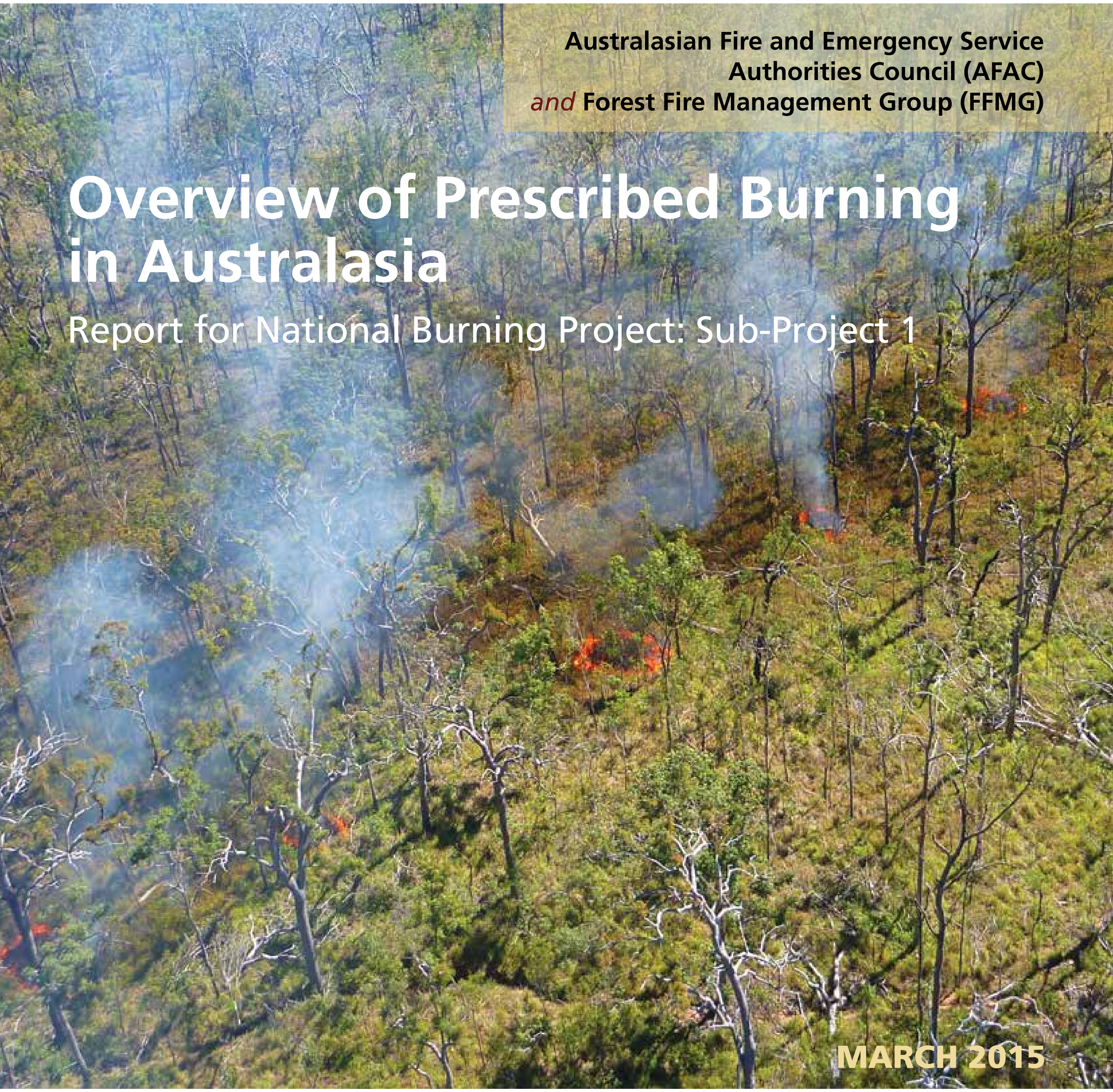
NATIONAL BURNING PROJECT

Australasian Fire and Emergency Service Authorities Council (AFAC) *and* Forest Fire Management Group (FFMG)

Overview of Prescribed Burning in Australasia

Report for National Burning Project: Sub-Project 1



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SUMMARY

This report is a comprehensive overview of prescribed burning within Australasia written for an interested reader that may or may not be experienced in the topic. It includes an overview of the science and knowledge which underpins the use of prescribed burning. The report is designed to stimulate discussion whilst supporting, where appropriate, the active management of fuels across the Australasian landscapes.

General

Naturally occurring fires and fires used by Aboriginal people are increasingly understood to have played important roles in shaping the distribution and composition of much of Australia's native flora and fauna.

Many of Australia's native plants and animals possess characteristics proven to constitute effective survival strategies when exposed to natural stresses, such as fire and drought. A number of species require fire or similar disturbances to regenerate or renew their habitats, and many temporarily flourish in the post-fire environment. Conversely, there are species and ecosystems requiring long fire-free intervals to ensure their continued abundance.

The understanding of fire's effects on biota and its application to ecological management objectives continues to evolve. Much of this understanding must, of its nature, be ecosystem specific.

Today, prescribed burning is widely used in Australia to mitigate bushfire threat and to restore and conserve biodiversity in fire-adapted landscapes. In New Zealand, the natural vegetation is largely not fire-adapted and so prescribed burning is rarely used in public land conservation areas.

In northern and central Australia, prescribed burning is primarily being used to help restore ecological processes and revive indigenous cultural traditions adversely impacted by European settlement over the past 150 years. In these largely remote and sparsely populated regions, prescribed burning appears to enjoy wide community support and is seen as being both desirable and beneficial.

SUMMARY

In temperate southern Australia, prescribed burning is used primarily to reduce bushfire threat, but also to maintain and revive biodiversity affected by changed fire regimes associated with European settlement over the past 240 years. In these more closely settled and densely populated regions, there is reasonably good support for small-scale burning targeting public lands adjacent to private property. Conversely, the extensive application of prescribed burning across the broader landscape can be more contentious due to its greater potential to impact on biodiversity as well as other community values and interests. Much of the community concern about extensive prescribed burning in southern Australia appears to relate to a lack of understanding of how prescribed burning is planned and conducted, and how it differs from a severe summer bushfire.

At the scientific and academic level, debate about extensive prescribed burning persists largely on the basis of uncertainties about its detailed environmental impacts, critics effectively invoking interpretations of the 'precautionary principle'; while others take a more pragmatic view that, despite these uncertainties, its mitigation of the extent and severity of most bushfires helps to prevent far greater environmental and community impacts.

Prescribed burning as a bushfire management tool

The notion of prescribed burning being used as a bushfire management tool has a sound basis in research into the relationship between fuel load and fire behaviour. Further, both documented and anecdotal observations of generations of fire managers attest to how the practice has assisted bushfire suppression under a range of conditions. However the difficulty of empirically quantifying the purported benefits of prescribed burning in mitigating bushfires ensures that uncertainties are likely to endure.

Nevertheless, the lowered incidence and intensity of bushfires in areas that have been subject to extensive prescribed burning is compelling in south western WA and in the tropical savannah, but less so elsewhere.

Its effectiveness in temperate southern Australia appears to be most significant if undertaken at a rate which maintains at least 25% of land area with fuels younger than or equal to five years old. This condition is currently not achieved in any of the southern states.

There is also debate about the value of prescribed burning in improving the controllability of bushfires burning under extreme fire danger conditions, when weather appears to become the main driver of fire spread and extent. While the majority view amongst fire researchers is that low fuel levels have little effect on directly improving bushfire controllability under such conditions, reduced fuel levels can provide indirect benefits by freeing-up suppression forces and improving asset protection opportunities. Further, the mapping of burn severity after recent major bushfires has shown that low fuels from previous burning can significantly reduce the damage to a range of environmental values under extreme conditions, particularly in comparison to the damage incurred in forests with heavier fuel loads.

As the vast majority of bushfires burn under less than extreme conditions, it seems that most can be mitigated to some degree by lighter fuels derived from prescribed burning. However, predicting or empirically measuring this degree of mitigation is complex due to a range of factors including the variability of vegetation types and ages, the time since burning, the effectiveness of the burn in reducing fuel loads, and the weather conditions driving the bushfire.

Prescribed burning and biodiversity

There is general agreement that inappropriate fire regimes, including those resulting from prescribed burning, can damage biodiversity and other environmental and community values and that there is an ongoing need for more research.

However, some of the scientific concern about prescribed burning appears to be based on modelled impacts derived from currently incomplete knowledge of plant survival and regeneration; on research of biodiversity impacts after bushfires which burn with greater intensity; or on observations of repeated fires at frequencies that are unlikely to be replicated in well managed prescribed burning programs.

In Australia's temperate southern forests, the magnitude of concerns about the ecological impact of prescribed burning is generally not supported by the results of field monitoring of longer-term prescribed burning trials. As these trials are limited to only a few key vegetation associations however, and have not been monitored closely in the last decade or two, the research thus far does not definitively exclude the prospect of longer-term biodiversity damage under repeated burning regimes.

Equally however, detailed studies of the ecological impact of regular, intense bushfires are few in number, an unfortunate situation in one of the most fire-prone areas on Earth.

In northern Australia – although prescribed burning is widely used in tropical savannahs to lessen threats to biodiversity from high intensity late-dry season bushfires – the ecological implications of the approach has not, until recent years, received attention. Although it has now become a focus for research, the ecological significance of different burning patterns in the northern tropical savannahs has yet to be quantified and the most desirable fire mosaics have yet to be determined.

Nevertheless, it is presumed that the spatial patchiness of burnt, unburnt, and less recently burnt parts of the landscape is important for conservation management. While this is fostered by topographic roughness (e.g. rocky outcrops) and proximity to roads and drainage lines which can break-up the spread of fires; creating and maintaining fire-induced heterogeneity on unbroken flat ground is challenging. Accordingly, active landscape management, through prescribed burning, is necessary to meet conservation objectives and its use is being revived with the assistance of local indigenous communities and private landholders. This is proving to be beneficial.

In central Australia, relatively little research has specifically targeted the ecological impacts of prescribed burning, as distinct from investigations of the ecological impacts of relatively recent past bushfires; fires which have burned with unnatural severity since the decline of indigenous land management over the past 150 years. As in the north, greater involvement of local indigenous communities, both on their traditional lands and more widely, is being sought to help better understand the role and impact of prescribed burning, while efforts continue to develop a conceptual framework for vegetation-fire interactions to guide appropriate land management.

Prescribed burning, carbon and climate change

There is a growing scientific consensus that climate change will exacerbate bushfire threats across much of Australia and New Zealand in the future. This may increase the importance of prescribed burning, with a hotter and drier climate potentially extending the opportunities for its application into formerly unsuitable times of the year in some regions.

Prescribed burning in Australia's northern tropical savannahs has great potential to lessen carbon emissions by reducing the extent to which the landscape is burnt in hot late-dry season bushfires (late-dry season fires emit far more CO_2 and CH_4). The development of markets for off-setting carbon emissions offers potential for prescribed burning in northern Australia to generate substantial income which can fund improved land management.

In temperate southern Australia, the potential to similarly reduce carbon emissions through prescribed burning is more limited due to a range of topographic, ecological and demographic factors. The enormous contribution that southern Australian bushfires can make to the release of atmospheric carbon, and the role that prescribed burning can play in mitigating these impacts is the subject of increasing research.

Smoke and associated issues

Smoke from prescribed burning is increasingly becoming a problematic issue in the more populous regions of temperate southern Australia, particularly where tourism and viticulture are economically significant. Smoke impacts on community and firefighter health are also receiving increasing research attention.

Agencies in southern Australia are increasingly incorporating consideration of smoke amelioration into prescribed burn planning and implementation.

SUMMARY

Conclusions

While there is an acknowledged widespread appreciation of the need for continuing research into all aspects of landscape fire in Australasia, including the role and effects of prescribed burning, it is also apparent that the associated complexities can, at times, seem daunting.

No single fire regime can ever hope to optimise all biodiversity, fuel hazard reduction and community risk outcomes. If prescribed burning is to play a role in the management of landscape-scale fire, then the associated compromises will need to be based on the best known science and associated expertise. Burning under cooler conditions in order to achieve ecological objectives – even if less than fully scientifically-informed – is presumably less damaging to the environment (both its human and non-human elements) than the alternative of allowing heavy fuel accumulations to build and burn in severe summer bushfires.

Clearly, the evolution of a greater understanding and appreciation of the issues associated with the planned use of fire requires continuing research, adaptive management and enhanced community engagement.

1. INTRODUCTION

1.1 Background to this report

This report is part of sub-project 1 of the National Burning Project, a joint undertaking of the Australasian Fire and Emergency Service Authorities Council (AFAC) and the Forest Fire Management Group (FFMG). The full list of National Burning Project sub-projects is provided in Appendix A. The report is targeted at a reader interested in the knowledge base and operational considerations underpinning prescribed burning regimes in use across Australia and New Zealand. Readers may also be interested in the more technical reports from the National Burning Project on 'risk' and 'best practice'. The full list of planned publications is provided in Appendix B. Sub-project 1 was designed to provide a review of the fire science and knowledge on prescribed burning throughout Australasia; however the priority task was to provide an overview document aimed at a broader readership.

Detailed reviews of the science and knowledge of prescribed burning have been undertaken previously by Gill, *et al.* (1994), for Victoria by Tolhurst and Cheney (1999), for Tasmania by Marsden-Smedley (2009) and for Australia's southern forests by Adams and Attiwill (2011). The subject also received detailed analysis in the 2009 Victorian Bushfires Royal Commission final report (Parliament of Victoria 2010), Chapter 7 (p. 277), in the earlier Victorian Parliamentary Inquiry (2008), and in the 2003 Esplin Inquiry (State Government of Victoria 2003).

Periodic detailed reviews of the science and knowledge of prescribed burning are required to include new knowledge. Research by the universities, land management agencies, the Bushfire Cooperative Research Centre and, most recently, by the Bushfire and Natural Hazards CRC is regularly reporting new findings. This sub-project of the National Burning Project will undertake a more detailed scientific review in the future. It will also include a review of the traditional knowledge held by Aboriginal communities and by land management agencies.

This report provides an overview of the policy and practice associated with prescribed burning rather than a detailed review of the science and knowledge underpinning its use. It does however include a comprehensive reference list for those readers seeking additional information.

1.2 Prescribed burning definition

In the context of rural land management, prescribed burning can be used to describe a range of activities including broad-scale landscape burning, localised hazard reduction burning, and the disposal of logging slash, crop stubble, weeds, or other unwanted vegetation.

The Australasian Fire and Emergency Services Authorities Council (AFAC) (2012) Bushfire Glossary defines 'prescribed burning' as:

> The controlled application of fire under specified environmental conditions to a pre-determined area and at the time, intensity, and rate of spread required to attain planned resource management objectives. It is undertaken in specified environmental conditions.

And 'prescribed fire' as:

> Any fire ignited by management actions to meet specific objectives. A written, approved burn plan must exist, and approving agency requirements (where applicable) must be met, prior to ignition.

1. INTRODUCTION

For the purposes of this review, prescribed burning has been taken to mean the managed broad-scale burning of vegetation in forests, woodlands, rangelands, grasslands, pastures or savannahs specifically for ecological and/or human benefit. This interpretation can include fires not necessarily lit by managing authorities, but which are allowed to continue burning as part of a land management strategy. The management objectives which are addressed by prescribed burning can include fuel management, asset and property protection, the maintenance of ecological processes and biodiversity, silvicultural treatment, structural vegetation change, and the management of greenhouse gas emissions. These various objectives are often inter-related and can be variously complementary or conflicting.

1.3 Community attitudes to prescribed burning

Prescribed burning can be a contentious issue given that management objectives for its use often conflict with other land management objectives (e.g. effective fuel management can alter habitat features), and its use can have a range of off-site consequences (e.g. smoke can cause discomfort and disruption to affected communities).

In southern Australia higher population densities and the movement of urban boundaries into the rural hinterland create enhanced bushfire risks. In these situations there can be many and varied views on the merits of prescribed burning and these at times can be ardently debated in the public arena. The resulting mix can involve varying perceptions of 'risk', scientific disagreement, legal and policy issues, and media hype.

The aftermath of Australia's deadliest bushfires, the 2009 Victorian Black Saturday fires, featured extensive media coverage that addressed the full gamut of, at the time, highly polarised emotions and opinions about prescribed burning. The issue was subsequently, and reportedly by a large margin, the most discussed topic in public and in expert submissions made to the subsequent Royal Commission.

From this discourse, it seems that attitudes to prescribed burning can be grouped into three categories:

- ***Strong support*** – including support for increasing the annually burnt area as part of an extensive, and presumably a professionally conducted program.
- ***Conditional support*** – subject to only small, presumably strategically-targeted burns with a lengthy interval between and increased research into the associated environmental impacts.
- ***Opposition*** – based on a view that prescribed burning is environmentally destructive, unnecessary, and probably ineffective in reducing bushfire threat.

Anecdotally, support for prescribed burning is perhaps stronger amongst rural Australians who work or live in close proximity to forests or other flammable vegetation and have an appreciation of a regular bushfire threat, and perhaps the link between fuel level and fire severity. Conversely, opposition to prescribed burning appears to be stronger amongst those who live in urban situations where there is little or no bushfire threat. The middle ground is ostensibly occupied by Australia's most prominent environmental lobby groups who effectively adopted a position of 'conditional support' for limited burning following the 2009 Victorian bushfires. They have often advocated this position in conjunction with qualifying statements questioning prescribed burning's effectiveness as a bushfire management tool (VNPA 2009; Taylor 2009).

2. FIRE IN THE AUSTRALASIAN LANDSCAPE

2.1 Australia

Fire has been a feature of the Australian landscape for tens of thousands of years, pre-dating human habitation. Since the arrival of aboriginal people, at least 40,000 years ago, deliberate firing of the country – or 'firestick' farming as it is sometimes referred to (Jones 1969; Pyne 1991) – coupled with periodic lightning-ignited 'natural' fire, has shaped the evolution of much of Australia's landscape and its ecosystems.

Over the millennia large elements of the country's flora have developed a dependency on fire for their long-term survival and renewal (Luke and McArthur 1978). In combination with prevailing climatic conditions, these factors have made parts of Australia amongst the most fire-prone landscapes in the world. Examples include the open eucalypt forests of the south-east (Luke and MacArthur 1978, p. 303 – 316), and the savannah woodlands of the north (Russell-Smith *et al.* 2009, p. 229 – 255).

In late 2011, the ANU-based historian Bill Gammage published The Greatest Estate on Earth: How Aborigines Made Australia. The book references some 1,500 sources to argue how, by a repeated seasonal mosaic of burning, the landscapes of the continent now known as Australia were maintained in a variety of states advantageous to human habitation. While his argument is not new – Ludwig Leichhardt and others had made similar observations in the early years that followed the arrival of Europeans (Fensham and Darragh 2013) – Gammage sets out to prove how persuasive the visual and documentary record of the impact of Aboriginal land management ultimately is.

