Australian Forestry

ISSN: 0004-9158 (Print) 2325-6087 (Online) Journal homepage: https://www.tandfonline.com/loi/tfor20

Prescribed burning in south-eastern Australia: history and future directions

G. W. Morgan, K. G. Tolhurst, M. W. Poynter, N. Cooper, T. McGuffog, R. Ryan, M. A. Wouters, N. Stephens, P. Black, D. Sheehan, P. Leeson, S. Whight & S. M. Davey

To cite this article: G. W. Morgan, K. G. Tolhurst, M. W. Poynter, N. Cooper, T. McGuffog, R. Ryan, M. A. Wouters, N. Stephens, P. Black, D. Sheehan, P. Leeson, S. Whight & S. M. Davey (2020) Prescribed burning in south-eastern Australia: history and future directions, Australian Forestry, 83:1, 4-28, DOI: 10.1080/00049158.2020.1739883

To link to this article: https://doi.org/10.1080/00049158.2020.1739883

Published online: 21 Apr 2020.

AUSTRALIAN FORESTRY
2020, VOL. 83, NO. 1, 4–28
https://doi.org/10.1080/00049158.2020.1739883

Taylor & Francis
Taylor & Francis Group

Prescribed burning in south-eastern Australia: history and future directions

G. W. Morgan[a], K. G. Tolhurst[b], M. W. Poynter[c], N. Cooper[d], T. McGuffog[e], R. Ryan[f], M. A. Wouters[g], N. Stephens[h], P. Black[i], D. Sheehan[j], P. Leeson[k], S. Whight[l] and S. M. Davey[m]

[a]Principal Consultant, Global Wildland Fire Management Services, Ballarat, Australia; [b]Associate Professor, School of Ecosystem and Forest Sciences, University of Melbourne, Creswick, Australia; [c]Melbourne, Australia; [d]Senior Director, Fire Forest and Roads, ACT Parks and Conservation Service, Canberra, Australia; [e]State Fire Manager, Forestry Corporation of NSW, Sydney, Australia; [f]Corporate Fire Manager, Hancock Victorian Plantations, Ballarat, Australia; [g]Manager, Fire Knowledge & Mapping Fire & Flood Management, Parks and Regions, Department of Environment and Water, Adelaide, Australia; [h]Executive Director Park Operations, NSW National Parks and Wildlife Service, Sydney, Australia; [i]State Fire Manager, Tasmania Parks and Wildlife Service, Hobart, Australia; [j]Manager, Fire Management, Sustainable Timber Tasmania, Hobart, Australia; [k]Principal Conservation Officer, Fire Management, Operational Support, Park Services, Queensland Parks and Wildlife Service (Retired), Department of Environment and Science, Gympie, Australia; [l]Director Community Fire Safety Division, Tasmania Fire Service, Hobart, Australia; [m]Canberra, Australia

ABSTRACT

Fire has been part of the natural environment of south-eastern Australia for tens of millions of years. Aboriginal people used fire selectively, with skill, for many reasons. The removal of Aboriginal people from most of the region after European settlement changed fire regimes and the composition and structure of vegetation. This study explores the history of fire in south-eastern Australia, describes the development of prescribed burning as a forest management tool, and discusses the factors that have influenced changes in fire regimes. It draws on published and unpublished literature and data held by the Forest Fire Management Committee of the Institute of Foresters of Australia. The study finds that the use of prescribed burning in south-eastern Australia in the past 100 years has been driven primarily by political and legal factors. Since 1939, more than 50 public inquiries, reviews and royal commissions have been held into matters concerning the management of fire in landscapes, including prescribed burning. Prescribed burning has been used for wildfire mitigation, agricultural practices (such as stubble reduction and grazing land management), property protection, the maintenance of ecological processes and biodiversity conservation. Prescribed burning in the region has only ever been practised on a small percentage of forest and land each year.

