# Changes in Flammability of Vegetation in Relation to Fire Frequency: Fuel Dynamics after Prescribed Fire and Wildfire in Forests of the ACT

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## Summary

The following synthesis of knowledge has been prepared by CSIRO. The Australian Flora Foundation funded collection of some of the data on the re-accumulation of litter and understorey biomass following prescribed fires in sub-alpine eucalypt forests in the ACT.

The pattern of change in fuel mass and fuel structure after fire is a major factor affecting development of fire risk, fire behaviour, and the impacts of fire on a range of ecological values. Burning for fuel reduction must consider the impact of such fire on a range of ecological values.

A range of fuel characteristics have been included in recent fire behaviour models, which incorporate changes in structure and composition that occur with time since last fire (McCaw et al. 2003). These fuel characteristics include quantity, condition and height distribution of fine fuel, the quantity and arrangement of understorey, and the condition of bark on standing trees. A spatial and temporal description of fuel is fundamental to assessing fire hazard and risk across a landscape. Characterisation of all sources of fuel – litter layer, ground layer, understorey, bark and coarse woody debris – includes description of quantity, structure, composition and continuity, which influence fire behaviour and thus suppression difficulty (Gould 2003).

Fine surface litter dynamics following low-intensity prescribed burns have been quantified for sub-alpine eucalypt forests. In Alpine Ash (*Eucalyptus delegatensis*), Broad-leaved Peppermint (*E. dives*) and Snow Gum (*E. pauciflora*) forests, fine (<6 mm diameter components) litter re-accumulates rapidly after prescribed burning reaching a mass of 10-12 t $ha^{-1}$ within 4-5 years (Raison et al. 1986). Under severe fire weather such fuel quantities create difficulties for fire control. Understorey vegetation can accumulate a further 3 $t.ha^{-1}$ of combustible biomass in this time period (Raison et al. 1993).

The quasi steady-state mass of accumulated litter has been estimated for a range of forest types. This ranges from about 15 $t.ha^{-1}$ in low altitude open forests to about 25 $t.ha^{-1}$ in mature, high-altitude wet sclerophyll forests (Australian National University Resource and Environment Consultant Group 1973; Cary 1997). The dynamics of another important fuel component – stringy and ribbon bark on tree trunks which form firebrands and result in spot fire development – is less well understood, but its importance for fire behaviour and hence difficulty of fire suppression is discussed by Ellis and Gould (2004).

The rapid accumulation of litter on the forest floor results in a rapid increase in fire risk in sub-alpine forests (Raison *et al*. 1993). It is clearly not practical or desirable to maintain low fuel loads (<10 $t.ha^{-1}$) throughout the entire forest over time. This would require burning at intervals of about 3 years, which would threaten other values such as nutrient cycles, tree recruitment, and development of understorey habitat. As an alternative to broad-scale burning, a strategy involving exclusion of prescribed fire from sensitive areas, and use of rotational prescribed burning applied across selected areas of the landscape is suggested. For example, if a fire rotation of 12 years (compatible with maintenance of nitrogen (N) cycles) is adopted in those forests

subjected to rotational burning, at any time 25% of the area will contain fuels less than 3 years old. A mosaic of areas with varying degrees of fuel reduction can thus be created at critical locations within the landscape to assist fire control (increase opportunity for initial containment, or suppression during moderate weather). Strategically-placed buffer zones that are more frequently burnt can also be used to complement less-frequent prescribed burning in the majority of the forest. Clearly, fuel management is only one part of good management planning for control of wildfires. Adequate capacity for detection and suppression are also critical.

It is significant that the partly combusted and fragmented litter which remains after low-intensity prescribed fire becomes incorporated into the soil within 1-2 years and hence does not contribute to re-accumulation of available fuel and subsequent fire risk (Raison et al. 1986). By burning when the surface soil and lower litter layer are moist, a thin cover of litter with a mass of 4-8 $t.ha^{-1}$ can be retained. Incomplete combustion of the litter is desirable because this lowers transfer of nutrients to the atmosphere during burning, prevents direct loss of organic matter and N from surface soils, and reduces erosion potential. Earlier work has shown that retention of ground cover equivalent to about 8 $t.ha^{-1}$ can be valuable in protecting against soil loss in erodible landscapes (Gilmour 1968; Raison *et al.* 1993).

