a. (Photo: Don Oswin).

2e
Immediately after 2R fire in autumn, four years after first fire. Note disintegration of old log in foreground compared with 2b. Scorch height 5.5 m, 98% of area burnt, 7.5 t.ha-1 fine fuel burnt, fire intensity 199 kW.m-1. (Photo: Don Oswin).

2f
One year after 2R burning. Note the rapid recovery of litter, bracken and other understorey plants. (Photo: Don Oswin).

3a
Weather station near Blakeville FESA. Weather data are used to help explain differences in: the recovery rates of vegetation after fire; reptile, bat and invertebrate activity between treatments; and fire behaviour. (Photo: Kevin Tolhurst).

3b
Understorey vegetation structure is measured on permanent plots using the line intercept technique. (Photo: Kevin Tolhurst).

3c
Bush Rats are common in moist gullies with sedges and rushes which usually do not get completely burnt in fuel reduction burns. (Photo: Robert Humphries).

3d
Feather-tail Gliders inhabit tree hollows. Artificial hollows are being used to help understand the effects of fuel recution burning on these possums. (Photo: Ballarat University College).

4a
Gould's Wattled Bat is one of seven bat species found to inhabit the study areas. Very little is known about the possible effects of fire on bats. (Photo: Ed McNabt).

4b
Coventry's Skink is one of eight species found in the study areas. Although the skinks usually survive a fire, little is known about the longer term effects of fire on their populations. (Photo: Robert Humphries).

4c
Flame Robins and other birds have not been significantly affected by fire in this study because no pre-existing habitat was completely removed and no new habitat has been made. (Photo: Andrew Corrick).

4d
Invertebrates in the litter and soil are abundant in these forests, but very little is known about their ecology. Test-tubes inserted in the ground are used as pitfall traps for mobile litter invertebrates. (Photo: Kevin Tolhurst).

- Scientific names are given in Appendix 1.
- Priority 1 Zones adjoin high value assets such as townships and pine plantations, and
- Priority 2 Zones form strategic barriers to the spread of large wildfires.