The study finds that a substantial body of fire and ecosystem science has been generated in the past 50 years, with rapid technological developments to support prescribed burning and fire management. Research has provided tools and methods for broadscale prescribed burning, but negative public perceptions of fire have prevented the deployment of comprehensive fire management programs in the region. Although much has been achieved, considerable changes are still required in fire management for it to be sustainable and optimal in protecting economic, social and environmental values. The risks to human lives, property, biodiversity and the environment associated with wildfire are increasing in south-eastern Australia due to climate change, and the wider use of prescribed burning is essential for managing these. The increasing extent and occurrence of wildfire disasters in the region indicates that current fire management will not sustain the full range of ecosystem processes and biodiversity, nor reduce to an acceptable level the impact of wildfires on human lives and property. There is compelling evidence for the greater use of prescribed burning to reduce wildfire risks and impacts, rather than committing increasing resources to wildfire suppression. The potential negative impacts of prescribed burning can be managed effectively using existing knowledge and tools. Clear communication of the benefits of prescribed burning can influence political and public opinion in its favour. More investment in training, human capacity and supporting resources is required to safely and effectively deploy prescribed burning more widely to reduce future wildfire risks.

ARTICLE HISTORY
Received 14 April 2019
Accepted 25 February 2020

KEYWORDS
prescribed burning; climate change; wildfire; forest management; South-Eastern Australia; inquiries; history

Introduction

Fire is a dominant and intrinsic feature of Australian landscapes and has played a significant role in the evolution of Australian biota (Recher & Christensen 1981). Much of Australia's native vegetation has evolved to be tolerant of fire: many plant species require fire to regenerate and have adaptations that promote the spread of fire (Gill 1975; MPIGA & NFISC 2013, 2018). Planned and unplanned fire are both important elements in the management of land and forests in Australia (MPIGA & NFISC 2018).

Prescribed burning (also called 'planned burning', 'fuel-reduction burning' and 'hazard reduction burning') is the controlled application of fire, under specified environmental conditions, to a pre-determined area, at a time, intensity and rate of spread required to attain desired management objectives (AFAC 2012). Prescribed fires are carefully planned and documented before implementation under clearly prescribed conditions based on fire science. Prescribed burning contrasts to wildfires (also called bushfires in Australia; the two terms are used interchangeably here), which are not planned and which originate from human-caused accidental or deliberate ignitions or from natural causes such as lightning strikes.

This paper reviews the development of prescribed burning in the temperate and subtropical areas of the Australian Capital Territory (ACT), New South Wales, South Australia, Tasmania, Victoria and south-eastern Queensland (Fig. 1) (referred to here as south-eastern Australia). This region is generally characterised by average annual rainfall above 500 mm, warm summers and

CONTACT G. W. Morgan Gary.Morgan.Aust@gmail.com Global Wildland Fire Management Services, Ballarat, Australia

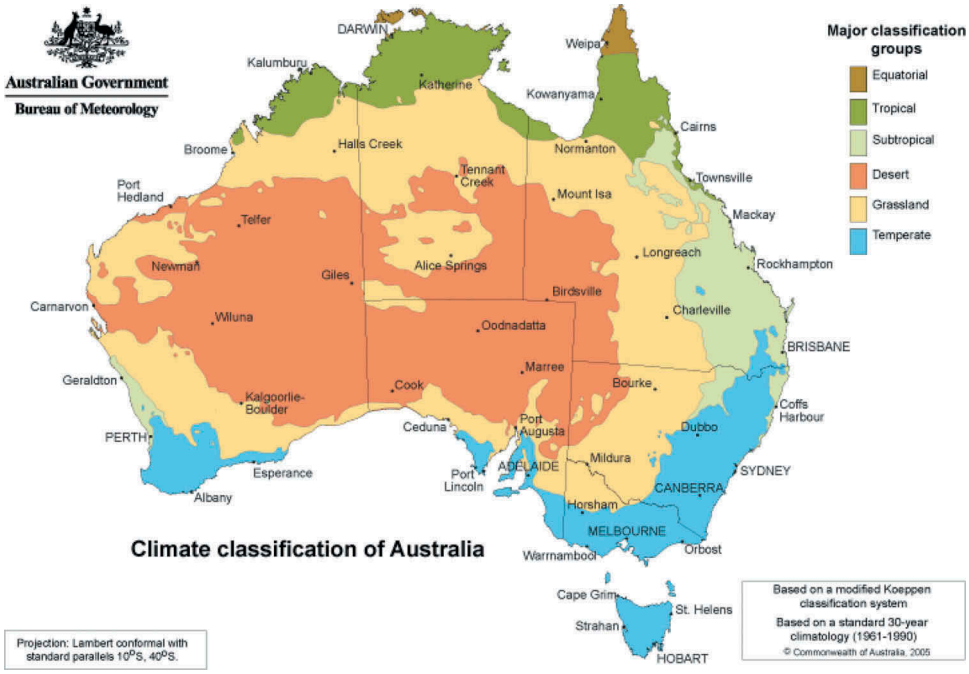

Figure 1. Major climatic zones in Australia based on a modified Koeppen classification system (source: http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications)

cool winters, and native vegetation dominated by forests and woodlands of eucalypts interspersed with other forest types, grasslands, heathlands and shrublands.