In relation to fire, the historian Henry Reynolds says, in the book's foreword, that Gammage's work:

> …dramatically changes the way we will in the future see Australian history…

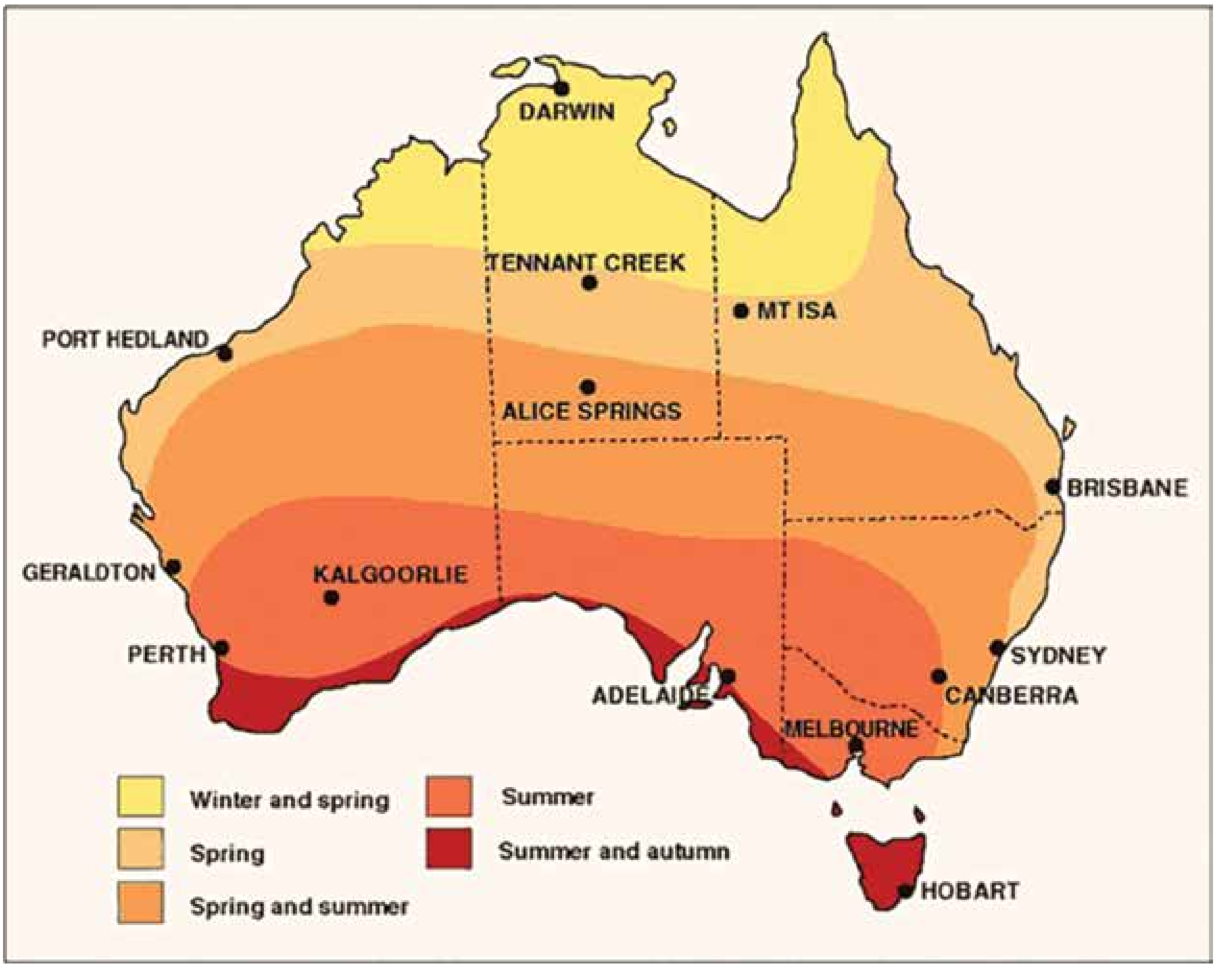
Bill Gammage concludes his book by suggesting that post-1788, and in terms of aboriginal use of fire:

> …an ancient philosophy was destroyed by the completely unexpected, an invasion of new people and ideas. A majestic achievement ended. Only fragments remain…

It is increasingly clear that in many landscapes indigenous communities had developed a sophisticated understanding of fire and they harnessed it to manage land and resources. Together with frequent and extensive natural fires, a mosaic of freshly burned areas carrying lighter fuels would have generally acted to limit the intensity and spread of most summer fires.

The size of the Australian continent and its profound climatic variation sees, at any time of the year, some part of the country being prone to bushfire (See Figure 1).

Figure 1 *Patterns of seasonal fire occurrence in Australia*
From Appendix 1 of COAG (2004).



Considering the vastness of the Australian land mass there was undoubtedly considerable variation in the respective importance of natural and human-induced fire. For example, in northern Australia the influence of Aboriginal burning is likely to have been greater given that the nature of the topography and climate allows fires lit at certain times of the year to often burn unchecked for months over huge areas (Luke and McArthur 1978). Whereas in the south-eastern mainland, natural, lightning-induced fire is thought to have been the more significant influence in foothill and mountain forests given doubts about the extent to which aboriginals lived away from coastal areas or inland flood plains, where food was presumably more plentiful (Jurskis 2005; Hateley 2010).

Since the arrival of Europeans more than 200 years ago, the natural fire regimes which had evolved over such a long period have been profoundly altered due to the:

- Loss of Aboriginal influence over their ancestral lands;
- The gradual loss, in many parts of Australia, of the detailed knowledge of plants, animals and ecosystems that was possessed by Aboriginal people post-1788, and the associated changes in land ownership, settlement patterns, and the institutionalisation of land management;

- The replacement of huge swathes of forest and woodland and other vegetation with towns, farmed pastures and crops, and other private and community infrastructure that must now be protected from bushfire; and
- In many rural areas a reduction in the fire-related skills in local communities due to more recent changes in land management and ownership associated with:
  - Fewer, larger farms and the increasing mechanisation of agricultural production;
  - The conversion of traditional farms, particularly around larger towns and cities, into smaller 'hobby farms'; and
  - The consolidation of park and forest service agency depots in larger regional centres and associated reductions by governments in agency resourcing.

Over the past century, these changes have led to a decline in the annually burnt area; with, in many areas, a shift from the frequent, small and low intensity fires of the past to less frequent, but larger and more intense summer fires with greater environmental impacts. This has reduced the 'patchiness' or the burnt/unburnt mosaic across the landscape; a change which is implicated in a loss of biodiversity. The 'woody thickening' that is now prevalent in substantial areas of northern Australia exemplifies the effect of changed land management and fire regimes on bushfire risk and ecological outcomes (COAG 2004).

Nowadays, bushfires burn an average of around 29 million hectares (about 4 per cent) of Australia's land mass each year. With seasonal fluctuations, however, this area can be higher or lower by a factor of four. For example, in 1974 and 1975, 115 million hectares or 15 per cent of Australia was burnt (COAG 2004).

2.1.1 Tropical savannah region

Around 90 per cent of the area burnt each year in Australia is found north of the Tropic of Capricorn, with burning occurring in tropical savannahs during the dry season, generally between April and November. These fires usually have a relatively low economic impact because of the low population density and the dispersed nature of built assets (COAG 2004).

In northern and central Australia, the arrival of Europeans, from around 1860, did not initially result in a build-up of their presence at the expense of aboriginal people. Rather it gradually saw a de-population of vast areas of country as aboriginal people increasingly succumbed to introduced diseases and to the settlers' view that Aboriginal Australians were nomads with no concept of land ownership, who could be driven off land wanted for farming or grazing and who would be just as happy somewhere else.

Over time, aboriginal lifestyles and community life re-established in proximity to cattle stations, missions, or other remote settlements (Russell-Smith *et al.* 2009, Chapter 2, pp. 23 – 40).

This signalled the beginning of the end of what has been described in northern Australia as the "era of systematic indigenous fire management" (Russell-Smith *et al.* 2009; Gammage 2011). Under this regime most indigenous communities were semi-nomadic, moving in a regular cycle over a defined territory, following seasonal food sources and returning to the same places at the same time each year.

The sudden loss of aboriginal influence over land management in just a couple of generations had a profound effect on the fire regime (Russell-Smith *et al.* 2009). Without regular burning, fuels were allowed to built-up to largely uniform levels of flammability over huge tracts of country. This increased the threat of far more intense and damaging fires inevitably ignited by lightning (Central Land Council 2014).

Although the mechanism has somewhat differed compared to the more populous regions of the country, the arrival of Europeans in northern and central Australia has ultimately had the same effect of reducing the incidence of fire in the landscape and facilitating a shift from frequent gentle fires in light fuels to less frequent but far more damaging fires in fuels allowed to build-up to unnaturally, in historical terms, high levels. This has had a detrimental environmental impact (Russell-Smith *et al.* 2009, Chapter 8, pp. 201 – 227).

In more recent times, concerted efforts have been made to redress this situation by encouraging indigenous participation to reverse the loss of aboriginal land management skills (Central Land Council 2014).

2.1.2 Arid and semi-arid regions

Fires in Central Australia are generally driven by fuel loads that result from periodic rain events. In most years fires occur in discontinuous fuels and are not sustained for long periods. Prescribed burning can be used along roads and near settlements to protect assets and access. Following extensive heavy rain events usually associated with *La Nina* seasons, such as occurred in 1974/75 and 2010/11, grass fuels accumulate rapidly and when cured provide continuous fuels. At these times huge areas of the interior are often burnt by fire.

2.1.3 Southern temperate regions

Generally, around 10 per cent of Australia's annually burnt area is located in the far more densely settled, temperate regions of southern Australia. In these environments (especially in the south east), occasional but severe bushfires have significant social and environmental impacts. Indeed, almost all bushfire-related impacts to human life and property have been recorded in southern Australia (Attorney-General's Department 2012).

2. FIRE IN THE AUSTRALASIAN LANDSCAPE

Several million hectares of south-eastern Australia were burnt by the 2002 – 03 and 2006 – 07 bushfires, while the catastrophic 2009 Victorian Black Saturday Bushfires were one of Australia's deadliest natural disasters, resulting in the loss of 173 lives, the destruction of over 2000 homes, major disruption to industry (including the agricultural, viticultural and forestry, tourism and recreation sectors) and temporary loss of essential services (including transport, power supplies and drinkable water supplies).

Since 2000, southern Australia has experienced fire seasons as devastating as any in the two hundred years since European settlement. The best available science now suggests that a warming, drying climate, particularly in southern Australia, will increase the frequency, intensity and size of bushfires in some of the most densely populated regions of the continent. The weather conditions which predisposed Victoria to catastrophic fire danger in February 2009, and the consequent tragic loss of life and property, are predicted to occur more frequently in future (CSIRO 2009; Hughes and Steffen 2013).

However, and as set out above, there is also a substantial human dimension to the problem of damaging bushfires in southern Australia. The spread of farming and rural settlement over the past 200 years has seen the replacement of the former semi-nomadic aboriginal presence with far greater numbers of non-aboriginals living in permanent dwellings and settlements, growing crops, keeping stock, and working in a range of other rural industries.

With increasingly more people owning property and living in permanent dwellings, often located amongst or near natural vegetation, summer bushfires became undesirable and for almost a century have been actively excluded by increasingly sophisticated suppression focussed agencies. These trends have progressively changed the 'natural' fire regime from one of frequent small fires burning from spring through to autumn in generally light fuels; to a regime comprised of a mix of managed cool burning, small and quickly controlled bushfires, and occasional large and very intense summer bushfires running out of control in heavy fuels, with devastating environmental and social impacts.

The strategy of trying to exclude fire from the hottest period of the year has reduced its incidence, but facilitated a situation whereby hot summer bushfires, when they inevitably do occur, can be far more damaging than they ever were – both in environmental and human terms.

This situation sees community pressure to take steps that sees the inevitable bushfire impacts both mitigated and minimised. A key element in any associated strategy is the managed use, in ecosystems where it is appropriate, of cool burning (or prescribed burning) to reduce the fuels available for unplanned summer bushfires.

Concurrently however, prescribed burning in southern Australia has become increasingly difficult to conduct on a significant scale due to a range of social and demographic factors and, over time, flammable fuels have continued to built-up as fuel loads have grown due to lengthy intervals between burns.

International bushfire historian and analyst Stephen Pyne (2006, Part Three, pp. 67 – 106) believes this has been exacerbated by Australian State governments, particularly since the 1970s, responding to perceived community concerns, centred largely but not exclusively in urban-based electorates, and excluding economic uses from many public lands. The redesignation, for example, of many areas of State forest as National Parks has left management agencies largely dependent on the 'public purse' to finance their management activities.

Evidence tendered in various recent bushfire related inquiries has claimed that changes in public land tenure has typically been accompanied by reduced public funding of natural areas which, of themselves, can generate little regular income. This in turn has resulted in a shift in focus away from broad-scale land management activities (such as fuel management) to a park visitor-focus targeting only a small proportion of the areas under public management (Commonwealth of Australia 2003; State Government of Victoria 2003; Victorian Parliamentary Environment and Natural Resources Committee 2008; Parliament of Victoria 2010a).

These trends have seen a significant loss of agency workforce expertise in many areas and a shift in the fire management emphasis on public lands. The approaches that had developed by the 1960s/70s saw bushfire prevention focussed on a year-round approach, through 'cool' season burning and associated infra-structure maintenance, and emergency suppression of hot summer bushfires. But recently agencies have increasingly focussed on the final element (Pyne 2006). These trends are not unique to Australia, being observed variously in other fire-prone developed countries, as traditional rural land uses and management has declined, and opposition to the economic uses of publicly-owned forests and woodlands has increased (Pyne 2006a).

Redressing this by re-defining the bushfire threat as a year-round land management issue rather than a 'suppression' one is now increasingly the focus, as are greater efforts to quantify the nature of 'risk'. These developments follows a decade or so where governments have been investing increasing funds on improved fire-fighting technology and enhanced emergency capacity, a trend perhaps most evident in the U.S.A. but one also obvious in Australia (Pyne 2006a; Williams 2010).

Across southern Australia, the 2009 Victorian Bushfires Royal Commission's recommendation to substantially increase prescribed burning rates in Victoria has been viewed as part of this international phenomena, while for others it has re-ignited concerns about the potentially adverse impacts of prescribed burning.

2.1.4 Composition of Australian fire – planned burning and unplanned bushfire

The amount of planned burning and unplanned bushfire varies from year to year.

Thackway *et al.* (2008) assessed the extent of planned and unplanned fire in Australia's forest and woodlands over a five-year period using a mix of satellite imagery and data supplied by State land management agencies. As is shown in Table 1, Australian fire over the period from 2001 – 06 was dominated by unplanned bushfires.

Even though this period included one of southern Australia's worst ever fire seasons, this trend is thought to exemplify the typical situation given that most fire (~90% each year) occurs in northern Australia. However, it should be acknowledged that a lack of burnt area data for private lands, and for some public land tenures, means that Table 1 doesn't show the complete picture.

Table 1 *Respective comparison of planned burning to unplanned bushfire by State and Territory during the period from 2001 – 06*

Modified from Thackway *et al.* 2008, Table 7, (p.19).

State/Territory	Landscape fire (% of total burnt area 2001-2006)		Average ratio of planned (prescribed burning): unplanned (bushfire) (2001-02 to 2005-06)
	Planned	Unplanned	
Queensland[a]	9%	91%	0.10
NSW[b]	16%	84%	0.19
WA (except SW)[c]	17%	83%	0.20
Victoria[d]	20%	80%	0.25
Northern Territory[e]	21%	79%	0.27
Tasmania[f]	43%	57%	0.75
South Australia[g]	73%	27%	2.75
WA (South West)[h]	76%	24%	3.11
Australia	19%	81%	0.24

a. Queensland – estimated from MODIS satellite imagery
b. NSW – only for public land multiple use and conservation reserve tenures (supplied by Forestry Corporation NSW and NSW National Parks and Wildlife Service)
c. WA – all regions of the state except the south west forests
d. Victoria – only for public land tenures (supplied by Department of Environment, Land, Water & Planning)
e. Northern Territory – estimated from MODIS satellite imagery
f. Tasmania – planned fires for State Forests only
g. South Australia – only for Forestry SA plantations and public nature conservation reserves
h. WA South West – only for South West forest region (supplied by Department of Parks and Wildlife)

2.2 New Zealand

New Zealand has a relatively small land mass – just a bit larger than Victoria's. However, due to its long, narrow orientation it has a varied climate ranging from warm sub-tropical in the north to cool temperate in the south. This, coupled with mountain chains running the full length of the country, has created many diverse micro-climates. Accordingly, fire risk varies considerably, although as a general rule the northern and eastern parts of both major islands tend to have the most frequent high fire danger conditions (Pearce and Clifford 2008).

Unlike most of Australia, New Zealand's native ecosystems are comprised of species that are not specifically adapted to fire. Nevertheless, fire has played a part in influencing the distribution of some species and communities (Pearce *et al.* 2008).

Prior to European settlement, the country experienced infrequent bushfires ignited by lightning and volcanic activity. Carbon records suggest that fire became more frequent about 1800 years ago when the climate became drier. This led to an expansion of tussock grasslands at the expense of tall woody vegetation, particularly on the South Island, but to a lesser extent elsewhere (Pearce *et al.* 2008).

Others suggest that natural fire was driven more by vegetation flammability than climate in southern NZ and that its frequency and severity increased over the past 2,000 years in conjunction with human settlement (Rogers *et al.* 2007).

Over the last 1,000 years one or both factors significantly reduced forest cover from an estimated 80%, to 50% of the land mass by the time Europeans arrived. Fire was then widely used by Europeans to clear more forests for settlement and agriculture, and this led to some large bushfires which extensively damaged remnant forests and other native vegetation (Pearce *et al.* 2008).

This burning continues today on a much reduced scale as farmers use fire as a management tool for clearing dense vegetation, to create or maintain stock access, control woody weeds, clear land for reseeding, enhance palatable growth for stock, control bracken fern, and to dispose of stubble and waste. Land management burning remains a controversial issue as occasional escapes can burn neighbouring land, damage conservation values, or create issues associated with smoke or aesthetics.

