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Submission from CSIRO

to

House Select Committee

on the

Recent Australian Bushfires

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Executive summary

This submission is a summary of the state of knowledge of Bushfires in Australia based on more than 40 years of research and observation by CSIRO. It provides a context and background for the Select Committee's evaluation of the recent fires.

Fire is a natural phenomenon in the Australian landscape. Even the high intensity, widespread fires of the past summer in south eastern Australia can be expected every few decades. Fire is important for shaping and maintaining biodiversity and yet is one of the most significant threats to human population and infrastructure. Fire fighters are put at risk in protecting material assets and land managers and fire management agencies rightly attempt to reduce this risk through a range of measures both preceding, and at the time of the fire. While actions taken at the time of the fire can be more readily evaluated for efficiency and effectiveness, the impacts of actions and activities undertaken in the months and years leading up to the fire are more difficult to evaluate.

A complete fire history of Australia is not available and hence it is difficult to assess how human intervention impacts on 'natural' fire regimes (season, frequency and intensity). It is clear that the landscapes of northern and southern Australia respond in differing ways to the fire regimes which act upon them. Some of these are well understood but, in general, the observed combinations of flora and fauna defy simple cause and effect explanation in terms of fire alone, even though they are clearly influenced by the fire regime.

Bushfire is a chaotic system that is difficult to model. The key variables are fuel, weather and topography, and together they produce predictable rates of fire spread and flame heights for a given forest, heath or woodland type. Research has produced good predictors of grassland fire conditions, but forest fuels are more variable and our ability to accurately predict fire behaviour is more limited.

There are large differences in the type of fires and the drivers of fire between northern and southern Australia. In the tropical north, the combination of fuel conditions (mostly grass), fire weather, flat terrain, generally sparse trees and lower leaf flammability, means that the canopy conflagrations of temperate southern Australia do not occur. . As a result, throughout most of the region protection of life and property is not a driving factor in fire management. The extensive bushfires of northern Australia are mostly lit by people for the purposes of habitat management. In southern Australia the combination of heavier forest fuel loads, greater urbanisation and infrastructure drive fire management towards protection of life and property. This must be balanced against the need to protect and encourage natural biodiversity – yet these objectives can be at odds. On one hand, prescribed burning for fuel reduction is a key strategy to reduce the frequency and intensity of damaging wildfires which in turn reduces the risks to life and property. But on the other hand frequent low intensity burning for fuel reduction purposes has effects on ecosystems and the species in them that are not always positive.

High intensity wildfires kill many animals, and so they are considered by the public to be a threat to our fauna. However, studies indicate that such fires may not be a threat to the fauna, and in the long term may be critical to their survival as populations.

High intensity wildfires close to human settlement and infrastructure also represent extreme and unacceptable risk to the community and, by their nature, occur during times when control and suppression are at their most difficult. Land managers and fire agencies attempt to reduce the risks to fire fighters and the community by taking action to reduce the intensity and frequency of large, damaging fires.

Fires are a result of combining of fuel, air (oxygen) and an ignition source. Fuel is the only one of these elements that can be managed in advance of a bushfire. Hence fuel reduction burning (prescribed, low intensity fires deliberately lit to reduce fuel loadings during seasonal weather conditions when control and suppression are easier) is an essential management tool for protection of life and property. Suppression is greatly enhanced by a fuel reduction program, but the extent of enhancement decreases over time related to the particular forest or woodland type and the prevailing climatic conditions. Burning guides are a key to achieving prescribed burning objectives and yet relatively few exist for particular vegetation types.

Fuel reduction must also be balanced by the biological requirements of flora and fauna and carried out within resource and climatic constraints. Even with a complete alignment of fuel reduction and biodiversity objectives, it would be exceedingly difficult to carry out the area of burning required each year because of unfavourable weather conditions or lack of available trained staff.

When bushfires strike population centres, there is widespread community belief, reinforced by the news media, that bushfires move at the speed of express trains, that houses explode into flames and burn down in minutes, and that there is not much that can be done to prevent it. Scientific research into the behaviour of houses under bushfire attack has shown otherwise.

Our scientific results suggest that the majority of houses destroyed in bushfires actually survive the passage of the fire front, only to burn down during the next few hours due to fire spreading from ignitions caused by wind-borne burning debris. Whilst direct flame contact and radiant heat also play a part in the ignition and destruction of buildings, these mechanisms are significant only during the few minutes it takes for the fire front to pass. Showers of burning debris, on the other hand, may attack a building for some time before the fire front arrives, during the passage of the fire front and for several hours after the fire front has passed. This long duration of attack probably explains why burning debris is a major cause of ignition of buildings, though this has not been adequately quantified at this stage.

Building design and community education programs are key elements in plans to increase community resilience in the face of bushfire threats.

To summarise the response according to the Terms of the Reference:

The bulk of this submission provides general background based on CSIRO research and experience. Specific comments on the Terms of Reference are given here.

(a) the extent and impact of the bushfires on the environment, private and public assets and local communities;

CSIRO has not comprehensively evaluated the recent fires and cannot comment on the extent of damage in either a qualitative or quantitative sense. However significant losses of plant and animal biodiversity, soil and other material assets has occurred. Substantial amounts of greenhouse gases were produced and community resilience and cohesion severely tested. Data on extent and impact have been collected by various Universities, and State and Territory management agencies, so that detailed, quantitative analyses of extent and impact can be undertaken in the near future. CSIRO is well-placed to partner State/Territory agencies in such analyses.

(b) the causes of and risk factors contributing to the impact and severity of the bushfires, including land management practices and policies in national parks, state forests, other Crown land and private property;

The severity of the recent fires was related to a combination of factors including the generally high fuel loads, the prolonged drought, and the weather conditions experienced during and after the fire ignition events (mostly lightning strikes and ember spotting). CSIRO has no data to definitively attribute cause, or link effect, to the various individual factors. CSIRO will be constructing a fire chronology from the available evidence for the ACT Coroner.

Based on research reported in the body of this document, and what CSIRO scientists know of the recent fires, several observations can be made:

The combination of fuel loads, drought, daily weather and fire ignition conditions on the worst days were a 1-20 to 1-30 year event. Canberra was experiencing a 1-10 year drought, could expect lightning storms of this nature about 1-20 years and experiences about 3 days per year of similar extreme weather conditions. The need to understand what happened and to plan for future events is thus an urgent priority.

Changes in land management policy (particularly to establish wilderness areas), for at least some parts of the land area burnt, have resulted in reduced accessibility, reduced response time and a reduction in trained staff for the management and suppression of bushfires. This, combined with the conditions outlined above, resulted in the windows of opportunity to control blazes early on being small and more easily missed. Fires built in size and intensity very rapidly and direct suppression actions became very difficult. Fire management emphasis has been shifted towards suppression by indirect means (allowing the fire to burn to a control line) because of inaccessibility issues. Safety issues (more acute with inexperienced personnel and volunteers) and a reliance on helicopters have resulted in greater emphasis on daytime suppression when fire fighting conditions are relatively less severe at night.

Responsibility for fire fighting is moving away from land managers and towards fire managers. This is placing greater emphasis on suppression (after a fire breaks out) and lesser importance on the pre-fire planning actions. This also results in greater reliance on volunteer, tanker based fire crews (a particular type of suppression resource suited to a particular fire fighting role). It is also more difficult to balance the objectives of easier fire suppression through fuel reduction burning and prescribed burning for biodiversity objectives.

The available, limited evidence suggests helicopters are only effective when used in conjunction with direct attack ground crews or on rapid initial suppression of spot fires.

Grazing by livestock, either present (Victoria and areas close to Canberra) or absent (much of the Kosciusko area), made little difference to the fire spread or intensity through alpine (high altitude treeless) regions.

Urban impacts

CSIRO carried out surveys of the Canberra suburbs affected by the recent fires to look at the effect of house construction and garden components and layout on house survivability. These data have not been fully analysed but it is clear that certain combinations increased the likelihood of house loss.

CSIRO surveyed the worsted effected areas of Duffy following the Canberra bushfires concentrating on urban design and vegetation. CSIRO's limited analysis of this data has indicated that no houses in Duffy were directly impacted by flames from the fire front. The separation distances between the main forest fuel and the houses were also sufficient to prevent radiation from the flame front directly impacting on the structures. The primary attack mechanism was from embers. The risk from ember attack is influenced by a number of factors:

The number of embers,
The quality of embers,
The amount of combustible wind born debris present during the ember attack,
The duration of the ember attack
The building design
Type and condition of vegetation surrounding the building
Ground fuel around the structure
Suppression activity during and after the ember attack.

The houses in Duffy were particularly vulnerable to this ember attack as they had no specific design requirements to mitigate the entry of embers into the structure. The extensive water restrictions and low rainfall left the vegetation immediately around the structures in a very dry and fire-susceptible state. This also led to the ground cover having very low moisture content and greater density due to the lack of natural composting. Many of the vegetation types found in Duffy were highly combustible. There were very few residents and suppression crews present during and after the fire front passed, these being the times when ember attack is most prevalent.

Duffy suffered most from indirect fire impact. The initial vegetation and structural fires in Duffy created an even more concentrated and enduring ember attack for those homes further down wind. Some of the structural fires provided direct flame attack and radiation impact on adjacent structures. These impacts persisted for hours rather than the minutes it takes for a flame front to pass. This effect was exacerbated by the placement of relatively larges houses on medium sized blocks and the presence of timber fences and vegetation between these close structures.

These impacts endured throughout the afternoon and well into the night. Many examples of community and agency suppression activities during this time were found, and examples of many houses being saved. It was apparent that if no suppression activity occurred during this time the house loss would have approached 100%. Many of the community members that performed suppression activities during the hours after the main bushfire attack had:

Not received advice to evacuate,
Ignored advice to evacuate or resisted forced evacuation, or
Circumvented road blocks preventing access to the effected areas and returned to defend their properties.

(e) the adequacy and economic and environmental impact of hazard reduction and other strategies for bushfire prevention, suppression and control;

The core of the debate over hazard reduction burning centres on a trade-off that is relatively straightforward to describe but highly complex in its resolution. That is that hazard reduction burning is an essential tool in the array of methods for mitigating risk to life and property from high intensity bushfires. And yet frequent low intensity hazard reduction fires can fundamentally alter the structure and composition of a range of vegetation types.

Science can describe and predict many of the impacts of this trade-off but ultimately the objectives will be set by social and political constraints and the policies of management agencies. It is possible to meet fire management objectives that are clearly framed against either protection of life and property, management of biodiversity objectives or the continuum of trade-offs in between but science cannot direct decision making in isolation.

CSIRO research shows that hazard reduction burning will reduce the intensity, rate of spread, flame heights and depths of subsequent bushfires and makes fire suppression easier under a range of weather conditions. However, the persistence of these effects depends on the type of vegetation and rate of regrowth of the vegetation.

Our research also indicates that frequent, low intensity hazard reduction burning has an impact on vegetation structure and habitat as well as affecting populations of plant and animal species and soil nutrients in at least some vegetation types. The relationship between prescribed burning for biodiversity and fuel reduction is complex both in terms of direct impacts and also the indirect interactions with long term fuel management.

The Canberra fires have highlighted that current fuel reduction practices and implementation are effective up to a certain point beyond which fire spread cannot be prevented. It is one of the best protected of the Australian cities in fire prone areas and yet still succumbed to fire once the perimeter was breached. Certain parts of Canberra received substantial ember attack where hundreds of meters of well grazed paddocks existed between them and the forest fuels. An effective balance between community preparedness and suppression activities needs to be found.

(d) appropriate land management policies and practices to mitigate the damage caused by bushfires to the environment, property, community facilities and infrastructure and the potential environmental impact of such policies and practices;

It is possible to develop management prescriptions to address bushfire frequency and severity but these are variable for different vegetation types and have varying levels of compromise between environmental, social and economic outcomes. Very few forest areas have adequate burning guides to assist land management staff with prescribed burning for fuel reduction and/or biodiversity management.

The reduction in full time field based work crews with training and experience in fire management in most land management agencies is reducing the options available to fire controllers for tackling large bushfires.

Policies and practices are generally not well understood by the community and, in addition to refinement following these sort of fire events, need to be articulated and integrated into community preparedness activities

(e) any alternative or developmental bushfire mitigation and prevention approaches, and the appropriate direction of research into bushfire mitigation;

The Canberra bushfire event highlights the need for more extensive community understanding of bushfire risk and impact and the need for these communities to voluntarily adopt strategies to mitigate these risks. As in all post bushfire surveys CSIRO has performed, community understanding has ranged from complete ignorance to extremely well informed and prepared. We have also found examples where residents clearly over-estimated the level of risk and implemented strategies at considerable cost to themselves.

A Cooperative Research Centre has been initiated to combine bushfire research from across a range of agencies to address issues defined by fire and land management agencies. Considerable emphasis has been placed on research into community preparedness and resilience, volunteer needs, infrastructure protection as well as fire behaviour and the impacts of fire on the landscape. The CRC program represents a significant refocussing of research efforts on bushfires in Australia and will result in a range of beneficial outcomes for the land managers, fire fighters, the community and the environment.

(f) the appropriateness of existing planning and building codes, particularly with respect to urban design and land use planning, in protecting life and property from bushfires;

AS3959 is not applied retrospectively and there were no houses in the Duffy area that had prescribed mitigation measures. The general town planning design of providing perimeter roads as a buffer zone between houses and forest fuels is considered to be a very effective measure to prevent direct flame and radiation impact.

AS3959 specifies that houses within one hundred meters of forest fuels require specific measures to mitigate ember attack. Had this been implemented, it would have significantly reduced the levels of house loss in Duffy but would not have prevented loss all together. It will also not prevent loss once houses are alight inside the one hundred meter perimeter.

Traditionally it has been accepted that suppression activities by agencies and residents are sufficient to mitigate the spread of structural fires deep into urban areas. However the house loss in Duffy stands as an isolated example of how this assumption is not always true.
Measures need to be taken to identify the specific risks and the way they have compounded to result in this level of loss.

(g) the adequacy of current response arrangements for firefighting;

As the available pool of full time, paid fire fighters in land management agencies reduces, fire control and management is trending towards indirect suppression and greater emphasis on tanker crews and helicopters. This often delays the initial response time following and ignition event. It is also reducing the amount of pre-fire, hazard reduction burning that can be done.

There is a greater reliance on volunteers as a primary response group rather than as support crews. This means the primary response is limited by the availability and the time which volunteers can commit to fire fighting. This is compounded when they are moved long distances and used for long periods of time such as in the last two fire seasons.

Helicopters are increasingly being seen as a major part of bushfire fighting resources. Our limited research suggests they are most effective when used to support well directed and resourced ground crews and where they can be rapidly deployed at the early stages of a fire or spot fire.

There is a need to evaluate the effectiveness of various suppression techniques and equipment and some work in this area is planned through the Bushfire CRC.

Home-owner response and training also a critical factor requiring more work in fire prone areas. Again the bushfire CRC will abe carrying out research on community resilience and preparedness.

(h) the adequacy of deployment of firefighting resources, including an examination of the efficiency and effectiveness of resource sharing between agencies and jurisdictions;

There is little or no benchmarking of agencies in their fire suppression activities and this makes it difficult of for assessment of the adequacy of response to individual events. Agencies tend to be isolated in their individual analyses and the required performance standards, against which actions could be assessed, are generally unknown.

With regard to urban areas in bushfire, as identified in previous sections, due consideration needs to be given to the deployment of fire fighting resources during the event given that most of the house loss occurs in the many hours after the fire front has passed. Should fire fighters be deployed to suppress the fire front itself or provide follow up suppression once the fire front has impacted on the urban interface?

(i) liability, insurance coverage and related matters; and

The threat of litigation against fire and land managers has reduced the level of open and self-critical de-briefing following bushfires. From CSIRO's point of view, this has an impact on our ability to gather and evaluate data and information from the fires.

(j) the roles and contributions of volunteers, including current management practices and future trends, taking into account changing social and economic factors.

There is no question that volunteers are essential to fire operations in Australia. The issues surrounding their participation relate to adequate training and preparation, their response time and availability, particularly in the time immediately after fire ignition. Volunteer training and preparation should be integrated with community preparedness and training.

Introduction

This submission synthesises the work of CSIRO and collaborating scientists on bushfire in the Australian landscape including: ecological effects and impact; behaviour, management and suppression; and the interaction with the urban environment. This spans 60 years of fire research in Australia.

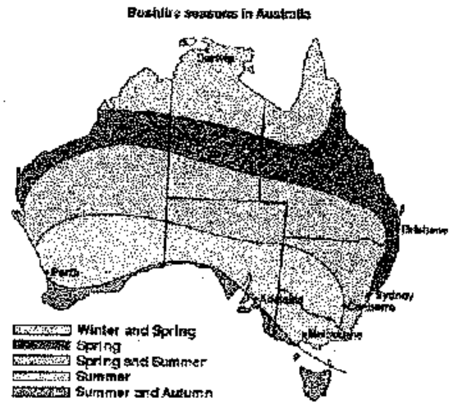
Figures 1 and 2 show the bushfire seasons across Australia and the potential for disaster respectively. While hundreds of thousands of hectares burn in northern Australia each year, the recent disastrous fires in southern Australia occur, on average, every few decades.

Land and fire managers are aware of the potential for serious fires and implement measures to reduce the risks to their staff, the community, and to assets (natural and economic) that they protect. However some key fire management objectives are in conflict – for example the need to reduce fuel loads to assist with the protection of people and property from wildfire and the need to burn less frequently and under more extreme conditions to meet biodiversity requirements.

This submission covers what is known, or can logically be inferred and highlights the complexities facing land and fire managers in developing objectives and implementing management plans to realise these objectives. It explores the limitations of our knowledge and discusses research progress and directions. It contains relevant data and graphics to aid understanding and is extensively referenced.

Research to build this knowledge has tended to follow a boom and bust cycle aligned with major extreme bushfire events. Table 1 shows major CSIRO efforts linked often to the aftermath of significant damaging fires. The Bushfire Cooperative Research Centre due to commence in July this year and described in a following section below along with work in the existing Tropical Savannah CRC will provide much need continuity in a number of research areas.

Bushfires in Australia



- Australia suffers frequent wildfire disasters that have a profound impact on communities.
- The climate and vegetation combine to ensure that during almost every summer there is a threat of a bushfire disaster somewhere in the country.

Figure 1. Map of fire seasons in Australia

Bushfire disasters

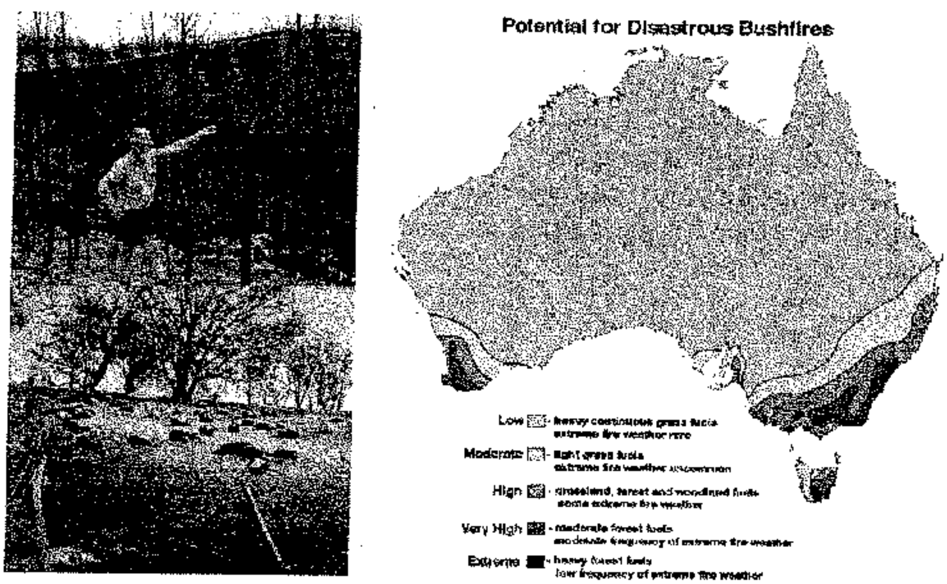


Figure 2. disastrous fire potential

Table 1. Overview of past bushfire research in CSIRO

1940s	House destruction in the Beaumaris fire in Melbourne studied by the forerunner of Manufacturing and Infrastructure Technology.
1950s	Division of Chemical Technology investigated fire retardant chemicals- physics and chemistry of combustion, fire safety.

1960s	CSIRO worked closely with Commonwealth Forestry and Timber Bureau and Forest Research Institute- prescribed burning and aerial ignition.
1970s	Fire Ecology was studied by Plant Industry, Wildlife and Ecology, Forestry, and others.
1980s	Ash Wednesday fires led to the formation of National Bushfire Research Unit (mainly within Division of Forestry and Atmospheric Research).
	Expected to be self-funding in 5 years.
	Unsuccessful → returned to Divisions
	Commonwealth funded $2.5M over 3 years to evaluate large air tankers (Project Aquarius) – Division of Forestry (collaboration with other Divisions).
	Manufacturing and Infrastructure Technology (CMIT) performed largest building impact survey undertaken.
1990s	Kapalga fire experiment established in Kakadu National Park by Sustainable Ecosystems.
	NSW Jan '94 fires stimulated support of Project Vesta and spot fire project in Forestry and Forest Products.
	CMIT continued to survey every bushfire involving significant house loss forming our current understanding of bushfire attack on infrastructure.