The pattern of fuel re-accumulation after wildfire is more poorly understood, but will depend to a significant extent on the intensity of the wildfire and on the post-fire rainfall that drives the rate of vegetation recovery. If wildfires are very intense (leaf consumption in crown fire), *Eucalyptus delegatensis* trees are killed, and species such as *E. pauciflora* and *E. dalrympleana* (Mountain Gum) can be either killed or be so badly damaged that only basal re-sprouting occurs. Slightly less intense wildfire often leads to epicormic re-spouting in tree species other than Alpine Ash.

Where tree damage has been severe, litter input in subsequent years is greatly reduced but there may be compensating growth of understorey (observed increases in grasses and woody shrubs). Crown scorch can increase leaf fall soon after fire, but then reduce it for several years compared with unburnt forest. Wildfires clearly reduce the mass of coarse woody debris (large branches and logs) on the forest floor, and consume much bark (potential firebrands) so that the risk of spot fire development will be reduced for many years. There exists a good opportunity to measure the rate of fuel development after intense wildfire in representative vegetation types in the ACT. Funding should be provided to collect this critical information.

## Introduction

Information on fuel dynamics and rates of re-accumulation are critical for estimating the time course of fire risk. Of the factors influencing the rate of spread and intensity of forest fire: fuel quantity and moisture content, air temperature and relative humidity, wind speed and terrain; fuel quantity is the one factor that can be altered by fire managers.

The quantity of fuel is an important factor because it is directly proportional to fire intensity, in theory (Byram 1959). This relationship was used to develop the McArthur Fire Danger Index and has been used for predicting behaviour of low intensity fires (Luke and McArthur 1978). Additional fuel characteristics have been included in recent fire behaviour models, which incorporate changes in structure and composition that occur with time since last fire (McCaw *et al.* 2003). These fuel characteristics include quantity, condition and height distribution of fine fuel, the quantity and arrangement of understorey, and the condition of bark on standing trees (McCaw *et al.* 2003). A spatial and temporal description of fuel is fundamental in assessing fire hazard and risk across a landscape. Characterisation of all sources of fuel, litter layer, ground layer, understorey, bark and coarse woody debris, includes description of quantity, structure, composition and continuity, which influence fire behaviour and thus suppression difficulty (Gould 2003).

## Synthesis of findings

Fine fuel accumulation can be estimated from maximum observed amounts in the field, and the results from three studies are summarised in Table 1. Some variation in methods of sampling occurred between studies, particularly the size of the sampled quadrat. Small quadrats are more likely to give biased results because of greater edge effects. The forest floor is highly variable and so a more robust sample is obtained by using larger quadrats. A range of forest types in the Cotter catchment, which had not been subject to recent fire, were sampled for the Australian National University Resource and Environment Consultant Group (1973) report (<6 mm fine fuel sampled in 10 × 0.09 $m^2$ quadrats per site) and fuel loads ranged from 14 to 30 $t.ha^{-1}$. Considerable variability occurred across sites and within forest types. Highest fuel weights (22–30 $t.ha^{-1}$) occurred in high elevation wet forest types (*E. delegatensis/E. viminalis/E. fastigata*), and much lower fuel weights in the lower elevation forest types on poorer soil (*E. dives/E. mannifera/E. macrorhyncha*). Cary (1997) sampled fuel loads (<6 mm fine fuel sampled in 3 × 0.5 $m^2$ quadrats per plot) in 33 plots in the Brindabella Range in conjunction with a vegetation survey by Doherty (1998). Fuel load varied from 8.2 to 27.9 $t.ha^{-1}$, with higher fuels at higher altitudes due to the interaction of rainfall with productivity and temperature with decomposition rate. Variability in fuel load occurs within a vegetation type due to these altitudinal effects. Low altitude open forest generally has fuel loads of less than 15 $t.ha^{-1}$ and high altitude and montane and tall open forest have fuels greater than 15 $t.ha^{-1}$. Forest types with the highest fuel loads (>25 t $ha^{-1}$) are *E. viminalis/E. dives/E. robertsonii* and *E. fastigata/E. dalrympleana*. In subalpine *E. pauciflora* and *E. dives/E. dalrympleana* forest, the litter layer (<6 mm fine fuel sampled in 10 × 0.5 $m^2$ quadrats per plot) reaches a steady state mass of 17 $t.ha^{-1}$ after 10 to 16 years, and in mature *E. delegatensis* forest a mass of 26 $t.ha^{-1}$, with equivalent rates (approximately 5 $t.ha^{-1}.yr^{-1}$) of litterfall and decomposition (Raison *et al*. 1986).