Wildfires in south-eastern Australia have the potential to reach higher intensities than other parts of Australia (Tolhurst 2003; Fig. 2), the South Pacific (Luke & McArthur 1978), and perhaps even the world (Pyne 2006). Southwest Western Australia has similar potential (Fig. 2). This fire potential is the result of the fire environment—the effects of climatic conditions, fuel availability, topography, weather

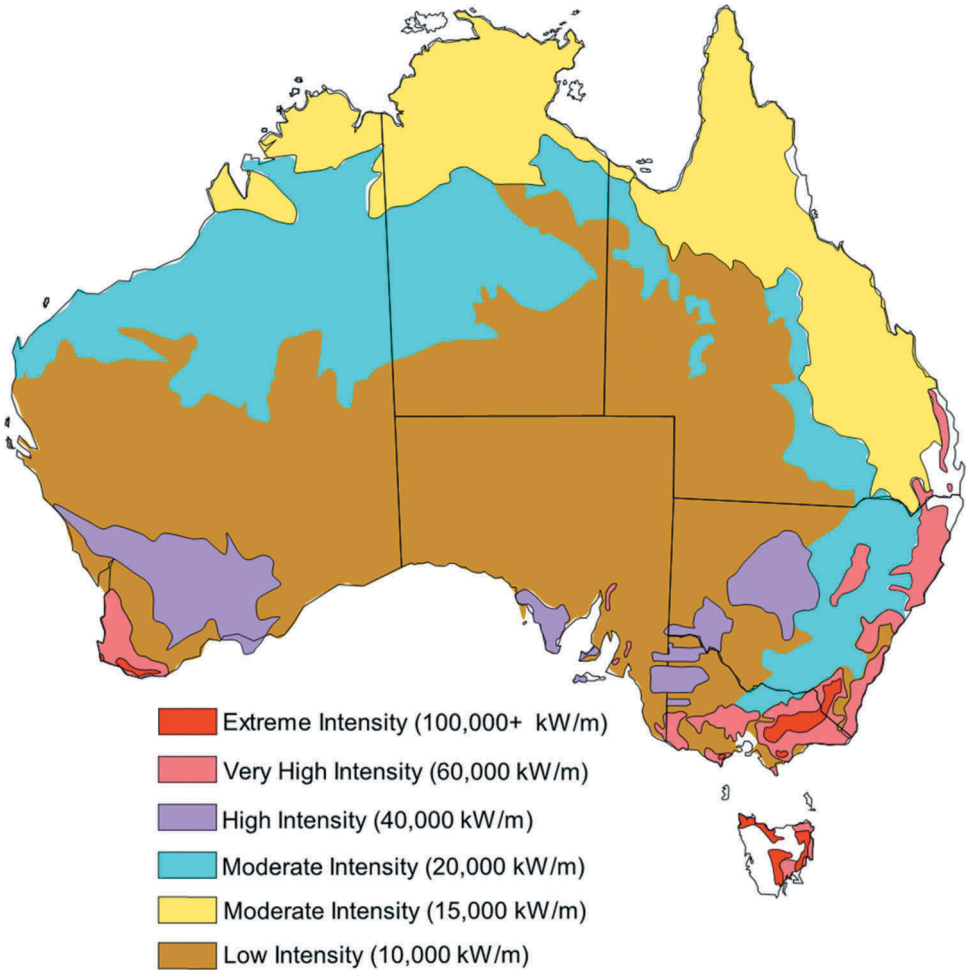

Figure 2. Potential fire intensity across Australia based on a combination of vegetation types, terrain and weather patterns (source: Tolhurst 2003)