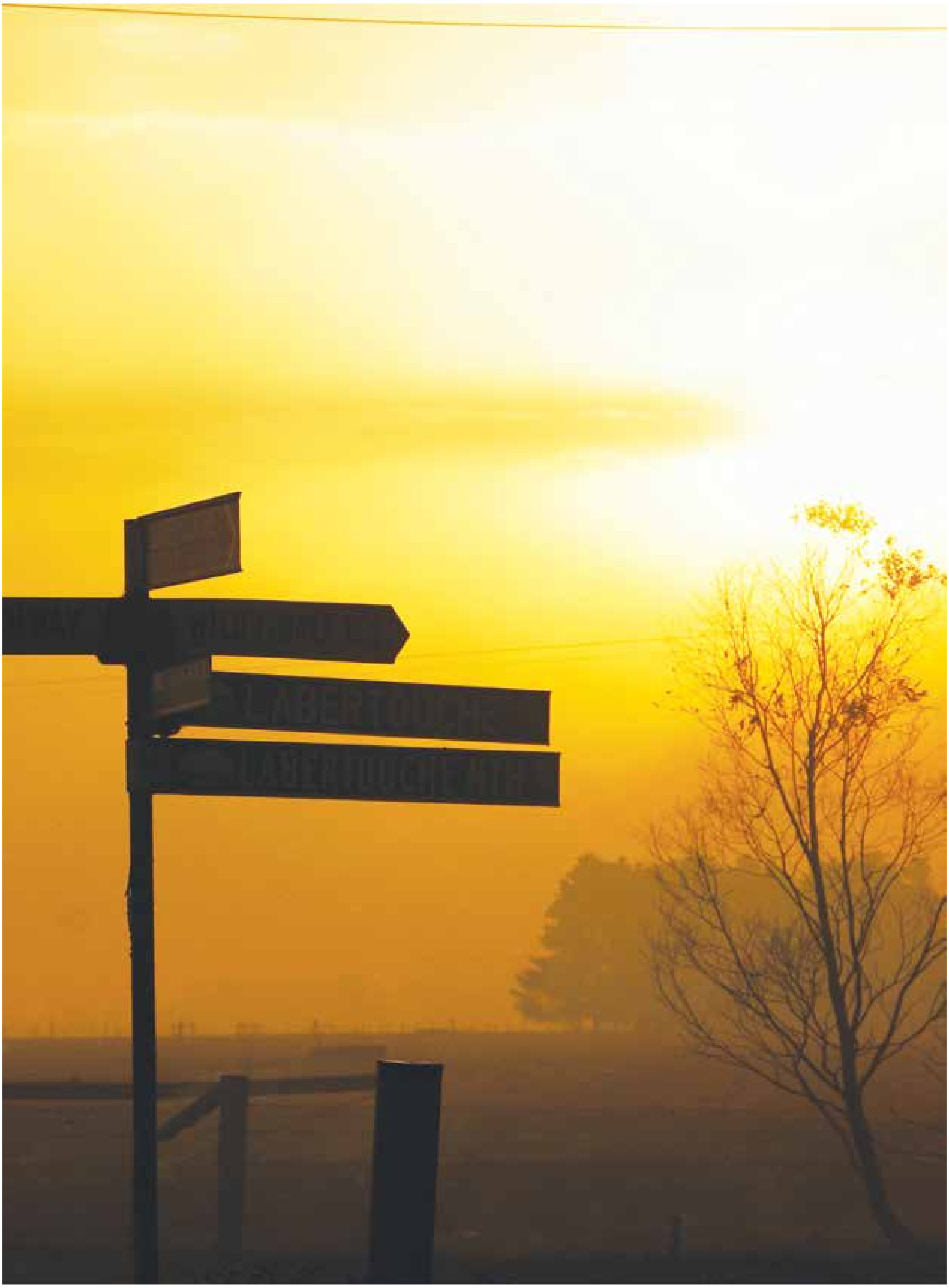
An analysis of fire records from 1991 to 2007 has shown that NZ, on average, has just over 3,000 bushfires burning around 5,900 hectares per year. During this period, over 30% of bushfires were caused by human activity and these accounted for nearly 65% of the area burned (Anderson *et al.* 2008).

Based on climatic, edaphic and biological indicators, New Zealand's fire environment is rated as low to moderate compared to other world bio-regions (Burrows 1999). Certainly by Australian standards, bushfire in NZ is of relatively low significance with little associated loss of life or property. However, it continues to pose a potential hazard and there has been a notable upward trend from around 1,200 to 4,000 fires recorded per year over the 1991 to 2007 period (Anderson *et al.* 2008).

Despite its relatively low significance, fire endures as an important consideration in forest management, especially in relationship to the country's valuable plantation estate which is mostly comprised of exotic *Pinus* species that are not resistant to fire. During the past 60 years, an estimated 40,000 hectares of exotic plantation has been burnt, resulting in significant economic loss to its owners and managers (Pearce *et al.* 2008). Nevertheless in 1993, it was estimated that any given stand of NZ plantation had a 98% chance of growing on to final harvest without being affected by fire (Maclaren 1993).

Fire also has impacts on lands being managed for conservation. Studies show that the level of impact varies with the time of the year when burnt (Pearce, *et al.* 2009), and with the frequency of burning. Recovery times can be slow in some affected ecosystems (Whiting pers comm. 2012).

2. FIRE IN THE AUSTRALASIAN LANDSCAPE



3. THE ORIGINS OF AUSTRALASIAN PRESCRIBED BURNING

3.1 Australia

3.1.1 Southern temperate region

While indigenous communities had been burning parts of the landscape for tens of thousands of years, their influence began to decline soon after contact with Europeans due to the factors previously mentioned. However, fire was quickly adopted as a tool by early European settlers intent on clearing forests and woodlands for agriculture, for controlling or preventing woody regrowth, and for promoting 'green pick' for stock grazing.

The initial period of European settlement, until the 1870s, was notable for largely unrestrained clearing of forests for agricultural expansion and for the exploitation for timber and firewood (Carron 1985).

There then followed a period where efforts were made to end uncontrolled exploitation by permanently reserving a substantial public land estate by placing it under government control. However, it was not until the early decades of the 1900s that dedicated areas of public land came under the control of trained professional foresters (Carron 1985). At that time, the accessible forests were the major source of wood for construction and fuel, and the relatively few, and generally under-funded forest officers of the time were pre-occupied with regulating timber yield and regeneration. Efforts to manage the fire threat associated with the little understood ecosystems were a challenge that lay largely in the future.

On private lands, fire continued to be widely used as a management tool, often indiscriminately, while on public lands, it was generally viewed negatively for its destructive capacity. Little could be realistically done to guard against threats posed by uncontrolled pastoral burning on adjacent agricultural lands, or illicit burns lit to promote grazing in the reserved forests themselves. In addition, there were still huge areas of remote forests, woodlands and other lands where a lack of access precluded any realistic efforts to deal with fire (Moulds 1991).

By the early 1920s the critical importance of fire management was starting to be recognised across southern Australia. In Victoria, in 1923, the then Forests Commission warned the State government that the neglect of fire protection would continue to be a major threat and was indeed a "tragedy waiting to happen" (Moulds 1991). Whereas in WA, the then Conservator of Forests, Steven Kessell, acknowledged that "the basis of all forestry in the State must be fire protection" – he further advised that "controlled bushfires play an important part in silvicultural operations", although – significantly for the time – he also recognised that not everyone would agree (Meyer 1985).

Accordingly during this period, there was considerable reflection on the problem of bushfires. This included the competing notions of permanently excluding fire or accepting it as inevitable and harnessing and controlling it. Two schools of thought developed about the use of fire as a management tool. Most field-based forestry personnel were of the belief that regularly using fire to 'clean up' the forest floor and maintain a light fuel load was the key to controlling subsequent bushfires. However, this was heresy to the more academic professional foresters, particularly those with exposure to European training, who believed that bushfires would largely vanish as tangled wilderness was converted to organised, tended forest (Pyne 2006, pp. 54 – 55).

The result of this uncertainty was that some deliberate burning was done but not in accord with any organised plan or approach, at least prior to 1939 (Pyne 2006). In January of that year, the infamous Black Friday conflagrations burnt huge areas of forest and other lands in Victoria, southern NSW and south-eastern SA. These fires would ultimately herald the start of a new era in fire management.

In Victoria, the subsequent, seminal Royal Commission placed the blame for the 1939 bushfires squarely on 'the hand of man' a reference to the human mismanagement of fire often deliberately lit at the most inopportune times. Judge Stretton, who presided over the Royal Commission, clearly recognised the absurdity of the notion that fire could ever be permanently excluded and saw the sense in using fire against itself. He concluded that the problem was not human burning itself, but poorly controlled human burning (Pyne 2006, p. 57). (See ABC website http://www.abc.net.au/blackfriday/home/default.htm)

Despite the Royal Commission's findings, it was not until after WWII, under a new generation of foresters, that there was real reform. Pyne (2006, p. 58) credits the 1951 – 52 fire emergency in the NSW Snowy Mountains as the catalyst for Australian forestry to firmly adopt prescribed burning as a preventative measure – rather than relying exclusively on emergency bushfire suppression.

This was a strategy that no other developed nation had as yet dared to adopt. But it was rooted in a sensible recognition and acceptance of factors such as:

- The adaptation to fire of the country's indigenous flora and fauna;
- The long tradition of Aboriginal burning;
- The on-going use of burning in other rural land uses; and
- An admission that Australia could never afford a paramilitary campaign against fire such as was then emerging in North America (Pyne 2006, p. 58).

Gradually, from the mid-1950s onwards, integrated systems of broadscale prescribed burning were introduced into public forests – firstly in WA, but then extending throughout the more settled southern and eastern States.

Initially, prescribed burning was conducted by ground crews averaging around 40 hectares burnt per person-day. This was simply inadequate for large burning programs, given the limited available opportunities that were subject to the vagaries of weather and the vegetation's fuel moisture content. This problem was resolved in part by the development of aerial incendiaries (dropped from aircraft) from the mid-1960s. This enabled large remote areas to be lit quickly and inexpensively when conditions were suitable (Luke and Macarthur 1978, pp.144 – 145).

The uptake of aerial ignition wasn't uniform around the country. For example, it wasn't until 1975 that it was introduced into Queensland (Taylor 1994).

The combined effectiveness of using ground ignition for smaller strategic burns in sensitive areas and aerial ignition for large-scale burning of remote country is illustrated in Victoria's forests. Between 1972 and 1982, the gross area annually treated by fuel reduction burning varied from 37,000 hectares in 1973 – 74 to 477,000 hectares in 1980 – 81 – the latter representing some 6% of the State's public lands (Minister for Forests 1983). While this reflects the variability of seasonal conditions, the upper end of the range arguably affirms the structures, resources, and political backing that enabled the then Forests Commission to effectively take advantage of suitable conditions.

Since the mid-1960s in WA between 6 to 8 percent of the forested Crown lands were, until the last several years, prescribed burned each year.

3.1.2 Tropical savannah and arid regions

While indigenous communities in central and northern Australia had been extensively burning the landscape for tens of thousands of years, their population levels began to significantly decline soon after contact with Europeans, from the mid-1860s. For example, it is estimated that the indigenous population of the Northern Territory's 'Top End' was reduced to just 10% of its pre-European level within two generations (Russell-Smith *et al.* 2009, p. 29).

Although this severely disrupted traditional burning practices, by the early 1900s surviving indigenous communities had developed ways to at least maintain some traditional burning, generally by incorporating it into their work on more progressively managed pastoral properties, and in the buffalo hunting industry, which had begun operating in eastern Arnhem Land during the 1880s (Russell-Smith *et al.* 2009, p. 31).

Compared to southern Australia, in northern and central Australia government influence over land management was generally minimal until much later. In the Northern Territory it wasn't until 1933 that M.R. Jacobs of the then Commonwealth Forestry Bureau visited and made "recommendations for the inauguration of a forest policy for the Territory" – But this was far more focussed on the potential for a reliable timber supply than on managing fire (Carron 1985).

In contrast to the more closely settled parts of southern and eastern Australia, it seems that early European society never seriously considered the prospect of excluding fire from northern and central Australian landscapes. The country was simply too vast and the populace so sparse to contemplate such a strategy, although there is evidence of some early pastoralists actively discouraging burning on their stations (Russell-Smith *et al.* 2009).

Even today, the stark difference in rural population densities between the most populous southern State (Victoria at 6.6 persons per km2) and the least populous Northern Territory (at just 0.1 persons per km2) tells a story about different imperatives for fire management and the use of prescribed burning (ABS 2011). Whereas in the more settled south and east, prescribed burning is largely viewed as a means of protecting human life and property; this is a lesser consideration in northern and central Australia where its use is more rooted in meeting physical, cultural and ecological needs.

These days, and relative to the southern States, government influence over land management in northern and central Australia remains comparatively minor. For example, in the Northern Territory most lands are either privately-owned, leased public lands, or lands set aside for indigenous uses. Only around 4% of lands tenured for nature conservation, including National parks that are being jointly managed by the federal government and local traditional owners, are subject to the intensive land management planning that is typical of public lands in southern and eastern Australia (Bryant 2008).

Consequently, prescribed burning in the north has always been much more closely tied to the maintenance of traditional burning practices by indigenous communities. These, as set out above, had declined until the 1970s for a range of reasons, not least being long-standing attempts to encourage aboriginals to assimilate into European society; and associated efforts to discourage traditional affiliations with the land and the cultural practices, such as burning, which underpinned them (Russell-Smith *et al.* 2009).

Shifts in indigenous policy since the mid-1970s, including the recognition of Native Title, have gone some way to reversing this trend (Russell-Smith *et al.* 2009, p. 36). Burning is now being revived on large tracts of land being managed by indigenous traditional owners in conjunction with technology and expertise provided by government fire agencies such as Bushfires NT (Central Land Council 2014).

The National Bushfire Management Policy Statement (FFMG 2014) has as one of its fourteen national goals as the promotion of indigenous Australians use of fire.

3.2 New Zealand

As few NZ ecosystems have evolved with naturally occurring frequent fire, the adaptations found in other countries, where the biota has long been exposed to periodic fire, are largely absent. Consequently, prescribed burning is not widely practiced for broad scale fuel reduction or ecological purposes in New Zealand (Pearce *et al*. 2008).

However, as previously discussed, fire was widely used as a tool to clear and manage vegetation as soon as humans arrived in New Zealand and its use in agricultural roles continued to be significant until quite recently. For example, in Otago from 1995 to 1997 between 63 and 79 ‘consents’ covering some 22,000 – 37,000 ha for burning were issued annually by Crown agencies (Whiting pers comm. 2012).

Although prescribed fire could potentially meet some management objectives in New Zealand’s protected natural areas, the scant knowledge about its potential impact on many ecosystem components has led to caution in its use as a management tool (Allen *et al.* 1996). There are often other ways of dealing with risks that are less complex, costly and risky compared to burning (Whiting pers comm. 2012).

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

The effectiveness of prescribed burning in mitigating subsequent unplanned summer bushfires has been subject to considerable dispute in the more settled areas of southern and south-eastern Australia, where almost all bushfire-related impacts to human life and property have been recorded (Attorney-General's Department 2012). The discussion in this chapter focuses on the southern temperate applications of prescribed burning.

These days, and despite the periodic impacts of severe bushfires, there are often pockets of opposition to the extensive use of prescribed burning. By contrast there is widespread general support only for small targeted burns confined to the public/private land interface, where the bushfire threat to human life and property is seen to be greatest. There is less general opposition to prescribed burning, in the immediate wake of serious bushfires.

Proposed burns close to human settlement can also be opposed by individuals and community groups over potential localised impacts. Adams and Attiwill (2011, p. 110) nominated ten 'key reasons' used to justify opposition to prescribed burning. The major ones cited include the risk of escape, complaints about smoke, concerns for ecological damage, lack of sufficient knowledge about environmental impacts, and disquiet about intervention in nature.

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

In the aftermath of Victoria's 2009 Black Saturday bushfires some critics of a proposal to significantly expand the State's prescribed burning program elected to by-pass such specific concerns by lodging an overarching claim that there was no scientific evidence that prescribed burning was an effective means of mitigating the bushfire threat. The inescapable corollary being that there is therefore no point in expanding its use irrespective of specific arguments.

This position was widely quoted at the time by mainstream environmental non-government organisations (ENGOs):

> *"In particular, the suggestion that having had more fuel reduction burning over larger areas more frequently during the drought of the last decade in Victoria would have prevented these fires – and by extension that doing even more of it is essential in the hotter, drier climate we are moving into – is not backed up by the best available science. Andrew Campbell, quoted in Australian Conservation Foundation (2009)."*

While this and similar statements were made in the context of extreme fire events such as experienced on Black Saturday, they arguably appear to underscore long-standing disquiet amongst mainstream ENGOs over the concept of human intervention in nature. However, the assertion that prescribed burning is not 'evidence-based' seems largely dependent on what is perceived to be acceptable as evidence.

4.1 What constitutes acceptable evidence?

It is well known, and scientifically supported, that a low intensity fire burning in light fuel is far easier and safer to control than a fire burning in heavy fuel accumulations.

While the concept and logic of prescribed burning, as an aid to bushfire management, is well established, scientifically quantifying and formally measuring its effectiveness in the landscape has been problematic (Parliament of Victoria 2008, p. 81). This is due to an array of inter-related variables which both determine its effectiveness yet present difficulties for controlled experimental study (Gould *et al.* 2011; McCaw *et al.* 2012; Cheney *et al.* 2012).

While there is a growing base of peer-reviewed scientific papers quantifying the effectiveness of prescribed burning, it is also important to consider the decades of unpublished applied research and documented case studies undertaken in-house by government scientists working for Australian land and fire agencies (including the CSIRO). When applied research and case studies are considered, it becomes clear that there is a significant body of knowledge which constitutes a compelling case that prescribed burning can play an important role in mitigating bushfire frequency, extent and damage (Parliament of Victoria 2008, p. 79).

Having developed and honed the practice of prescribed burning over the past 50 years, in a range of ecosystems, it has been logical for Australian park and forest management agencies to take the lead in investigating and documenting the science underpinning the practice.

The difficulty of quantitative study has in part fostered the development and use of simulation modelling to assess the mechanics of bushfire and the respective significance of various parameters which influence it. For example, Cary *et al.* (2009) used five different landscape-fire-succession models to assess how various parameters influence burnt area. While other fire scientists have developed 'scenario modelling', based on the findings of experimental burning, to retrospectively analyse past bushfires events and predict future events under various fire management options (Tolhurst 2007; Sneeuwjagt 2008).

The creation, in 2003, of the Bushfire CRC to foster and coordinate research partnerships between universities, relevant government agencies and related organisations, has led to more peer-reviewed, published research papers about fire and the publication of a major book Burning Issues (Adams and Attiwill 2011) being added to the public record. This work continues and will be supported by further research by the Bushfire and Natural Hazards CRC.

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

Evidence supporting prescribed burning as being an effective bushfire management tool has been garnered over a lengthy period in a variety of forms. Some of Australia's leading fire researchers have concluded that drawing on this broad range of knowledge is necessary to quantify the effectiveness of fuel management programs, including prescribed burning (McCaw *et al.* 2012).

McCaw *et al.* (2012) categorised this available knowledge into four forms:

- ***Empirical scientific study*** of the relationship between fuel characteristics and fire behaviour, and associated scenario modelling;
- ***Case studies*** illustrating the effects of different fuel conditions on bushfire behaviour, environmental values, and suppression difficulty;
- ***Landscape-scale remote sensing*** monitoring the varying severity of bushfires on vegetation in areas subject to recent and older prescribed burns or areas that have been long unburnt; and
- ***Statistical trends and analysis.***

The need to take account of all available knowledge accords with the findings of the Report of the Inquiry into the 2002 – 03 Victorian Bushfires (State Government of Victoria 2003, p. 108) which noted that there is currently no one "unequivocal and immediate choice of an appropriate measure for (quantifying) the effectiveness of prescribed burning".