Fire in the Australian landscape

Fire as a natural phenomenon

Fire is a natural phenomenon in the Australian landscape. It is impossible to say at this stage of our knowledge whether the major elements of the Australian fauna are adapted to the eucalypt forests or whether both are adapted (co-adapted) to an environment in which intense wildfires are the norm. Fire is a an environmental factor that both affects and is affected by vegetation, but it can by no means be seen in a simple light as the major determining factor of vegetation in any given area. This is because there is a complex interaction between aspect, slope, climate, geology, fire behaviour and vegetation which does not permit simple cause and effect explanations. There seems little doubt that Australia's sclerophyll vegetation has been associated with fire for 10,000 to 15,000 years (Singh et al. 1981) and that fire has been an environmental factor for 100,000 years (Kemp 1981). As the temperate rainforests contracted in the late Tertiary they were replaced by *Eucalyptus* and *Acacia* (Crocker and Wood, 1947), genera which are widespread today. Associated with this change in vegetation was the radiation of Australia's unique marsupials (Stirton *et al.* 1968). Accordingly, the fauna may have evolved in a complex, interrelated system of increasingly dry climate, fire, and a vegetation that enhances and is enhanced by fire. In regard to fire little is known of the ecology of the higher vertebrates, without even considering the reptiles and frogs or the invertebrates. However, Catling and Newsome (1981) concluded that further understanding will support the hypothesis of fire-adaptiveness for the majority of the Australian vertebrate fauna, and such data challenge the traditional Clementsian view of succession (Clements 1920), thereby supporting conclusions for the Australian vegetation also (Noble and Slatyer's 1981; Gill 1981).

A complete fire history of Australia is not available and hence it is difficult to assess how human intervention (pre and post European), has impacted on fire regimes (seasonality, frequency and intensity). Unravelling the nature of the disturbance environment before the advent of closer settlement and exploitation 200 or so years ago is a significant challenge. While the large tracts of forest remaining today provide us with information on the plant species present, and much of the fauna, our knowledge of disturbance processes centuries ago is far from clear (Gill and Catling 2001). Aboriginal people, firesticks in hand, had a presence in some forests, at least (Jones 1969, Hallam 1975). Fires occurring as a result of their presence seem inevitable either as accidents or as deliberate management acts. Some forests had open understoreys (Ashton 1981a, b), a condition that could be created by frequent fires (Catling 1991) but also by long periods without fire (Catling and Burt 1995). In other places, forest understoreys were dense (Ashton 1981a,b), a condition that can be explained by the appropriate combination of fire events and their characteristics.

Despite the initial devastation the studies have shown there are more mammals and birds in forests in the first five to ten years after a high intensity wildfire than in mature forests unburnt for 40 years. However, there are large changes in the abundance of the fauna and its composition, which are linked to changes in vegetation structure. When the understorey becomes suitable, it is quickly colonised by animals which survived the fire in the unburnt refuges. Populations of wildlife resurge and flourish in the understorey which provides food, home sites and protection from predators such as the fox and cat. Studies to date indicate rapid recovery of the fauna in eucalypt forests even after summer fires of high intensities, most species taking only 5 or 6 years to do so. Indeed, in that short time, most species had attained levels well above their abundances before the fire with little or no change in faunal diversity in that time. It seems that all species inhabiting eucalypt forests have the capacity to survive fires and to recover quickly.

Forest statures and structures vary widely with forests from 10 m tall to over 80m tall. Understorey structures reported by early European observers have been an important part of the debate over what fire regimes existed when Aboriginal people were the only human inhabitants of Australia (Benson and Redpath 1997). Mature trees with sparse understoreys were reported to be common but dense thickets have been reported as well. Rather than debate the proportions of forest with particular structural attributes, it is sufficient to say that both existed.

Fires are a natural part of the forested landscapes of Australia. The extent of exposure to fire in forests may be expressed in terms of the intensities of fires encountered and the intervals between fires. There is a great deal of conjecture about what burning practices were carried out by Aboriginal people in Australian landscapes (*e.g.* McBryde and Nicholson 1978, Williams and Gill 1995, Benson and Redpath 1997). Just as prescribed fires today do not prevent intense fires occurring from time to time, it seems likely that intense fires, ignited by lightning or people, were a part of the forest environment hundreds of years ago. Indeed, it appears that intense fires were necessary for the perpetuation of some forests like Mountain Ash forests (Ashton 1981b). Fires encompassing a range of intensities were inevitable from time to time and place to place.

Fire and biodiversity

The role of fire in determining the abundance of plants and animals is best considered as a fire regime rather than as one fire event. A fire regime has been considered to have three main components: season, frequency and intensity (Gill 1975). There are many combinations of intensity, frequency and season (the fire regime) (see box below), and species may be adapted to a particular fire regime but not to fire per se (Gill 1975).

Fire intensity and frequency

Fire intensity

The biological and physical impacts of a fire event are directly proportional to its intensity and spread, both of which are controlled by the concentration and distribution of fuel from flammable vegetation, topography and weather prevailing at the time of the fires. The greater the amount and vertical profile of the fuel, and the greater the fire danger conditions and the greater the damage will result. Fire occurring in high fuel loads will burn a higher proportion of the area within the fire perimeter, will burn at higher intensity (high flame heights, rates of spread and heat output) and will have a greater adverse soil impact that fires burning at low intensity (which comparatively will burn less area, be more patchy and produce less heat). The higher the fire intensity, the greater will be the impact to the environmental and community values of the area burnt.

Fire frequency

Fires in the landscape are not one-off events- each fire is part of a '*fire regime*' for an area, with the frequency of fire occurrence being an important factor in the fire regime. The frequency and intensity aspects of fire regimes are linked. In general, more frequent fire regimes have lower intensities, and less frequent fires have higher intensities. This can be linked to season in the case of prescribed fires for fuel reduction where the fires are deliberately set during mild weather conditions such as in autumn or early spring in southern Australia.

Flora

Plant mortality varies with fire intensity. Some species have individuals that are readily killed by fires whereas others are remarkably resilient to even high fire intensities. If a comparison between species or even individuals is to be made, however, it should be made with a biologically equivalent degree of exposure to fire. A mistletoe high in a tree may have quite a different response to one of the same species situated close to flames in the same fire. Using a threshold condition - such as complete scorch (when all the foliage of the plant is just killed) - is useful for making inter-specific comparisons (Gill 1981b). Two classes of plants emerge from such comparisons – the 'seeders', which are killed by such exposures and regenerate from seed after fire, and the 'sprouters' which resprout after this degree of damage. Noble and Slatyer (1980, 1981) described a system for modelling the effects of fires which is dependent on "vital attributes" like these but open ended with respect to intensity and therefore more generally applicable. Mechanisms affecting the mortality and recovery of plants exposed to fires have been reviewed by Gill (1995).

Many of the trees of tall open-forests are seeders. *E. regnans*, aforementioned, is a classic. *E. grandis*, *E. delegatensis* and *E. pilularis* in eastern Australia, and *E. diversicolor* in WA, are other examples (Ashton 1981b). This is not to say that populations of these species will always be killed by fire although even-aged regeneration after fire is common. Rather, fires may burn in mature forests of these types without killing the dominants and multi-aged stands may occur also (Ashton 1981b, Bowman and Kirkpatrick 1984, McCarthy and Lindenmayer 1998). Open-forest dominants when mature are resprouters. In closed forests there are resprouters like *Nothofagus cunninghamii* (Ashton 1981b) and seeders like *Phyllocladus aspleniifolius* (Read and Hill 1981). Peat fires could kill all plants present whether seeders or sprouters (Cremer 1962, Wark 1997). Seeders in the form of short shrubs or herbs will be killed by any fire, whether a surface- or a peat-fire.

Of greater significance to the species dynamics of the forest may be the number of seeders with canopy-stored seed (*cf.* seed in the soil); these species seem more prone to extinction than others (Gill and Bradstock 1995) especially if their juvenile periods are long. Such species are relatively uncommon in open-forests (probably for this reason) although the dominants seeders of tall open-forests are often in this category. Seeders of the shrubby-understorey genera like *Casuarina*, *Hakea* and *Banksia* – all with woody fruits - fall into this category also. Some native conifer species may be members of this group. Epiphytic cryptogams like mosses and liverworts are likely to be sensitive to any fire that reaches them. With fires of intensities at least sufficient to kill the tissues leading to the serotinous capsules of eucalypts, accelerated seed dispersal will result. Where canopies are scorched seed fall may be rapid and heavy (*e.g.* O'Dowd and Gill 1984). Seed-harvesting ants foraging on the ground after the fire may be satiated by the prolific supply of seed to the extent that many seeds survive to generate a new crop (*e.g.* O'Dowd and Gill 1984). Seed survival like this is essential for the persistence of the tree species if the trees have been killed by the fire.

Shrubby thickets may be created by fires under certain conditions. Precursors to these are 'banks' of protected buds (in lignotubers, roots and rhizomes of particular species) and seeds (in the soil or in woody capsules on living plants). The 'bank' will be obvious on 'serotinous seeders' (*i.e.* seeders with canopy-stored seed) but can be completely hidden as dormant seed in the soil in other species. The forest understorey may be mostly free of shrubs before a fire but be followed by a thicket. A high intensity fire is the most likely trigger for thicket formation (Catling 1991) because: canopy damage (due to high intensity fire) may lead to compensatory growth in the understorey (Specht 1983); fire-stimulated germination of seed is a function of fire intensity, fuel loading, moisture content of the litter (Christensen and Kimber 1975) and probably soil moisture; seed dispersal from serotinous seeders may be augmented by crown-scorching fires (*e.g.* O'Dowd and Gill 1984) but some seed death may occur particularly where crown defoliation occurs (Ashton 1986, Bradstock *et al.* 1994); a mineral-soil seedbed (free of organic matter and competing plants) is ideal for the establishment of seeds from serotinous seeders (*e.g.* O'Dowd and Gill 1984); and, stimulation of root suckering will occur when the stems of species with suckering ability are killed (Gill 1981b).

Fauna

Fauna are affected directly by fire and indirectly by the effect of fire on vegetation which supplies food and habitat. The effects of fire on fauna must be mediated by the plants. In addition to food they provide favourable microclimates, as well as home sites and refuges from predation. The change that fire produces in plant communities can have a long reaching influence on animals beyond the direct mortality due to the fire itself. There is a reasonable understanding of the effects of some fire regimes on fauna, particularly the extremes i.e. wildfire (high intensity, low frequency in summer) and control burning (low intensity, high frequency in autumn). However, little is known about the effects on the fauna of the many fire regimes in between. Also, present knowledge mainly applies to drier forest types and for ground-dwelling mammals and birds. Little is known for other groups such as bats or arboreal marsupials.

A single fire may set the scene for changes in habitat that may have significance for decades. Important habitat elements may be affected by a single fire, but the extent of the affect will depend on the properties of the fire and of the system at the time of the fire (Gill and Catling 2001). Cover, protecting animals from adverse weather and predators, whether in the form of hollow logs, tree hollows, shrubs or grass tussocks, may be affected. In the same way, food items may be lost (*e.g.* invertebrates in litter, foliage, nectar) or, for carnivores, made temporarily more available because of lack of cover for the prey. Diet switching may occur because of changed availabilities of food items after fire (Newsome *et al.* 1983). Of particular interest is the creation of shrubby thickets after fire (see also above). These thickets create substantial cover for animals which is an important factor affecting the abundance and species composition of mammals in forests (Catling 1991; Catling and Burt 1995).

Although mammals and birds can escape fires of low to moderate intensity (Komarek 1969; Leonard 1972; Christensen and Kimber 1975), they may not be able to persist in the long term if structural complexity is reduced. Habitats regenerated by high intensity wildfires can be lost by the use of frequent low intensity fires. An example comes from the semi-arid woodlands of south-eastern Australia, where prescribed burning is the recognized method to remove woody plants and ensure production of grasses for stock (Hodgkinson and Harrington 1985). In forests, if shrubs, litter and ground cover are removed permanently, the reduction in complexity of forest structure leads to a reduction in abundance and species diversity of small mammals (Braithwaite and Gullan 1978; Fox 1978; Fox 1979; Newsome and Catling 1979; Friend 1979; Recher et al. 1980; Catling 1986; Lunney et al. 1987) and birds (Recher 1972; Christensen and Kimber 1975; Recher and Christensen 1980; Recher et al. 1980; Lloyn 1987;). This has been found also for medium-sized and large mammals (How 1972; Newsome et al. 1975; Lunney 1987; Lunney & O'Connell 1988).

Tree hollows have particular significance for many species of Australian animals. For example, over 40% of Australian mammals may depend on hollows (Ambrose 1982 in Gibbons and Lindenmayer 1997). Their size varies widely from large (*e.g.* Mountain Brushtail Possum, weighs up to 4kg) to tiny (Feathertail Glider weighs only about 15g) (Lindenmayer 1996). The same may be said of birds; large owls and tiny pardalotes occupy hollows (Gibbons and Lindenmayer 1997). It is obvious that large animals need large hollows and that large hollows are more likely to be found in large trees. Indeed, trees need to have reached certain minimum dimensions (and ages) before hollows will form while hollows in general predominate in the older and larger trees (Gibbons and Lindenmayer 1997). For hollow-dwelling species to persist at a site, fire must not destroy hollows of a type necessary for any particular species. If the fire is of a stand-killing type, hollows may persist in stags (Lindenmayer 1996) but there will be long periods at the site without hollows after the stags have fallen and before the new stand has individuals big enough to develop them. For example, stags in *E. regnans* forests may last decades but hollows suited to Leadbeaters Possum in live trees only appear in trees over about 190 years old (Lindenmayer 1996). Once hollows have formed, animals have to migrate from other suitable sites if colonization is to take place.

That vertebrate animals die in a fire is not a foregone conclusion. Sometimes some do; sometimes many do. Among birds, death rates in severe fires in an East Gippsland area of closed forest, heath and open-forest was about 40% (Lloyn 1997) while in heaths and woodlands in south-eastern New South Wales the figure was 54% (Fox 1978). The numbers of dead mammals to be seen after fire may be only a small proportion of the total present before the fire. For these animals post-fire predation seems to be the most important cause of death (Christensen 1980, Newsome *et al.* 1983, Kinnear *et al.* 1984). Arboreal animals such as koalas, fully exposed in tree canopies, can be killed by direct exposure to the heat of the fire - which varies according to location height and fire intensity. Among invertebrates, however, the death rates for those animals living only in litter may be expected to be high if the litter is totally consumed while foliage-feeding invertebrates in the canopy may be lost when canopies are defoliated by crown fire (Majer *et al.* 1997).

Activity of herbivores and feral predators

The regenerating vegetation on a burned patch – the 'green pick' - is an attraction to herbivores. Wombats and macropods (kangaroos and wallabies) may find new shoots of grasses and shrubs particularly palatable. With complete concentration of animals on the burned patch, the stocking rate of animals is magnified above the norm, provided that only part of the home range has been burned. Leigh and Holgate (1979) have demonstrated experimentally that the mortality of resprouting plants due to the burning-grazing interaction on small burned patches is greater than that of either burning or grazing alone. After unplanned fires the regeneration of grasses may be immediate in certain parts of the landscape (*e.g.* on deeper soils) and precede that of shrubs. While this has not been formally studied it suggests that there may be spatial and temporal effects on plant populations due to the burning-grazing interaction that extend beyond those related to the overlap of home ranges with a burned area.

Some fire regimes reduce and eventually eliminate dense forest understorey and, as this occurs, many native mammal species may be disadvantaged and exotic species may be advantaged (Catling 1991). If suitable forest habitat is restricted to small pockets such as along creeks and drainage lines this greatly increases the risk of predation, especially by foxes, cats and raptors, most importantly upon the rare fauna. For example, predation by dingoes on the small uncommon Potoroo was particularly severe in the first two years after fire (Newsome et al. 1983). Also, Christensen (1977) demonstrated that another small macropod, the Brush-tailed Bettong could survive a fire, but 11 of 24 survivors were subsequently lost to predators. Such predation could lead to local extinction of some of the rare fauna (Kinnear et al. 1984). This resembles the situation in arid Australia, where the degradation of refuge habitats during drought by introduced herbivores and the added pressure of introduced predators is suggested to have increased probabilities of local disappearance and finally extinction of many native mammals (Morton 1990).

Animals left without hiding places as a result of a fire may be especially vulnerable yet fidelity to original home ranges is usually strong, *e.g.* in the case of the Woylie, in the south-west (Christensen 1980). The absence of particular predators – like the introduced fox and the native dingo - may alleviate the need for cover in some animals, like the Tammar, in the south-west, (Christensen 1980). Thus, survival of populations of animals subject to predation after fire may be greater where the fire has intersected their home ranges but not burnt them completely, *i.e.* a burned area that is patchy at the scale of the home range of the animals. As the home ranges of animals in any one area vary widely (usually in relation to their body weight) the scale of patchiness appropriate to the maximum persistence of all ground-dwelling animals is that appropriate to the one with the smallest home range. In reality, the populations of animals would be expected to fluctuate within a region according to the scales of fire patterning occurring with each event. The caveat concerning predation is emphasized; Johnson (1995) found no post-fire predation of the Eastern Bettong in Tasmania, the island State without foxes or dingoes.

Even after high intensity wildfires some small mammals can survive for a few weeks before the populations disappear for several years (Newsome *et al.* 1975; Recher *et al.* 1975; Catling *et al.* 1982). Catling *et al.* (1989) examined the postulate that fires would induce shortages of food and water and this would be reflected in changes in water influx and efflux and loss of body weight and body fat. They found a low intensity, prescribed fire had no effect on any parameter and it was concluded that water and food supplies appeared adequate for the survivors in the short term. The disappearance of small mammals a few weeks after fire is most likely due to loss of cover and protection from predators (Christensen 1977; 1980; Catling 1991; Catling and Burt 1995) and possibly for displaced arthropods also.

Fire ecology and management in Australian Alpine Landscapes

Introduction and background

The widespread fires of January 2003 burnt large tracts (tens of thousands of hectares) of the high altitude alpine and subalpine country. Australian alpine landscapes are rare, occupying only about 0.1% of the continent. They are those treeless landscapes that occur above treeline, or just below tree line in frost hollow valleys, at altitudes above about 1600m (see **Figure 1**). The vegetation is typically short, due to the extreme climatic conditions - low temperatures, winter snow, frost, wind - typical of high altitude environments; fire is rare in these environments (Williams & Costin 1994; Williams et al. 2003). Australia's alps are of international significance (Kirkpatrick 1994).

Most Australian alpine landscapes occur within National Parks. In Victoria, much of the Alpine National Park is currently grazed by cattle. Most of the Kosciuszko National Park was grazed by domestic stock up until the 1960s. There is considerable controversy about the role of cattle grazing in land management in the alpine country, especially in relation to fire. "Alpine grazing reduces blazing" is a well-known slogan, and there have been calls for a reintroduction of stock as a fire management tool in some alpine areas. Indeed, there has been controversy and debate around this theme for many decades.

There is a long and proud history of ecological research in the Australian Alps, and CSIRO has been at the forefront of this research. Dr Alec Costin, of CSIRO Plant Industry, pioneered work in the NSW Alps, commencing with his seminal 1954 monograph "Ecosystems of the Monaro". Dr Costin and colleagues published numerous CSIRO Technical Publications, scientific Journal articles, book Chapters, and the highly acclaimed "Kosciuszko Alpine Flora", published by CSIRO. Mrs Masie Carr and Prof JS Turner of Melbourne University established long-term experiments in the 1940s on Victoria's Bogong High Plains. In the early 1980s, Dr Dick Williams (now of CSIRO Sustainable Ecosystems) commenced work in the Victorian High Country; Dr Williams and colleagues are still actively involved in alpine research in Australia, as is Prof. Jamie Kirkpatrick, from Tasmania.

Because of this rich research tradition, which has resulted in hundreds of scientific papers, the basic ecology of the Australian Alps is relatively well-understood. Research has addressed the evolution of the landscapes, the climate and soils, vegetation dynamics, the fauna, conservation values, and, importantly, the responses of soils, plants and animals to disturbance, including grazing by domestic livestock and fire (Williams et al. 2003). This research tradition is of fundamental significance to the current questions of fire and land management in the Australian alps.

Fire regimes in Australian alpine landscapes

Fire is relatively rare in Australian alpine landscapes, because the combinations of events that are need for alpine country to burn – drought conditions, and severe fire weather – occur only several times per century (Gill & Moore 1990; Wahren et al 2001). Prior to 2003, the high country was last burnt extensively in 1939. On both occasions, most of the snowgum woodlands on the Bogong High Plains were crown-killed, most heathlands were burnt, some areas of grassland burnt, as did numerous sphagnum bogs (Carr & Turner 1959; Parks Victoria, unpublished data).

The landscape is differentially flammable. The most flammable parts of the alpine/treeless subalpine landscape are the heathlands (See **Figure 3**). Experimental work by Roger Good in Kosciuszko (Good 1982) and Williams and colleagues on the Bogong High Plains has shown that the shrubs are more flammable than the grasses, basically because of fuel architecture. The closed heathlands also occur on the steeper slopes (see **Figures 3; 4a**), and intensity and rate of spread increase with increased slope. Thus, where the 2003 fires have burnt alpine country, these communities have been severely burnt, causing 100% shrub canopy kill, and 100% exposure of bare ground.

Grasslands, on the other hand, occur on the gentle slopes, and the grass fuels are less flammable than the shrub fuels (see **Figure 4b**). There are many examples from the Bogong High Plains where the 2003 fires burnt through dense heathland, causing 100% scorch in the shrub canopy, but went out as soon as they came up against the adjacent grasslands on gentle slopes. There are even examples on steep slopes, where 0.2- 1ha areas of snow patch herbfield/grassland were unburnt, even though the surrounding heath was severely burnt. This is pattern is quite clear on the Spion Kopje ridge (see **Figure 4a**), and is clearly visible from Falls Creek ski village.