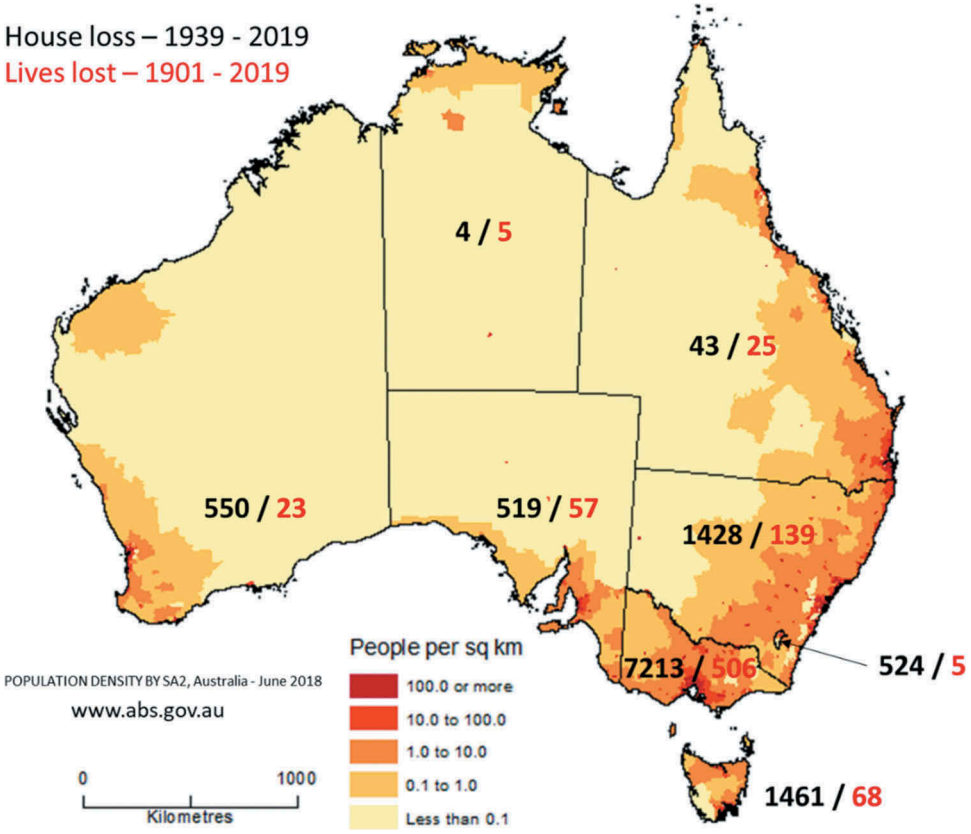

Figure 3. House loss due to wildfires in Australia between 1939 and 2019 and lives lost between 1901 and July 2019 (source for house and life loss: Blanchi et al. (2012), updated with data from the Emergency Management Australia database to June 2019. House losses and deaths for late 2019 are not included in the figure. The population density map is from the Australian Bureau of Statistics)

patterns, sclerophyllous vegetation and ignition sources. Combined with an increasing human population at the urban–forest interface, this fire environment has meant that wildfire disasters affecting people and infrastructure have been a relatively regular occurrence (Fig. 3). The implementation of prescribed burning in such an environment is difficult and complex, but the consequences of not reducing fuel levels through prescribed burning may be greater for human lives, property and the environment.

South-eastern Australia has had various regimes of prescribed burning and wildfires over geological time (Gill et al. 1981; Pyne 1991); some of it is related to climate and weather conditions and some to human interventions. Human welfare in the region is partly dependent on how well the fire environment is managed. This paper discusses the history of fire and fire management in south-eastern Australia, with a focus on prescribed burning and the factors that have influenced changes in fire regimes. It outlines developments in prescribed burning knowledge and policy using published and unpublished literature and data held by the Institute of Foresters of Australia's Forest Fire Management Committee. The aim of the review is to provide an evidence base for the informed consideration of fire management strategies and to guide the formation of sound policies and operational fire management practices in the region and elsewhere in the country.

Evolution of prescribed burning in Australia

Fire and fire management in Australia can be divided into phases (Table 1) driven by events, drivers, political direction and policy responses (Table 2). The phases are described below.