4.2 Brief review of supporting evidence

The following review of existing knowledge is focused on the temperate forests of southern Australia (mostly Victoria and WA) where the debate over prescribed burning and subsequent study and research has been arguably the most intense. While not necessarily exhaustive, it suggests that the notion of prescribed burning playing a key role in bushfire mitigation is supported by more than just casual observations and anecdotes.

4.2.1 Empirical scientific study, including scenario modelling

Arguably, Australia's most comprehensive scientific study of forest fire behaviour has been Project Vesta which ran from 1996 to 2007. It was a collaborative research project undertaken by the CSIRO in partnership with the then WA Department of Environment and Conservation, with support from most of Australia's other land management and emergency services agencies (Gould *et al.* 2007; Gould *et al.* 2011; McCaw *et al.* 2012; Cheney *et al.* 2012).

Project Vesta's findings were derived from data generated by lighting and monitoring over 100 experimental fires in eucalypt forests in south western WA during the summers of 1998, 1999 and 2001. These fires were lit in 4-hectare plots under dry summer conditions of moderate to high forest fire danger at two sites with differing understorey fuels ranging in age from 2 to 22 years.

Project Vesta's key findings were that:

- Hazard reduction by prescribed burning will reduce the rate of spread, flame height and intensity of a (subsequent) bushfire and its potential for spotting, by changing the structure of the fuel bed and reducing the total fuel load;
- The persistence of this effect will be determined by the rate of change in fuel characteristics over time, but a measurable benefit may last for up to 20 years in some forest types;
- Stimulation of understorey shrub regeneration after burning will not increase the rate of spread of a fire until such time as a significant near-surface fuel layer accumulates; and

- Younger fuels produce fewer firebrands (i.e. flying pieces of burning bark) because fire intensities are lower and less bark is consumed than in older fuel types. This reduces instances of spotting (Gould *et al.* 2007; Gould *et al.* 2011; McCaw *et al.* 2012; Cheney *et al.* 2012).

Project Vesta identified a broad range of 'measurable benefits' from prescribed burning (up to 20 years for bark fuels) for the forests of south-western WA. The length of time over which prescribed burning provides a bushfire mitigation benefit seems to be highly variable both within and between forest and other vegetation types (Raison *et al.* 1983; Burrows 1994; Morrison *et al.* 1996; Tolhurst and Cheney 1999).

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

Project Vesta's empirical study of fuel dynamics and fire behaviour has contributed to the development of predictive models that have been applied retrospectively to several past major bushfire events to examine likely outcomes under various alternate fuel management regimes.

Phil Cheney (2010) reports on a retrospective analysis of the Mundaring-Karragullen fire which burnt nearly 30,000 ha of forest near Perth WA in January 2005. This fire was only prevented from entering the city's outer eastern suburbs by the presence of low fuels from recent prescribed burning which reduced what was an unmanageable head fire to a controllable intensity.

Using fire spread equations developed during Project Vesta, Cheney reconstructed the path of the bushfire under an alternate scenario where the forest had not been burnt over the previous 20 years. This analysis predicted that under the same weather conditions, the fire would have remained uncontrollable and would have burnt deep into residential suburbs with a high likelihood of severe impacts on human life and property (Sneeuwjagt 2008; Cheney 2010).

Kevin Tolhurst (2007) retrospectively applied his Bushfire CRC-funded PHOENIX fire characterisation model to the Deans Marsh fire which burnt through Victoria's eastern Otway Ranges on Ash Wednesday, in February 1983. This fire ultimately burnt more than 40,000 hectares of forest – most of which had not been burnt for over 40 years – destroying 780 structures and taking three lives (Pyne 1991).

The Deans Marsh fire represents a bushfire outcome inflicted on an area almost entirely burdened with a heavy pre-fire fuel accumulation. Tolhurst's PHOENIX model simulated the path of the same fire burning under the same weather conditions under three alternate fuel management regimes with three different outcomes:

1. Forests which had been fuel reduced on a 10 year prescribed burning cycle, i.e. 10% of their area is burnt per annum. Under this scenario, the modelling suggested that the Deans Marsh fire would have been only about 50% as extensive, with the forests burning at a significantly lower and patchier intensity, thereby inflicting far less environmental damage;
2. Forests which had been fuel reduced on a 20 year burning cycle, i.e. 5% of their area is burnt per annum. Under this scenario, the model predicted that the extent of the Deans Marsh fire would have been reduced by about 33% – with significantly less severely burnt area; and
3. Forests which had been fuel reduced on a 40 year burning cycle, i.e. 2.5% of their area is burnt per annum. Under this scenario, the model predicted that the extent of the Deans Marsh fire would have been reduced by about 20% with significantly more of the affected area burnt at low intensity by patchy fire compared to what actually occurred (Tolhurst 2007).

Both Cheney's and Tolhurst's retrospective analyses of actual past bushfires highlighted the likely benefits of regular prescribed burning, even on a lengthy cycle, in increasing controllability and thereby reducing bushfire impacts, compared to that incurred in long unburnt forests with heavy fuel accumulations.

In the period since Tolhurst's Deans Marsh study, work has continued on the development and enhancement of his PHOENIX model, and it has now been implemented as a tool for operational fire planning in Victoria. It is currently being evaluated in NSW, South Australia and Tasmania. It is also being used in Victoria to simulate suites of hypothetical fire events to evaluate landscape risk and to determine the relative costs and benefits of alternative management decisions. Further, PHOENIX RapidFire has now become an integral component of the Bushfire CRC developed Fire Impact & Risk Evaluation Decision Support Tool (FireDST) and acts as the computation engine that provides predictions of fire impacts for each scenario evaluated.

4.2.2 Case studies

Some critics of prescribed burning have tended to dismiss case studies for being observational rather than scientific. However, others believe that the difficulties associated with empirical scientific study of fire have heightened the importance of case studies in developing an understanding of fire behaviour under different fuel types and ages, despite them being descriptive and lacking replication (Sneeuwjagt 2008).

Victorian case studies

In Victoria, three sets of case studies have documented the role of earlier prescribed burning in assisting fire suppression at 15 bushfires over the period from 1978 to 1991.

Rawson *et al.* (1985) examined ten significant bushfires which occurred from 1978 – 83 near the end of a decade of the most extensive prescribed burning thus far recorded in the State.

In five of these fires (Lorne-Anglesea 1983; Mt Macedon 1983; Stawell 1980; Barkstead 1980; and Dimboola 1980), private assets directly threatened by bushfire were saved when firefighting was assisted by the presence of low fuel zones from previous burning. In some of these cases, fuel reduced areas had stopped bushfire spread, while in other instances it reduced fire intensity to an extent that allowed firefighters to undertake effective asset protection work. This occurred despite these fires being uncontrollable in adjacent areas carrying heavier fuel loads.

Rawson *et al.* (1985) also identified inter-related factors which can influence the effectiveness of a previously fuel-reduced area in mitigating bushfire threat. These include:

- The nature of the fuel reduction treatment in terms of:
  - The proportion of the treated area that has actually burnt; and
  - The degree to which it reduced fuel quantities and other hazardous fuel properties;
- The size and distribution of fuel reduced areas;
- The time since they were fuel reduced (and therefore the extent to which new fuel has accumulated); and ultimately
- The intensity and size of the approaching bushfire.

They also noted that, compared to instances of private asset protection, it has been more difficult to quantify the extent to which extensive fuel reduction treatments can mitigate the environmental impact of bushfires. However, they noted several instances where extensive fuel reduced areas had played an important role in limiting the spread of multiple fires in remote country, including the Dargo fires of January 1978 when more than 60 fires were simultaneously ignited by lightning.

They also noted that extensive fuel reduced areas assisted the control of bushfires burning under 'moderate' to 'high' fire danger conditions near Cann River in 1982/83 by:

- Reducing fire intensity and spread to a level that allowed direct control work to be undertaken close to the fire edge; and by
- Creating low fuel zones where control lines for back-burning could be safely constructed.

They also acknowledged several instances (at Mt Disappointment and Mt Elizabeth in 1982) where extensive fuel reduced areas had no substantial impact on bushfire mitigation, and speculated that this may have been related to an unsatisfactory level of fuel-reduction achieved by prescribed burning in the first instance.

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

Grant and Wouters (1993) examined the effects of prescribed burning on four bushfires ignited in the Little Desert and Grampians area of western Victoria during the 1990/91 fire season. They noted that prescribed burns conducted from several months to three years earlier had prevented each of these fires from attaining a much larger size, thereby saving considerable suppression resources and, in one case, avoiding damage to private property.

Further, as three of the studied bushfires were burning on a day when there were 17 going fires, the earlier prescribed burning had provided a considerable strategic benefit by freeing-up suppression resources which could be diverted to other, more dangerous fires. Their paper also noted that:

- The successful containment of each of the four studied bushfires showed that, for at least two years, a fuel reduced area in heath, and in heathy woodland can be effective in restricting bushfire spread under a Fire Danger Index (FDI) of up to 40 (i.e. 'very high'); and that
- A prescribed burn in Brown Stringybark (*E. baxteri*) woodland can reduce bark hazard for up to 10 years, thereby reducing spotting potential which greatly assists bushfire suppression.

Buckley (1990) examined the 5,700 hectare Bemm River bushfire which burnt in spring 1988 under 'very high' to 'extreme' fire danger conditions (i.e. FDI up to 82 with measured rates of fire spread of up to 4 km/hr) in mixed eucalypt forest with an aerated, highly flammable shrub layer, and a total fine fuel load of approximately 20 tonnes per hectare.

Several fuel reduced areas were impacted by the Bemm River fire enabling the following conclusions to be drawn:

- Dramatic protection of forest was achieved under 'very high' fire danger conditions in areas which had been prescribed burnt one-and-a-half years earlier;
- Similar protection was achieved under 'high' fire danger conditions in areas which had been prescribed burnt 6 months and two-and-a-half years earlier;
- A measurable protective effect was still apparent in areas which had been prescribed burnt seven years earlier compared to areas which had been unburnt for long periods; and
- To provide a protective benefit, fuel reduction burns conducted in East Gippsland's coastal forests need to achieve more than 50% coverage of treated areas.

These conclusions were drawn from comparisons of documented fire history against the level of crown scorch mapped in the aftermath of the bushfire.

Findings from this fire regarding the protection afforded by previous prescribed burning concurs with McCarthy and Tolhurst (2001) who concluded that the highest probability of it being helpful to bushfire suppression in south eastern Australian forests was in the first four years, with decreasing effect up to 10 years after the burn.

Western Australian case studies

There have been numerous WA examples where the prescribed program has demonstrably assisted in the control of major bushfires thereby preventing or minimising impacts to lives, properties and environmental values.

Underwood *et al.* (1985) documented nine case studies of bushfires in south-west WA during the period from 1969 to 1984. These varied in size from 40 to 8,000 hectares and were selected for detailed analysis on the basis of providing a representative sample of forest and fuel types, fire behaviour, and damage potential.

The paper found that control of all these fires had been assisted by the presence of areas which had been prescribed burnt within the previous six years, and further concluded that in each case these bushfires would have had serious social and economic consequences in the absence of extensive fuel reduced areas.

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

Underwood *et al.* (1985) also found that an extensive program of prescribed burning is needed to optimise its benefit in bushfire mitigation. In the forests of south-west WA, they suggested an eight-year rotational program to ensure that at any time, around 50% of the forests are carrying fuels that are four years old or younger. It was envisioned that this would provide an excellent aid to bushfire suppression under 'difficult' conditions.

Sneeujagt (2008) reports on a celebrated example of the effectiveness of prescribed burning which occurred in 1978 when 92 fires associated with the passage of Cyclone Alby burned out-of-control in south-west WA under the influence of winds of up to 130 km/hr with extensive spotting driving rates of spread of up to 8 km/hr.

Although more than 54,000 hectares was eventually burnt, only 7,000 hectares of this was in State forest due to low fuel levels maintained by earlier prescribed burning. The fire intensity and rate of spread was so reduced in these forests that suppression resources were able to be freed-up for deployment to other more threatened areas.

Sneeuwjagt (2008) also documents the 18,000 hectare Mt Cooke fire of January 2003, which was ignited by lightning in a heavily forested Conservation Park which had been unburnt for 17 years. Under severe weather conditions the blaze quickly escalated into a crown fire which killed the vast majority of mature trees but was eventually slowed when it reached forest blocks which had been prescribed burnt 7 years earlier. Even though the severe weather conditions persisted, the fire was able to be directly attacked in these fuel reduced forests and was eventually contained when it reached areas that had been fuel reduced from three to five years earlier.

Boer *et al.* (2009) found that the quantifiable benefit of prescribed burning in mitigating bushfire threat in WA forests was maximised in the first six-years.

The already cited Mundaring-Karragullen fire of January 2005 arose from seven deliberately lit (arson) ignitions on public lands within 20 km of the Perth Hills suburbs. A detailed analysis of its behaviour (Cheney 2010) found that the fires burned vigorously in forest fuels varying from 16 to 26 years since last burnt with rates of spread in the first 24 hours varying from 600 to 1600 metres per hour. Some 36 hours after ignition the fire came under the influence of a strong north east wind which pushed it towards several outer Perth suburbs at a rate of spread of 900 metres/hour. Fortunately, it ran into two to four year-old fuels from recent prescribed burning and in these light fuels, was either stopped completely or slowed to a degree that made it easy to control. Other parts of the fire were also slowed by a landscape-scale mosaic of low fuel zones created by prescribed burning conducted during the previous six years. As a result of this past burning, a fire that could have destroyed hundreds of suburban homes and threatened lives was contained with minimal property loss or damage.

4.2.3 Landscape-scale monitoring of fire severity

Following each of the three major Victorian bushfires which have occurred since 2002, the predecessors of the Department of Environment, Land, Water & Planning have used remote sensing for landscape-scale mapping of fire severity based on levels of tree crown scorch.

Using this mapping to assess the effect of previous burns on areas burnt by the 2003 bushfire, Tolhurst and McCarthy (2003) found that bushfire intensity was significantly lower in recently burnt areas where fuels were relatively light, and noted a measurable reduction in fire severity in areas that had been burnt up to 10 years earlier.

In addition, they found that the effect of recent burning in reducing bushfire severity extends beyond the treated areas themselves in the form of downwind ‘shadows’ which also burn at a relatively lower intensity. These can be quite large areas with ‘shadows’ of low fire intensity of from 15 to 30 km long and 10 km wide identified. These findings emphasise the value of prescribed burning in lessening the damage to environmental values by reducing fire intensity.

4.2.4 Statistical trends and analysis

Statistical trends have long been cited as evidence of the effectiveness of prescribed burning in aiding bushfire mitigation.

Luke and McArthur (1978) detailed one of the most compelling statistical trends to support the effectiveness of prescribed burning when they compared Western Australian forest fire activity before and after the disastrous 1960 – 61 fire season. The exceptional severity of that season sparked a revision of forest fire management which was reflected in a dramatically increased rate of annual prescribed burning, which corresponded with a significant reduction in the number of unplanned bushfires and the average area burnt by these bushfires.

Their findings (presented in Table 2) were reinforced by Mount (1985) in a comparison of bushfire statistics for similar forest types in WA and Tasmania over the previous thirty years. He found that whilst WA bushfires averaged just 15 hectares in size over that period, Tasmanian fires averaged 270 hectares, which he presumed to be primarily due to the far less extensive use of prescribed burning in Tasmania.

Table 2 *Comparison of forest fire activity in south-west WA before and after the revision of fire management in response to the disastrous 1960 – 61 bushfires (from Luke and McArthur 1978, Chapter 18, pp. 244 – 245)*

	Pre-1960-61 (1953-1960)	Post-1960-61 (1961-70)	Change (%)
Average area of prescribed burning	148,000 ha/yr	360,000 ha/yr	+ 140%
Average number of bushfires	350 per year	290 per year	- 17%
Average area burnt by bushfire	24,000 ha/yr	7,000 ha/yr	- 250%

The effectiveness of WA's extensive use of prescribed burning was also endorsed by Underwood *et al.* (1985) who noted that the average sizes of Victorian and NSW bushfires up to the mid-1980s was respectively 12 and 13 times greater than the average WA bushfire in what were perceived to be comparable climate, terrain, and forest types.

In addition, Lang (1997) analysed fire patterns in the Jarrah forests of the Collie District in south west WA from 1937 to 1987 and found that there was a rapid decline in unplanned bushfires once the prescribed burning program began to treat more than 10,000 hectares per year (or 6% of the district's forest).

Similarly, Abbott *et al.* (1993) in studying the history of prescribed burning and bushfire from 1940 to 1990 in an area near Manjimup in south west WA, found that there was a dramatic decline in the size and number of serious bushfires after the introduction of prescribed burning by the Forests Department in 1958.

Arguably, one of the most comprehensive examinations of fire statistics to support the effectiveness of prescribed burning was undertaken by Boer *et al.* (2009). They examined bushfire and prescribed burning records dating back to the early 1950s in the ~1 million hectares of forest in the Warren Region of south-west WA.

Their principal finding was that the area treated annually by prescribed fire had had a significant effect on the annual number and extent of unplanned bushfires over a 52 year period. During this time, an average of more than 80% of the annual burnt area was attributable to prescribed fire. They also concluded that a six-year cycle of prescribed burning significantly reduced bushfire hazard.

According to Jurskis (2003), the value of prescribed burning in improving bushfire management is further illustrated by NSW experience over the 10 year period from 1993 – 94 to 2002 – 03 (see Table 3). He attributes the stark difference in the success of bushfire management between NSW State forests and National parks over this period to their respective land management philosophies. In National parks at that time, prescribed burning was primarily focused on community protection and restricted to boundary areas in close proximity or adjacent to urban and rural communities. Conversely, in State forests, prescribed burning was being undertaken for a broader range of values and was both more extensive and more widespread across the landscape.

Table 3 *Comparative success of bushfire management in NSW State Forests and National Parks during the 10 year period from 1993 – 94 to 2002 – 03*

	NSW public lands	
	National parks	**State forests**
Average % of land tenure prescribed burnt per year	0.4%	3%
Average area prescribed burnt per year	20,500 ha/yr	73,000 ha/yr
Average area burnt by bushfire per year	250,000 ha/yr	70,000 ha/yr
Prescribed burn: unplanned bushfire ratio	8 : 92 [0.09]	51 : 49 [1.04]

Even though a lower than optimal amount of prescribed burning was being undertaken in NSW State forests during this period, it was sufficient to ensure that just more than half of the fire which occurred each year was prescribed fire, applied with a degree of planning and control. Conversely, as less than 10% of the annual fire in National parks was attributable to prescribed burning, over 90% was unplanned bushfire initially burning out of control, often in hot summer conditions which maximised the threat to neighbouring communities, in-park infrastructure, and environmental values.