Many sphagnum bogs on the Bogong High plains were burnt by the 2003 fires. Despite the peaty soils being moist, the bogs are dominated by shrubs, and are often surrounded by closed heath. Thus, in 2003, if the surrounding closed heath burnt, the bog invariably burnt. This is a similar pattern to the fires of 1998 in the subalpine heathlands and bogs of the Wellington and Holmes Plains regions following the 1998 Caledonia fire in Victoria.

Does alpine grazing reduce blazing?

The basic answer is 'no', for the reasons outlined below.

Studies on the diet and behaviour of cattle by Harm van Rees 20 years ago showed quite clearly that cattle have clear preferences about which species they eat, and which communities they graze in (van Rees 1982; van Rees & Hutson 1983). These findings have important implications for the alpine grazing/blazing issue.

Cattle prefer the open grassy communities, where there is the greatest abundance of palatable species. The country is also naturally open, on gentle slopes, so cattle can move freely. In contrast, cattle avoid the dense, closed heath communities, because there are few palatable species, the grasses and herbs are not very apparent to the cattle (under shrubs so they are harder to get at) and the dominant shrubs (*Prostanthera, Phebalium, Orites*) are not palatable. The heath also has a more or less closed shrubby canopy, about 1-2 m tall, and is thus difficult to move through. Consequently, cattle, by avoiding the closed heath, are avoiding the most flammable component of the alpine landscape.

The long term monitoring plots set up by Carr & Turner in the heathlands around Rocky Valley in 1946, and which have been monitored ever since, show quite clearly that there has been no effect of cattle grazing on shrub cover – and therefore fuel loads- over this 60 year period (see **Figure 5**). This was also the case for shrub cover at Mt Fainter, on the Bogong High Plains, over a 15-year period following a low intensity fire in 1984 (see **Figure 6**; Wahren et al. 1999). This has been a consistent finding – no effect of grazing on overall shrub cover - at several other long-term monitoring plots in heathland on the Bogong High Plains (Wahren et al. 1994).

Cattle may cause tracks within the heath, but there is no evidence from any of the sites visited on the Bogong High Plains in Feb-June 2003 that these acted as fuel breaks. There is no reason why they should, or indeed could, either, under conditions of extreme fire weather, because the fuel is still basically continuous.

The closed heath communities cover about 25% of the treeless plains, and are the dominant understorey component under most of the snow sum woodlands as well. Thus, they are the natural 'wicks' through which fire will pass, whether grazed or not. This was the case in both 2003, and 1939, when, incidentally, the stocking rates on the Bogong High Plains were about double those of the present time.

The parts of the landscape where cattle have most impact in terms of biomass/fuel reduction are in the grasslands, herbfields and open heaths. These are the communities in which the cattle prefer to graze, and where the abundance of the preferred species (snowgrasses, snow daisy, most other herbs, and some shrubs such as *Asterolasia* (star bush) and alpine grevillea – is highest, as shown by Dr van Rees' work.

With respect to the herbaceous vegetation in these communities, even though grazing does reduce biomass, cover and therefore potential fuel loads, (Wahren et al 1994) grazing has little effect on fire behaviour. As already mentioned, these elements are the least flammable fuel types, and the grasslands also occur on the gentle slopes. The example from Spion Kopje of the unburnt snow patch herbfields on steep slopes surrounded by severely burnt heath (see **Figure 4a**) was from country that had been ungrazed for 12 years.

Our preliminary data from burnt sites on the Bogong High Plains do not support the notion that alpine grazing reduces blazing. Our observations and measurements in February/March 2003 show that the pattern of burnt heath abutting unburnt grassland appears to be just as common in ungrazed country (e.g. the Mount Nelse/Heathy

Spur/Watchbed Creek region which has been ungrazed for 12 years) as in grazed country (e.g. Rocky Knobs, Cope Creek region). Much more detailed examination of this is obviously needed, but there are no obvious effects of grazing on burning patterns that can be attributed solely or primarily to grazing. Detailed companion measurements within heathland of minimum twig diameter on burnt shrubs (a measure of fire intensity/severity) in March 2003 at a number of burnt locations on the Bogong High Plains (both grazed and ungrazed) showed no difference between grazed and ungrazed sites in fire severity.

Thus, there is no consistent body of evidence that shows cattle reduce fire extent and severity in alpine vegetation under conditions of extreme fire danger, such as occurred in 2003, and 1939. Indeed, from our knowledge of basic alpine ecology, combined with preliminary observations of fire impact and extant on the Bogong High Plains, there is no known mechanism by which alpine grazing could "reduce blazing".

Management implications

There are two primary management questions:

1. Should grazing be expanded in Victoria or re-introduced in Kosciuszko to lessen the impact of future wildfires in alpine vegetation? On the basis of the scientific evidence, the answer is clearly "no".

2. How do we best manage alpine areas that have been burnt? The primary action is to remove stock, and this will need to be for decades. The heathlands will take from 5-10 years to recover to an acceptable state (Wahren et al 1999; 2001a). The most sensitive units -- the bogs- will take decades to recover, based on known tares of post-disturbance regeneration (Wahren et al. 2001b). Stock are free ranging, and many areas will be now more attractive and/or accessible to them, post fire. Stock reduce the rate of recovery of vegetation, at least in the early recovery phases of regeneration, as has been consistently shown by the long-term experimental and monitoring studies in the Australian Alps. It will be impossible to keep stock out of burnt bogs, and off steep, burnt slopes - areas that will be particularly susceptible to trampling. Thus, continued grazing post-fire is a threat to both catchment and biodiversity values.

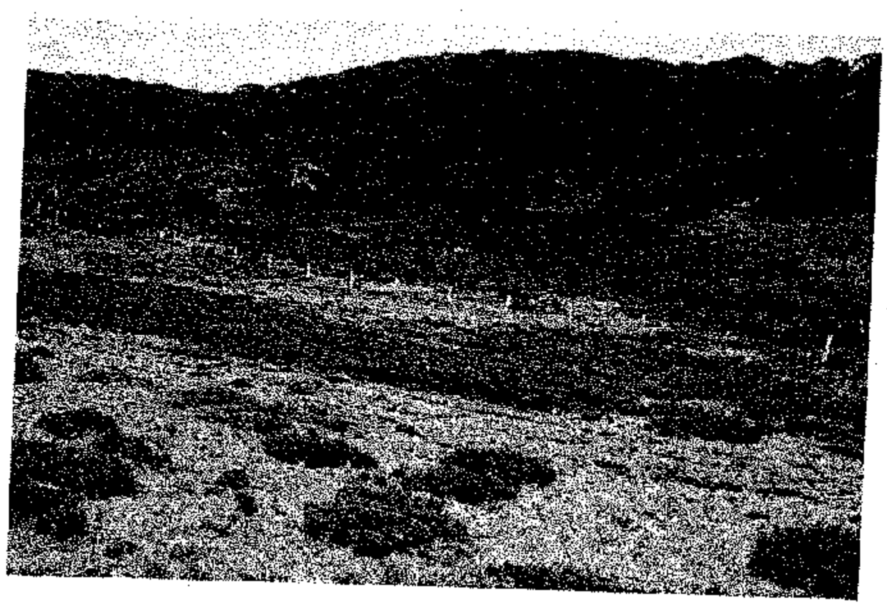
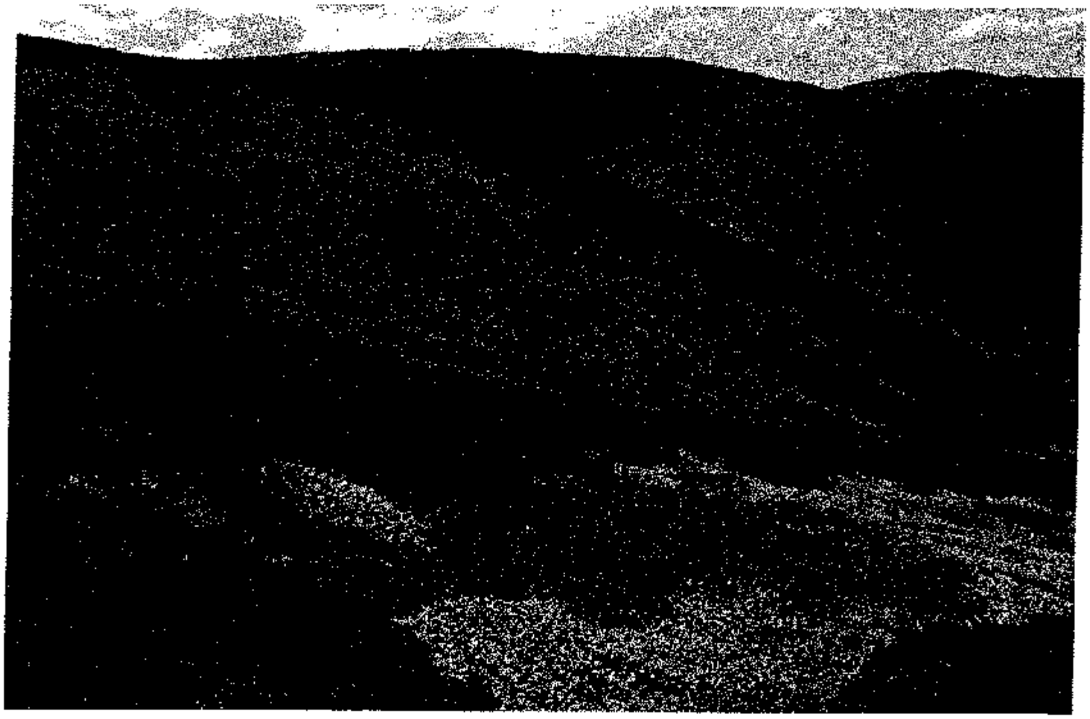


Figure 3 Typical high mountain, alpine landscapes on the Bogong High Plains. (a, upper photo) snow patch herbfield vegetation (with late lying patch of snow), surrounded by heath on steep slope, above treeline near Mt Nelse (1880m), Victoria. (b, lower photo) Snowgum woodland, closed heath open heath, and sphagnum bog complex in high subalpine valley (1770m) Rocky Valley, Bogong High Plains. The fenced plot was established in 1946; data from Figure 3 come from this and other long-term monitoring plots.



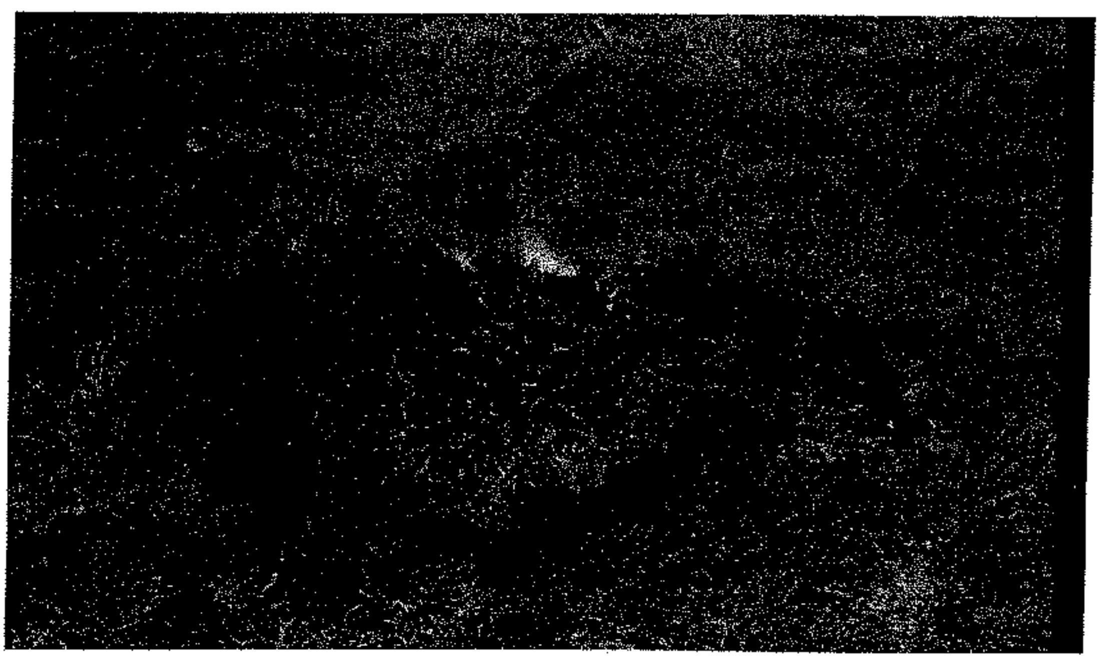


Figure 4 Differential flammability in shrub and grass fuels, Bogong High Plains. (a, upper photo) Burnt closed heathland and unburnt grassland/herbfield on Spion Kopje Ridge (ca 1800 m) following 2003 fires. (b) Experimental ignition of *Grevillea australis* shrub has consumed close to 100% of the shrub fuels; surrounding snow grass (*Poa*) has remained virtually

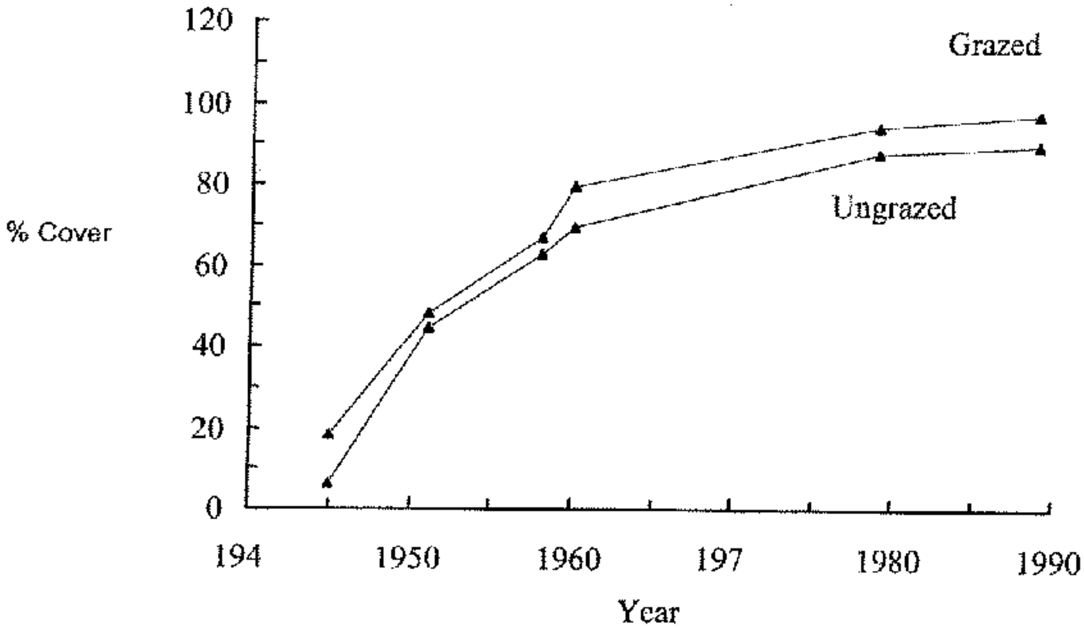


Figure 5 Effect of grazing on changes in percentage overlapping cover of shrubs at the Rocky Valley closed heathland plots, Bogong High Plains, 1945-1989. (Source: Wahren et al. 1994). The cover of shrubs in 1999, when last measured, was similar to that of 1989, in both grazed and ungrazed treatments (approx. 90%).

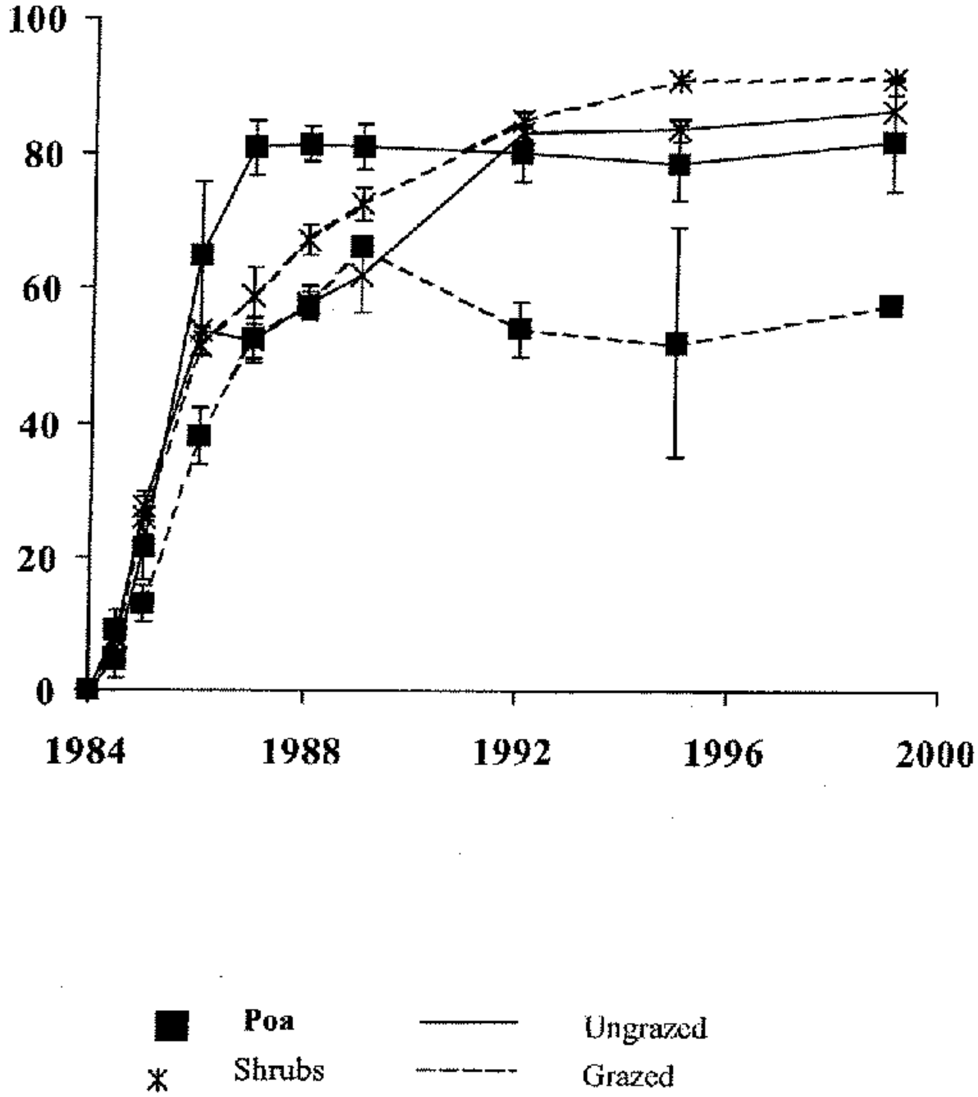


Figure 6 Effect of grazing on changes in percentage overlapping cover of shrubs and snowgrass (*Poa*) at the Mount Fainter closed heathland plots, Bogong High Plains, 1984-1999. (Source: Wahren et al. 1999, RJ Williams unpublished data). The plots were burnt by low intensity fire in 1984.

Fire Management in the Brindabellas

The Brindabella area, particularly those areas in the north, have been previously managed with rotational hazard reduction burns over many years. These burns have occasionally escaped and burnt into the more mesic forest types such as *Eucalyptus fastigata*. Unfortunately, no monitoring work on the effects of these burns was ever undertaken, so their effects can only be surmised. The fire tolerances and requirements of many plant species are still very poorly known, despite a large amount of recent work that has been undertaken (see Gill, Moore and Martin 1995 for a recent bibliography and Williams and Gill 1995 for a discussion on the impact of fire regimes on native forests in eastern NSW). From observations in the field and knowledge of the species, it is apparent that many of the woody plant species in Brindabella National Park and the surrounding VCL can resprout after fire, although the regime that they can tolerate in terms of frequency, intensity and seasonality is not known. The major exception to this in the study area are stands of Alpine Ash (*Eucalyptus delegatensis*) which do not resprout after crown scorch but will regenerate en masse from canopy stored seed released from capsules after a hot fire. However, this species can withstand very low intensity burns if there is no canopy scorch. This contrasts with other high altitude dominant species such as Snow Gum (*Eucalyptus pauciflora*), Mountain Gum (*E. dalrympleana*) and Broad-leaved Peppermint (*E. dives*) which will resprout from epicormics and lignotubers as adults as well as from lignotubers at the late seedling stage (Noble 1984). Stands of Alpine Ash are therefore found in more protected situations, usually south east facing slopes, where the frequency and intensity of intense fires is low and stands tend to be even aged. This vegetation type represents the most fire sensitive unit found in the study area, although in the longer term (100-300 years) catastrophic fires may be necessary for stand replacement. However, the long term effects of hazard reduction burns are not known.