Pre-human fire—pre-60 000 years ago

Fire has been a part of the Australian environment for about 30 million years—from after the final break-up of Gondwanaland (Beard 1977). Fire first became an integral part of the Australian environment in the north-west and gradually spread across the land mass as the continent drifted northwards and the environment became more suited to supporting fire (Beard 1977). Australia's unique fauna and flora evolved in this developing fire environment, including eucalypt and acacia forests and woodlands (Kershaw et al. 2002), and the main sources of ignition were lightning and volcanic activity. Fire has probably been a part of the south-eastern Australian environment for at least 5 million years, but the landscapes of today are largely the result of fire and climatic conditions in the past 12 000 years, since the last ice age (Kershaw et al. 2002). Climatic changes have always led to changes in the fire regime (Kershaw et al. 2002). Knowledge of past fire regimes can provide insights into how future climate change might affect fire regimes.

Aboriginal period—60 000 years before present to 1788

The Australian continent has shifted over geological time, and climates and sea levels have changed widely (Bowler 2002). Sea levels were relatively low around 60 000 years ago, and there was significantly less separation between Australia and the islands of New Guinea and Indonesia. The first humans migrated to Australia during this time and successfully established (Bird et al. 2002; Bowler et al. 2003; David et al. 2019). This was the beginning of the Aboriginal occupation of Australia. Over time, the Aboriginal people

Table 1. Phases in the evolution of prescribed burning and fire management in Australia

Phase	Guides	Outcomes
Pre-human fire *Pre-60 000 years ago*	None	Random fire, natural ignitions
Aboriginal period *60 000 years ago to 1788*	Culture Totems Stories	Utility and productivity for food, shelter and culture
European settlement *1788–1901*	*Laissez-faire*	Land clearing Asset protection at a local level Haphazard management
National development *1901–1960*	Government reviews Regulations, legislation Land management, enforcement Research by agencies, universities, CSIRO	Formal silviculture Biodiversity management Protection of human life and property Strategic planning
Development of science-based fire management *1961–1985*	Public reviews, inquiries Litigation, liability Political and public pressure Smoke and health issues Preservation ideology	Formal planning processes Public accountability Strong media interest Demand for more knowledge and skills related to fires Nationally coordinated fire policy
Political pressures and land management *1985–present*	Public review and inquiries Accelerating research efforts Social science research Wildfire risk analysis Rapid technological developments Climate change and sustainable development	Nationally coordinated fire research (Bushfire Cooperative Research Centre (CRC) and the Bushfire and Natural Hazards CRC) Strong political direction Public involvement in decision-making Landscape-level strategic planning Indigenous culture inclusion

Table 2. Process and factors driving the evolution of prescribed burning in Australia

Events (and triggers)	**Drivers** (and measures)	**Directions** (and policy)	**Responses** (and processes)
Wildfires Wildfire impacts Wildfire disasters	Economic Political Legal Social Environmental	Reviews Inquiries Litigation Research results	Research programs Strategies Processes Policy

gained considerable knowledge of fire management and developed and implemented management regimes to promote productivity and habitability. Pre-European Aboriginal fire management was not towards some 'grand plan', but it assisted hunting and the gathering of other foods and increased ease of movement; over time, it produced fire-managed landscapes (Bowman 1998; Gammage 2011; Mooney et al. 2011) and changed the vegetation of the continent (Tindale 1981). Fire was used universally by Aboriginal people, but fire regimes varied across the continent, depending on local climatic and vegetation conditions, with use 'prescribed' by totems, stories and customs (Bowman 1998; Gott 2005; Gammage 2011). Fire remains an inseparable part of Aboriginal life and culture today, with traditional fire management regimes prevailing on many Indigenous-managed lands (MPIGA & NFISC 2018).

European settlement—1788 to 1901

When the European settlement of Australia began about 230 years ago, the settlers arrived to fire-managed landscapes, although this was unrecognised at the time (Pyne 1991; Gammage 2011). The openness of many forests and woodlands and the extent of prime grazing lands found by explorers and early European settlers was the result of Aboriginal burning (Gammage 2011).