Whether this conclusively proves the value of prescribed burning is subject to conjecture for it has been noted that large bushfires have at times immediately followed years when huge areas have been prescribed burnt e.g. Victoria's 1983 Ash Wednesday bushfires followed a year in which the highest ever area of prescribed burning had been achieved in the State (climate factors add further complexity in these types of analyses). However, as the Jurskis study was based on average fire occurrences over a 9 year period, it carries more weight than single-year observations.

Reliance on fire area statistics to draw strong conclusions can also be problematic if it ignores other factors which could be affecting the results such as increased urbanisation, changes in the level of community fire awareness, or prevailing climatic conditions over the assessed period. However, the examples cited above certainly provide indicative support for the contention that increased levels of prescribed burning reduces the extent and impact of unplanned bushfire.

4.3 Effectiveness in improving bushfire outcomes under 'extreme' conditions

The range of evidence cited in section 4.2 suggests that prescribed burning can be an extremely valuable bushfire mitigation tool, particularly when undertaken extensively enough to maintain a significant proportion of the landscape under relatively light fuel loads.

There is general agreement amongst fire researchers that light fuel loads created by recent prescribed burning are highly influential in limiting bushfire behaviour and improving controllability under 'low' to 'very high' fire danger conditions (McCarthy and Tolhurst 1998). In the Victorian context, Tolhurst (2007) estimated that for around 95% of the time, bushfires burn under these conditions meaning that earlier prescribed burning can greatly assist the vast majority of bushfires to be quickly and safely controlled.

However, recent public discourse about the merits of prescribed burning has largely focused on whether or not it significantly improves bushfire outcomes under 'extreme' fire danger conditions, of the type which drove Victoria's 2009 Black Saturday catastrophe. Under such conditions there are divergent evidence and views about the influence of fuel loads on the behaviour of bushfires.

4. PRESCRIBED BURNING AS A BUSHFIRE MANAGEMENT TOOL

Fernandes and Botelho (2003), Tolhurst (2007), Boer and Bradstock (2011), Gibbons *et al.* (2012), and amongst others, prominent ENGOs (Taylor 2009), believe that fuel modifications have little effect under 'extreme' conditions as fire behaviour is then driven by the prevailing weather. This is supported by simulation modelling which indicates that weather is more influential than fuel loads in determining the extent of unplanned bushfire (Cary *et al.* 2009; Penman *et al.* 2011).

Bushfires that are burning as crown fires under extreme conditions consume the entire fuel profile including elevated live fuels thus increasing the total available fuel. Fires, both planned and unplanned, under milder conditions consume mostly surface and near surface dead fuels. These are the fuels that can be removed by prescribed burning.

Conversely, some fire practitioners and researchers contend that as fuel provides the energy for a fire it is always the main driver of its intensity – not withstanding that weather (i.e. wind) can certainly increase its rate of spread – and that low fuel loads from prescribed burning can therefore be effective in limiting the spread of bushfires even under 'extreme' conditions (Conroy 1996; Underwood pers comm. 2009; McCoy 2010).

Irrespective of these opposing views, the evidence suggests that prescribed burning plays an important role in mitigating bushfire risks, including those burning under 'extreme' conditions, because:

- By improving the ability to quickly control the vast majority of fires, low fuel loads created by prescribed burning can minimise the likelihood of there being active, going fires when 'extreme' fire danger conditions arise;
- The presence of extensive areas of light fuels throughout the forested landscape can ease demands on suppression forces and can thereby, even on days of 'extreme' fire danger, enable their efforts to be concentrated in areas of greatest threat to life and property. An example from Black Saturday was the White Timber Spur fire near Dargo which burnt through 13,000 hectares of low fuel areas from an earlier bushfire and so required only minimal suppression effort (Parliament of Victoria 2010);

- The lighter fuels and reduced propensity for loose bark created by recent prescribed burning lessens spotting and reduces the rate of fire spread compared to fires burning in long unburnt forests with heavy fuel accumulations (Cheney *et al.* 2012); and
- Insufficient prescribed burning which allows the development of heavy fuel loads, makes fires burn more intensely under any conditions and thereby may increase risks to human life and property even on days when conditions are less than 'extreme'.

Not all prescribed burning is equally as effective in bushfire mitigation. The experience from south-west WA suggests that prescribed burning effectiveness in those forests is substantially better when programs are extensive enough to maintain a significant proportion (at least 25%) of the forest estate under light fuels (5 years old or less). This was the case in WA south-west forests where, until recent years, 6 – 8% of forests were prescribed burnt each year (Sneeuwjagt 2008).

This was far from the case in the huge areas burnt by Victorian bushfires since 2003. Forest Fire Victoria's submission to the 2009 Victorian Bushfires Royal Commission drew on records of past prescribed burning to show that in the 13 year period leading up to 2006 – 07, just 1.4% of Victoria's public forests were being annually treated. Under such a burning regime, no more than 7% of Victoria's public forests would at any time consist of light fuels less than or equal to five years old, excluding the effects of bushfires (Forest Fire Victoria 2009, p. 17).

This relative lack of prescribed burning arguably explains why doubts have been expressed about its value in mitigating bushfire behaviour following the recent Victorian bushfires. The effect of insufficient burning had previously been quantified by an analysis of Victorian bushfires during the period from 1990 to 1997 which showed that past burning had been a positive factor in aiding suppression in only 11% of those fires (McCarthy and Tolhurst 2001).

Further to this, following recent major bushfires in Victoria, ENGOs and others have put forward several examples where light fuels from recent burning (conducted only several years earlier) had no obvious effect on mitigating bushfire behaviour (VNPA 2007; Taylor 2009; OREN/MWCN 2009). Conversely, there are other examples from these same fires where light fuels from prescribed burning or earlier bushfires had definitely constrained fire behaviour and reduced environmental damage (Institute of Foresters of Australia 2009; McCaw 2010).

As the ostensibly ineffective prescribed burns do not appear to have been subsequently examined by fire specialists in the field, it is difficult to know whether they exemplify a failure of the concept or are indicative of poor burning practice and/or strategy. Certainly, Rawson *et al.* (1985) found that there are many variables which can influence the effectiveness of prescribed burning in mitigating subsequent bushfire threats. More recently, McCarthy and Tolhurst (2001) and McCaw (2010) have found that intense, fast-moving bushfires can readily pass over or around fuel reduced areas that are relatively small, isolated, old, and/or separated by long unburnt areas with far heavier fuel loads.

Accordingly, prescribed burning has been more effective in WA where, until recently, it has been more extensively applied with around 6 – 8% of the south-western forests treated each year. This appears to have substantially reduced the extent and threat of the vast majority of unplanned summer bushfires since the early 1960s, and through this, has demonstrably reduced the threat of unplanned fires even under 'extreme' fire danger conditions (Sneeuwjagt 2008).

Recently, severe property damage incurred from escaped prescribed burns in the Margaret River region have drawn attention to south-western WA's burning program which has been progressively reduced since the late 1990s (Bush Fire Front 2012). Some WA fire management experts are fearful that more destructive bushfires lie ahead if prescribed burning is further curtailed in response to this event (The Australian 2011). If their prediction comes to pass, it would ironically add further weight to the notion that prescribed burning significantly mitigates bushfire threat, including under 'extreme' conditions.

4.4 Extensive versus strategic prescribed burning

A further area of debate over prescribed burning concerns the respective merits of extensive burning right across the landscape (including very remote areas) versus an ostensibly more strategic approach targeting only vulnerable areas adjacent to the public land/urban fringe.

In Victoria, most ENGOs have given tacit support for prescribed burning based on the premise of it being mostly small-scale and strategic (VNPA 2007; Wilderness Society 2009; Taylor 2009), and have criticised the 2009 Victorian Bushfires Royal Commission for imposing an increased annual burn area target which they fear will encourage more extensive burning of remote areas (Wilderness Society 2010). This view is also supported by some scientists (Driscoll 2010; Clarke 2012).

The case for concentrating prescribed burning in strategic locations around the public-private land interface is also supported by Gibbons *et al.* (2012) who found that 15% fewer houses were destroyed on Black Saturday where prescribed burning had been located 500 metres away rather than the observed mean distance of 8.5 km away. On this basis, they favoured "a shift in emphasis away from broad-scale fuel reduction to intensive fuel treatments close to property".

On the other hand, most forest fire practitioners agree that extensive prescribed burning, located well away from property and settlement, including in remote areas, plays a critical role in mitigating bushfire threat by making it easier to suppress fires that could otherwise gain momentum and spread to settled areas (Tolhurst 2007; Sneeuwjagt 2010). Such a scenario was exemplified by the 2003 Victorian Alpine fires which started as a series of lightning strikes in very remote areas which eventually joined to burn for two months over an area exceeding 1.1 million hectares. During this time they both threatened and resulted in property losses in many small rural communities (State Government of Victoria 2003).

A more specific example of the benefit of extensive prescribed burning in avoiding potential property loss was the Tostaree fire in eastern Victoria in February 2011. It started on farmland about 20 km west of the town of Newmerella under 'severe' to 'extreme' fire danger conditions (temperature exceeding 40 degrees with strong winds). The fire burnt through 11,400 hectares of mostly forested country largely under the influence of a strong south-westerly change, before being slowed and eventually contained in extensive areas of low fuels from prescribed burning conducted from one to four years earlier (State Government of Victoria 2011).

It has been acknowledged that this extensive prescribed burning played a significant role in avoiding potential property loss in small settlements at Waygara and Simpsons Creek. The larger Newmerella township was never directly threatened because the fire was contained in fuel reduced areas some 10 – 12 km away. Unfortunately, the role of extensive prescribed burning in mitigating bushfire threats well before they can directly impact on distant life and property is rarely acknowledged.

Conducting extensive prescribed burning in remote areas also helps to avoid significant land and water degradation that can otherwise occur when bushfires burn in heavy fuel accumulations in long unburnt forests. Significant ecological impacts were noted in remote country within months of the 2003 Victorian Alpine fires in areas where heavy fuels had burnt with destructive ferocity. Of particular concern were impacts on water quality and stream biota in the headwaters of relatively pristine streams in the remote Cobungra and Buckland catchments (Wareing and Flinn 2003).

The environmental benefit of prescribed burning in remote areas is also supported by studies showing that post-fire recovery of flora, fauna and soils is far more rapid and complete following low intensity prescribed burns compared to high intensity bushfires burning with destructive severity in heavy fuels. High intensity fires tend to remove a greater proportion of the tree canopy, a much greater portion of woody debris from the forest floor, more of the tree bark, and more of the potential wildlife refuge areas such as damp gully vegetation. In addition, they induce greater soil heating and plant death and can cause higher wildlife mortality (Department of Sustainability and Environment 2003).

As science and observation supports the need for both strategic and extensive prescribed burning, it seems that overly focussing on one at the expense of the other is likely to create perverse outcomes.

Considerable scientific uncertainty surrounds prescribed burning and biodiversity. While there is unanimous agreement that much is yet to be learnt, there is – particularly in temperate southern Australia – ongoing debate over whether or not there is sufficient knowledge to justify extensive prescribed burning programs.

5. PRESCRIBED BURNING AND BIODIVERSITY

What could be learnt about the environmental implications of fire (both planned and unplanned) is almost limitless given the hugely variable array of Australian ecosystems and their plant, animal and invertebrate components. This includes the impacts of a prolonged lack of fire, as well as impacts associated with very frequent fire. Accordingly, there is an almost universally acknowledged need for ongoing research in this area (Gill and Bradstock 2003).

Nevertheless, there is much that is already known after around 50 years of study and a century or more of observation. For many fire researchers and practitioners, this is more than adequate to justify the extensive application of prescribed fire (Parliament of Victoria 2010a).

Prior to Victoria's 2009 Black Saturday bushfires, academic opinion about broad-scale prescribed burning may well have been more divided. The subsequent Royal Commission appears to have reduced some of the differences between opposing views given the broad consensus reached amongst the Commission's expert forum of seven specialist scientists advising on land and fuel management (Adams and Attiwill 2011, p. 83).

However, while it may have been hoped that Black Saturday would engender a broader acknowledgement that prescribed burning – even if based on imperfect knowledge – is better than severe bushfire, this may not necessarily be the case. With the passage of time since the Royal Commission, there has been an increasing reiteration of former concerns about prescribed burning amongst some scientists, including at least one who participated in the Commission's expert forum (The Australian 2012; Clarke 2012).

5.1 Perceptions about the ecological impacts of prescribed burning

The need for more research into the potential ecological impacts of prescribed burning has been widely supported since ecologist Harry Recher observed in 1985 that:

> *"Considering the frequency with which fires occur in eucalypt forests and woodlands and their dramatic impact on the landscape, there is remarkably little information about the effects of fire on fauna or the long-term consequences of burning of forest ecosystems" (Gill et al. 1999).*

However, Recher's measured concern has at times morphed into alarmism amongst some scientists:

> *"The long term effect of the prescribed burning regime currently used in the management of the drier forests of south eastern Australia will reduce the habitat suitable for native fauna to islands. Suitable forest habitat will only remain along creeks and drainage lines or in places where vegetation can recover quickly after fire. … the reduction of faunal habitat due to prescribed burning is insidious and not readily apparent. Such restriction of the wildlife to small pockets greatly increases the risk of predation by dingoes, foxes, cats and raptors" (Catling 1994).*

Comments such as this raise a question about the level of understanding about prescribed burning, particularly with respect to its frequency, extent, and intensity. For example, Bradstock *et al.* (1998a) based their concerns about NSW prescribed burning on expectations of fire frequency of one to four years which is unrealistically high for a well-managed prescribed burning program.

A further example comes from Tran and Wild (2000) who refer to the dangers of:

> *"… periodically burning-off high risk vegetation such as Eucalyptus every 5 – 10 years (because it) does not provide enough time for the trees to flower and produce enough seed bank reserve, so in one fire season with an inappropriate fire frequency the natural inhabitants of an area may be lost …"*

In addition, they use mountain ash (Eucalyptus regnans) as an example of a species which needs a longer interval between burns. This suggests a lack of appreciation of prescribed burning as low intensity fire with generally minimal effect on overstorey trees, and a lack of awareness of mountain ash forest as almost never being deliberately burnt due to its sensitivity to fire and the forests' typically wet condition.

Arguably, expectations of very frequent prescribed burning in temperate southern Australia reflect misconceptions about the logistical capacity of government land management agencies, the planning and regulatory processes which govern prescribed burning, and the magnitude of social and demographic constraints that have to be confronted. Even in south-western WA, where prescribed burning has been employed at greater frequency than other parts of temperate southern Australia, the average prescribed burn frequency was 12 – 16 years when the practice was at its peak, burning 6 – 8% of its forests annually. This regime was still able to protect long unburnt fuels to add diversity (Underwood *et al.* 1985; Abbott *et al.* 1993; Lang 1997).

Strongly expressed scientific concern about prescribed burning has been used by those ENGO's which remain ideologically opposed to the concept of extensive human intervention or management of 'natural' ecosystems. For example, the Victorian National Parks Association has stated that:

> *"We are strongly opposed however to broad-scale burning that is likely to alter ecological functioning … If current strategic fuel reduction burning is increased to broad-scale burning, there will be concomitant losses in biodiversity and environmental services, such as water quality. In the medium term, some of the forests will be made more flammable by repeated burning" (VNPA 2007).*

Given the support enjoyed by ENGOs, it is hardly surprising that a level of concern about the use of prescribed burning has developed amongst the wider community. However, Jurskis (2003) contends that much of this community concern appears to be linked to misunderstanding of the objectives and practice of prescribed burning, including misconceptions of environmental damage based on extrapolations from observations of hot summer bushfires.

Other community misconceptions of prescribed burning may include:

- A misunderstanding of prescribed burning as being a fuel removal rather than fuel reduction measure. This manifests itself in unrealistic expectations of it as being able to prevent or act as a barrier to the progression of bushfires, and a subsequent loss of support for its use when an extreme bushfire inevitably proves this to be incorrect;
- An under-appreciation of broad-scale prescribed burning as being slow-moving, low intensity fires lit under cooler conditions so as to keep them controllable and limit their environmental impact. The intention is for it to burn in a patchy manner (burning between 50 and 90% of the planned area) leaving scattered remnant habitat from which flora and fauna can recolonise adjacent burnt ground. This is very different to unplanned summer bushfires which can be hugely more intense and fast-moving as they burn almost everything in their path over extensive areas; and
- A lack of appreciation of the natural prevalence of fire in the landscape, particularly in the more developed and urbanised southern states. The records of early pastoralists and explorers are full of observations about the incidence and extent of fire either from Aboriginal burning or other means, such as lightning. They also paint verbal pictures of the indigenous vegetation as often being quite different to what we see today (Hately 2010; Gammage 2011).

Such misconceptions are likely to be much stronger in urban settings where the vast majority of Australians live far removed from forests and other public lands where prescribed burning is used. Rural communities which live with the threat of bushfires, generally display greater understanding and acceptance of prescribed burning (Bell and Oliveras 2006).

If misconceptions about prescribed burning were fully explained and a wider understanding of its role and purpose ensured, there may well be far broader community support for its use (FFMG 2014).

5.2 Ecological impacts of prescribed burning

Debate over the ecological impacts of prescribed burning seems to be largely based on whether or not the frequency (or proposed frequency) of burning matches 'natural' (pre-European) fire regimes. This is a complex question because there is such a range of vegetation types, each with its own presumed optimal fire regime based on time intervals required by major structural components to recover after disturbance (Gill *et al.* 2003).

For this reason, many fire scientists advocate variable fire frequencies across the landscape to create favourable conditions for a broader array of species despite a lack of knowledge of what constitutes optimal habitat age mosaics (Keith *et al.* 2002; Bradstock *et al.* 2005; Parr and Anderson 2006).

Despite a relative lack of qualitative data on the long-term effects of repeated prescribed burning (Clarke 2008), there is broad agreement amongst scientists that inappropriate fire management is a major threatening process for both flora and fauna (Cowling *et al.* 1990; Morrison *et al.* 1996; Bradstock *et al.* 1997; Woinarski 1999; Garnett and Crowley 2000; Keith *et al.* 2002; Jurkis 2005; Horton 2011).

This concern is reflected in efforts to formally list fire as a key threatening process in environmental legislation. In Victoria, 'inappropriate fire regimes' was listed as a 'potentially threatening process' under the state's *Flora and Fauna Guarantee Act 1988* in July 2009 (Department of Sustainability and Environment 2009). In NSW, only 'high frequency fire' (as distinct from too little fire) is listed as a key threatening process under its *Threatened Species Conservation Act 1995* (Department of Environment and Heritage 2012).

At the national level, a nomination for 'fire regimes which causes biodiversity decline' to be listed as a key threatening process under the federal *Environment Protection and Biodiversity Conservation Act 1999* was considered but rejected during 2009/10 (DSEWPC 2012).