Remaining vegetation a few days after a wildfire in the Brindabella Ranges, ACT
Photo: John Raison

State of understory and litter fuels 6 years after a low-intensity prescribed burn in *Eucalyptus pauciflora* forest. John Raison

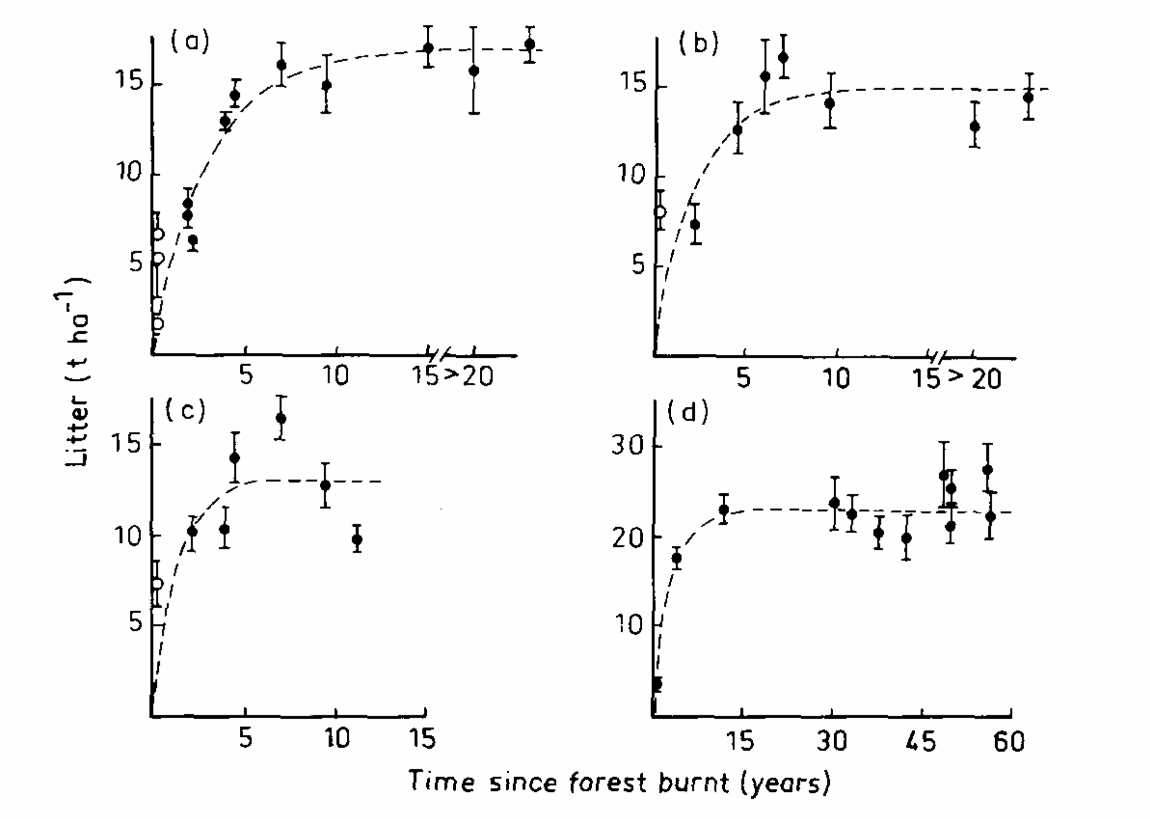
Fuel accumulation curves can be derived from measured amounts at various times since fire for different forest types. In *E. pauciflora, E. dives / E. dalrympleana* and *E. delegatensis* forest types, litter layer mass accumulated after a low-intensity fire to 8 $t.ha^{-1}$ after 2 years and 12 $t.ha^{-1}$ after 4 years. (Raison *et al.* 1986) (Figure 1). Understorey vegetation can accumulate a further 3 $t.ha^{-1}$ of combustible biomass in this time period (Raison *et al.* 1993). These values are averages as large spatial variation occurs in litter and shrub mass, and also temporal variation depending on seasonal litterfall patterns and annual variation in inputs and decomposition. Accumulation is rapid during the initial 5 years after low intensity burning because litterfall rates are maintained whereas the mass of the forest floor and the quantity of litter decomposing annually is greatly reduced by burning (Raison *et al.* 1986). Decomposition rates are also reduced due to drier surface conditions. Fine fuel accumulation up to 8 $t.ha^{-1}$ occurs in 2 to 8 years across a range of eucalypt forest types (Raison 1983).