Vegetation Types on Volcanics, Sediments and Granites Greater than 900 m Elevation

Woods and Raison (1983) determined decomposition rates for litter in sub-alpine forests of *Eucalyptus delegatensis*, *E. pauciflora* and *E. dives* finding that litter decomposition was slow in the first year due to lack of moisture but increased during the second winter and summer. A subsequent study (Raison, Woods and Khanna 1986) determined decomposition and accumulation of litter after a fire and found a rapid re-accumulation of litter due to a slow down in the decomposition process. Litter build up approaches 10-12 t ha after 4-5 years in these communities but levels off toward an equilibrium after this time. However, a minimum between fire interval of 10-12 years was advocated as being compatible with the replacement by natural processes of volatilised N. Raison, Khanna and Woods (1985) found that burning can have a major impact on losses of organic matter and volatile elements. Hence, too frequent burning has the potential to result in nutrient losses and potential changes in understorey composition. All indications from work undertaken in similar sub-alpine environments such as Kosciusko National Park (Leigh *et al.* 1987, Wimbush and Forrester 1988, Wimbush and Costin 1979a, 1979b, 1979c) indicate that any burning of the sub-alpine and montane vegetation is undesirable. In the absence of fire in the longer term, the shrub layer senesces and becomes replaced by snow grass (*Poa* spp.)

and herbaceous species. The more exposed and drier types within the higher areas are naturally shrubby and aspect will affect the floristic composition of any given site, but it is from these drier types that shrubs may invade after fire to exploit open spaces in the post fire environment. From a biodiversity conservation viewpoint, all existing evidence points to a no-burn policy as being the best short term strategy in those vegetation types occurring in higher altitude areas. Although lower in the landscape, the moister montane *Eucalyptus fastigata* forests also fall into this category and should not be burnt in the short term.

Banks (1989) studied the fire history of sites in Kosciusko National Park and in the southern end of the Brindabella Range by examining fire scars on specimens of *Eucalyptus pauciflora*. He concluded that fire frequency had definitely increased after 1860, with a greater frequency of fires due the activities of prospecters and pastoralists in these areas. Fire frequency then started to decrease in the late 1950's due to less intensive use of these areas and greater fire suppression efforts. Importantly, Banks stressed the need to identify areas which have been little affected by European burning practices as these islands can act as bench marks of pre-European vegetation types.

Given that the higher parts of the Brindabellas are a northward but drier extension of the Australian Alps, any policy of frequent burning may potentially lead to loss of the more mesic understorey vegetation. That is, the more mesic sub-alpine and montane elements of the flora may contract into gully refugia and may effectively contract to the wetter granite areas to the south over the long term, putting a further selective pressure on what is already an area at the drier end of the sub-alpine zone.

Vegetation Types on Volcanics and Smaller Lithological Units Less Than 900 m Elevation

Work undertaken in Canberra on similar dry vegetation types (Purdie 1977a, 1977b, Purdie and Slatyer 1976) points to a greater resilience and less impact in these communities to fire in general, most differences in the first year being due to structural changes rather than changes in floristics. However, this data was from one fire event, and long term changes will depend on the fire regime. The fact that the vegetation growing on metasediment parent material is adapted to cold, dry, nutrient poor conditions means that the species there are prone to resprouting after disturbances such as fire and drought. What is not clear is how severely these areas have been affected by past burning, grazing and clearing and whether frequent burning is detrimental to their long term maintenance. Observations in these communities suggest that the shrub layer can increase markedly after fire or mechanical disturbance, with *Cassinia* spp. forming dense thickets for up to 20 years or more and hence maintaining, rather than reducing, the fire hazard. Hence, while these areas seem less susceptible to impacts from burning, a fire regime which is too frequent may tend to induce fire promoting vegetation and may lead to areas becoming a greater fire hazard in the medium term.

Modifications through human impact (European and Aboriginal)

Although there has been much debate on the degree of modification of Australia's vegetation due to Aboriginal influences in relation to changes in fire regime (e.g. Rhys Jones concept of 'fire stick farming'), much of this debate has ignored the more fundamental environmental determinants of vegetation distribution such as climate, geology, slope and aspect. If we were to attempt to show that vegetation in the past has been fundamentally affected by Aboriginal burning regimes, we would have to show a disparity between the vegetation patterns that we would predict based on climate (both past and present), geology, slope and aspect and those that we would predict if human manipulated fire had in some sense 'modified' the vegetation of a region. While there is some evidence of this in some parts of south west Tasmania in relation to the distribution of Button Grass Plains, there is no such evidence from mainland SE Australia of such patterns other than in very small localised areas such as the Grassy Balds in the Bunya Mountains. Other areas cited as evidence for fire stick farming on the east coast can in fact be interpreted as being either naturally open woodland and grassland communities (e.g. Cumberland Plain Woodland in western Sydney; White Box Woodland in Central NSW; Monaro Grasslands on the Southern Tablelands) or else having varying degrees of shrubbiness depending on time since last fire. This is not to say that fire was not used as a tool by Aboriginal people nor that it had no impact, rather, that it was used as a management tool in appropriate ecosystems where factors such as inherent productivity and ease of hunting would make its use worthwhile. Much of the debate fails to differentiate between those systems which are fundamentally grassy and open in nature and those which are fundamentally shrubby in nature. What is required in this debate is a conceptual model of landscape use by Aboriginal people revolving primarily around the factor of productivity, but which also explains European use of the land as well. Using such a model, it can be argued, and there is much environmental data to show, that those areas which form the bulk of our National Park system and exemplified by such areas as Namadgi – Brindabella are steep, unproductive (from a human perspective) and hence do not 'compete' with the flatter more fertile lands below for human use and occupation. This concept is termed the 'Worthless Lands Hypothesis' (Hall, 1988) and has much bearing on how we expect to manage such areas. We should not expect that steep, low productivity parts of the landscape should look like the flatter fertile parts nor that fire behaviour in such areas can be readily managed given the steep terrain and varying types of vegetation.

Evolutionary impacts

The Australian biota has been exposed to the influence of fire long before either Aboriginal or European occupation. The fossil record and charcoal particles show that fire had become an important environmental factor in the Late Miocene, at least 10 million years before Aborigines arrived in Australia (Martin 1994).

Fire ecology and management in northern Australia

Much of the preceding sections cover fire in southern Australia. However the vast majority of bushfires in Australia occur in the tropical north (Fig. 7), where hundreds of thousands of square kilometres are burned each year during the winter dry season. Rainfall is highly seasonal throughout most of tropical Australia, producing a savannah landscape that is characterised by a continuous grass-layer under a sparse canopy of trees. Fire is an inevitable consequence of the annual cycle of profuse grass production during the summer wet season (Fig. 8a), producing abundant fuel for fire over the following dry season (Fig. 8b). Savannah vegetation throughout the world owes its very existence to frequent fire, as without fire, savannah is replaced by forest. Northern Australia has probably experienced frequent fire for millions of years. Although frequent, these fires are of relatively low intensity, and rarely if ever burn the canopy. The combination of fuel conditions (mostly grass), fire weather, flat terrain, generally sparse trees and lower leaf flammability, means that the canopy conflagrations of temperate southern Australia do not occur in the tropical north. As a result, throughout most of the region protection of life and property is not a driving factor in fire management.

The extensive bushfires of northern Australia are mostly lit by people, in the context of habitat management. This has been the case since Aboriginal occupation up to 50,000 years ago. Prior to this, fires were started by lightning during the 'build up' storms of October and November. Since Aboriginal occupation, fire has occurred primarily during the dry season (May to October) rather than build-up, although lightning fires are still common. Landscape burning is an extremely important tradition for Aboriginal people, and plays a key role in spiritual and cultural life in addition to resource management. This tradition continues to be practised in some areas (Stevenson 1985; Haynes 1985; Russell-Smith et al. 1997), but most fires in northern Australia are now lit by people of European descent.

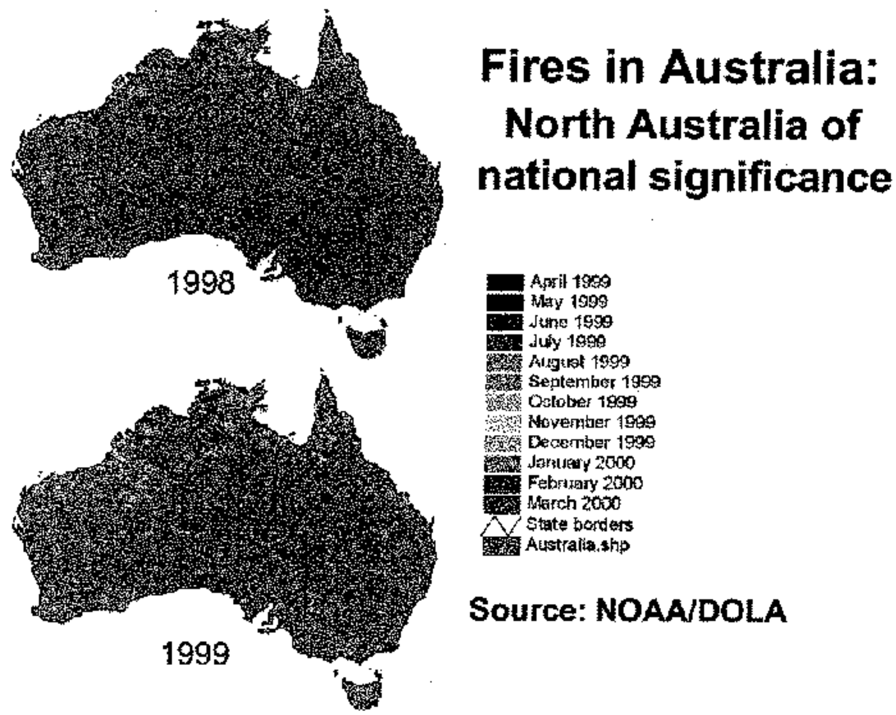
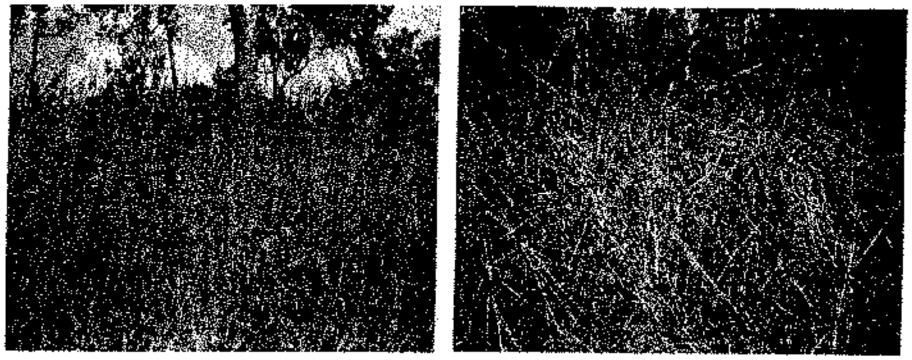


Fig. 7. The vast majority of Australian bushfires occur in the tropical north (source: NT Bushfire

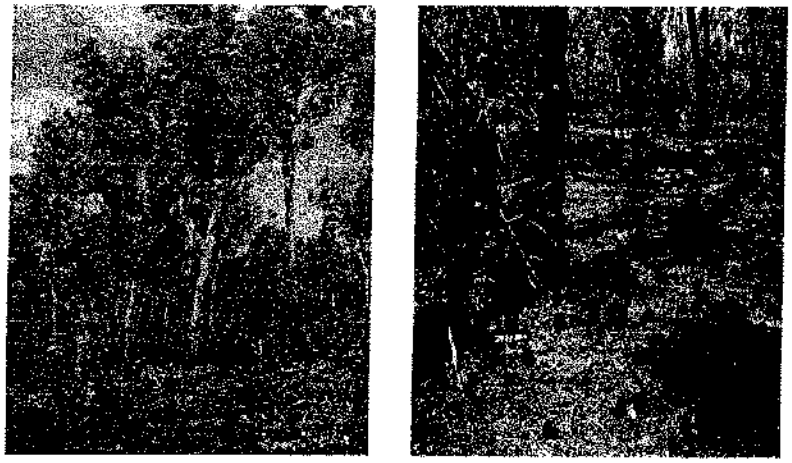


a b

Council).

Fig 8. Fuel production in northern Australia. Profuse grass production during the summer wet season (a), which cures during the winter dry season (b).

Fig 9. Landscape burning continues to play a key role in traditional Aboriginal life in northern Australia.



a b

Fig. 10. Seasonality in fire intensity, showing effects of fires lit early (a) compared with late (b) in the dry season.

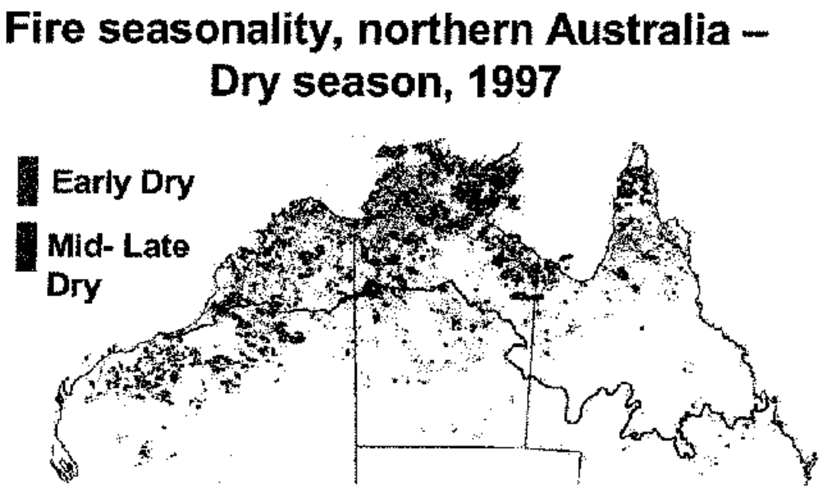


Fig. 11. Fire seasonality in northern Australia during 1997 (source: NT Bushfire Council)

Fire behaviour varies markedly during the dry season. Fires lit early in the season, when the ground-layer is still moist, tend to be low in intensity, patchy, and limited in extent (Fig. 10a). Those occurring late in the dry season (September-October) often completely incinerate ground-layer vegetation, cause substantial leaf scorch in the canopy, and cover larger areas (Fig. 10b). The dominant contemporary fire management paradigm, especially in conservation areas, is to burn extensively during the dry season in order to limit the extent of late dry season wildfires (Andersen 1996; Williams et al. 2002). Such burning can also be an important part of pastoral management, especially to prevent the proliferation of shrubs (at the expense of grass) that occurs in the absence of fire (Dyer et al. 2001). Despite extensive prescribed burning, much of northern Australia is burned by late season fires (Fig. 11), and there is widespread concern that this is having a significant impact on biodiversity.

In response to the need for an improved understanding of the ecological impacts of fire in northern Australia, during the 1990s CSIRO and its partners conducted one of the world's largest fire experiments. The experiment was conducted at Kapalga in Kakadu National Park, with a variety of fire management treatments applied to catchment-scale landscapes (Andersen et al. 2003; Fig. 12). Results from the experiment showed the biota to be remarkably resilient in relation to fire, with many plant and animal groups remaining unaffected, even by frequent, high intensity fire late in the dry season. Surprisingly, many fire-sensitive groups were affected more by whether or not fire occurred than when (and therefore how intensely) it occurred. Clearly, late season wildfires do not nearly have the ecological impact that the appearance of burnt landscapes suggest.

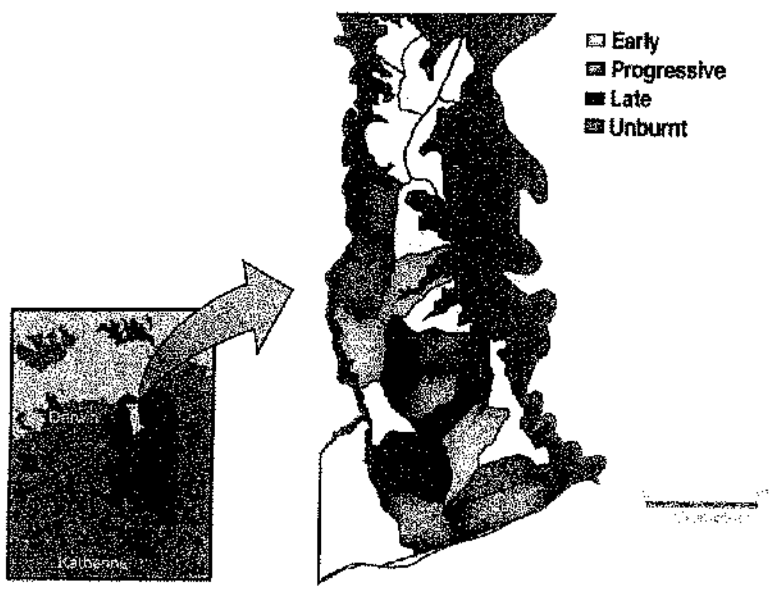


Fig. 12. Design of CSIRO's Kapalga fire experiment in Kakadu National Park. Four different fire treatments, each replicated three times, were applied to catchment-scale compartments over a 5-year period.

The Kapalga experiment showed that fire frequency has a far greater impact in tropical Australia than was previously appreciated. This is especially the case for small mammals of conservation significance, which in recent times have undergone significant population declines throughout northern Australia (Woinarski et al. 2001). Results from Kapalga show they strongly favour habitat that has remained unburnt for several years. This is a conservation concern given that very little of such unburnt habitat occurs due to such frequent burning (Fig. 13). CSIRO has recommended to conservation managers that burning be managed so that the area of land remaining unburned for several years is increased. Minister McGauran will be launching a book summarising the results of the Kaplga experiment (Andersen et al. 2003) in October 2003.

Fire frequency, Top End, NT, 1993-98

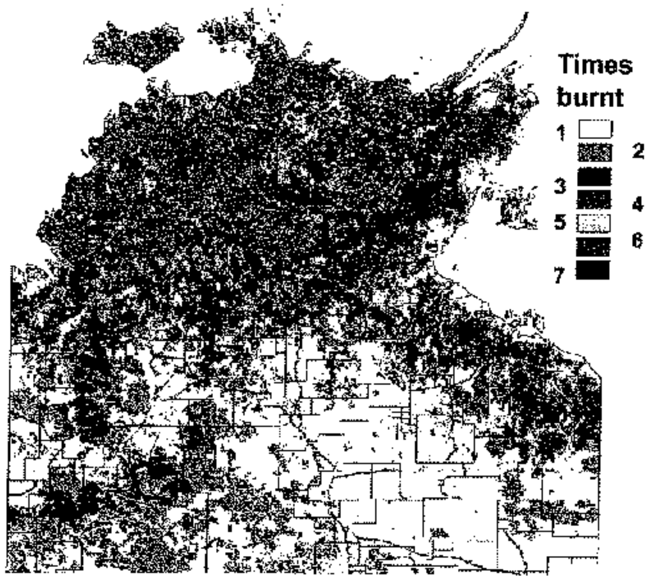


Fig. 13. In the northern Top End of the NT, very little country remains unburnt for more than one or two years. CSIRO is recommending that fire be managed so that more habitat remains unburnt for several years.

On a regional basis, the frequent fires in north Australia contribute substantially to greenhouse gas emissions through the production of nitrous oxide and methane (Hurst et al. 1994). In the Northern Territory, savannah burning represents as much as 50% of emissions listed in the National Greenhouse Gas Inventory. As well, the fires reduce the rates of carbon sequestration in the ecosystem. The potential for modifying fire regimes to reduce emissions and sequester carbon is great on a national scale because of the vast extent of these frequent fires. The development of a greenhouse trading economy could produce important regional benefits, but would need to be supported by sound science.

Fire management and suppression

Fire management

Fire management encompasses all those activities that involve the use of fire and the suppression of wildfires. These activities include the provision of access and firebreaks, communications, risk assessment and threat analysis, burning for fuel management, species regeneration and habitat management, wildfires suppression and rehabilitation after wildfires. Fire management is the legal responsibility of State agencies who manage government land and individuals or corporations who manage private land. For specific activities such as fire suppression and fuel management volunteer bushfire brigades have been formed throughout the rural and peri-urban areas and are coordinated by a State fire authority.

CSIRO has maintained a philosophy that fire management must be based on a sound understanding of fire behaviour and has focused much of its research over many years towards gaining a better understanding of fire behaviour and how this knowledge can be applied to provide safe and efficient bushfire management.

Fundamentals of fire behaviour

Fire behaviour is everything a fire does. It covers the way a fire ignites, builds up or grows, its rate of spread, the characteristics of the flame front and all other phenomena associated with the moving fire front. Most of the research effort in fire behaviour has focused on the prediction of fire rate of spread, the dimension of the flames and the likelihood of firebrands being thrown ahead of the fire to start new fires. It has not been possible to apply traditional physical theory to the prediction of fire spread. The problem involves a chaotic chemical reaction (combustion) moving through a fuel bed that varies spatially in three dimensions, across a variable topography and interacting with a turbulent atmosphere (principally the wind) that varies widely both in space and time. So prediction of fire behaviour at any specific point in space or time usually has a wide error margin because it is difficult to predict the fuel that will be consumed the direction and speed of the wind that will affect the combustion process at that point.

However, as fire builds up from ignition it does reach a quasi-steady rate of spread that can be correlated to some mean value or characteristics of the fuel and the mean wind speed measured at a standard location. The error in prediction is reduced by selecting a suitable period of time (often 30 minutes or more) to encompass the inherent variation in wind and fuel. The key factors that influence how fire spreads are the fuel characteristics, the moisture content of the dead fuel, the slope of the ground, the wind speed and its orientation to the fire. Mostly, predictions are made for the fastest spreading part of the fire called the head fire.

Fuel

The fuel that influences fire spread is the fuel that actually burns, or the available fuel.

It is determined by the stratification of moisture within the fuel bed and by the intensity of the fire. The available fuel is predicted from the antecedent weather conditions. After recent rain only the top layer of the litter bed will burn but after prolonged drought even a low-intensity fire will consume all the fuel on the forest floor.