While these listings (and attempted listings) may reflect concern over the use of prescribed burning, they also acknowledge the arguably far greater biodiversity threat posed by large severe bushfires which can homogenise habitat over vast swathes of landscape.

5.2.1 Temperate southern Australia

While the potential for prescribed fire to cause ecological damage has long been a concern in temperate southern Australia, this has somewhat inexplicably overshadowed concerns about the far more observable damage caused by severe summer bushfires.

Up to 2003, there were many studies of the impact of fire on individual species and ecological communities, but there have been only modest additions to the knowledge base since then. This includes a lack of published research on the ecological impacts of the several severe bushfires that have hugely afflicted the forests of south-eastern Australia since 2002 (Attiwill and Adams 2011).

Despite the lack of formal peer-reviewed research into these recent conflagrations, in-house government agency analyses, observations, and measurements confirm that they were hugely damaging to the environment. For example, the 2003 Alpine fires which, in just 59 days, burned around 1.7 million hectares of land in Victoria, ACT and NSW, reportedly:

- Killed an estimated 370 million reptiles, birds, and mammals (Franklin 2007);
- Killed substantial areas of forest, some of which may not regenerate back to its pre-fire form (Wareing and Flinn 2003); and
- Initiated post-fire forest regeneration of killed areas in the most severely affected half of the burnt area that will reportedly reduce inflows to the Murray River headwaters by an estimated 430 billion litres per year until 2050 (CRC for Catchment Hydrology 2003).

5. PRESCRIBED BURNING AND BIODIVERSITY

In contrast to the severe bushfire impacts, a large body of work has been devoted to analysing the impacts of prescribed fire which burns slower and cooler in milder conditions and is presently far less extensive. In essence, this reflects a disproportionately greater research effort being devoted to an activity that is far less damaging. For example, for the period from 2002 – 2009, about 3 million hectares of Victorian public lands were burnt by summer bushfires, whereas about 850,000 hectares were prescribed burnt. The prescribed burn area over this period equates to just 28% of the bushfire-affected area (Adams and Attiwill 2011, p. 92).

The findings of research into prescribed burning impacts can be quite variable and contentious. There are some concerns that presumptions about the ecological effects of prescribed burning in southern Australia are becoming increasingly reliant on modelling. The veracity of modelling is reliant on inputs about species life history attributes which are often generalisations, or worse, 'best-guesses' that have often not been properly researched or field-tested. According to Adams and Attiwill (2011), these models invariably recommend very conservative burning regimes that may be unnecessarily at odds with the fire protection responsibilities of land managers.

Provisional recommended fire frequencies for a range of vegetation communities have been available for over 30 years (Chambers 1977). By the early 1990s, Gill and Bradstock (1992) were compiling a national register of 1500 plant species and their fire recovery attributes, although the data collected did not provide quantitative predictions of the effect of fire regimes on species populations.

5. PRESCRIBED BURNING AND BIODIVERSITY

In Victoria, in 1998, the agencies responsible for park and forest management entered into a then unique partnership that was designed to improve the understanding of the role of fire in the maintenance of biodiversity. Among the aims of the joint initiative was the …"better integration of broadscale fuel management strategies with fire related ecosystem needs …".

In 1999, Interim Guidelines and Procedures for Ecological Burning on Public Land in Victoria were published following some initial trialling. Finalised guidelines were released in 2004. Concurrently, considerable effort was also put into improving the quality of the information contained the State's flora and fauna data bases.

By 2002, the NSW National Parks and Wildlife Service had developed a Flora Fire Response Database (Adams and Attiwill 2011), and a similar database had been developed for threatened plant species in WA by 2010 (Shedley *et al.* 2010).

The value of such databases was questioned by Vivien *et al.* (2009) who found substantial divergence between predicted plant responses to fire in the NSW Flora Fire Recovery Database and actual responses in the field following the 2003 fires in the Brindabella Ranges near Canberra. This finding suggests that there is considerable within-species variation in fire response traits, and that databases which classify species into single trait categories are likely to substantially understate the capacity of plants to survive and recover from fire.

While this finding will hopefully stimulate improvements to current systems of plant classifications and lead to expanded databases that take better account of fire responses, it also highlights the shortcomings of some models used to predict the ecological impacts of theoretical prescribed burning regimes.

A further shortcoming of modelled responses to theoretical fire regimes is that they are based primarily on vegetation, and take little or no account of fauna species and their requirements (Clarke 2008; Driscoll 2010). To date, no systematic functional classification of the responses of fauna to fire has been developed, although several scientists have identified some of the ecological and life-history attributes that are important in determining the response of some vertebrates to fire (Kenny *et al.* 2003).

In NSW, these are included as primary variables in the Threatened Fauna Fire Response Database. However, it is notable that fire response information was found for just 29% of threatened fauna species, with 'good' fire response information available for only 3%. Even for species with well documented fire responses, such as the eastern bristlebird (*Dasyornis brachypterus*) and Hastings River mouse (*Pseudomys oralis*), the implications of such information for fire management remains unclear (Kenny *et al.* 2003).

As there is such uncertainty associated with planning fire regimes based on modelled ecological traits, a better picture of the actual ecological impacts of prescribed burning may be garnered from field burning trials and associated monitoring over a long period.

Arguably, Australia's most significant prescribed burning trial is the ongoing Wombat Fire Effects Study located in central-western Victoria's mixed species foothill forests. The Study's Summary Report, prepared after the first 15 years of research, provided a range of findings about the ecological impacts of prescribed burning in this forest type (Department of Sustainability and Environment 2003). These included:

- Over a 14 year period, no plant species were either lost or gained as a result of up to four successive spring or three successive autumn fires;
- No long term changes were noted in the activity or abundance of invertebrates following a single low intensity prescribed burn;
- Three low intensity prescribed spring burns within eight years had no impact on litter arthropods;
- None of several studied reptile species was favoured by a particular burning treatment;
- Unburnt microhabitats (particularly logs, deep beds of leaf litter and areas frequently not burned by low intensity fire such as damp gullies) provide important refuges and food, shelter and oviposition sites in the post-burn period;
- No particular burning treatment favoured either of two small mammal species which were studied;
- Populations of the Brown Antechinus (*Antechinus agilis*) were significantly higher two to three years after prescribed burns than in long unburnt areas;
- Some birds respond positively to fire and some species may depend on it. Prescribed burning provides ephemeral patches of bare ground habitat at the landscape scale which may be advantageous; and
- Low intensity prescribed fires repeated at intervals of less than ten years can be expected to lead to a decline in soil organic matter and soil fertility. At intervals of 10 years or greater, there was little if any change in carbon and nitrogen levels, suggesting that such a strategy would maintain soil organic matter in the long term.

Whilst the Wombat Fire Effects Study found that prescribed burning on three to five-year frequencies would be ecologically undesirable, regular burning on frequencies in excess of ten years appears to have no adverse implications given the rate of ecosystem recovery following low intensity fires in these forest types.

It is pertinent to note that the frequency of prescribed burning undertaken in various treatments associated with the Wombat Fire Effects Study far exceeds the likely frequency of burning across Victoria's public forest estate. If the 2009 Victorian Bushfires Royal Commission's recommendation to triple prescribed burning is fully implemented, the average frequency across the treatable forest estate will be an approximate 15 year interval between burns.

Another prescribed burning trial is the Eden Burning Study which began in 1986 in the Yambulla State Forest, in south-eastern NSW. It is based on a study area of 830 hectares of shrubby dry sclerophyll forest and was established to determine the effects over time of timber harvesting and repeated prescribed burning on parameters including vegetation structure and floristics, and impacts on some faunal groups (Binns and Bridges 2003).

5. PRESCRIBED BURNING AND BIODIVERSITY

Penman *et al.* (2008) reported some of the principal findings of the Eden Burning Study, including that:

- Prescribed burning regimes have caused only minor changes to plant species diversity, far less than what had been predicted by other studies;
- The major change occurring within the study area appears to be a natural response of the vegetation to increasing time since the last bushfire. This was occurring independently of imposed management regimes;
- Frequent fire resulted in a relative increase of vegetation species less than one metre in height, and in total species richness, but caused a decline of shrub species;
- There has been a general decline of plant species richness for the ground and shrub layers, but this has occurred independently of imposed management regimes; and
- The natural decline in species richness irrespective of prescribed burning treatments, suggests that higher intensity bushfire and the time since it occurred is the greatest arbiter of vegetation species richness in these dry sclerophyll forests. This is presumed to be because prescribed fire may not burn with sufficient heat to stimulate regeneration in many plant species.

Also in NSW, the Bulls Ground Frequent Burning Study was established in 1970 in the Lorne State Forest, near Port Macquarie. It consists of 14 one-hectare representative sites within even-aged Blackbutt (*E. pilularis*) regrowth forest, selected for either frequent burning treatments (every three years) or left unburnt for comparison (Andrew *et al.* 2000).

York *et al.* (2006) reported that studies at the Bulls Ground site show that frequent prescribed burning has a marked effect on litter inputs by causing them to oscillate substantially compared to long unburnt sites where litter inputs reach equalisation with rates of decomposition. This is linked to other findings such as:

- Less soil moisture in the top soil of frequently burned plots compared to long unburnt plots;
- Lower percentage of total carbon in the frequently burned plots compared to long unburnt plots; and
- Significantly lower numbers of all groups of litter dwelling invertebrates in the frequently burnt plots compared to the long unburnt plots.

However, Andrew *et al.* (2000) found little difference in the species richness and abundance of ants on Bulls Ground sites that had been either frequently burnt (every three years from 1970 to 1992) or had not been burned for 25 years. However, they did note that a distinct group of ant species was not present in open areas of the frequently burnt plots.

Christie and York (2009) studied the impact of frequent burning on forest health at Bulls Ground and found that parameters such as foliar nutrient content and degree of insect browsing on canopy leaves showed no significant differences between sites which had been excluded from fire for 45 years, sites that had been frequently burnt (every three-years over a 35 year period), and sites which had been recently burnt after decades of fire exclusion. This suggests that these aspects of forest health are resilient to both frequent burning and fire exclusion.

Jurskis (2003) reports that unpublished State Forest NSW findings from vegetation studies at Bulls Ground show that the species richness of understorey vegetation was greater in frequently burnt plots compared to long unburnt plots, and that unburnt plots contained more woody understorey species.

As with other experimental burning studies, any presumed implications for prescribed burning arising from findings derived from Bulls Ground need to be treated with caution due to the frequency of burning on treated plots being far in excess of the actual frequency of burning that could realistically be applied in extensive prescribed burning programs.

In south-western WA, several studies have also examined the ecological impact of variable fire frequencies including those resulting from prescribed burning programs.

Wittkuhn *et al.* (2011) studied ecological community responses to different fire interval sequences resulting from both planned and unplanned fires in forests and shrublands in the Warren bioregion of south western WA. This included surveying vascular plants, invertebrates, vertebrates, and macrofungi at 30 sites to investigate responses to various short, long, and mixed fire intervals over a 32 year period from 1972 – 2004.

They found that occasional short intervals between fires (3 – 5 years) are unlikely to have a persistent effect on the composition of forests and shrublands, whereas maintaining a steady regime of either short or long fire intervals may alter species composition and/or abundance. They concluded that prescribed burning programs which incorporated variability in burning intervals were best placed to achieve the dual objectives of bushfire mitigation and maintenance of biodiversity conservation. This finding concurs with other scientists such as Catling (1991), Bradstock and Kenny (2003), Watson and Wardell-Johnson (2004) and Gill (2008) who had previously advocated the importance of variable fire intervals.

Also in WA, Burrows *et al.* (2010) applied five different prescribed burning treatments (including a 25 year unburnt control) to mixed Jarrah (*Eucalyptus marginata*) and Marri (*Corymbia calophylla*) dry forest to investigate the respective effects of fire frequency on tree stem diameter growth, stand basal area increment, and tree mortality. They could find no clear pattern of effects associated with burning treatments – including both the number of fires and between-fire intervals – on these parameters, including crown health. Accordingly they found no evidence that could link regular low intensity burning to deteriorating tree or stand health in this forest type.

Again in south-west WA, Pekin *et al.* (2009) measured the variation in a range of tree and stand parameters across 16 mixed Jarrah and Marri forest stands along an aridity gradient displaying variable fire history. As with Burrows *et al.* (2010), Pekin *et al.* found that total stand biomass and leaf area index did not vary with fire frequency. However, they did note that Marri was adversely affected by more frequent fire, but that this was compensated by increased growth of Jarrah.

In Tasmania, there has also been considerable discussion and reflection on the ecological impacts of fire (including prescribed burning), but most research has been descriptive rather than experimental in nature (Marsden-Smedley 2009).

With regard to the ecological effects of fire frequency, buttongrass moorlands have been the most comprehensively studied Tasmanian vegetation association. Various researchers have found that species diversity in low and medium productivity moorlands is highly resilient to changes in fire frequency and time since fire, although frequent fire appears to have minor influences on species and structural diversity on medium productivity sites. In contrast to this, high productivity moorlands at low altitudes in northern Tasmania have been found to structurally transform to a wet scrub association after about 30 years without fire (Marsden-Smedley 2009).

Although there is no quantitative information about the ecological effects of fire frequency in buttongrass moorlands, considerable research has uncovered information about recommended recovery times for a range of bird, mammal and invertebrate species that could influence prescribed burning programs in this vegetation type. Conversely, less research has been undertaken in Tasmanian eucalypt forests, although tentatively recommended prescribed burning intervals have been developed for several threatened species (Marsden-Smedley 2009).

In south-east Queensland long term experiments in forests at Bauple, Peachester, Beerwah and Cooloola are maintained by Agri-Science Queensland of the Department of Agriculture, Fisheries and Forestry (DAFF). The Bauple fire experiment is the longest running in Australia being burnt on an annual basis since 1952, and with a good portion of the long-unburnt site remaining unburnt since 1946. In Beerwah there are three sites that have been prescribe burnt since 1972 on a cycle of every three years, five years and unburnt respectively. At Peachester, there are three replicated blocks with treatments of biennial, quadrennial and no burning since 1972 (Lewis and Debuse 2008).

Research at these sites over the last decade or so has considered the influence of frequent fires on soil nutrients, tree health and density, and the composition and abundance of flora and fauna. Frequent fire has had a variable influence on soil nutrients. For example, biennial fire in the wet sclerophyll forest resulted in lower total carbon and nitrogen levels, while frequent fire at the dry sclerophyll forest showed no significant effect (Guinto *et al.* 1999).

At the Bauple experiment, McBeth (2008) found that tree canopy density was greater in the triennially burnt treatment than in annual and unburnt treatments and that overall tree health was better in the triennually burnt treatment. Hannah *et al.* (1998) found that the unburnt treatment supported a greater richness of reptile species while Porter and Henderson (1983) found that the unburnt site supported bird species that favour more complex understoreys, and the annually burnt treatment supported bird species that favour grassy habitats. Ant species richness and total ant abundance was higher in the annually burnt area than in the unburnt site, although the unburnt site favoured some different ant groups (Vanderwoude 1999).

Also in south-east Queensland, Watson and Wardell-Johnson (2004) studied the effects of recent fire frequency and time-since-fire on the flora of open forests and woodlands in the Girraween National Park. They examined areas which had burned at least three times over the previous 25 years to compare them with less frequently burnt areas, including woodlands which had not been burnt for 28 years.

They found little variation in species richness with either time-since-fire or variations in fire frequency, although community composition was noted to be somewhat sensitive to fire frequency in particular. Less than 10% of the 67 plant species were significantly affected by time-since-fire, whereas about 16% varied significantly in response to fire frequency. However, the majority of species did not vary significantly under different fire regimes.

Not all studies of the ecological impacts of frequent prescribed burning find it to be so relatively benign. For example, Bradstock and Myerscough (1988) predicted the possibility of extinctions or at least likely declines of several coastal vegetation species under then current fire regimes in the Sydney region of NSW. Catling (1991) and Bradstock *et al.* (1998) have also made findings that frequent and extensive prescribed burning is threatening Australian biodiversity while having little impact on bushfire control. More recently, Keith *et al.* (2002) and others have speculated that repeated fire at short intervals will lead to extinctions amongst obligate seeding plants.

There is also some concern that predicting the ecological impacts of prescribed burning only on the basis of fire frequency ignores other critical parameters such as fire intensity and spatial variability which can affect the survival and health of species in areas ostensibly considered to have been burnt (Jurskis 2003), while failing to consider the health of the ecosystem prior to the fires (Gill 2008).

In conclusion, science-based concerns of significant biodiversity impacts from prescribed burning in temperate southern Australia appear to be partly based on observations and modelled assumptions of fire frequencies that are unlikely to be deliberately replicated in well-managed prescribed burning programs. They also appear to be partly based on questionable generalisations and 'best guesses' about the processes by which vegetation species and communities recover after fire (Adams and Attiwill 2011).

Such concerns are not currently supported by long term monitoring of field trials testing the ecological effects of successive prescribed burning treatments. However, these trials are not widespread across the full spectrum of vegetation types and may not have been monitored for long enough to definitively exclude the prospect of significant biodiversity damage, particularly under burn frequencies of less than ten years. Prescribed burning frequencies of less than ten years however, are unlikely to be widely implemented in temperate southern Australia.

5.2.2 Tropical savannah region

Although prescribed burning is widely used in northern Australia's tropical savannahs to lessen threats to biodiversity from high intensity late-dry season bushfires, its ecological implications have traditionally received little attention (Andersen *et al.* 2005; Scott *et al.* 2008). This is echoed by Parr and Andersen (2006) who examined the presumption that heterogeneous burning begets biodiversity and found that the ecological significance of different burning patterns in Australia's tropical savannahs remains unknown and that the most desirable fire mosaics are yet to be specified.

5. PRESCRIBED BURNING AND BIODIVERSITY

Despite the lack of understanding of what constitutes optimal landscape heterogeneity, it is clear that the spatial patchiness of burnt, unburnt, and less recently burnt parts of the landscape is important for conservation management (Russell-Smith *et al.* 2003). Price *et al.* (2005) have found that fire-induced heterogeneity progressively increased in Kakadu National Park from the early 1980s to 2000, and that it is fostered by topographic roughness (e.g. rocky outcrops), and proximity to roads and drainage lines which can break-up the spread of fires. Another important contributor is between-fire intervals (Gill *et al.* 2003).

However, on unbroken flat ground, creating and maintaining fire-induced heterogeneity is far more challenging. Accordingly, active landscape management through prescribed burning is necessary to meet conservation objectives because remoteness is no barrier to the development of inappropriate fire regimes (Woinarski *et al.* 2007).

Concerns about the dearth of science regarding fire-induced landscape heterogeneity, as well as a tangible decline in biodiversity across northern Australia, have led to fire experiments being recently undertaken at Kapalga and Boggy Plains in the Kakadu National Park, and in the Territory Wildlife Park near Darwin. These build on earlier fire experiments at Annaburroo, Munmarlary, and Kidman Springs (Russell-Smith *et al.* 2009, p.183).