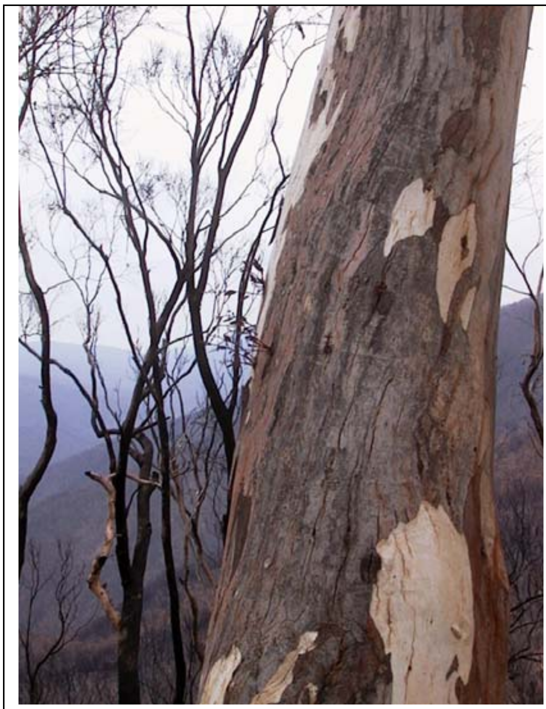
**Table 1**. Summary of maximum fuel loads measured in a range of forest types in the Brindabella Ranges.  SE = standard error of the mean.

| **Forest type** | **Species** | **Mean fuel mass ($t\ ha^{-1}$)** | **SE** |
|---|---|---|---|
| High altitude | *E. pauciflora* [1] | 25.8 | 1.1 |
| Open forest | | 23.0 | 7.1 |
| | *E. pauciflora / E. dalrympleana* [1] | 21.6 | 0.8 |
| | | 25.1 | 1.0 |
| | *E. pauciflora / E. dalrympleana* [2] | 18.8 | 3.0 |
| | | 27.0 | 4.3 |
| | | 27.9 | 5.2 |
| | *E. pauciflora* [3] | 17.2 | 1.0 |
| | *E. pauciflora / E. dalrympleana / E. dives* [2] | 17.0 | 2.6 |
| | *E. pauciflora / E. dalrympleana / E. robertsonii* [2] | 22.3 | 8.6 |
| | *E. pauciflora / E. dalrympleana* [2] | 21.6 | 2.0 |
| | *E. pauciflora / E. dalrympleana* [2] | 24.3 | 2.8 |
| | *E. pauciflora / E. dalrympleana / E. robertsonii* [2] | 22.9 | 1.7 |
| | **Mean** | **22.6** | **3.2** |
| High altitude | *E. dives / E. dalrympleana / E. robertsonii* [1] | 14.5 | 0.5 |
| Tall open forest | | 22.1 | 1.5 |
| | | 30.1 | 2.7 |
| | *E. delegatensis / E. dalrympleana* [1] | 22.8 | 1.2 |
| | *E. fastigata / E. viminalis* [1] | 24.8 | 2.2 |
| | *E. delegatensis / E. pauciflora / E. viminalis* [2] | 20.2 | 0.6 |
| | *E. delegatensis / E. dalrympleana / E. dives* [2] | 18.8 | 0.7 |
| | *E. dalrympleana / E. robertsonii* [2] | 23.2 | 4.6 |
| | *E. dalrympleana / E. robertsonii* [2] | 20.7 | 3.9 |
| | *E. delegatensis* [3] | 26.2 | 2.3 |
| | **Mean** | **22.3** | **2.0** |
| Riparian & Montane | *E. fastigata / E. dalrympleana* [2] | 27.4 | 2.8 |
| Tall open forest | *E. fastigata / E. dalrympleana* [2] | 13.9 | 2.9 |
| | *E. viminalis / E. dives / E. dalrympleana* [2] | 17.6 | 3.5 |
| | *E. viminalis / E. robertsonii / E. dives* [2] | 25.5 | 5.9 |
| | *E. fastigata / E. viminalis* [2] | 19.6 | 8.5 |
| | *E. robertsonii / C. cunninghamia / A. melanoxylon* | 9.4 | 1.7 |
| | **Mean** | **18.9** | **4.2** |
| Low altitude | *E. dives / E. dalrympleana* [2] | 22.6 | 3.7 |
| Open forest | *E. dives / E. dalrympleana / E. robertsonii* [2] | 20.9 | 2.5 |
| | *E. dives / E. mannifera* [1] | 16.5 | 1.3 |
| | *E. mannifera / E. macrorhyncha* [1] | 14.5 | 0.7 |
| | *E. dives / E. mannifera* / E. *macrorhyncha* [2] | 14.5 | 1.0 |
| | | 11.9 | 1.5 |
| | *E. dives / E. robertsonii* [2] | 12.6 | 3.0 |
| | *E. dives / E. robertsonii / E. dalrympleana / E. macrorhyncha* [2] | 12.9 | 1.2 |
| | *E. mannifera / E. dives* [2] | 19.4 | 4.6 |
| | *E. dives / E. dalrympleana* [3] | 17.0 | 1.9 |
| | *E. dives / E. dalrympleana / E. mannifera* [2] | 22.8 | 2.2 |
| | *E. mannifera / E. macrorhyncha / E. dives* [2] | 10.3 | 0.9 |
| | *E. macrorhyncha / E.u dalrympleana / E. robertsonii* [2] | 9.6 | 1.1 |
| | *E. mannifera / E. dives / E. macrorhyncha* [2] | 17.1 | 4.2 |
| | *E. dives / E. dalrympleana* [2] | 17.1 | 0.3 |
| | *E. mannifera / E. macrorhyncha / E. dives* [2] | 13.5 | 4.8 |
| | *E. dives / E. dalrympleana / E. robertsonii / E. rubida* [2] | 18.9 | 0.1 |
| | **Mean** | **15.2** | **2.1** |