The characteristics of the fuel that influence fire spread are primarily those factors that influence the speed of ignition of the fuel particle and the length of the flame. These include:

The fineness of the fuel particle (the finer the particle and the faster it will ignite)
The height of the fuel bed (the higher the fuel bed the longer the flames)
The compaction of the fuel bed. This determines whether the fire first burns across the top of the fuel bed and then down into lower layers or whether the fuel is mostly consumed at the same time. There is an optimum compaction that yields the maximum rate of spread:
if the fuel is too compact the fire will spread slowly; or,
if the fuel is too widely spaced the flames from one fuel particle cannot easily heat and ignite the next fuel particle.
The fraction of live to dead material (green material generally has a moisture level greater than 120 percent ODW (oven dry weight) and must be dried out by fire before it will burn. Thus green material can act as both a damper to fire spread or it can contribute to the length of flame particularly if it is fine and elevated above the surface fuel; after prolonged drought the live moisture content can reduce to 80% and require less heat for ignition)
The total amount of fuel consumed; and,
the continuity of the fuel bed.

These factors are difficult to describe numerically. To overcome this fuels have been grouped into specific fuel types with similar characteristics (e.g. grassland, scrubland (heath) and forest fuel) and a number of conventions have been adopted. It is generally accepted that the fuel that contributes most to the dimensions of the flame front, and thereby contributes to the heat flux that ignites new fuel are the available fuels <6mm diameter. These are defined as fine fuel. Fuel larger than this diameter either does not burn or burns slowly, well behind the leading edge of the fire.

Although this assumption is an oversimplification of the process it does allow fine fuel load to be a predictor variable for fire spread and appears to work are reasonably well provided it is used only for prediction in a specific fuel type.

Weather

The important weather variables that are used for the prediction of fire spread are those that determine the moisture content of the dead fuel, the amount of available fuel and that provide the dynamic force to drive the fire forward.. These are:

Rainfall. The amount and duration of rain not only determines the immediate of moisture content of the fine fuel but also, over a longer period of determines the amount of available fuel. Several indices of drought have been developed to predict the amount of forest fuel available for combustion. The level of drought determines the seasonal severity of fire season and the potential for conflagration fires in either forest grassland.

Fires can burn severely in dry forest earlier in the season before grass has fully cured and is capable of supporting a moving fire (e.g. Linton fire Victoria, December 1998).

A conflagration grass fire can occur after a short drought period of 6 – 8 weeks to completely cure all grasses, usually after a wet spring that has provided abundant grass growth. Under these conditions the tall wet forests and montane forests are usually too moist to support a severe fire.

After a period of prolonged drought, fuels in all forests become available including tall wet forests and forests in Montane areas. Natural barriers, which may be effective in a normal fire season such as swamps riverine areas and shallow lakes, dry out and fires become extremely difficult to suppress even under mild weather conditions. During these seasons grasslands are usually heavily grazed and grass fires spread are relatively slowly and are easy to suppress.

Temperature and the relative humidity. These weather variables determine the moisture content of the dead fuel. These follow a diurnal cycle so that fuels may be moist at night and driest in the late afternoon.

Wind. The wind speed is the dynamic variable that drives the fires forward. This can change in strength and direction extremely rapidly and both forest and grass fires respond almost immediately to this change.

Other weather variables that affect fire behaviour include solar radiation, atmospheric stability and upper wind strength. The interaction between the convection of the fire and the wind field above the fire can influence the surface wind in and around the combustion zone. This interaction is poorly understood and future advances in fire behaviour prediction of will probably come through research that are links the convection of the fire to the circulation in the lower atmosphere.

Topography

Depending on its position in the topography the fuel and the fire they react at different rates to changes in weather variables. The terrain can have a dramatic effect on the speed and direction of the wind near the ground. The hills and their associated valleys provide important channels that establish a local wind direction. Generally, wind blowing across mountain ridges is lifted along the surface to the gaps and crests. It will increase in speed as it crosses the ridge so that ridge top winds tend to be somewhat stronger than winds in free air of the same level. Ridges at right angles to the wind direction create considerable turbulence and often produce a strong eddy on the lee side so that the wind near the ground is blowing in the opposite direction to the prevailing wind. Under strong winds it is extraordinarily difficult to predict the direction and strength of winds in the valley and lee slopes of rugged terrain. The two features of the topography that most influence fire behaviour are aspect and slope:

Aspect: Early in the fire season the aspect of the terrain has a strong influence on the moisture content of forest fuel. Fuel on southerly and easterly aspects dries slower than fuel on northerly and easterly aspects that are more directly exposed to solar radiation. In mild fire seasons southerly aspects may remain moist and fires burn slowly throughout the summer. However, after a period of moderate drought and by early summer fuel on all aspects becomes uniformly dry so that the main influence on fire behaviour is the orientation of the aspect to the prevailing wind.

Slope: The slope of the ground, when aligned with the direction prevailing wind, has a strong influence on fire behaviour. The rate of spread of a fire up a slope of 10 degrees will be double the rate of spread of the fire on level ground. The rate of spread of the fire up a slope of 20 degrees will be four times the rate of spread of the fire on level ground. Although the effects of the slope and wind interact to determine the direction of fire spread, the magnitude of this effect depends on the strength of the wind. Under light wind the slope of the ground will determine the direction of fire spread but a strong winds can overcome the effect of slope and dominate the direction of fire spread driving fire across quite steep slopes.

Scales of fire behaviour

In addition to the rate of spread of fire there are two commonly used scales that are used to qualify fire weather and fire behaviour. These are the McArthur fire danger rating systems for forests and grasslands and the Byram fire intensity scale. These scales are important for fire managers to appreciate the range of fire weather that can occur and the range of a bushfire behaviour that is possible, particularly under extreme weather conditions.

Fire Danger

The McArthur fire danger rating systems combine a measure of seasonal drought with the weather variables of temperature, relative humidity, and the wind speed to provide a numerical index of the difficulty of suppressing a fire in a standard fuel type. The fire danger rating systems have been used throughout Australia for more than 40 years and have provided the basis for setting levels of preparedness, such as the manning of lookout towers, placing fire fighting resources on standby and providing public warnings. The fire danger rating system are used to derive the maximum daily fire danger in either forest or grasslands, and during summer these warnings are displayed on the roadside fire danger signs throughout rural areas. The difficulty of suppression associated with each fire danger class is given in Tables 2 and 3.

Table 2. Grassland Fire Danger Rating and difficulty of suppression in an average pasture carrying 4 t/ha.

Fire danger rating	Fire danger index	Difficulty of suppression
Low	1 - 2.5	Low. Head fires stopped by roads and tracks.
Moderate	2.5 -7.5	Moderate. Head fire easily attacked with water.
High	7.5 - 20	High. Head fire attacked generally successful with water.
Very high	20 -50	Very high. Head fire attack may succeed in favourable circumstances. Back-burning close to the head may be necessary.

Extreme	50 - 200	Direct attack on the head will fail. Back burns from a road for wide fire line will be difficult to hold because of blown embers. Systematic attack from the rear up along the flanks of the fire is usually successful.

Table 3. Forest Fire Danger Rating and difficulty of suppression on level ground in a dry eucalypt forests carrying 12.5 t/ha.

Fire danger rating	Fire danger index	Difficulty of suppression
Low	1 - 5	Low. Fire easily suppressed with hand tools.
Moderate	5 - 12	Moderate. Fire usually suppressed with hand tools and easily suppressed with bulldozers. Generally the upper limit for prescribed burning.
High	12 - 24	Fires generally controlled with bulldozers working along the flanks to pinch the head out under favourable conditions. Back burning[1] may fail due to spotting.
Very high	24 - 50	Initial attacked generally fails but may succeed if fires are below potential rate of spread on favourable lee-slopes. Back burning will fail due to spotting. Burning-out[2] should be avoided.
Extreme	50 - 100+	Fire suppression virtually impossible on any part of the fire due to the potential for extreme and sudden changes of fire behaviour. Any fire suppression actions such as burning out will only increase fire behaviour and the area burnt.

1. Back burning is setting fire downwind of the head fire in order to create a break wide enough to stop the head fire.
2. Burning out is setting fire to consume unburned fuel inside the control line.

The Bureau of Meteorology forecasts for the maximum fire danger for the day for planning fire suppression. However the weather variables of temperature relative humidity and wind speed usually follow a diurnal pattern so on a day of forecast extreme fire danger the actual hourly fire danger may be low in the early morning and rise to extreme fire 1100 hours as the temperature and the wind speed increase. Similarly the fire danger may rise by one or two fire danger classes in a very short time if the wind speed suddenly increases.

The standard fuel types for forests and grasslands are common and widespread so the fire danger rating system provides a good guide for planning and suppression preparedness. However, suppression difficulty depends very much on the type and structure of the fuel and the intensity of the fire in a particular fuel type.

Fire intensity

Fire intensity is a calculated number that represents the rate at which heat is released from a lineal segment of the fire perimeter. Expressed in kilowatts per metre of fire edge (kW/m), it is given by the equation:

$$I = H \times w \times R$$

> Where H is that the yield of the fuel burnt (kJ/kg), w is the amount of fuel consumed (kg/m^2), and R is the rate of spread (m/s).

The intensity of the fire varies greatly around the perimeter because the rate of spread of each m of fire perimeter varies depending on its location in relation to the prevailing wind. At the head of the fire where the rate of spread is greatest the fire intensity is greatest, and that the back of the fire where the rate of spread is least the intensity is least. Normally the fire intensity is quoted for the head fire unless otherwise specified and is the maximum for the whole perimeter.

The intensity of a grass fire may range from 10 kW/m for a slow-moving backing fire in light fuels to around 60,000 kW/m at the head of a very fast wildfire.

The intensity of the forest fire can range from 50 kW/m to a maximum of around 100,000 kW/m for a fire burning under extreme fire danger conditions in heavy fuels. Figure 14 shows a range of forest fire intensities from major wildland fire events and selected experimental fires conducted by CSIRO.

The calculated fire intensity figure is useful for comparing fires in the same fuel type. However, because fire behaviour and a rate of spread depends on the structure of fuel as well as the available fuel load, fires in fuels that are structurally very different will have very different fire behaviour for the same calculated fire intensity.

Never the less, fire intensity is useful to illustrate the capacity for suppression by different techniques in the same forest type (Table 4).

Table 4: Limits of suppression capacity in a stringy-bark eucalypt forest.

Fire intensity (kW/m)	Suppression technique	Comments
1000	Hand tools Medium helicopters with buckets (500 l capacity)	Limit for systematic suppression with hand tools and medium helicopters with buckets due to short distance spotting. Helicopters alone will fail below this intensity if the fire is more

		than two hectares but can support crews with hand tools by rapid suppression of the new spot fires.
2000- 2500	Bulldozers,	Limit for bulldozers in the easy terrain provided they can surround more distant spot fires before they reach their full potential. Bulldozers are effective if they can work the flanks and suppress the head fire when the intensity is reduced due to a break in fuel or terrain.
3500	Large air tankers (> 10 000 l capacity)	Large air tankers may successfully suppressed small fires of this intensity if they have not started spotting intensely. On larger fires they may help to reduce the intensity but will be most effective in supporting systematic fire line construction by bulldozers or ground crews.

All systems of fire suppression will fail at fire intensity that is only to 2 to 3.5% of the maximum intensity possible for a forest fire burning in heavy fuels under extreme conditions. In most forests for limits of suppression will be exceeded at high to very high fire danger and is the reason why initial attack needs to be fast and concentrated when the fire is small, and why fire fighters need to take advantage of milder conditions at night when the fire intensity is usually reduced.

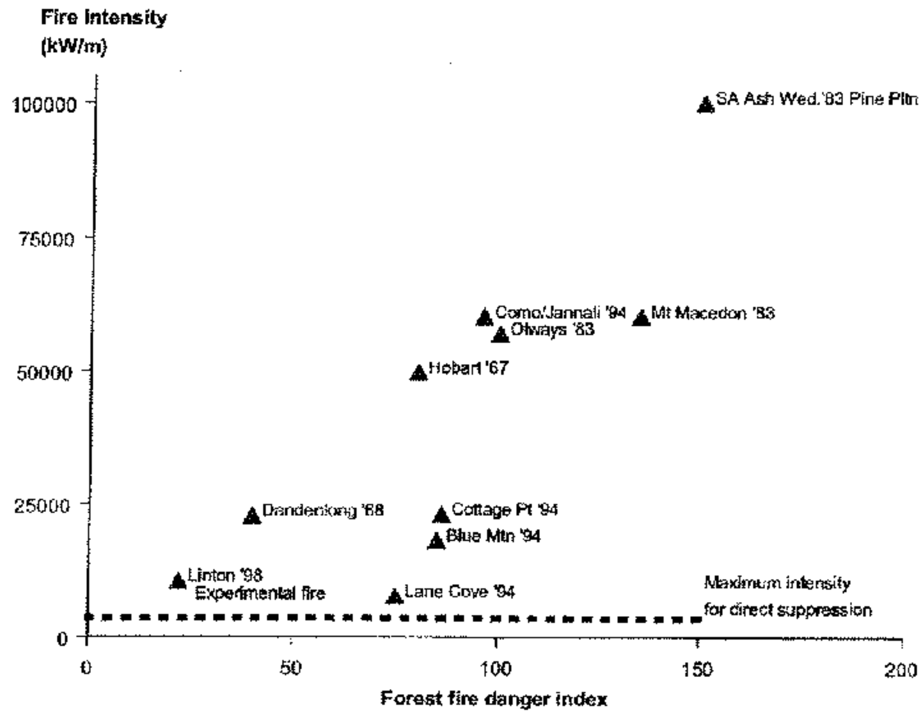


Figure 14. Range of forest fires intensities burning under a range of McArthur's Forest Fire Danger indices.

Suppression strategies

The fundamental requirement for extinguishing a forest fire is that the fire must be totally surrounded by a trail that completely separates the fire from unburnt fuel and is constructed down to the mineral earth. The entire fine fuel within the control Line must be burnt out and smouldering logs and trees within 50 m of the line extinguished. This basic requirement has not changed since man successfully started suppressing forest fires. It is labour-intensive and any failure to fulfil this requirement will mean that the fire will escape from control if very high to extreme weather subsequently occurs.

Water is very effective in suppressing the flames but a waterline cannot be relied upon, because smouldering fuels will reignite as the water dries out. Fires that are suppressed by water, be it from ground or air tankers, must be followed up with a bare-earth fire line around the fire and mopped up within the fire perimeter to ensure that embers will not be blown out and breach the fire line.

Because fire suppression can only be successful at relatively low fire intensity and under relatively mild weather (see Table 3 and 4) it is essential that fire fighters attempt to suppress the fire when it is small before it has reached its potential intensity for the prevailing conditions and take advantage of periods of mild weather when the fire line intensity is low. The fire intensity is normally low during night-time conditions and fire management agencies must train and equip their fire fighters to carry out fire fighting at night.

The most effective fire fighting will be enhanced if there is good access and preparedness to ensure that fire fighters get to the fire without delay. Fire trails should be maintained and cleared prior to the fire season so that valuable time it is not lost opening up overgrown or abandoned roads and repairing unsafe bridges.

The primary objective of an initial attack is to control fire at minimum size in minimum time. If this is not possible because of the remote location of the fire or the nature of the terrain then the primary objective must be to control fire in minimum time before the next period of dangerous fire weather occurs. This decision will determine whether the fire fighting strategy is direct or indirect.

Direct fire fighting

This is primarily deployed during an initial attack when the objective is to contain the fire in minimum size. The flames are either suppressed directly or a fire line is constructed parallel and close to the fire edge. Different techniques of direct fire fighting are:

Fire line construction with hand tools: a bare earth fire line between 0.5 and 1.0 m wide is constructed with a combination of hand tools (generally an axe or slasher, several McLeod tools and chainsaw) around fires of low intensity less than 1000 kW/m. This is sustained strenuous work so fire fighters need to be fit healthy. Their deep into body temperature rises by 0.8 degrees C, heart rates by 70 beats per minute and they will sweat and average rate of 1.4 litres per hour (Budd et al 1996). These physiological stresses are almost solely due to physical exertion and the psychological arousal caused by the fire.

In dry eucalypt forest carrying 12 t/ha of fine fuels and a moderate shrub layer up to 2 m and on undulating terrain, a six man crew of fit and experienced fire fighters can maintained this level of exertion for several hours and build and hold fire line at around 400 m /h (Budd et al 1996). Slow rates of line construction would be expected in heavy fuels and in steep terrain.

The capacity to maintain this level of exertion and a rate of fire line construction should be expected of the staff of land management agencies and seasonal fire fighters employed for fire fighting. It is probably unreasonable to expect this of volunteer fire-fighters, particularly those whose main experience is largely grass fire suppression with water tankers.

In general fire line construction with hand tools is limited to fires of only a few hectares in extent. However, on larger fires hand tool crews have been used to successfully build and hold fire line over sections of the perimeter which are steep and inaccessible to bulldozers.

Ground tankers and hose-lay: water applied directly to extinguish the flames is probably the fastest and safest way of containing a forest fire. Water can be pumped to the fire edge over more than 1000 m using multiple sections of hose and relay pumping with portable pumps. Direct suppression with water can control fires up to 2000 kW / m and is most effective in flashy shrubland fuels when fire-fighters work systematically from the base of the fire and extinguish the flames from inside the burnt area. Often fires in this type of fuel are too dangerous to attack by any other tactic.

Using this technique ample water is available for mop-up but fires in heavy forest fuels should not be considered secure until a bare earth line has been constructed around the fire perimeter either by hand tools or bulldozer.

Extensive use of this technique is not common although some agencies e.g. National Park Service Tasmania have trained, specialised and efficient crews for the relay hose lay in rugged terrain.

Bulldozers: once the fire is more than a few hectares in area there is really no alternative but to set about systematic fire line construction using bulldozers. Rates of fire line construction can exceed 2000 m per hour although the use of bulldozers is limited when slopes exceed 25 degrees. In moderate or undulating terrain bulldozers can be supported by ground tankers for a immediate mop-up and vehicular patrol.

Bulldozer operators need to be skilled in working in tall forest and particularly on rocky terrain. The operators employed on forestry operations were a key resource but with the current trend of downsizing forestry in native forests and the contracting of bulldozers from operators primarily engaged in rural work such as road building or dam sinking a dearth of skilled operators is rapidly developing. This needs to be addressed in the future.

Aircraft: Small to medium helicopters are no more effective in suppressing fires than crews with hand tools. Helicopters have the advantage that they can be deployed rapidly to fires while they are small but they have the disadvantage that the attack is not systematic or continuous. Even when multiple helicopters were used, the intermittent nature of their attack meant that sections of the fire that had been partially extinguished by the drops re-lit or burnt around the area of dampened fuel.

Helicopters are most effective when supporting ground crews who can work in a continuous manner to systematically surround fire. Helicopters can be used to reduce the intensity of the fire but more importantly they can detect and immediately suppress spot fires as soon as they occur beyond the fire line.

This summer saw a dramatic increase in the numbers and types of helicopters deployed for fire fighting. Although there will be claims of spectacular "saves" it appears that deployment of helicopters was largely ad hoc and there was considerable use under emergency conditions which had no effect on containing the fire. To achieve efficient aerial suppression of wildland fires, optimum conditions on the performance of the air tankers, drop pattern (i.e. footprint of the retardant drop) and retardant coverage are required for specific fuel and fire situations. Research performance and effectives of aerial suppression in Australian was mostly done in the 1980's by Rees(1983), Rawson and Rees (1983) and Loaned and Gould (1986). A study in evaluation of aerial suppression in Western Australia has been conducted in the outer region of metropolitan region of Perth and southwest region (T. Maher, personal communication). A wide range of fixed-wing and helicopters are available for aerial suppression delivering both chemical suppressant and/or water. The effectiveness of the retardant application depends on:

Amount of retardant actually need on the critical fuel,

Interception of retardant by the forest canopy above the critical fuel,
Pattern of the retardant drop, and
Chemical characteristics of the retardant drop reaching the fuel.

One of the prime aims of Project Aquarius (Loaned and Gould 1986) was to gather evidence on the effects of retardants on the behaviour of moderate to high-intensity fires in dry eucalypt forest. The depth (application rate) required to stop the fire burning through the retardant-coated fuel in the drop zone depends on the type of chemical suppressant, fuel burning, fire intensity and depth of the retardant required. The Aquarius studies indicated that unsupported retardant drops in stringy-bark forests were ineffective when fire intensities were > 2000 kW/m due to heavy spotting across the drop zone. If ground crew supported the retardant drops within one hour after the retardant drop had been dropped, the effective limit would be around 3000 kW/m (Loaned and Gould 1986).

Loaned and Gould (1986) concluded that there was no useful retarding effect for forest fire intensities > 5,000 kW/m, i.e. rate of spread around 700 m/hr in a forest litter fuel load of 15 t/ha. Although the retardant drop may have a temporary dampening effect on the flames and fire intensities, the fire will throw numerous spot fires across the retardant line which rapidly reform a new fire front. Thus, even if the retardant coated fuels remain unburnt the progress of the fire may be delayed by only a few minutes.

Low-intensity fires may be completely extinguished by a retardant drop, or halt a fire until fire weather conditions improve. Long-term chemical suppressants project a fire retardant effect even after drying out. However, fire controllers expect the fire to creep through gaps in the retardant lines where coverage is low, for example in the lee of large logs etc. The time taken for the fire to burn trough the drops depends mainly on fire intensity, retardant type, concentration and width of the retardant type and fuel type.

The application of fire-fighting chemicals is accomplished using a wide range of aircraft equipped with different configurations and aircraft speeds, which results in a wide range of dorp patterns, Drop patterns and the resulting ground pattern are also modified by drop height, retardant type, canopy intercepting, relative humidity, temperature and wind speed and directing. Although there has been a substantial effort to improve the performance and operation aircraft there is considerable need to improve the efficiency and effectiveness in aerial fire fighting (Gould et al 2002)..