The five-year Kapalga experiment found that most of the savannah biota is remarkably resilient to fire, even of high intensity. Exceptions to this are riparian vegetation and extinction-prone small mammals which have suffered serious population declines across northern Australia in recent decades. It was found that their primary sensitivity was to the occurrence of fire regardless of its intensity, thereby highlighting the importance of maintaining a proportion of area that has remained unburnt for relatively long periods. As such areas are now quite rare, this creates a challenge for land managers (Andersen *et al.* 2005).

5. PRESCRIBED BURNING AND BIODIVERSITY

The Boggy Plains fire project is part of the Bushfire CRC's Burning for Biodiversity project. Under this project, the CSIRO has worked with a family of traditional owners in Kakadu National Park since 2001 to examine the cultural benefits of Aboriginal fire management as it is re-applied to floodplains associated with the South Alligator River. This includes monitoring any resultant vegetation changes (CSIRO 2008).

The re-introduction of regular fire by indigenous custodians at Boggy Plains and Yellow Water has reportedly transformed these Ramsar-listed wetlands from a dense thicket of grass into a mosaic of habitats rich in biodiversity and of greatly enhanced cultural value (DSEWPC 2006; Andersen *et al.* 2009). Vegetation change is being assessed using a combination of historical aerial photographs (from 1950 to 1991), Landsat satellite imagery, real-time, high resolution Quickbird satellite images, and ground-based surveys (DSEWPC 2006).

The Burning for Biodiversity project in the Territory Wildlife Park also aims to improve understanding of the effects of fire on biodiversity. The research focuses on the effect of fire frequency and time-since-fire on a variety of taxa (both plants and animals), as well as abiotic aspects including fire behaviour and soil ecological processes (CSIRO 2005).

Starting in 2004, the project tested six different burning regimes in eighteen one-hectare plots to assess fuel dynamics, fire behaviour, soil biology and ecological function, grass and tree dynamics, the role of herbivores in vegetation recovery, invertebrate biodiversity, and the population dynamics of small lizards. This work has direct application to fire management issues in WA, Queensland and the Northern Territory (Bushfire CRC 2014).

With respect to the grass-layer, the study found that over four years, the species composition of understorey plants remained unchanged by different fire regime treatments, including the extremes of annual burning and fire-exclusion. Instead, their distribution in the landscape was strongly influenced by other environmental factors such as rainfall and soil moisture, shading from trees, and litter cover. The resilience of the grass-layer to high fire frequencies was found to be attributable to their ability to sprout after fire and avoid heat-related mortality through seeds being buried in a soil seed bank. Adults of dominant perennial grasses showed a similar survival rate within annually burnt and unburnt plots, after a three-year observation period (Scott *et al.* 2008).

While the demonstrable short term resilience of the grass-layer under different fire regimes may be reassuring to land managers, the effect of different fire regimes in tropical savannahs in the medium term (from 4 to 15 years) remains unknown (Scott 2008).

In the Kimberley region, the prevailing regime of frequent, large and intense mid-to-late season bushfires is contributing to biodiversity decline as well as destroying or degrading pasture, soil health, cultural sites and landscape aesthetics. Incipient declines in small mammals, seed-eating birds, riparian species and fire-sensitive plants is attributed to a mix of altered fire regimes, grazing by introduced herbivores, and predation by feral cats (Kingswood and Legge 2011).

Efforts to address this are being undertaken by the Australian Wildlife Conservancy (AWC) through its collaborative EcoFire project which now covers 4.5 million hectares across a range of land tenures. This includes both prescribed burning and research to gauge its effectiveness. Management is focussed on shifting back to a fire regime promoting landscape heterogeneity from the altered regime of large bushfires which has had a homogenising effect and is thus thought to be responsible for negative impacts on biodiversity, pastoral production and cultural values (Kingswood and Legge 2011).

Prescribed burning over such a huge area is mostly being achieved by aerial ignition conducted earlier in the dry season when fires are less intense and tend to burn in a patchy manner leaving a mosaic of unburnt areas of variable size. The success of this strategy in improving biodiversity outcomes is being measured by satellite imagery and ground-truthing in terms of:

- Increased occurrence of unburnt patches measured by reduced average separation between patches; and
- An increase in the average age class distribution of the vegetation driven upwards by the increased unburnt area (Kingswood and Legge 2011).

This approach is expanding as the AWC is entering into partnerships with adjacent landowners, including public land management agencies. While the question of whether this shift in fire regime will optimise conservation outcomes remains, it appears that the WA Government recognises it as an active improvement on the long-standing piece-meal management of the regional landscape (The Australian 2012a).

While further research is needed to identify the mix of burning needed to optimise both bushfire mitigation and conservation outcomes in Australia's tropical north, it is clear that a range of biodiversity responses to variation in fire regime is possible, and that no single regime can hope to optimise all biodiversity outcomes. In the face of such complexity, effective biodiversity conservation depends on developing and working towards explicit conservation objectives (Russell-Smith *et al.* 2009, p. 184).

5.2.3 Arid and semi-arid region

The inland arid and semi-arid regions of Australia are typified by low rainfall of less than 350 mm per annum and cover a vast 70% of Australia's land mass (DSEWPC 2008).

Arid and semi-arid Australia contains a unique mosaic of vegetation types with varying susceptibilities to fire (Marsden-Smedley *et al.* 2012). It is therefore difficult to generalise about the potential or actual effects of prescribed burning on vegetation communities as diverse as shrublands, low mulga woodlands, mallee woodlands, and spinifex grasslands.

In central Australia, it is widely agreed that current fire regimes on all land tenures are unfavourable for some species and ecological communities due to the unnatural prevalence of large, intense bushfires; and that the use and extent of smaller, more scattered, and less intense prescribed burning needs to be increased (Edwards and Allan 2009; Central Land Council 2014). However, there is a critical knowledge gap for land managers attempting to develop and apply appropriate burning regimes for biodiversity conservation (Crowley and McGuire 2011; Marsden-Smedley *et al.* 2012).

In the arid centre, the determination of optimal fire regimes has been hindered by a paucity of ecological data on the reproductive and recovery capacity of the flora, and the habitat and food requirements of the fauna (Marsden-Smedley *et al.* 2012).

In the centre's extensive spinifex grasslands, while the distribution and abundance of fauna has been widely studied including after recent fire and in long unburnt areas, little is known of the effects of fire seasonality on either the fauna or flora, and no studies have addressed the impact of fire intensity (Allan and Southgate 2002).

Recent research in the mallee-dominated woodlands and forests occupying close to 10 million hectares in semi-arid regions of SA, WA, Victoria, NSW, and Queensland (Montreal Process Implementation Group for Australia 2008), has assessed the effects of past fires to test the assumption that creating a mosaic of different vegetation types and seral stages will benefit plant and animal diversity (Clarke and Bennett 2008).

The Mallee Fire and Biodiversity Project found that older age-class vegetation appears to be particularly important (e.g. 20 – 50 years post-fire for spinifex-dependent species). The best predictor of the number of bird species in the landscape was found to be correlated with the overall amount of vegetation >35 years since fire. While the species richness of small mammals was strongly correlated with the amount of vegetation >10 years since fire coupled with past rainfall. For other groups – i.e. reptiles and invertebrates – species richness was not clearly related to fire history or vegetation type (Latrobe University 2010).

While this project has recognised the need for prescribed 'ecological' burning (Latrobe University 2010), the relevance of its findings for such burning is unclear as its consideration of biodiversity impacts were based mostly on past summer bushfires (stretching back to the early 1970s) that are acknowledged to burn hotter and be more destructive compared to prescribed burns conducted at cooler or more stable times of the year.

Letnic (2003) studied the effects of experimental patch burning on small mammals in the Simpson Desert and found that other factors, including rainfall, had a greater effect on their abundance than fire treatments. Nevertheless, this study concluded that patch-burning regimes are likely to increase the resilience of 'fire-sensitive' species dependent on dense spinifex by reducing the extent of bushfires. Similarly, Letnic and Dickman (2005) concluded that while patch-burning regimes do not directly benefit small mammals residing in dense spinifex, they are likely have an indirect benefit by reducing the extent of bushfires.

Apart from this, there appears to have been little research which has specifically targeted the ecological impacts of prescribed burning as distinct from the ecological impacts of relatively recent past bushfires which are acknowledged to have burned with unnatural severity since the decline of indigenous land management over the past 150 years.

Nevertheless, efforts continue to develop a conceptual framework for vegetation-fire interactions to guide appropriate land management in central Australia (Marsden-Smedley *et al.* 2012).

5. PRESCRIBED BURNING AND BIODIVERSITY

5.3 Ecological impacts of a lack of fire

The ecological impact of a lack of fire has been largely ignored in the public discourse about prescribed burning thus far. However recent research is showing that in some forests and woodlands, it may be at least as significant, if not more so than too frequent fire, in shaping forest ecology. Such findings support the need for prescribed burning.

5.3.1 Temperate southern region

Long-term Victorian research – the Wombat Fire Effects Study – has found that there are likely to be adverse ecological implications if forests are left unburnt for considerable periods. In the absence of fire there were subtle changes to forest understories. Whilst only small on a year-to-year basis, they can amount to significant changes over a period of a decade or more (Department of Sustainability and Environment 2003). Jurskis (2005; 2005a) has contended that the unnatural exclusion of fire from NSW forests is responsible for eucalypt decline and death by changing soil and nutrient recycling processes, thereby creating an unfavourable environment for eucalypts while creating conditions that favour their arbivores and competitors.

Further research undertaken in forests in coastal WA and central Tasmania compared frequently burnt sites with long unburnt sites in the same forest type. It was found that on the long unburnt sites, a greater tall shrub mid-storey had developed which exposed the eucalypt overstorey to greater water stress and contributed to respective deficiencies in foliar nutrients such as copper and phosphorous. This was leading to premature eucalypt decline on the unburnt areas compared to the frequently burnt areas (Davidson et al. 2009).

Horton (2011) has postulated that eucalypt decline in central Tasmanian *E. delegatensis* forests is related to reduced fungal activity stemming from changes to soil chemistry resulting from an absence of fire. As ectomycorrhizal fungi form important symbiotic relationships with trees and play a critical role in nutrient recycling, their relative absence due to a lack of fire has a substantial impact on forest health.

More recent research has found that 18% of NSW coastal forests have been degraded by a lack of fire which is linked to important soil and nutrition processes, and that there are common topographic and soil factors which can be used to predict further areas likely to be at risk (Jurskis and Warmsley 2011).

The implications for biodiversity conservation of the unnatural decline and death of overstorey eucalypts in southern Australia's temperate forests are likely to be profound in terms of both flora and fauna (Jurskis 2005). On this basis, fire is integral to the maintenance of biodiversity conservation in these forests (Jurskis and Warmsley 2011).

5.3.2 Tropical savannah region

Fire effects studies have noted the importance of long unburnt areas for faunal abundance (Woinarski *et al.* 2004; Letnic 2003; Letnic and Dickman 2005) and diversity (Latrobe University 2010).

In a comparison of a tropical savannah open forest unburnt for 23 years with similar adjacent areas annually burnt over the same period, it was concluded that a sizeable and distinct set of vegetation and faunal species associated with long unburnt areas is being disadvantaged by contemporary fire regimes which prevent successional change towards rainforest-associated traits (Woinarski *et al.* 2004).

Long unburnt tropical open forests are also associated with significantly diminished species richness and abundance of ants, but a dramatic increase in specialist forest taxa compared to frequently burnt areas where vegetation succession is being suspended (Andersen *et al.* 2006). While with respect to arthropods, the Kapalga experiment showed that a 5 year absence of fire had little impact on the overall diversity and abundance of arthropod taxa in tropical savannahs compared to those found in areas subject to very frequent burning (Andersen and Muller 2001).

In tropical savannahs it has also been found that long term fire exclusion may have a profound effect on the species composition of the understorey vegetation. A comparison between a long unburnt (15 years) and frequently burnt site revealed a significant difference in grass species composition, owing to the loss of common species such as *Sorghum intrans* with fire exclusion, although there was little difference in total grass species richness (Scott 2008).

Overall, it seems that the implications for prescribed burning from research into the effect of excluding fire for lengthy periods are unclear.

5.3.3 Arid and semi-arid regions

In arid Australia, the little examination of this topic suggests that prescribed burning has no direct ecological benefit apart from preventing or reducing the incidence of more damaging hot bushfires (Letnic 2003; Letnic and Dickman 2005). Whereas in the tropics it can play an important ecological role by creating and maintaining a mosaic of different vegetation stages, including long unburnt areas, which is acknowledged as the key to biodiversity conservation (Russell-Smith *et al.* 2009).

5.4 Will prescribed burning make forests more flammable?

One of the concerns expressed in regard to prescribed burning is that it may ultimately increase vegetation flammability by drying out the land and promoting the prolific growth of fire-prone plants which then perpetuates a cycle of increasing flammability.

In tropical developing countries, there is some evidence to support the concept of a ‘fire feedback loop’ in relation to hot fires used to clear forest understoreys (Nepstad *et al.* 2001). In south-eastern Australia, dense regrowth after hot bushfires has been found to have an initial phase of higher flammability followed by a decline as it matures (Zylstra 2009). Also, burning can create conditions that can favour invasion by exotic or indigenous weed species which can increase the overall flammability of post-fire regrowth compared to pre-fire vegetation (Keeley 2006).

Despite these findings, it is debatable as to whether prescribed burns conducted as part of a well planned program in temperate southern Australia would ever be hot enough and/or frequent enough to create a feedback loop which promoted increased flammability. It can be argued that frequent low intensity fires under the ‘natural’ fire regime have already made many ecosystems more flammable and to remove fire will have more impact on their function and survival.

However in tropical northern Australia, the shift to more late-dry season bushfires coupled with the invasion of the introduced African Gamba grass, has already increased the flammability of parts of the tropical savannahs by creating a cycle of hot fires which increasingly favours its proliferation at the expense of native species (Russell-Smith *et al.* 2009, p. 189). However, this is again associated with unnaturally hot bushfire rather than prescribed burning.

6. PRESCRIBED BURNING, CARBON, AND CLIMATE CHANGES

Prescribed burning is a significant source of greenhouse gas (GHG) emissions. In 2009, it was estimated that 9% of Australia's rural emissions (or 2.1% of the nation's total net GHG emissions) were attributable to the combination of prescribed burning of northern Australian savannahs and field burning of agricultural residues (ABARES 2011).

The Hughes and Steffen (2013) suggest:

> …Emission of CO_2 from bushfires generally represents a redistribution of existing carbon in the active carbon cycle from vegetation to the atmosphere. As long as the vegetation is allowed to recover after a fire, it can reabsorb a very large fraction of the carbon released. Indeed, the release and absorption of CO_2 from fire is often assumed to be in balance from landscape fires in flammable vegetation like savannas and eucalypt forests…. (pg. 39)

The timescales associated with the re-absorption of the released carbon may be a significant factor however – see 6.2 below.

There is currently little published information on the impacts of prescribed fuel reduction burning on net CO_2 emissions from southern Australia's temperate forests either from the burning itself or in the following years and decades as a result of changed bushfire regimes (Volkova and Weston 2011). The Bushfire CRC has research projects currently underway to address this knowledge gap with several papers being close to publication. In the north, methods for estimating the net carbon benefits of prescribed burning in tropical savannahs are more advanced and are already being used in fire abatement projects (Russell-Smith et al. 2009).

6.1 Climate change and bushfire management

There are expectations that climate change will exacerbate the bushfire threat across Australia and New Zealand in the future through a greater frequency of hot windy conditions conducive to the spread of intense fires. However the nature of this change is difficult to accurately predict, is likely to be variable between bio-geographic regions, and is reliant on modelling with inherent uncertainties (Bushfire CRC 2006; Hughes and Steffen 2013; IPCC 2014).

Based on climate modelling, the CSIRO has predicted that the frequency of extreme fire danger days will increase by 4 – 25% by 2020 and by 15 – 70% by 2050. It has further predicted that the greatest increases would occur in inland areas with relatively less change apparent in Tasmania and coastal areas (CSIRO 2006). Further impacts on bushfire threat are likely from changed rainfall patterns and increased lightning activity, although the nature of these changes also remains uncertain at this stage (Bushfire CRC 2006).

More recently, Clarke *et al.* (2011) predict FFDI as projected to decrease or show little change in the tropical northeast while in the south-east, FFDI is projected to increase strongly by end of the 21st century, with the fire season extending in length and starting earlier.

With respect to prescribed burning, the increased threat of summer bushfires would be expected to greatly increase its importance given its value in mitigating bushfire extent and severity and providing areas burnt under low intensity conditions. A hotter and drier climate may extend the opportunities for its application in some regions into times of the year which were previously unsuitable. Others are predicting a shorter prescribed burning season (Stefan 2013). Changes to the nature of vegetation communities may raise new ecological concerns that further complicate, at least in the shorter-term, the use of prescribed fire. Overall, the exact implications of climate change for prescribed burning remain uncertain.

6.2 Potential for prescribed burning to mitigate climate change impacts

The smoke from hot summer bushfires can release huge emissions of GHGs to the atmosphere, including CO_2. For example, it has been estimated that 20 – 40 million tonnes of CO_2 was emitted by Victoria's 2006 – 07 Great Divide Fires – the annual emissions of eight million cars (Flinn *et al.* 2008); and 165 million tonnes of CO_2 was emitted by the 2009 Black Saturday fires – the latter being equivalent to approximately one-third of Australia's annual carbon emissions (Berners-Lee 2010).

Further, Flinn *et al.* (2008) considered one key ecosystem that was widely burnt by Victoria's 2006 – 07 Great Divide Fires – Alpine Ash (*Eucalyptus delegatensis*) and suggested that it would take 80 to 100 years for it to again attain maximum and stabilised carbon sequestration levels.

It follows from this that if occurrences of severe bushfires can be reduced in frequency, severity and extent, a substantial reduction of GHG emissions may be achieved. As prescribed burning is a recognised means of mitigating the extent and severity of such bushfires, it offers potential to reduce carbon emissions and help mitigate predicted climate change, certainly in the short to mid-term.

In addition, the shift to a low carbon economy is creating valuable markets for off-setting carbon emissions thereby creating potential for prescribed burning to generate substantial income (Stephenson 2010). This is already happening in Western Arnham Land in the Northern Territory where, since 2005, the Darwin Liquefied Natural Gas Plant has paid local indigenous communities to off-set its GHG emissions through their use of early-dry-season prescribed burning to avoid the greater emissions that would otherwise be incurred by much hotter and more frequent late-dry season bushfires (Stephenson 2010).