European settlers had completely different lifestyles and land-use systems to those of the Aboriginal people (Pyne 1991). While there is evidence of Indigenous agricultural systems (Pascoe 2018), Europeans brought new grain crops, domestic farm animals and a land ownership system favouring individuals, townships and fences. European settlers focused on establishing a sustainable agricultural and governance system. This was largely a period of exploring and exploiting available resources and adapting to an alien environment. Fire was an agent of agricultural clearing (the conversion of forests, woodlands and shrublands into pastures and croplands) rather than a tool for sustainable land management. Settlers also saw fire as a destructive force because of the threat it posed to buildings, fences, livestock and crops. There was little recognition of how Aborigines had used fire to manage landscapes to maintain productive potential. In this period, fire management in south-eastern Australia was hampered by, among other things, a profound lack of understanding of the role of fire in landscapes (Pyne 2006).

It is reasonable to assume that fire regimes changed in Australia after European settlement (Gill 1975). Authors, reported in Gill (1975), observed or suggested an increase in intensive and damaging fire following European settlement, while the area burnt annually reduced. This was not universal: Gill reported that, following European settlement, fire regimes altered in southern Australia but not, for example, in the Northern Territory.

In the first 70 or more years of European settlement, the population of Australia was less than 500 000 people

(Lahmeyer 2003). The discovery of gold in south-eastern Australia in the 1850s, however, led to a massive increase in population and the establishment of many dispersed rural townships. By the early 1900s, the Australian population had increased to about 4 million (Lahmeyer 2003).

Fire in the landscape became much more common and widespread in south-eastern Australia in the period 1850–1900. There were a number of significant wildfire events, starting with the fires of 1851, which reportedly affected about one-quarter of Victoria's 21 million hectares in a single year (AIDR 2018), and many settlers lost everything (Luke & McArthur 1978). Wildfires had become a significant threat to economic development. Land and forest management was the subject of various government inquiries (Parliament of Victoria 1869; Bindon 1871; Anon 1884; Tucker 1898a, 1898b, 1899, 1900b, 1901) in response to the rapid rate of forest destruction and the need to provide forest resources, food and work for a growing population.

In 1890, the explorer and naturalist Alfred Howitt reflected on the impacts of European settlement and farming on the pre-European fire regime. In a report to the Royal Society of Victoria, he recounted his extensive observations of the previous 25 years in eastern Victoria, linking a thickening of forest growth and an expansion of forest cover to the decline of Aboriginal influence on land management, thereby overturning a regime of regular light fire in favour of periodic but more intense and damaging blazes in heavier fuels (Howitt 1890).

By 1900, various efforts had been made to better manage land for agriculture and forests for timber and water production (Tucker 1901). Fire management was part of this improvement.

National development—1901 to 1960

Australia became an independent nation in 1901 with the federation of its states and territories, although fire management remained the responsibility of the individual states and territories. The governmental forest management agencies that established in south-eastern Australia in the early 1900s started to formalise land management, including planning the management of forests for the future, although they had very limited resources (Tucker 1901; Carron 1985). Wildfires were an increasing threat to the viability of many productive resources and settlements (Tucker 1900a).

This period coincided with major advances in technology and industrial development, including the aircraft and vehicles used in the two world wars. Wildfire suppression was considered the best way to deal with forest fire. Fires had to be 'fought' (Luke & McArthur 1978), and there was little reflection on how fire regimes had changed since European settlement (Pyne 1991; Gammage 2011). With immigration following the Second World War, the Australian population increased to about 10 million people by 1960 (Lahmeyer 2003), of which the majority (about two-thirds) lived in south-eastern Australia.

Science-based fire management—1961 to 1985

The forest industry was active in this period, harvesting large quantities of timber in native forests to supply the growing population. There was also a significant expansion of softwood plantations, primarily to meet local timber requirements, and forest science developed rapidly (Carron 1985). This was a period of rapid learning about the science of fire behaviour and the use of fire in controlled, predictable ways to achieve stated management objectives. Fire was developed as a management tool to regenerate eucalypt forests after harvesting and to prepare for the establishment of softwood plantations. Prescribed burning at a landscape scale was increasingly used to reduce the risk of wildfire to timber assets. There were significant differences in the seasonal implementation, extent and intensity of these types of prescribed burns. Wildfire-mitigation prescribed fires were conducted over large areas at low intensities in relatively mild weather conditions, while prescribed burns to promote eucalypt regeneration or to clear areas for plantation development were generally high-intensity and conducted in dry conditions (although milder than those of peak summer).