[1] ANU Resource and Environment Consultant Group (1973); [2] Cary (1997); [3] Raison *et al* (1986).

**Figure 1**. Pattern of accumulation of litter after fire in subalpine forest communities, (a) *E. pauciflora*, (b) *E. dives*, (c) *E. delegatensis* (pole stand), (d) *E. delegatensis* (mature stand).



Epicormic shoots emerging from a leafless *Eucalyptus* about 4 months after a severe fire. Photo: John Raison

Fine litter accumulation after a high-intensity fire is different because the complete litter layer and sometimes the organic surface soil is combusted. Litterfall immediately after the fire varies depending on intensity; whether the canopy is scorched and then leaves fall, or the canopy is completely combusted. Leaf turnover and litterfall are greatly reduced for several years after the fire as canopies re-establish. Considerable variation in this timing depends on the degree of tree damage and type of regeneration, from epicormic shoots on branches or stems, to basal coppicing, as well as rainfall and environmental conditions for regeneration.

Understorey biomass contributes to the fuel load, where the oven-dry mass equivalent is combustible fuel. A higher fire intensity is required to ignite green fuel than dry fine litter, however even low-intensity prescribed fires readily combust green fuels. Fuel structure that includes the height of shrubs affects flame characteristics. Population dynamics of shrubs, such as *Daviesia mimosoides,* respond to fire frequency. The shrubs regenerate rapidly from rootstocks after fire, of varying intensities, and form a dense understorey layer within a couple of years after fire. Dry biomass of the understorey is approximately 7 t $ha^{-1}$ where fire frequencies of 4 to 10 years have maintained vigorous shrub growth; this mass does not increase beyond 12 years. The shrubs start to senesce after more than 20 years without fire (Hoare and Jacobsen *pers. comm*.). During this senescent phase, the dead biomass also contributes to fuel loads. The shrubs are not known to completely die out with the exclusion of fire, however their density and vigour is reduced. Shrub cover, biomass and composition is variable across vegetation types and ranges from 5 to 70% cover and 0.5 to 4 m high estimated in a survey of fuels across the Brindabella Range (Cary 1997).

Coarse woody debris (>6 mm diameter) is only available for combustion in high intensity fires. Once ignited, however, these fuels produce higher intensity fires and combustion of underlying soil. Loose ribbon bark held high in the tree at branch forks (eg *E. viminalis, E. delegatensis, E. fastigata*) is a source of fuel for bark spotting. However, this fuel cannot be reduced by prescribed burning due to its height up the tree. Stringybarks (eg *E. macrorhyncha*) are sources of fire brands along the whole length of the stem. Potential management to minimize spotting is discussed by Ellis and Gould (2004) in an accompanying report. Post-fire bark loss occurs due to stem damage in high-intensity wildfires, and to a lesser extent after relatively high-intensity prescribed fires. This extra bark contributes to fuel loads around the base of trees, which then increase the risk of damage to trees in the next fire. Additional bark loss can also occur during prolonged dry periods.