Operational research in the United States has shown that the single most important action in improving the efficiency of aerial suppression by helicopter or fixed wing aircraft is skilled and direct supervision by an airborne supervisor (George et al. 1990) Because there are anecdotal reports of gross wastage of money on aerial fire fighting for little confirmed or tangible effect, there appears an urgent need to carry out similar operational research in Australia.

Indirect fire fighting

Indirect fire fighting involves constructing a fire line, or using an established road as the control line, located at some distance from fire. The same principles that apply to direct fire fighting apply to indirect fire fighting: the fire must be surrounded by a bare-earth trail or road and the fuels between the trail and fire burnt out and mopped up before the next period of dangerous fire weather re-occurs.

Close indirect fire fighting: this is when the fire line is constructed relatively close to the fire primarily taking the easiest route to construct the fire line quickly. This is the most dangerous form of fire fighting particularly for inexperienced fire-fighters. Because the line is relatively close to the fire edge and there is no immediate access to the safety of the ground fire-fighters are vulnerable to sudden changes of wind direction that can escalate the speed and intensity of the fire. After the deaths of fire-fighters at Wingello and Linton, CSIRO demonstrated with the analysis of initial results from Project Vesta that a sudden changes wind could immediately increase the intensity of the fire by three to five times, or much more in the case of a flanking fire (Cheney et al 2000). CSIRO in conjunction with the Fire and Emergency services Authority of Western Australia produced a training video "The Dead-man Zone" to explain the danger of this form of fire fighting. This video has been widely distributed throughout Australia and North America and incorporated into fire safety training programs.

Another form of close indirect fire fighting is burning out from established roads and trails. This is often carried out by inexperienced fire-fighters under inappropriate weather conditions of very high fire danger and sometimes before a proper incident command structure has been put into place. It appears that this tactic may be carried out because fire-fighters feel that they have to undertake some form of fire fighting and this is the only option available to them under the prevailing conditions. The tactic is dangerous and usually only serves to increase the size of the fire and complicate the suppression task. During the Linton fire, attempts to control fire by burning out under conditions of high to very high fire danger created two incidents where fire-fighters were trapped and burnt over and other fire-fighters were in danger of being trapped between the main fire to the fire lit from the control line.

Remote indirect fire fighting: this tactic is employed when the fire is burning in inaccessible terrain and to bring it under control in minimum time fire-fighters need to fall back to use established roads and fire trails as control lines and immediately commit a much larger area to fire. In recent years this technique appears to have been adopted a more frequently in National Parks to avoid using bulldozers within the park.

The tactic is appropriate if it can be accomplished speedily and the entire area burnt out before the onset of severe weather. However there are disadvantages. In recent cases the area committed has meant a twenty-fold increase in the planned final fire size, say from 500 hectares to 10,000 hectares. This means that a large amount of manpower and resources are required to secure the perimeter roads and skill to burn-out inside the control lines, usually with aerial incendiaries, without increasing the fire intensity to a point where the fire throws spot fires beyond the control line.

The tactic may have attraction because of the availability of a large number of tanker-based volunteers but if they do not have the skill in forest fire behaviour they may not be able to secure the control line in sufficient time to allow burning out to proceed before the weather deteriorates.

During the recent fire season there were claims that fires were contained within control lines when in fact there were technically out-of-control. For a fire to be contained it must be within an accessible control line. Their appears to be an increasing tendency to assume that rivers are effective control lines whereas in reality that are not: they are difficult to access, and inevitably a fire will cross if weather deteriorates.

A fire is considered controlled when the area within the control line is burnt out and mopped up to a point where there is no possibility of smouldering combustion starting fires beyond the control line. In a dry summer, patrol of the fire perimeter is required for several weeks after the fire appears to be extinguished to ensure that deep-seated combustion does not burn to the surface under extreme weather.

In summary, forest fire fighting is tough arduous work that is most effective if it is carried out by trained experienced fire-fighters who are physically fit. During summer it is essential that response time is rapid and fire fighters are able to take every opportunity to attack the fire under mild conditions that reduce the intensity of the fire.

CSIRO believes that it is essential that a land management agencies maintain the responsibility for fire management and fire suppression on areas under their control and that this responsibility is not passed on to emergency service organisations who rely heavily on volunteer fire-fighters. Forest fire fighting requires a level fitness skill training and experience that is difficult to achieve with volunteers. Agencies are responsible for the total fire management package. This includes the responsibility for maintaining effective access and fire trails, fuel management and a providing a rapid and effective first response capacity. If the land management agencies do not have this responsibility then essential preparedness is unlikely to be carried out.

Fuel management

The aim of fuel management is to alter of the structure of the fuel bed and the load of the available fuel to make fire fighting safer and easier. The cheapest and most ecologically sound way to do this is by prescribed burning.

Prescribed burning is defined as burning under specified environmental conditions and within a predetermined area to achieve some predetermined objective. The objective may include habitat management for native fauna, species regeneration, maintenance of specific eco-types or hazard reduction, etc.

Hazard reduction burning will reduce the total load of fine fuel and is also effective in reducing the height and flammability of elevated fine fuels such as shrubs and suspended dead material. Burning is the only practical way of reducing the fibrous bark on trees, which is the prime source of firebrands that causes spotting. Hazard reduction reduces fire behaviour by:

reducing the speed of growth of the fire from its ignition point;
reducing the height of flames and rate of spread;
reducing the spotting potential by reducing the number of firebrands and the distance

they are carried downwind; and,
reducing the total heat output or intensity of the fire.

Prescribed burning is not intended to stop forest fires but it does reduce their intensity and this makes fire suppression safer and more efficient. Prescribed burning does not provide a panacea nor does it work in isolation. It must be used in conjunction with an efficient fire fighting force.

The effective reducing fuel and on the efficiency of direct suppression by hand crews is illustrated in figure 15.

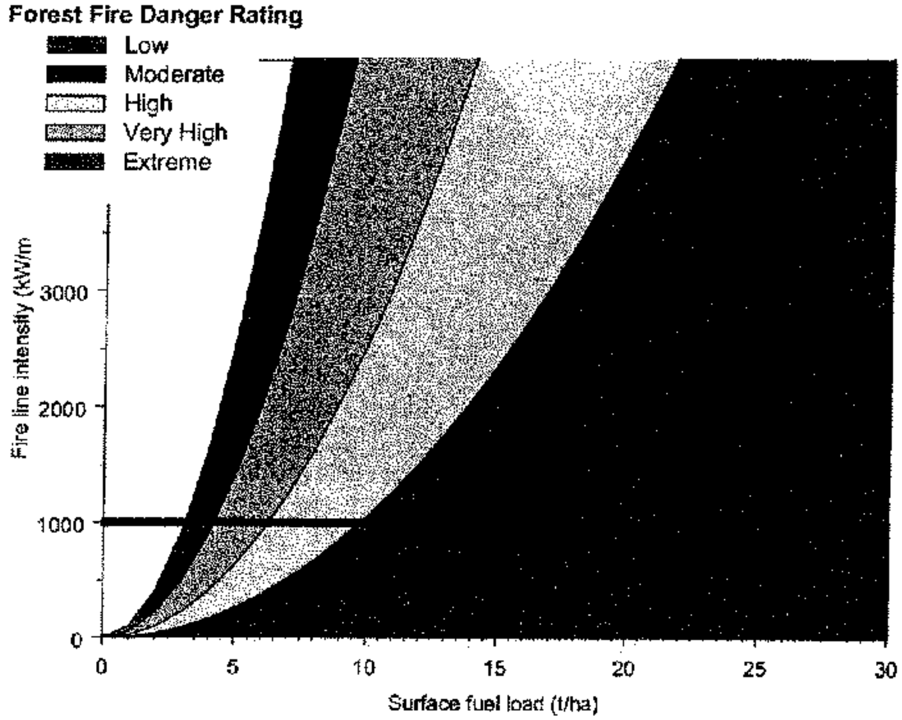


Figure 15. Surface fuel loading and fire line intensity at different forest fire danger rating classes. Black reference line is the maximum intensity hand crews can suppress.

Hand crews can suppress a fire up to a maximum intensity of 1000 kilowatts per m. If the fuel load > 15 t/ha (which is typical of dry eucalypt forests between 8 - 15 years since the last fire) this intensity will be exceeded under low to moderate fire danger conditions. If the fuels are reduced to 10 t/ha fires will not develop an intensity of 1000 kW/m until fire danger gets into the moderate to high range. This means that the range of weather conditions that fire fighting with hand tools is effective is increased and more time is available to bring the fire under control. If the fuels are reduced further to a less than 7.5 t/ha then suppression with hand tools is effective under weather conditions of very high fire danger. Under extreme conditions, provided there is sufficient fuel to carry fire, fire suppression by any means is virtually impossible because the strong dry winds associated with conditions will cause burning embers to breach any fire line. Nevertheless the result of the light fuel load will reduce the rate of spread of the fire and the area burnt so that the fire suppression task will be easier when the weather conditions ameliorate.

A similar relationship between fire intensity, forest fire danger and the effectiveness of direct suppression with air tankers or bulldozers is shown in figure 16.

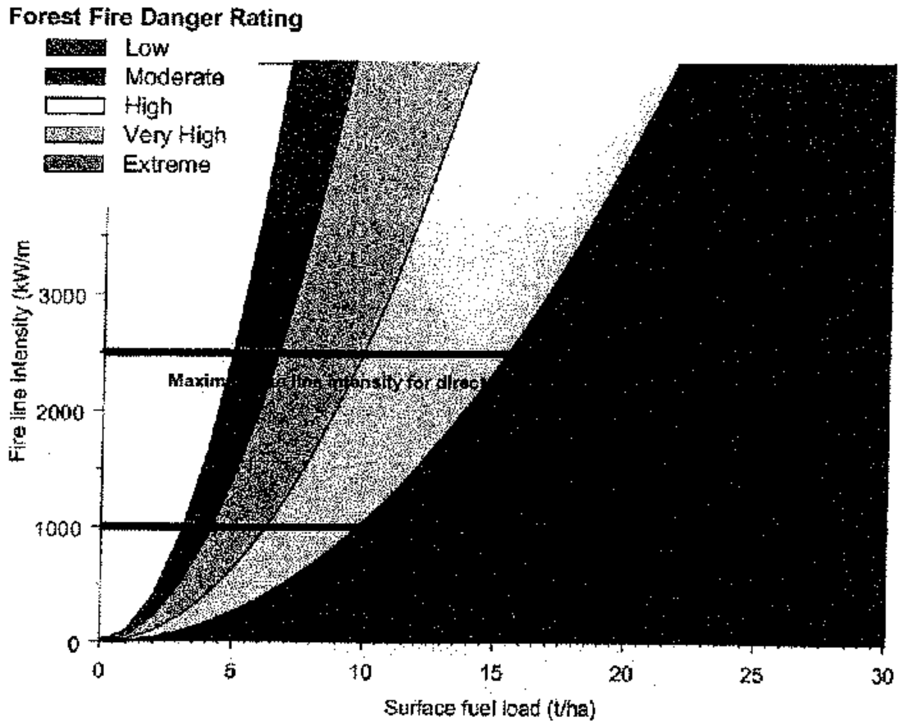


Figure 16. Surface fuel loading and fire line intensity at different forest fire danger rating classes. Top black reference line is the maximum fire line intensity for effectiveness of direct suppression with air tankers and bulldozers..

Application of prescribed burning

There is a perception among people unfamiliar with forest fire management that prescribed burning is simply lighting fires to burn-off the undergrowth and that this can be carried out with only a basic understanding of fire behaviour. Indeed, where burning-off has been one has been carried out in this way the results have been less than optimal and has resulted in injury and death (e.g. Kur-Ring Gai National Park 2000). Like any land management operation, prescribed burning requires setting clear priorities and objectives, planning, and the application of technical guidelines to meet those objectives. In general terms of the process of conducting a prescribed burn is as follows:

set the objectives and desired outcome for the fire.
determine the fire intensity and the associated heat pulse that is required to meet that objective (in forestry and for fuel management this may be determined by an

acceptable height of scorch on the overstorey canopy or an acceptable level of heat damage to the cambium of regenerating trees).
Determine the level of fire behaviour that will produce this heat pulse for the particular fuel type.
Determined the weather conditions and the ignition pattern that will produce this fire behaviour.
Light the fire in a planned way and confine it to a predetermined area.

The key to conducting the operation is a good fire behaviour guide that predicts fire behaviour in the selected fuel type. In Western Australia, the Department of Conservation and Land Management has been conducting prescribed burning to meet fire protection, forestry and ecological objectives in a scientific way since mid-60s. The planning process starts seven years in advance of each prescribed burn. Individual burning guides have been developed through empirical research for all their major fuel types including dry jarrah forest, tall wet to Karri forest, conifer plantations and Mallee shrublands.

In the eastern states prescribed burning is largely carried out using rules of thumb based on a MacArthur's original burning guide for dry eucalypt forests produced in the 1960s (MacArthur 1962). Only one has specific new burning guide has been developed and that was for burning under young regeneration of silver top ash in New South Wales State Forests (Cheney et al 1992). Clearly, if prescribed burning is to be conducted in a more professional way in New South Wales there is an urgent need for new and better burning guides that can be applied to a whole range of different fuel types.

Advances in fuel management

The development of more sophisticated burning guides requires a better understanding of fire behaviour in fuels of different structure and composition. Recent work by CSIRO (Project Vesta (Cheney et al 1998, Gould et al 2001) -- work in progress) has identified the importance of fuel structure in determining fire behaviour and has developed a system for quantifying fuel structure with a numerical index that can be used as a fuel predictor variable to replace fuel load.

Although fuel structure is difficult, if not impossible, to measure reliably and consistently, all natural fuels can be divided to easily recognisable layers. It is the characteristics of these layers that determines the particular fuel type and its characteristic fire behaviour and the difficulty of suppression.

For example, the simplest fuel type is annual grassland like wheat. This is a single layer of relatively uniform compaction. The main factor that determines rate of spread is the continuity of the grass. Although the height of the sward the affects the flame height and thereby the suppression difficulty it has only a minor effect on the rate of spread.

A perennial grass like *Poa* sp.tussock as a compacted layer near the ground commonly 20 cm high composed of the tussock base and accumulated in dead material from previous year's growth, and a less compact layer of a bright grass stalks and leaders and flower heads above. The layer of a upright grass burns before the compacted lower layer and its continuity also is the main factor that determines rate of spread. The fuel load, which is mostly made up of the compacted fuels, does not influence the rate of spread because it burns well behind the leading edge of flame. It does influence the suppression difficulty because more water and effort is required to extinguish the compacted fuel and the smouldering combustion within the tussock.

A dry eucalypt forest was a tall shrub understorey has fuel that can be identified into several layers of different compaction. These are in order of decreasing compaction:

a compacted surface litter bed of leaves twigs and bark that makes up about 60 percent of the total fuel load.
A near surface layer above it of the low shrubs containing suspended litter and bark.
An elevated layer of tall shrubs.
An intermediate layer of small trees and the fibrous bark of the over story trees.
The canopy of the over story trees.

All of these layers make an important contribution to the fire behaviour and each layer becomes progressively involved in fire as the intensity increases. The hazard rating system developed by CSIRO takes into account the height continuity and a fraction of dead flammable material in each layer. The most forests the delay of that appears to be most important in determining fire spread is the near surface fuel layer and the best fuel variable for predicting the rate of spread is an index based on the hazard score and height of the near surface fuel layer (Project Vesta – work in progress).

As fuels accumulated over time the development of each layer is co-related and the pending on the composition of the understorey different layers may present a greater or lesser hazard at any one time (see Figure 17). Figure 17 illustrates four different fuel layers- surface fuel loading, near-surface fuel hazard score, elevated fuel hazard score and overstorey bark hazards scores and the rate of change since last burnt i.e. function of age. Each of these four fuel layers reach it steady state of fuel accumulation and fuel hazard rating up to 7 to 10 years of age.

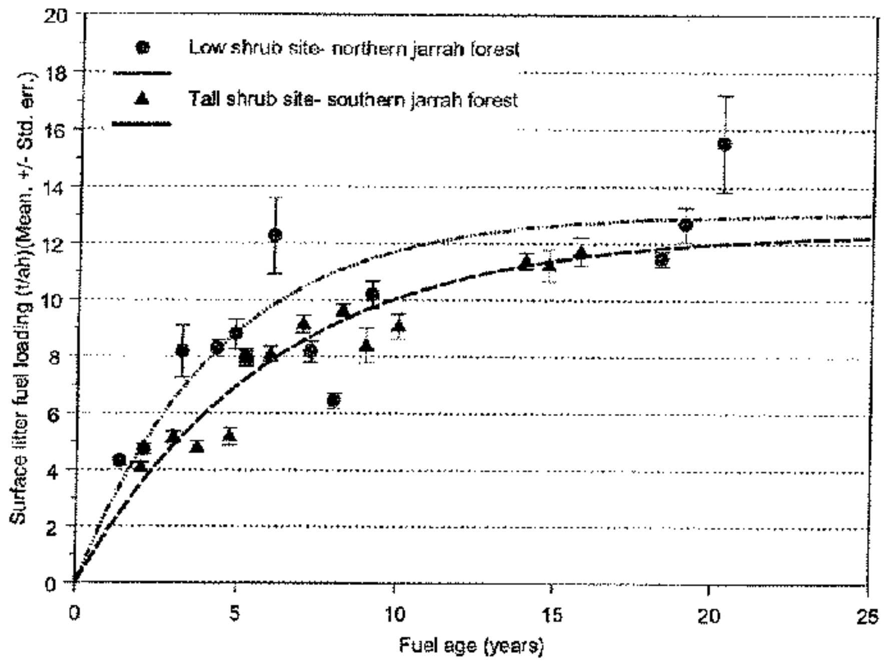


Figure 17a Surface litter fuel loading for two jarrah forest types as a function of age from Project Vesta experiments in Western Australia.

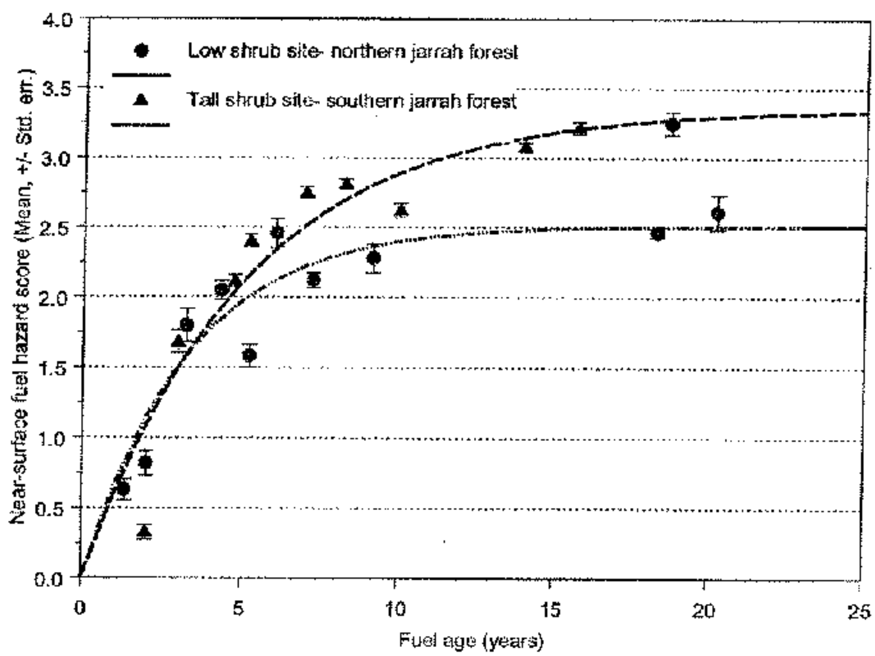


Figure 17b. Near-surface fuel hazard score for two jarrah forest types as a function of age from Project Vesta experiments in Western Australia.