State government forestry agencies undertook most of the research into fire behaviour and prescribed burning in this period, as well as most of the practice of burning to scientific prescriptions. These agencies became strong advocates of prescribed burning for wildfire-risk mitigation and began researching ways to scale it up. Burning for the maintenance of ecosystem health and diversity began to emerge as an area of research interest but was not a practice on any significant scale.

Political pressures and land management—1985 to present

The rise of environmental consciousness in the 1960s and 1970s among a more educated suburban middle class led to an increased focus on public land management and new political drivers in south-eastern Australia. This coincided with greater domestic and international consideration of conservation, sustainability and sustainable development (Davey 2018). The shift was evident for fire management following the Ash Wednesday fire events in South Australia and Victoria in 1983. From 1985, operational decisions and forest fire management policy came under increasing political scrutiny and direction. Politicians no longer delegated all operational decisions to professionally trained land managers. A more politically focused rationale for land management developed, with the mainstream media and non-government organisations exerting increasing influence on government decision-making. Given this politicisation, land and fire managers became increasingly risk-averse in planning and implementing prescribed burning.

Controversy over prescribed burning was reflected in submissions to the Federal Government Resource Assessment Commission Inquiry into the Forest and Timber Industry (1989–1992). The Inquiry addressed the question, 'is fuel reduction burning a significant threat to environmental values?'. In its 1992 report, the Commission found prescribed burning to be controversial in both environmental impact and its effectiveness in controlling wildfire and reducing its impacts. It concluded, however, that, although knowledge of prescribed fire impacts on the environment was limited, 'the use of fuel reduction burning as a management tool in forests must continue in areas where

reduction of hazards from wildfires is a prime management concern. Fuel reduction burning is the only tool currently available that successfully reduces the hazards due to wildfires' (Resource Assessment Commission 1992, p. 174). Australia's first 'State of the Forests' report, published in 1998, stated that planned fires were excluded from conservation reserves and that there was 'debate over the extent to which present-day fire regimes reflect the regimes in place in pre-European times' (NFI 1998, p. 94).

Major wildfire events and their impact

Major wildfires and management change

Major wildfires affecting life and property (Table 3) have generally been followed by government inquiries to examine causes and to improve preparedness and response capacity.

One of the most influential inquiries followed the Black Friday event in 1939, which occurred after a prolonged drought and towards the end of the Great Depression. Wildfires (mostly) in Victoria burnt 1.3 million ha, killed 71 people and destroyed more than 1000 homes. These tragic fires were the subject of a Royal Commission of Inquiry led by Judge Leonard Stretton, which found that the fires' destructive force and magnitude of impacts were preventable (Stretton 1939).

Wildfires in 1939 had also burnt southern parts of the ACT and threatened the national capital of Canberra. In their wake, the Commonwealth Department of the Interior leased about 20 000 ha of the northern and western slopes of the Brindabella Ranges from New South Wales to be managed by the ACT for fire protection. This included the construction of fire trails, ridgetop burning and fire suppression. As part of the summer field exercises for students at the Australian Forestry School, Alan McArthur, working for the Commonwealth Forestry and Timber Bureau, conducted experimental burning in the ACT. This was mostly in dry forest on Black Mountain immediately adjacent to Canberra, but McArthur also used students to carry out grid ignitions of prescribed burns in dry forest and montane mountain gum and alpine ash forest in the Brindabella Ranges to demonstrate the application of his burning guide (McArthur 1962).

Victoria experienced another tragic wildfire season in 1943–1944. A new Royal Commission, led again by Judge Stretton, was critical of the Victorian Government for not taking up the recommendations of the Royal Commission into the 1939 wildfires.

Wildfire research began in this post-Second World War period. James Foley, a climatologist and Chief Scientific Officer at the Bureau of Meteorology, described in detail the meteorological conditions that prevailed during wildfires (Foley 1947). Harry Luke, a strong advocate in his role as the Fire Control Officer for the NSW Forestry Commission for prescribed burning to mitigate wildfires, published training materials on the principles of fire control for fire-control schools aimed at field foresters (Pyne 1991).