In high altitude and montane tall open forest, moisture content of the litter layer is usually high (>20%) and this reduces the likelihood of ignition and spread of fire, except under drought conditions when fuels dry out and will combust under extreme fire weather conditions. Fuel loads maintained at a low level by regular burning will also be drier, and this reduces decomposition rate. Prescribed burning can be difficult in heavy fuel loads in these wet forests. Days when suitable conditions for burning occur are limited, for example an average of 15 to 17 days in subalpine areas (Department of Urban Services 2001) and may be less than 15 days per year in montane forests. Two-stage burning may be necessary to reduce fuels in drier north and wetter south aspects.

The landscape can consist of a mosaic of fuel loads representing different fire management zones, such as asset protection, strategic fire management, protection of sensitive areas and species, and sustainable management of natural resources. Strategically located areas that have low fuel loads in any one year may aid suppression of wildfires under moderate weather conditions. This may be useful before extreme weather conditions occur, or during periods of improved weather conditions, such as at night. Considerations include first, the area of low fuel loads required to be effective for aiding suppression under a range of FDI. Second, the location of low fuel loads within the landscape to minimize ecological effects on these burnt areas, to protect sensitive or valuable areas, and to be effective for suppression in terms of position in the landscape, weather patterns and potential movement of fires. A regime of low-intensity prescribed burning that reduces fuel loads will not prevent wildfires, but can aid suppression if located at the right place and time. The trade-off involves the ecological effects of repeated prescribed burning, resources required to maintain this fire regime, and the risk of fire escapes, compared with the likelihood of the low fuel loads modifying wildfire behaviour, and occurring at the right place to aid suppression and weather conditions being conducive at the right time.

A critical question is the relationship between the annual probability of fire of sufficient intensity to threaten property and the percentage of landscape treated by prescribed burning. This relationship must be defined for specific ecosystems and landscapes in order to assess the importance of prescribed burning on the probability of unplanned high intensity fire. Other factors that will influence the occurrence of severe unplanned fire that should be included in this analysis include rates of arson ignition, fire suppression technology and resources, vegetation fragmentation, terrain complexity, and climate change. The relative effectiveness of prescribed burning for asset protection compared with ecological impacts is ecosystem specific, and depends on plant and animal species present and their life stages, spatial patterns of fire intensities and unburnt ground, post-fire weather, past fire regimes, fragmentation of the vegetation.

Tolhurst (*pers. comm.* 2004) investigated the effects of fuel reduction burning and recent wildfires on the fire intensity and control of the 2003 Alpine Fire in Victoria. Within the area studied, 19% had been burnt in the previous 10 years by either fuel reduction burns or wildfires. In the Gelantipy Fire, which burned for 60 days, 50% of the total area burnt was burnt in a period of only 26 hours. Although fuel reduced and previously burnt areas assisted in control line construction, control line effectiveness, breaking up the heads of some fires and in final fire control, they were not effective in stopping the major run of a fire. Importantly, the strategic location of fuel reduced areas was most important. That is, broad area burning and burning away from access points was of limited use. Overall, Tolhurst found a strong relationship between fire severity and weather but only a weak relationship between severity and time since fire.

Guidelines for prescribed burning developed in Victoria (Friend *et al.* 1999) describe a framework for information gathering, planning and implementation that includes development of vital attributes tables, fire history data and analysis, and development of ecologically based fire regimes. This forms a valuable basis for planning in other regions. Key fire response species and tolerable fire frequencies for key vegetation types are defined, and combined with derived fire cycles to produce models of age distribution within each plant community. Planned fire regimes should also incorporate the whole suite of ecological effects that have been described in this review, such as population structure and dynamics, tree damage, nutrient cycles, soil erosion, hydrological processes. The concept of the fire cycle is used, that is the period of time over which an area equivalent to the total area of the community will be burnt; it is not the period of time each segment of the community will be burnt. In a relatively random fire regime, the post-fire age of segments of a community will fall into a negative exponential frequency distribution. The fire cycle is defined as the time period half the maximum tolerable inter-fire period, and areas younger than the minimum tolerable inter-fire period are excluded from burning.

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