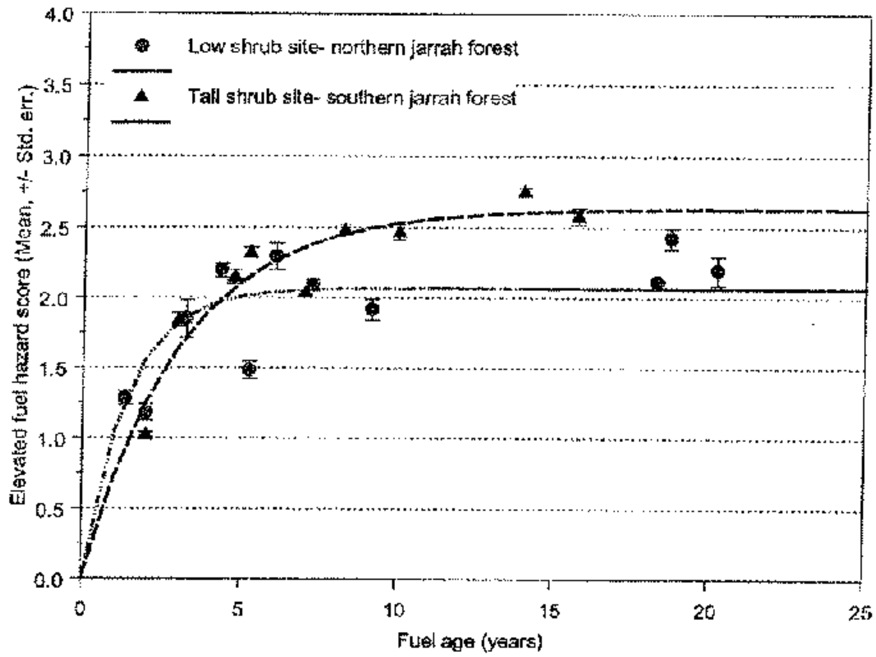


Figure 17c. **Elevated fuel hazard score for two jarrah forest types as a function of age from Project Vesta experiments in Western Australia.**

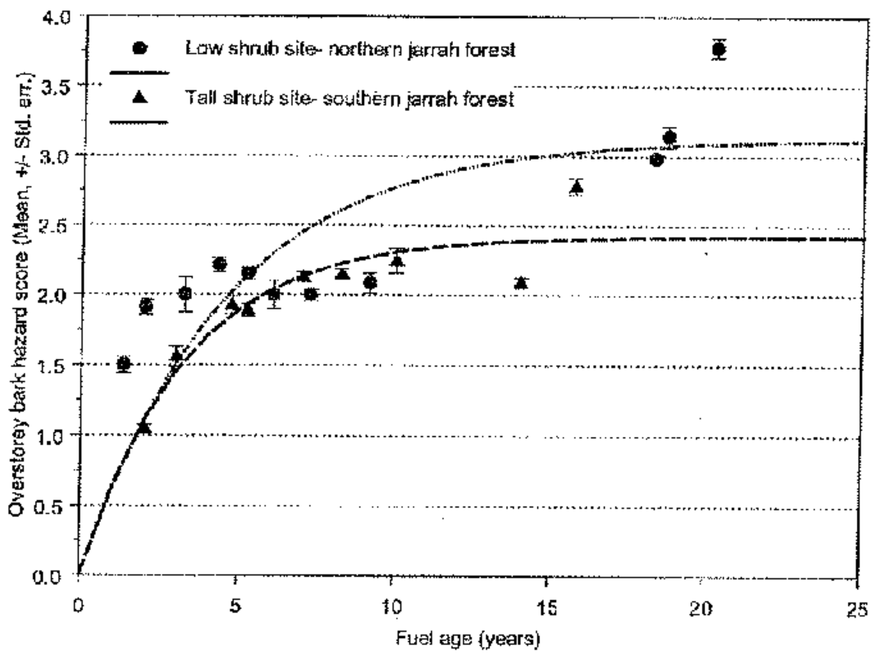


Figure 17d. **Overstorey bark hazard score for two jarrah forest types as a function of age from Project Vesta experiments in Western Australia.**

The period that fuel reduction remains effective to assist suppression depends upon the number of fuel layers involved, the rate of accumulation of fuels and the time that it takes for the key layer to build up to its full potential hazard for the site. This may be relatively short time for fuels with a simple structure or take many years in more complex fuel types – see Table 5.

Table 5. Period that fuel reduction burning will assist suppression activities and the main factors that contributing to difficulty of suppression.

Fuel type	Persistence of reduced fire behaviour (years)	Factors contributing to difficulty of suppression
Annual grass	1 (year of burning)	
Tussock grassland	5	Development of persistent tussock fuel
Tall shrubland	10 - 15	Height of shrubs accumulation of dead material (ROS, flame height)
Forest, short shrubs, gum bark	10 – 15	Surface fuel, near-surface fuels structure (ROS flame height)
Forest, tall shrubs, stringybark	15 - 25	Near- surface fuel, shrub height and senescence, bark accumulation (ROS, flame height, spotting potential

Although prescribed burning may persist for a considerable time most fire management agencies consider that sufficient fuels have accumulated after 5- 8 years to warrant re-burning.

Prescribed fire as a management tool for biodiversity

Biodiversity and Time-since-fire

Generalizations as to the patterns of plant species richness to be found after fire in forests must be seen as hypotheses only at present (Gill, in press). Methods and time scales used may affect the results and there is a need for many more case histories having regard to species characteristics and homology of sites. There are likely to be many variations in patterns according to species' characteristics (*e.g.* see Noble and Slatyer 1981), soil fertility, regional floral contexts and site histories. Non-vascular plant patterns need further study, the few data available suggesting a rise in richness with time after intense fire (Wark 1997).

Several patterns have been observed for the numbers of vascular-plant species to be found at different times after fire in Australian ecosystems (see Gill, in press). The most common one for the drier eucalypt forest was one in which the numbers of species to be observed after a short recovery period were more or less constant, or slowly declined, for the first decade or so (Christensen and Kimber 1975; Bell and Koch 1980; Purdie and Slatyer 1976; Venning 1978). This pattern may be repeated in wetter eucalypt forests too (Ashton and Martin 1996a). In south-west Karri forests the number of species can increase quite substantially soon after fire (Christensen and Kimber 1975). Tall open-forests can also be colonized by rainforest species causing, over time, a turnover of species (Ashton 1981a) and a net decline in the number of species present in cold climates (see Gill in press). Burned rainforests could return to rainforest or be displaced by eucalypt forest (Noble and Slatyer 1981).

In the south-east (central Victoria) in a detailed study of plots examined for over a decade, Ashton and Martin (1996a) found a shift in dominance of both canopy and understorey species after fire in a 74 year old stand of *E. regnans*, *E. cypellocarpa* and *E. obliqua*. Three native ephemeral species of a total of over 60 species present appeared for at least a few years after fire. Pre-fire mosses took 6-8 years to return to the site. After 50–100 years some species of vascular plants may be expected to be present only as seeds in the soil (Ashton and Martin 1996b).

Species numbers (richness) are not the only objects of post-fire studies. Thus the numbers of individual plants of a species can be tracked as a function of time since fire (Tolhurst and Oswin 1992, Ashton and Martin 1996b) also. The patterns in density with time will vary according to patterns of germination (and processes like suckering) and mortality and these, in turn vary according to the characteristics of the species and the effects of fires (see above). Thus a species able to disseminate seed and establish in the intervals between fires (some *Callitris* species) will show a different pattern to a species with hard seed stimulated to germinate by fires with appropriate properties (like many *Acacia* spp.) but unlikely to regenerate at other times. Shrub species with regenerative properties stimulated by fires will show a marked increase in density soon after fire followed by a progressive decline with time due to thinning. Height and cover may show a similar pattern with time but shrubberies may collapse eventually to leave only a short, sparse understorey. Examples of this are to be found in open forest with *Pultenaea muelleri* (Gill 1964 and subsequent observations) and in tall open forests of Karri with *Bossiaea* understorey (L. McCaw, personal communication).

The development of a "habitat complexity score" has provided a way of describing habitats of mammals and birds. The score was plant-species independent. Newsome and Catling (1979) based their score on the tree canopy coverage, shrub canopy coverage, ground herbage, cover of rocks and debris and general soil-moisture condition. Most of these variables are affected by fires. As time after fire increases, the tree canopies may re-establish (if affected) and shrub canopies may thin after a period of proliferation. After fire on heathland and in adjacent forest, the abundance and species richness of small mammals increased as habitats aged and grew in complexity (Catling 1986). Survival and recovery was best on the sites of the most structurally complex habitats. However, although there were major positive and negative changes in abundance and even local extinctions, on a larger scale and in the long term, mammal species richness changed little (Catling and Newsome 1981).

The abundances of birds and species richness are highly correlated in eucalypt forests (Recher 1985; R. Lloyn, personal communication). The complexity of forest structure and bird numbers are also related, the more complex the structure the more birds (Recher 1985). Thus, as complexity of the forest changes over time so too will the abundance and species richness of birds. The extent of change will vary according to the immediate effects of fire and the subsequent rates of recovery of food sources and structure (Christensen *et al.* 1985). Lloyn (1997) found that, after an initial dip in the population, numbers increased for the following three years of the study. Similarly, Christensen *et al.* (1985) found increased numbers of bird species compared with an 'unburnt' area for three years after a fire. Following an intense fire in tall open-forest in the Australian Capital Territory species composition stayed constant but abundances changed (Catling and Newsome 1981).

Biodiversity and Fire Intervals

In a landscape with a mean fire interval of, say, 100 years there may be patches that have not burned for 500. There may be areas in which fire intervals have been very short and in which species have been eliminated. Vulnerability to extinction will be great where intervals have been short and fires large (reducing the chances of effective dispersal). If the area is large enough and dispersal processes natural then the expectation is of a pattern of occupancy and extinction, population boom and bust and greater and lesser herbivory according to the fire history of each point and the nature of the plants and animals in the landscape. We do not know much of the effects of the occupancy of the southern forests by Aboriginal people but by understanding the responses of the biodiversity found in temperate forests, and the nature of the disturbance regimes, a great deal of reconstruction may be possible.

Estimates of mean fire intervals in tall open-forests have varied from 35-80 years in tall open-forest in Central Victoria (McCarthy, Gill and Lindenmayer *in rev.*) to 300 or more for stand-replacing fires in tall open-forest in northern NSW. Busby and Brown (1994) suggested that the mean fire interval in a Tasmanian closed forest was 300 years but we suspect that the mean interval will vary widely between closed forests in different places. Mean fire intervals in open-forests may be expected to be lower than those in other temperate forests (Ashton 1981a) and be, perhaps, of the order of 10-20 years (Duncan and Brown 1995).

Short intervals between fires may eliminate some species. Plant-killing fires within the juvenile period (time to flowering) of 'seeder' species will eliminate them unless seed dispersal into the area is effective after the short inter-fire interval. Local extinction is to be expected in parts of the ranges of such species. Some, but not all, species of *Eucalyptus*, *Hakea* and *Banksia* could be affected in this way. There are few specific instances. *E. regnans* has a juvenile period of about 15-20 years (after Ashton 1981b) but juvenile periods of common *Hakea* and *Banksia* species would be expected to be of the order of 5-6 years (after Bradstock and O'Connell 1988). Arguably, the closed forest Tasmanian endemic, *Athrotaxis selaginoides*, has a juvenile period the order of 100 years (see Gill 1994). Of course, the 'sprouter' species are less prone to extinction (Gill and Bradstock 1995) because they can survive one or more fires. That does not mean they are not at all vulnerable because fires at intervals shorter than the time for seedling or sapling survival, repeated often, will mean that the adult population can be whittled away and all recruitment fail (Bradstock and Myerscough 1988). High intensity fires may cause mortality in plant populations of some 'sprouter' species.

Fires at intervals too long to allow for the persistence of propagules in the ecosystem could cause local extinctions. The most obvious case of this is where *E. regnans* exceeds its longevity; the understorey of these forests is too dense to allow any regeneration between fires (Ashton 1981a). For species with long dormant seed like *Acacia dealbata*, plant populations may die out but the species persist as seed in the soil; germination is ineffective then until a fire with suitable characteristics allows germination and seedling establishment. Long fire intervals can enable the accumulation of peat which does not necessarily burn every time there is a fire. When all propagules reside in the peat, and the peat burns, then dramatic changes may occur in the sense that all plants present – of any response type – may be killed and re-establishment take many years (Wark 1997). Peaty or humus substrates may occur around the bases of big trees and cause their demise when ignited (Cremer 1962, Ashton 1981b).

Season, intensity and frequency impacts

The conclusion drawn from the data presented below on the components of the fire regime (season, frequency and intensity) and their effect on the vegetation was that over time major changes could be imposed on the vegetation depending on the regime. This in turn has implications for the fauna.

A change in the season of burning can alter the vegetation composition and structure. Spring fires in southern Australia enhance shrub regeneration and autumn fires enhance herbaceous species regeneration (Baird 1977; Christensen *et al.* 1981). By enhancing shrubs, spring fires should, in the long term, increase structure and autumn fires, by enhancing herbaceous species, should reduce structure. A further important point concerns the vegetation along gullies and drainage lines. In Western Australia (and most likely also in south eastern Australia), if sclerophyll forest is burnt in spring on a 5-6 year cycle, the moist gully vegetation will burn only every second or third rotation (every 10-15 years), whereas fires in autumn, when it is drier (the usual prescription in both regions) also burn the gully vegetation every time (Christensen et al. 1981).

Fires do not burn evenly. Localised variations in fuel and topography are two factors which influence fire intensity. During a low intensity fire some understorey shrubs are damaged but there is little scorching of the tree canopy, and stands of seed-regenerating shrubs belonging to families such as Myrtaceae, Casuarinaceae, Proteaceae and Leguminoseae do not germinate (Christensen et al. 1981, Gill 1983). Leigh et al. (1987) studied two low intensity fires and found reduced shrub cover and total biomass of shrubby and herbaceous species, exposure of soil, invasion by alien species, and stimulation of grass seed production. Intense fires (over 3500 kw m^{-1}) usually defoliate the tree canopy, destroy the understorey shrubs and totally remove the forest floor cover (Fox 1978, Cheney 1981). Such fires result in prolific regeneration of scrub and coppice forest (Pryor 1939; Rowe 1967; Catling pers. obs.), seed-germinators (Christensen and Kimber 1975; Purdie 1977), vegetatively-regenerated species (White 1971) and nitrogen-fixing plants such as the native legumes (Shea and Kitt 1976). Fox & Fox (1986) examined two high intensity fires six years apart. They concluded that fire frequency was the reason for the increase in the number of plant species, shrub density and cover, but the influence of high intensity would swamp any effect of frequency as they studied two fires only. Two fires at low intensity would produce a different result as found by Leigh et al. (1987). In summary, low intensity fires by reducing the shrub cover appear to reduce forest structure and high intensity fires increase structure.

Fire frequency can be linked with fuel accumulation rate which is determined by rate of litter accumulation and the species composition of the community (Christensen et al. 1981). For dry sclerophyll forest it is as little as 3 to 4 years. Regular fire converts a multi-layered understorey to a single layer (Gilbert 1959), and sites burnt frequently have a grass-type or herbaceous understorey (Bradfield 1981; Hodgkinson and Harrington 1985; Bradstock 1981) or a dominance of monocotyledons and fern species (Gill 1975) compared with those burnt less frequently, which support a shrub type understorey (Gill 1975, Bradfield 1981; Christensen et al. 1981; Gill 1983; Whelan 1983). Frequent fires, i.e. less than every 5 years, appear to decrease forest structure and complexity, but with a low fire frequency shrubs will grow, litter will accumulate, gully vegetation will remain intact for longer and nitrogen-fixing legumes will be enhanced.

However, there may be differential effects of frequent burning on plants and animals. Species richness and diversity (of some invertebrate groups) can be reduced markedly in the absence of fire, and promoted with frequent, low intensity (< 500 kW m^{-1}) fire in some ecosystems, such as dry sclerophyll forests in southeast Queensland (Vanderwoude et al. 1997). Intensity and season of burning is likely to be important in moderating these effects.

The long-term effects of fire on other ecosystem properties such as nutrient status may depend on soils and vegetation as well as fire regime. Contrasting impacts of repeated prescribed burning were found by Guinto et al. (2001) between dry sclerophyll and wet sclerophyll forests in southeast Queensland - annual burning for more than 40 years had not resulted in any loss of topsoil nitrogen in the dry forest, but burning every 2 years for 22 years had reduced nitrogen by more than 40% in the wet forest. Such changes could have significant impacts on plant growth in the longer term if replenishment through nitrogen-fixing legumes is insufficient.

Single objective vs. multiple objective planning

In National parks and Wilderness areas the primary management goal is conservation of the natural ecosystems. Fire management plans consider fire in terms of required intensity, aesthetic values and the susceptibility of natural communities. However, frequent, low intensity prescribed fires are carried out in the vicinity of dwellings and camping areas to protect life and property (NSW National Parks and Wildlife Service 1979). In State Forests and on private land where the aim is to protect the timber resource, frequent, low intensity prescribed fires to reduce the fuel load are applied more often and more widely to reduce the incidence of high intensity wildfires (Cheney et al. 1992).

In an attempt to provide favourable habitat for all wildlife species, managers have traditionally maintained each vegetation community as a mixed-age stand or mosaic in the belief that this would provide a diverse range of ecological niches (NSW National Parks and Wildlife Service 1979; Department of Conservation and Land Management, Western Australia 1986; Griffin 1984). As knowledge of fire effects on individual wildlife species is accumulated, more direct, species-specific approaches to management become possible. Consequently, while fire management strategy will remain a compromise between competing objectives (Underwood and Christensen 1981; Sneeuwjagt 1989); not only between the requirements of different species or species groups, but also between the 'non-wildlife' fire management issues, it will increasingly aim at achieving species-specific objectives. To adopt a species-specific approach, managers must not only understand and predict fire effects on the selected species, but also monitor species population levels as they respond to habitat change. In that way, decisions to prescribe fire, or not, may be soundly based. Monitoring programs are essential, but are limited by resources, although techniques for minimising data requirements are becoming available (Gill and Nicholls 1989).

Hazard reduction vs. biodiversity trade-offs

High intensity wildfire and most prescribed fires are at opposite ends of the fire regime. As mentioned above the fire regime has three main components: intensity (how hot it is), frequency (how often it burns) and season (autumn, winter, spring, summer). There are many combinations of intensity, frequency and season (the fire regime), and species may be adapted to a particular fire regime but not to fire per se (Gill 1975). Basically, there are two fire regimes which dominate in the forests of southern Australia - infrequent, high intensity fire in summer (wildfires) and frequent, low intensity fires in autumn (prescribed fires). Over 150 bird species and 10-20 mammal species are wholly dependent on forest for their survival and a widespread major change could threaten that fauna (Tyndale-Biscoe & Calaby 1975). Change to the fire regime is one such major change.

The effects of fire on wildlife support the concept that no one fire regime is optimum for the fauna as a whole (Braithwaite 1987), rather several fire regimes are necessary if conditions favouring different species or species assemblages are to be met (Christensen and Kimber 1975; Good 1981, 1984; Catling 1991). Fire recycles nutrients, but resultant effects on animals must be mediated by the plants. In addition to food, the vegetation provides favourable microclimates, as well as home sites and refuges from predation. Newsome and Catling (1983) present indicative models of animal demography in relation to fire and shortage of food. They concluded that there was a complex range of responses of fauna to intense fire and there was no one response or sequence of them. Complexities arise due such factors as differences in life histories, longevities, diets and the type of shelter required, and that predation was probably the most complicating factor (Newsome and Catling 1983)(see above also.

High intensity wildfires and prescribed fires

Wildfires are those which burn at very high intensity and are generally out of control; the Ash Wednesday fires in Victoria, the 1994 fires in New South Wales and the recent ACT fires are examples. They usually occur on days of extremely high temperature coupled with strong winds. In southeastern Australia most wildfires occur in spring and summer and the region is one of the most fire-prone in Australia (Luke and McArthur 1978). Prescribed fires are of low intensity and are lit deliberately by management agencies with the aim of reducing the biomass of vegetation in the understorey and the amount of litter on the ground to help prevent wildfires. As a general rule they are burnt in autumn when forests are drier (Anon 1977) and when burning logs are less likely to cause other fires as the weather is becoming cooler and moister.

Catling (1991) examined the two extremes of the fire regime and found that occasional high intensity fire would encourage the growth of a dense understorey, whereas frequent low-intensity burns would reduce and eventually eliminate the dense understorey. Several studies have associated changes in the complexity of forest structure with fluctuations in the abundance of small mammals (e.g. Braithwaite and Gullan 1978; Recher *et al.* 1980; Catling and Newsome 1981; Lunney *et al.* 1987), birds (e.g. Recher and Christensen 1980), and for medium and large mammals (e.g. Newsome *et al.* 1975; Catling and Newsome 1981; Lunney and O'Connell 1988). In general, many native mammals are more abundant in forests with a dense understorey (Catling *et al.* 1982; Lunney *et al.* 1987).

The mammals of southeastern Australia considered to be advantaged or disadvantaged by simplifying the forest structure (as described for a typical prescribed burning regime) were tabulated (Catling 1991). There were 25 species (13 native, 12 introduced) which were considered to be advantaged and 26 (25 native, 1 introduced) which were considered disadvantaged. One major contrast emerged: many native species were disadvantaged, and many exotic species were advantaged. Native species considered advantaged included those which frequent open or grassy habitats, e.g. eastern grey kangaroo. Species considered disadvantaged frequent dense understorey, e.g. long-nosed potoroo, or require understorey shrubs for food and possibly cover, e.g. sugar glider. Species considered unaffected were those which rely solely on eucalypts, e.g. koala, or mainly on rainforest, e.g. red-legged pademelon or heathlands, e.g. heath rat.

Monitoring the Effects of Burning

The practice of control burning in reserves needs to be investigated in terms of its long term environmental impact on plant species and vegetation types. In the short term, any burns undertaken should be seen as a form of experiment which can be used to assess not only the effects on plant species and vegetation types but also the effectiveness of control burns in relation to their aim of minimising the severity of future fires. To this end, before and after information on species composition and cover abundance as well as fuel load before and after fires should be collected. Control plots of similar structure and floristics could also be established for each type that is burnt. Replication of treatment and control plots is also desirable. The time taken to establish this system should not be prohibitive, and many existing permanent plots (or a subset) could be incorporated into this framework as could fuel monitoring plots. An example of a simplified approach to the monitoring of fire-prone flora in reserves is given in Gill and Nicholls (1989) where sites are considered to be safe from extinctions after all species have flowered post fire and a conservative amount of time has elapsed for the build of soil stored seed reserves. It is important to stress that it is unwise to conclude that no species will become extinct after observing the restoration of species numbers after one fire (Gill and Bradstock 1995). Bradstock, Keith and Auld (1995) contend that there is a threshold in fire regime variability that demarcates a critical change from high species diversity to low species diversity and advocate a flexible management system where active use of fire is discretionary, only being required when fire regime variability tends to uniformity with a potential for reduced species diversity. The use of fire at regular intervals is to be avoided at any given point, although other parts of the landscape may be burnt at any given time. Each site will have temporal variability in fire regime while the reserve as a whole will have spatial variability in fire regime. It is recognised that property protection may require more frequent strategic burning in some areas particularly on the edges of reserves, but it must be recognised that there is a potential environmental cost associated with this practice and that broad acre hazard reduction burning is not necessarily compatible with nature conservation objectives.