The introduction of carbon trading can therefore enable land managers to contribute to a reduction in Australia's GHG emissions, while benefitting biodiversity by shifting current fire regimes back towards a more ecologically sustainable state. The opportunities for such fire abatement projects would seem greater in tropical northern Australia than elsewhere. Russell-Smith *et al.* (2009) give the advantages of northern tropical Australia as being:

- The better suitability of fire abatement projects to extensive lands where there are greater issues with unmanaged fire, and therefore greater scope for reducing fire frequency and severity;
- The quicker and greater gains which can be made in regions where fire is naturally more frequent;
- The greater ease of estimating fuel loads and verifiable GHG emissions savings in flatter landscapes with relatively uniform vegetation associations;
- The relatively low cost and low societal risk of active fire management in remote and sparsely populated landscapes which increases the likelihood of a positive income stream from payments for emissions savings; and
- The ready availability of considerable expertise in the management of savannah fire residing amongst local indigenous communities.

In temperate southern Australia, few regions come with all of these advantages. In particular, greater population density, more complex topography and vegetation, lower natural fire frequency, and a relative lack of indigenous fire management expertise combine to reduce the potential for mitigating climate change through fire abatement, at least in the immediate future.

Conversely, Australia's arid and semi-arid inland regions do possess many of the traits evident in the tropical north. However, as the natural fire frequency is lower, the realisation of benefits from a fire-abatement/carbon mitigation program would be a longer-term and therefore less attractive prospect (Russell-Smith *et al.* 2009, p. 323).

The suitability of the tropical northern savannahs for significant GHG emission savings through fire abatement programs is further exemplified by the fact that 21 million hectares of the area is affected by fire in an average burning year (COAG 2004, p. 16), which can be two to twelve times greater than the total annual fire-affected area across the rest of the continent (COAG 2004, p. 4).

In its first five years, the Western Arnham Land Fire Abatement (WALFA) project saved over 700,000 tonnes of projected CO_2 equivalent emissions (NAILSMA 2011) through avoiding late-dry season bushfires by early-season prescribed burning in a 2.4 million hectare project area (Russell-Smith *et al.* 2009, p. 333).

Building on the WALFA project, the North Australian Indigenous Land and Sea Management Alliance (NAILSMA) is planning to develop and administer four additional fire abatement projects using indigenous land managers with the goal of creating over 1 million tonnes of carbon credits annually. These new projects are planned for the north Kimberley Region of WA, central Arnhem Land in the NT, the Gulf of Carpentaria, and Western Cape York in Queensland (NAILSMA 2011a).

These projects have global significance given that land-use and biomass burning (including savannah bushfires) accounts for 10% of global greenhouse gas emissions, a large portion of which comes from Africa and northern Australia. NAILSMA, in partnership with United Nations University, is looking to share its experience with local communities and other stakeholders around the world through workshops, guides, video material and other sources (Collins 2009).

7. SMOKE AND ASSOCIATED SOCIO-ECONOMIC ISSUES

7.1 Public health

The public health impacts associated with smoke from bushfires and from prescribed burns are not well defined but are thought to have potentially adverse effects on respiratory and cardiovascular systems (Bushfire CRC 2008).

While studies of prolonged exposure to smoke have found it to adversely affect human health, the effect of episodic exposure to smoke for the short periods typically associated with bushfires or prescribed burning is more difficult to assess. Despite this, several Australian epidemiological studies have associated respiratory illness with exposure to bushfire smoke, although a causal link has yet to be established (Bushfire CRC 2008).

Community attitudes to smoke are thought to be variable. Whereas there may be greater acceptance of bushfire smoke as being an accidental or unavoidable nuisance, smoke from prescribed burning is arguably more objectionable and deemed to be unnecessary because it emanates from deliberate fire-lighting. In addition, because prescribed burning is usually undertaken during stable atmospheric conditions, its smoke can persist for prolonged periods adversely affecting visibility and human health, and disrupting industries such as tourism and viticulture (Bushfire CRC 2006a).

There is potential to better manage the problem of smoke associated with prescribed burning. The use of meso-scale meteorological modelling can predict the best time to burn so as to ensure that smoke disperses away from populated areas, while burning under less stable atmospheric conditions can achieve a similar outcome (Bushfire CRC 2006a).

Most agencies in southern Australia now routinely use, in their planning of prescribed burns, Bushfire CRC enhanced models of smoke movement that are integrated with related meteorological tools (as an example, the modelling was used in the autumn of 2006 to ensure the prescribed burning program did not disrupt the Melbourne Commonwealth Games). However, strategies to ameliorate smoke impacts potentially create a reduction in the ‘window of opportunity’ for effective burning. ‘Smoke-friendly’ atmospheric conditions can also be associated with an increased risk of escaped burns, thereby ensuring difficult trade-offs.

Aside from the broader community, concerns have also been raised about the effect of bushfire smoke on the health of firefighters. However, while there are some risks to firefighters from direct exposure to high smoke concentrations, these are mostly mitigated through fire-ground task management that minimises direct exposure (Bushfire CRC 2009; Reisen and Meyer 2009).

Research is continuing into the effects of bushfire smoke on public health (Bushfire CRC 2008) and this will potentially have some impacts on prescribed burning programs.

7.2 Smoke and industry – grapes, tourism

Smoke from prescribed burning is increasingly being cited for having adverse impacts on adjacent land-use enterprises such as viticulture and tourism.

Fears about the effects of smoke are largely based on impacts which have previously resulted from large bushfires. For example, research into smoke tainting of wine commenced in 2003 after huge bushfires straddling the NSW and Victorian border created high density smoke exposure to grape vines for prolonged periods (Fisher *et al.* 2009). These bushfires burnt for 59 days and also had a devastating impact on regional tourism (Sanders *et al.* 2008).

Just four years later in the summer of 2006 – 07, huge bushfires again burnt across north-eastern Victoria for 69 days. This time the region's wine industry reportedly lost $75 – 90 million due to smoke taint (Department of Primary Industries 2011). Further substantial losses also resulted from the 2009 Black Saturday bushfires (Howell 2009).

The subsequent Victorian Bushfires Royal Commission's recommendation to triple Victoria's prescribed burning rate has perhaps understandably raised concerns amongst wine-grape growers and wine makers (Department of Primary Industries 2011). Further concern has been raised by predictions from the Intergovernmental Panel on Climate Change that southern Australia can expect more numerous severe bushfires in coming decades (Howell 2009).

Western Australia's wine producers are also concerned about the potential for smoke taint, and considerable research into the problem is being undertaken by the Grape and Wine Research and Development Corporation, in conjunction with the WA State Government (Kennison *et al.* 2009). This research has included artificial applications of smoke to field-grown grapevines which have led to findings that the duration or number of smoke exposures to grapes is the critical driver of smoke taint in wine (Kennison 2009). Whether the damaging levels of smoke exposure to grapes experienced during very large severe bushfires are likely to be replicated by prescribed burning, under cooler conditions, requires further consideration.

The strength of concern about smoke taint within the WA wine industry is exemplified by the litigation launched by several producers against the then Department of Environment and Conservation (DEC) for alleged negligence in conducting an adjacent prescribed burn which caused smoke damage to wine grapes. In a landmark decision in March 2010, the WA Supreme Court found that the DEC had no duty of care to the wine producers when conducting its prescribed burning program, and even if it did, it had not been breached (Supreme Court of WA 2010).

An appeal against this decision was subsequently lost by a 2:1 majority, although the apparent opinion of the one dissenting judge, effectively dismissing the veracity of decades of research and inquiry that underpinned the use of prescribed burning as a bushfire mitigation strategy, should be a concern to both public land managers and practitioners of emergency law (Eburn 2012).

Despite this, the case has stimulated greater dialogue between the current Department of Parks and Wildlife (DPaW) and the WA wine industry in the hope of minimising future smoke problems. However, while DPaW has pledged to give this greater consideration when planning and conducting prescribed burns, it has also stipulated that it can't allow its public land management responsibilities to be compromised and so can provide no guarantees that smoke impacts will be completely avoided (AFAC 2014).

The claimed impact of smoke on regional tourism is also largely based on impacts measured during and after large bushfire events rather than prescribed burns (Sanders *et al.* 2008). However, there is plenty of anecdotal evidence that prescribed burning can reduce the quality of visitor experiences when it coincides with major tourism events such as the annual Autumn Festival in Bright, Victoria in north-eastern Victoria or the V8 Supercar races in Townsville, Queensland. The potential for smoke from prescribed burns to discourage visitors from returning to such economically-important regional events is likely to continue to require close liaison between public land managers and their stakeholders.

The aesthetics of recently prescribed burnt forest, and the values ascribed to a location by people living near forest is subject to current research by the Bushfire CRC. European derived sensitivities incline to see a burnt forest as a scene of damage and destruction while in Aboriginal culture mildly burnt areas are generally viewed as sign of rebirth and of cleansing. In the aboriginal world smoke is used in traditional ceremonies as a welcome and to cleanse the spirit.

7.3 Smoke as pollution

Bushfires release a range of 'volatile organic compounds' (VOCs) from burnt vegetation into the atmosphere. As yet there is little published data for bushfire-related VOC emissions from Australian vegetation despite the potential significance of eucalypt-dominated forests and plantations to be significant sources of VOCs (Bushfire CRC 2009). As further research creates a greater understanding of bushfire-initiated VOC emissions there will potentially be implications for the prescribed burning / bushfire relationship.

8. CONCLUSIONS

Prescribed burning is widely practiced across Australia, particularly in locations where natural vegetation communities are adapted to frequent or periodic fire and are in some way reliant upon it for their long-term survival.

Currently, in temperate southern Australia, its use is primarily driven by the imperative to protect human life and property from summer bushfires with, at least until recent years, ecological imperatives being generally a secondary driver. Whereas in the more sparsely populated arid inland and tropical northern regions, the use of prescribed burning appears to be driven more by ecological and cultural imperatives.

In NZ, the natural vegetation is not generally fire-adapted and prescribed burning is rarely used on public lands for ecological or fuel reduction purposes. However, burning of agricultural or plantation waste is widely practiced.

In Australia, the majority of landscape fire occurs in northern regions and is mostly comprised of unplanned bushfires burning with high ferocity at inappropriate times. Under these circumstances, prescribed burning appears to be widely supported by the communities of northern and central Australia as a beneficial agency which lessens the potentially greater impacts of bushfires and helps to conserve and maintain biodiversity. Increasingly, indigenous communities are being encouraged to help revive its use.

In contrast to this, prescribed burning can be a somewhat controversial issue in the more closely settled regions of temperate southern Australia despite these regions suffering almost all bushfire-related deaths and property damage since European settlement. While there is general support for small-scale strategic burning of public lands adjacent to private property, there can at times be considerable disagreement about the merits of burning more extensively across the landscape. This debate is essentially framed in terms of:

- Caution around uncertainties associated with the impacts of fire on biodiversity and other community values, effectively invoking variations of the 'precautionary principle' that would limit or reduce prescribed burning until more research can sufficiently increase the knowledge base; and
- A more pragmatic view that extensive prescribed burning – even if based on incomplete knowledge – reduces the extent and severity of far more damaging summer bushfires and that neither the community nor the environment can afford a suspension or overt restriction of its use while more research is undertaken.

Since Victoria's 2009 Black Saturday bushfires, and during and after the subsequent Royal Commission, new arguments have questioned the value of prescribed burning as a bushfire mitigation measure, particularly under extreme fire danger conditions.

Observational experience and research over a long period provides strong evidence that reduced fuel loads can directly improve the capability to suppress most bushfires. However, under extreme conditions, when weather becomes the principle driver of fire behaviour, it seems that reduced fuel loads are less influential in directly improving bushfire suppression. Less fuel however, still provides important indirect benefits by aiding asset protection and mitigating the severity of impacts on ecological and other values such as soil and water.

Nevertheless, concerns about prescribed burning are likely to persist in sections of the community on the basis of:

- Concerns about potential impacts to flora and fauna;
- Concern about the risk of burn escapes to private property and assets;
- Concern about the impact of smoke on human health, aesthetics, and on industries such as tourism and viticulture;

8. CONCLUSIONS

- Lack of knowledge and understanding of the natural role of fire in maintaining biodiversity and ecosystem processes, and in protecting environmental values;
- Lack of recognition that fire-fighter danger and suppression difficulty are greatly increased where bushfires burn in long unburnt areas with heavy fuel accumulations;
- Lack of appreciation of the high degree of planning, care and skill used to safely implement prescribed burning programs – particularly in the more developed parts of Australia;
- Lack of appreciation of the importance of the strategic distribution of fuel management across the landscape rather than just in close proximity to vulnerable community assets;
- Lack of appreciation of the level of heterogeneity of burnt area and intensity achieved within the prescribed fire perimeter on individual burns and across the landscape from the strategic program; and
- Undue focus on individual species or communities in lieu of a broader perspective which considers ecosystem impacts at a landscape scale. Single species management may be appropriate in some circumstances, but in general it is not possible to wholly benefit one species without impacting on others.

There is already considerable research being undertaken into many of these matters and it is imperative that the work should continue.

Concerns based around a lack of knowledge of what prescribed burning is and how it is planned and conducted, need to be addressed through improved engagement with the community, politicians, and the media.

Scientifically, it is apparent that there are almost infinite possibilities for learning given the array of flora and fauna that exists in a relationship with periodic or regular fire; while no amount of community engagement is likely to convince all critics of prescribed burning that deliberately disturbing nature can have a greater good.

In grappling with these issues, as part of the first national bushfire Inquiry conducted in Australia (COAG 2004), the Inquiry drew on COAG's (1992) National Strategy for Ecologically Sustainable Development and concluded:

> …In the area of bushfire and its effects on ecological processes, there is widespread agreement in the scientific community that our knowledge is far from complete. The response of land managers to this scientific uncertainty is covered in the guiding principle for ecologically sustainable development relating to the precautionary principle:
>
> > In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation….

Finally it needs to be appreciated that fire regimes that can fully optimise outcomes for the community, its safety and for the environment will be uncommon. If prescribed burning is to be effective in helping to manage the bushfire threat, then compromises will need to be made based on the best available science and the likelihood that prescribed burning in appropriate ecosystems and under cooler conditions – even if less than fully scientifically-informed – is less damaging to the environment than the alternative of allowing heavy fuel accumulations to build and inevitably burn in severe summer bushfires.

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APPENDIX A

National Burning Project – List of Sub Projects

The objective of the National Burning Project is to use a national approach to reduce the bushfire risk to Australian and New Zealand communities by the comprehensive management of prescribed burning at a landscape level that balances the operational, ecological and community health risks. The project will produce a series of outputs through sub-projects that together form a framework. The framework will endure long after the project and future projects will be required to add further elements to, update and refresh the framework. There are elements of the framework that are outside the scope of this project and will be delivered separately by the project partners. The current scope of the framework and the component sub-projects are listed in the table below.

#	Short Title	Long Title	Status as at 2015
1	**Review Fire Science and Knowledge**	Prepare and publish a review of the fire science, operational experience and indigenous knowledge at a national level for all fire bioregions.	Overview completed Science Review planned
2	**Analysis of Objectives**	Report on an analysis of the tools and methodologies available to balance competing objectives of burning programs and matching these to user's needs.	Planned
3	**Risk and Monitoring Framework**	Design a management and review framework to manage the major prescribed burning risks. Four risks are currently planned: • Fuel Hazard • Smoke and CO_2 emissions • Ecological • Operational (safety)	Risks 1 and 2 completed Risks 3 and 4 planned
4	**Best Practice Guideline for Prescribed Burning**	A review of the end to end processes, practices and systems of prescribed burning jurisdictions, land managers and across a range of burning objectives.	Review report completed Operational practice guideline underway. Strategic practice guideline planned.
5	**National Bushfire Fuel Classification**	Develop a best practice guide for the classification of bushfire fuels.	Underway
6	**National Position on Prescribe Burning**	A nationally agreed position is developed and communicated that outlines the principles for the use of prescribed burning.	Planned
7	**Prescribed Burning Competencies**	Define agreed standards for the tasks associated with the planning and conduct of prescribed burns.	Planned

#	Short Title	Long Title	Status as at 2015
8	**Develop Training Materials**	Develop training materials for prescribed burning for national application.	Planned
9	**Prescribed Burning Training Delivery**	Investigate the options for national training delivery and mutual recognition frameworks.	Planned
10	**Resource Optimisation**	Develop processes for the sharing of resource between prescribed burning programs.	Planned
11	**Performance Measures**	Develop performance measures for prescribed burning and design a reporting framework.	Planned
12	**National Tool Box**	Provide a set of tools that support prescribed burning activities	Planned

APPENDIX B

National Burning Project – List of Publications

The National Burning Project will progressively publish a comprehensive library of reports from the sub-project results. The list of planned publications is provided below:

Title	Description	Date of Report	Date of Publish	Authors	Contributors
Review of Best Practice for Prescribed Burning	A report to scope the development of a best practice guide for prescribed burning by reviewing current practices across Australia.	December 2013	March 2014	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Risk Management Framework – Fuel Hazards		30-Apr-12	2015	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Risk Management Framework – Smoke Hazards		1-Jul-12	2015	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Scope and Framework for an Australian Fuel Classification		30-Jun-11	2015	Hollis J, Gould J, Cruz M and Doherty M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Scope and Objective.		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Glossary		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Assessment Methodology		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Overview of prescribed burning in Australasia.	A review of the science and practice of prescribed burning written to provide background to practitioners and information to interested members of the public.	30-Jun-12	2015	Poynter M	AFAC, FFMG, AGD, CSIRO (reviewer)

Title	Description	Date of Report	Date of Publish	Authors	Contributors
Australian Bushfire Fuel Classification – Case Study Report		2013	2015	Gould J, and Cruz M	AFAC, FFMG, CSIRO
National Position on Prescribed Burning		2013	2015		AFAC, FFMG
Prescribed Burning Competencies		2013	2015		AFAC, FFMG
Prescribed Burning Training Material – Assist with Prescribed Burn		2014	2015		AFAC, FFMG, BCRC
Prescribed Burning Training Material – Plan Simple Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Plan Complex Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Conduct Simple Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Conduct Complex Burn		2014			AFAC, FFMG, BCRC
Best Practice Guide for Operational Prescribed Burning					
Best Practice Guide for Strategic Prescribed Burning					
Australian Bushfire Fuel Classification – Business Case					
Australian Bushfire Fuel Classification – Implementation					
Review of Prescribed Burn Training					
Report on the options for resource sharing in prescribed burning					
Performance Monitoring and Reporting for Prescribed Burning					

NOTES

Overview of Prescribed Bburning in Australasia

Report for National Burning Project – Sub-project 1

Author

Mark Poynter

Editor

Wayne Kington, *AFAC*

For millennia, fire has played an important role in shaping Australian environments, ecosystems and biota, including through indigenous burning practices and through natural causes such as lightning strikes. After European settlement of the Australian continent the use of fire changed dramatically, and continues to change today, with deep implications for bushfire management, ecosystems, traditional landscapes and species.

In New Zealand, although fire was used historically to clear vegetation, New Zealand ecosystems and biota have not evolved with fire, and prescribed burning is not widely practiced.

This report examines the role of fire in the Australasian landscape, the origins of Australasian prescribed burning, its use as a bushfire management tool, its use for biodiversity outcomes, smoke and climate change concerns, and the evidence base that underpins the use of planned fire.

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