Ecological Restoration following Fires – Major Issues

Survival of Flora and Fauna after a fire

While much public concern over the fires relates to the survival of individual organisms, it is the survival of populations and ultimately species that is of importance to biodiversity conservation.

Fauna: animals can in many instances avoid fire fronts. However, the more extensive and intense the fire, the less this is likely to be the case. Where animal populations are locally depleted, they must re-establish from adjacent un burnt, or less severely burnt habitat, over time. As different habitats regrow after a fire, different suites of species may be found.

Flora: plants, being immobile, have two strategies when faced with fire. They either survive the fire and resprout or else the parent plant dies, but is re-established from canopy or soil stored seed. The majority of species in the areas recently burnt will re-sprout after even such intense fires.

Potential Major Issues and Likely Strategies:

Local Extinction: for those species which cannot resprout after a fire, or which are restricted to specific habitats, the interval between successive fires is critical. If another fire occurs before such species have re-established and set seed or built up local populations, local extinction may occur. Hence the effect of the current fires could be manifested in one of two ways: a) on populations which have experienced a fire quite recently before this current event, increasing the likelihood of local extinction and b) on populations which may experience another fire soon after the current event, increasing the likelihood of local extinction. The majority of the area recently burnt is unlikely to fall into either category, although some specific species or rare communities will be of concern to land managers. Fire protection via strict exclusion in the short to medium term is one way of decreasing this risk.

Weeds: although perceived as a problem in some areas, weed invasion is unlikely to be an issue over the majority of the areas burnt. Those areas previously weedy are likely to remain so; areas which were not weedy are not likely to become so. Essentially, the species there before the fires are likely to be the dominant species over time after the fires. This is unlikely to be a major issue. However, the bulldozer tracks and other major soil disturbances created during back burning/suppression operations may increase the risk of weed invasion. Rapid return of topsoil, combined with active revegetation of these areas, in the weeks following the fires, is one strategy to minimise this risk.

Feral Animals: one potential issue is increased predation on native animals by feral

predators due to the lack of suitable cover or refuge, the potentially weakened condition of the animals and the general scarcity of available food. However, the effect may be moderated by a decrease in predator populations and in some cases, the temporary eruption of alternative food sources. An increase in baiting and trapping of feral predators is one strategy to minimise this risk.
Soil Erosion / Decrease in Water Quality and Yield: if heavy rain falls too soon in the affected catchments, there is a potential for ash and mineral soil to run off causing erosion and siltation of water supply areas. Additionally, the re-growing forests may reduce water yields in the short to medium term. Depending on the area of concern, there are a number of possible scenarios. If the area burnt is swampy, it is likely that these swamps will recover quickly via resprouting and still remain as buffers in the catchment. In steeper, wooded terrain, there may be less buffering capacity of such swamps and erosion may remain a potential problem. Similarly, if the tree species in the catchment are generally re-sprouters, the period of time to regain their canopy will be less than in those areas where the canopy species have been killed and need to re-establish from seed, and hence the water yield implications will be different. In either case, there is very little that is able to be done other than monitor the regrowing vegetation and hoping that rainfall is gentle or moderate rather than torrential. In the upper catchments, thousands of hectares of sensitive, treeless alpine and subalpine vegetation has been burnt. Cattle, however, graze some of these landscapes in Victoria. In the most extensive treeless communities at or above treeline - the grasslands, herbfields and heathlands – regeneration will be hastened, and hence the risk of soil loss reduced, by removing grazing. Bogs have also been burnt. These ecosystems filter water, and regulate its flow, and hence provide an essential ecosystem service. Following fire, regeneration in these ecosystems is slower than in grasslands and heathlands. Where fire has exposed peat, there is an increased risk of channel entrenchment and hence drying and retraction of the bogs. Grazing by livestock exacerbates channel entrenchment. Thus, in the Victorian Alpine National Park, livestock must be excluded from the whole alpine landscape. Limiting public access to, and removing grazing from, sensitive areas, especially at high altitude, will be an important short term strategy.

Despite some potential major issues, there is very little humanly possible to positively assist in the restoration process after the fires, other than those programs targeting the recovery of specific rare or threatened communities or species.
What is generally desirable is the establishment of post fire monitoring systems for flora, fauna and landscape variables that will enable us to learn as much as we can from what may be a relatively rare, in human terms, event.
The restoration process will be carried out primarily via the inherent resilience of the ecosystems that have been burnt. Vegetative cover and fauna habitat will be re-established over time, but the rate will vary across the landscape based on fire intensity, initial conditions and most fundamentally, the post fire weather.

Fire and the urban environment

It is well understood that under certain weather conditions conventional suppression activities can not prevent a bushfire reaching the urban interface, and that fuel reduced zones are able to propagate the bushfire front under the more extreme of these conditions. Thus it is imperative that the communities living at the urban interface are knowledgably and well prepared for bushfire impact.

There are many strategies that can be adopted to reduce the risk to life and property at the interface and it is clear that one generic approach is not suitable for all areas. It is also important to note that there are many value systems to be considered. The ideal outcome is one were the community understands the real risk of bushfires and voluntarily adopts strategies to minimize this risk with due consideration of all the other values systems that are important to them.

Building standards and survivability

Our research initiatives are focused towards giving the community the relevant information to assess the risk and a wide range of methodologies to reduce this risk. Until this broad community understanding is achieved it is necessary to implement minimum building performance requirements for the urban interface. However these should not prevent well informed members of the community creating their own unique solution to living with the risk of bushfire. AS3959 'Building in bushfire prone areas' provides this minimum requirement.

Risk assessment and management

To date there has not been a formal risk assessment methodology developed the for bushfire impact on urban areas. The bushfire CRC provides the framework and interdisciplinary links the develop this.

Community involvement and preparedness

There is considerable misunderstanding by the general public on the nature bushfire attack and the risks associated therewith. Investigations into the outcomes of past bushfire attacks have indicated that these misunderstandings have led to much unnecessary loss of property and injury. Methods of house construction and vegetation control can have very beneficial effects on saving property and reducing risk to life. However as there are numerous complex parameters associated with these effects, it is necessary that they be accurately quantified if an optimum choice is to be made between risks, costs and amenity. In addition, it is now accepted that there can be considerable benefits in saving property if a building owner stays to defend their house or returns soon after the fire front has passed; however the decision to stay can involve major risks to the people involved, and hence any advice to stay needs to be based on a sound knowledge of the hazard involved. Advice concerning decisions as to whether to stay and fight the fire is often the responsibility of various fire fighting and other government authorities and a sound fire knowledge is of extreme concern for them

Key Issues relating to the urban interface:

There is widespread community belief, reinforced by the news media, that bushfires move at the speed of express trains, that houses explode into flames and burn down in minutes, and that there is not much that can be done to prevent it. Scientific research into the behaviour of houses under bushfire attack has shown otherwise.

It is believed that the majority of houses destroyed in bushfires actually survive the passage of the fire front, only to burn down during the next few hours due to fire spreading from ignitions caused by wind-borne burning debris. Whilst direct flame contact and radiant heat also play a part in the ignition and destruction of buildings, these mechanisms are significant during the few minutes it takes for the fire front to pass. Showers of burning debris, on the other hand, may attack a building for some time before the fire front arrives, during the passage of the fire front and for several hours after the fire front has passed. This long duration of attack, to a large extent, probably explains why burning debris is a major cause of ignition of buildings, though this has not been adequately quantified at this stage.

It has been found that burning debris can ignite buildings in a number of ways. It can:

with other wind-borne combustible debris, pile up against combustible materials used at or near ground level such as stumps, posts, sub-floor enclosures and steps
accumulate on combustible materials used for decks, verandas and pergolas,
Lodge in gaps in and around combustible materials used for exterior wall cladding, and window and door frames and
gain entry to the interior of the building through widows broken by radiant heat or flying debris. Once inside the building the burning debris might possibly ignite furniture, fittings and other contents.

If these small ignitions are not extinguished they can grow to involve the whole building. It has been found that people who are well prepared and who return to their houses after the passage of the fire front can, in many cases, successfully save their houses without endangering their lives.

Survey work has revealed that many houses are ignited from radiation and flame contact from adjacent burning buildings or features such as timber fences. The duration of the radiation exposure from an adjacent burning structures may be for a significantly longer period (an hour or more) than the fire front itself (a few minutes).

With so many variables impacting on the survivability of buildings in the urban/rural interface, current advice is based on less research than is desirable for such an important aspect of our environment.

Vegetation

The fuel load, landscape and features in the area surrounding a building govern the magnitude of the radiant heat and flame contact the building is likely to be exposed to. It is thus desirable to have a fuel-reduced area around a building to reduce the level of hazard. The practical extent of the fuel-reduced area depends on the type of vegetation, slope of the land and its aspect. Further research into the appropriate size of this area under different conditions is required. The management of existing vegetation involves both selective fuel reduction (removal, thinning or pruning) and the retention of vegetation of low flammability, which may have beneficial effects by acting as windbreaks, radiant heat barriers and ember traps. Further work is planned by Griffith University to develop a reliable list of plant varieties of low flammability for use around buildings and as fire breaks.

Building design

It is important to determine whether a building will trap embers, and if so, whether those trapped will be in sufficient quantity and location to cause ignition of the building. Furthermore, it is important to know whether those ignitions will lead to continue burning and the destruction of the building. Very little work has been done to clarify these issues.

Windows

Windows are the most vulnerable features of a building exposed to bushfire attack. AS 3959 requires that wire mesh be installed on all opening windows including louvres. This reduces, to some extent, the levels of radiant heat impacting on the glazing and, if the glass cracks and falls away, it can help prevent wind-borne burning debris from entering the building. It is, however, less effective on the inside of hopper or awning windows, it is difficult to fit on non-opening sashes, especially with aluminium windows, and it impairs the view from picture windows.

Shutters can provide superior protection for windows, including protection from objects carried by the wind. Shutters, however, need to be closed to be effective. As well as protecting the glazing, shutters usually cover and protect windowsills. This is of considerable advantage in the case of timber windowsills, which like all horizontal timber elements of a building, are vulnerable to ember ignition.

Glazing options such as wired, laminated or toughened glass can provide enhanced passive protection. Laminated glass (both with thin and thick plastic layers) resists radiation cracking better than ordinary glass but its performance under high heat loads is not known. Whilst there are no published results of research into the performance of toughened glass under bushfire attack, experience suggests that toughened glass should withstand high levels of radiant heat.

Double-glazing, or the use of ordinary glass thicker than is required for a particular window size and wind zone, gives little improvement in window performance against intense radiant heat.

Decks

It has been found that timber decks are particularly vulnerable to ignitions from burning wind-borne debris, due to the large areas of horizontal timber surface they present. These ignitions lead to fire spread on windows and doorways opening on to the deck, allowing the fire to spread to the interior of the house. In the absence of successful fire fighting intervention, this can lead to total destruction of the house. Design alternatives such as suspended concrete decks or decks paved with highly compressed cellulose-cement sheet tend to be considerably more expensive and aesthetically less acceptable than timber decks. Further research is planned by CSIRO to investigate design alternatives to improve the performance of timber decks.

Building cladding and roofs

Previous research found that selection of particular materials for cladding external walls and for roofing did not have a great impact on the chances of a building surviving a bushfire. There are, however, some materials that have been effectively withdrawn from use in these applications on the basis of less-than-scientific information about their potential fire performance. Further research has to be done to clarify this issue.

Other infrastructure elements

A solution for defending buildings often proposed is the use of external sprinklers. The efficacy of these systems in high wind situations is totally unknown.

Domestic supply gas bottles are a common item in the urban/rural interface. They are known to fail catastrophically in bushfires in some cases. They have also been known to flare off and impinge flame onto a building. The extent of the problem relating to gas bottles is yet to be fully explored.

Communications during bushfires can be impacted on by loss of electricity and telephones that result from destruction of the treated pine poles used. The effect of treatments designed to improve the durability of poles has an unknown effect on their response to bushfire.

Information Transfer

Previous survey and research initiatives have given direction to designers, architects and regulators working to improve the performance of buildings in bushfire-prone areas. It has also formed the basis for the building-related components of Australian Standard AS3959 and the associated Handbook.
The CFA and others have addressed education in a number of successful ways, viz.:

Community Fireguard Program;
Educational videos and texts (e.g. Webster 1986);
Broad range of information leaflets;
Television advertisement campaigns;
Brigades in Schools Program; and
Bushfire Blitz meeting program.

Whilst these initiatives are effective, they require constant updating as new information comes to light. It is also necessary that accurate information is made freely available to the public through the most effective means. This might be achieved by strengthening links with the above-mentioned education programs, and incorporating previously purchasable information into freely accessible web based community education programs.

Other initiatives involve the use of product endorsements and the certification of specialised builders and landscapers who can supply appropriate bushfire resistant outcomes.

The research agenda - Bushfire CRC

A Bushfire workshop was held on the 29th of January 2002 at CSIRO Forestry and Forest Products Forestry House in Canberra. This resulted in the following eight priority research areas and, ultimately, to the development of a bid for a Cooperative Research Centre.

Land use planning: Provide better land use guidelines for local, state and national levels of government to assist in urban and peri-urban planning to reduce of the loss of human life, built assets and biodiversity from bushfires.

> Evaluation of policies and programs to help land managers, local government and other landowners in their land use planning to reduce the risk of bushfires. Better ways to use and manage Australian landscape that will minimise degradation and reduce impact of bushfires to communities and the environment is required. Our present systems are not sustainable because of loss of water and air quality, nutrients, and biodiversity. Designing systems that avoid these losses and to manage fire in the landscape to achieve better harmony with the fire in the landscape.

Fuel management: Expand and improve integration of fuel management programs to reduce severe bushfires to protect communities and the environment.

Balancing the positive and negative effects of fuel management programs requires that managers have extensive knowledge about the effectiveness of fuel treatment options and their effects on environmental attributes and resources at multiple scales of effects.

Fire managers have various environmental and legislative constraints to conduct hazard reduction burning and at times consider alternative methods of either fuel treatment or fire suppression. They are obliged to respond to assertions by various interest groups with incomplete and sometimes conflicting information. They need to understand the factors influencing the effectiveness of small and large-scale fuel treatment programs in reducing wildfire extent and severity. This includes quantifying the relative effectiveness of fuel treatment programs, and predicting the probable cumulative and long-term consequences of fuel treatment options.

Fire prediction: Improve the understanding the principles of fire behaviour – the manner in which a fire reacts to the variables of fuel, weather, topography and fire itself that can influence the fire to estimate what the fire will do- i.e. the spread and intensity of a specific fire.

Fire managers from forestry, national parks, rural fire authorities and other land management and fire agencies need to be able to anticipate how a bushfire behaves and interacts with the fuel, weather and topography. They require reliable predictions of all elements of fire behaviour critical for the allocation of fire-fighting resources and implementation of prescribed burning programs.

Fire control officers and fire fighters need spatially-specific predictions of fire spread and fire intensity, which are constantly updated in order to best locate fire fighter resources and avoid dangerous situations. Fire / fuel managers need information on fire severity, potential fuel consumption, and smoke production to better meet land management goals, manage smoke and comply with air quality emission requirements.

Fire control/suppression: Better strategies for integrating all the work and activities connected with fire-extinguishing operations, beginning with discovery and continuing until the fire is completely extinguished.

Fire controllers today must attempt to consider an array of resource, environmental, social, political, economic and fire behaviour parameters when considering and making fire suppression strategies. Through the use of technology such as geographic information systems, expert systems, risk analysis and modelling research can provide ways to improve the availability and usefulness of complex data to fire controllers. Dynamic and simulation models for fire growth, estimates of suppression, damage and rehabilitation cost of different suppression strategies using complex weather, terrain, fuels and resource data will help fire controllers evaluate how well alternative fire suppression strategies and tactics meet their objectives in controlling the fire and the land / resource management objectives. Methodologies to evaluate, predict, and monitor the effects (losses and gains) of various suppression strategies. This includes the ability to predict immediate fire effects on flora, fauna, water, air, etc at multiple scales. It requires improvements in core knowledge about how fire behaviour, fuel characteristics, and environmental conditions influence the ability to predict immediate fire effects. Also, incorporate the uncertainty and risk into analysis of fire suppression options.

Health and safety: Better information, training, incentive and others approaches for improving public and fire fighter health and safety

> Many inefficiencies and injuries in fire management are traceable to human behaviour organizational culture, or sudden change in fire behaviour. Fatigue, organizational factors, and the fire environment (i.e. fuel, terrain and weather) affect the safety, effectiveness and the efficiency of the fire fighter force. Guidelines for line crew supervisors to recognise crew fatigue, stress, dangerous fire situation and improve the safe work practice for the fire fighters.

In addition, the effect of smoke and other emissions on the health of the wider community during either bushfires or prescribed burning are becoming more and more important.

Environment: Better knowledge to assess the effectiveness and environmental effects of fire management programs and fire disturbance patterns at mid-scale and landscape scales.

Many important ecological processes operate at different scale in the landscape over long periods of times. Natural resource and fire/fuel managers need to be able to design strategies that incorporate the role of fire and other disturbances in ecological systems. Knowledge about these interactions can assure that planning land management strategies are feasible and do not assure irreversible losses. There are scientific gaps in theoretical and practical understanding of multiple disturbance regimes- interactions among fire, climate change, insects and diseases, invasive species and others. This includes the cumulative interactions of program levels fuel and vegetation treatment strategies with disturbance processes and other ecosystems patterns and processes.

Land and conservation managers require high-quality science-based information about the impacts of fuel treatment options and wildfires on flora, fauna, water and air. They need air quality information with which to compile air pollution emission and carbon inventories, and smoke haze and, community health exposure assessments, and determine compliance with air quality standards. They also need to assess the impact of hazard reduction programs and wildfire scenarios on the ecosystem and community assets.

The application of prescribed burning and other fuel hazard treatments on public and private land will have environmental consequences that must be anticipated and subject to public notice and review. This should include information about the effects of forgoing fuel treatment, allowing fire-adapted ecosystems to continue under minimal active management and fire exclusion polices. Program choices and tradeoffs can be made most rationally with the use of extensive science-based information on fuel treatment effectiveness on fire hazard and the human health consequences and ecological impacts of fuel treatment alternatives.

People and Property protection: Improved landscape and structural design and maintenance techniques that residents can use to reduce the likelihood of fire damage.

Houses in bushfire prone areas are often not located, constructed, or maintained to minimise the risk of their ignitions when there are bushfires in the surrounding bushland. The levels of protection of bushfire attack (flame, radiant heat, and embers) that cause buildings to be destroyed or damaged during bushfires are poorly understood. Information on specific characteristics of a site, the surrounding fuels and the planned or existing structure to help developers and home owners in construction and maintenance of fire-safe homes in bushland and help them mitigate potential bushfire related problems.

Community education: To reduce the risk of lives and property through prevention education.

A growing number of Australians are choosing to live in urban/bushland areas. These citizens are often unaware of the threat to life and property from bushfires. Without this awareness, individuals and communities will not take preventative actions.

Creating widespread awareness requires clear delineation of interface communities at risk and coordinated efforts by land management and bushfire authorities, local government, and homeowners to inform each other about changing elements of fire risk situation. Available information on simple and effective actions to reduce the bushfire threat is required.

Fire agencies and town planners are placing constraints on building in the bushland interface without sound scientific knowledge of the impact of bushfires on homes and fire fighters.

Successful fire and fuel management policies, including wildfire restoration, acknowledge public beliefs, attitudes and behaviour, and engage the public as partners in their design and implementation. Socially acceptable fire management is a prerequisite for implementing local or regional fire management plans and for public adoption of the findings of biological and physical research in wide-ranging areas of fire management. Numerous public controversies about fire management suggest that interactions between the public and fire management agencies have not always gone well. These interactions could be improved if they guided by a more sophisticated and scientific assessment of human knowledge, attitudes and behaviours that underpin these controversies. These assessments could identify opportunities for collaborative development of fire management programs

In order to group these headings at a higher level, three time phases may be used: before the bushfire; during the bushfire; and, after the bushfire. The following table shows where this different research areas fit in this time scheme.

Table 1: Grouping the research areas according to time

Activity	Before	During	After
	the Bushfire		
Land use planning	●		
Fuel management/ Habitat complexity	●		
Fire prediction	●	●	
Fire control/suppression		●	
Health and safety	●	●	●
Environment	●		●
Property protection	●	●	
Community education	●	●	

Existing and potential areas of research and the agencies with relevant capability are listed in Appendix 1 with key contacts.

As a result of this workshop and subsequent consultation between users and researchers, a bid for a Bushfire Cooperative Research Centre was launched. The latest draft Research Program for the CRC is attached in Appendix 2.

CSIRO is also a participant in the Bushfire Research Advisory Group which has the following Terms of Reference:

1. The Bushfire Research Advisory Group shall be responsible for coordinating bushfire research so that it is conducted in an effective manner by providing advice to the Commonwealth Minister for Science on:
current research activities
research needs and priorities
research strategies
ways of raising community awareness of the importance of bushfire research.
2. A key function of the Advisory Group shall be to facilitate the preparation by member organisations of an application to the Commonwealth Government to establish a Bushfire Research Co-operative Research Centre (CRC).
3. The Commonwealth Department of Education, Science and Training shall provide secretariat services to the Advisory Group.
4. The Advisory Group shall meet at least twice per year.
5. The continuing need for the Advisory Group will be reviewed upon formation of a Bushfire CRC in view of the role the CRC could be expected to take in coordinating and publicising bushfire research.

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