New South Wales established fire prevention schemes in its Eastern Fire Zone in 1951, from the border with

Table 3. Large wildfires and megafires in Australia, 1851–2016

Year	Fire location	Area burnt
1851	Vic (Black Thursday)	Approximately 5 million ha
1898	Vic (Red Thursday)	260 000 ha
1926	Glen Innes, Dubbo, Forbes, Cowra, Parkes, Wagga Wagga, Pambula and Eden, NSW	2 million ha
1938/39	Sydney and southern NSW	73 000 ha
1938/39	Vic (including Black Friday)	1.5–2.0 million ha
1944	Vic	1 million ha
1951/52	Pilliga, Dubbo, Forbes and Wagga Wagga, NSW	5.467 million ha
1957	Blue Mountains and Sydney, NSW	2+ million ha
1960/61	Dwellingup and other bushfires, WA	359 000 ha
1964/65	Snowy Mountains, Southern Tablelands, Nowra and Sydney, NSW	530 000 ha
1967	Hobart (Black Tuesday), Tas	Approximately 264 000 ha
1968/69	Blue Mountains/Illawarra, NSW	2+ million ha
1972/73	Southern Tablelands/Eden, NSW	300 000 ha
1974/75	Western NSW	4.5 million ha
1982/83	Blue Mountains, Sutherland and southern NSW	60 000 ha
1983	Vic and SA (Ash Wednesday)	418 000 ha
1984/85	Western NSW	3.5 million ha
1990/91	Hay/Murrumbidgee/Central Coast, NSW	280 000+ ha
1993/94	Sydney/Blue Mountains/North Coast, NSW	800 000+ ha
1994/95	South-eastern Qld	333 000 ha
1997/98	Hunter/Blue Mountains/Shoalhaven, NSW	500 000+ ha
1997/98	Caledonia River, Gippsland, Vic	32 000 ha
2001/02	Greater Sydney area, NSW	744 000 ha
2002	Stanthorpe/Toowoomba, Qld	40 000 ha
2002/03	Eastern Highlands, Vic	1.1 million ha
2002/03	Brindabella Ranges,, ACT/NSW	157 000+ ha
2002/03	East coast including Greater Sydney, NSW	1.46 million ha
2002/03	Arthur Pieman area, Tas	100 000 ha
2005	Eyre Peninsula, SA	145 000 ha
2006/07	Eastern Highlands, Vic	1.05 million ha
2007	Kangaroo Island, SA	95 000 ha
2009	Eastern Highlands (including Black Saturday), Vic	430 000 ha
2013	Southern Highlands, Shoalhaven, Blue Mountains and Central Coast, NSW	768 000 ha
2016	Waroona-Dwellingup, WA	69 000 ha
2018/19	Tasmanian Wilderness World Heritage Area	94 000 ha

Note: Large wildfires and megafires are devastating (catastrophic) fires that exhibit fire-behaviour characteristics that exceed all efforts of control and result in human and significant asset losses. Bartlett et al. (2007) provides details of these types of fire. Total area burnt includes vegetation types other than forests (sources: NFI (1998); ABS (2004); Bartlett et al. (2007); MPIGA & NFISC (2013); Montoya (2014); Parks and Wildlife Service Tasmania (2019)). ACT, Australian Capital Territory; NSW, New South Wales; Qld, Queensland; SA, South Australia; Tas, Tasmania; Vic, Victoria; WA, Western Australia.

Queensland in the north to the border with Victoria in the south. The aim of the schemes was to create trails to provide firefighters with greater access to the Snowy Mountains and vacant crown lands for the burning of firebreaks (Luke & McArthur 1978). Substantial burning was carried out from these trails but, because they were often located on ridges, fires often only spread downslope for tens of metres. The trails later became essential as boundaries for aerial burning blocks.

Before the Black Tuesday wildfire event that affected Hobart in 1967, the Tasmanian community was unconvinced of the need for high fire protection standards (Luke & McArthur 1978). The regulation of fires then was like that in Victoria before 1939—minimal. Burning off under the fire warden scheme was subject to little regulation, and wildfires were commonly allowed to burn in the 'back country' over summer. Eighty-one fires were burning across Tasmania on the morning of Black Tuesday. With the onset of extreme fire weather, these fires coalesced and burnt 250 000 ha over an eight-hour period, killing 62 people and destroying more than 1400 homes. Although most of the fires had been burning for days, others were deliberately lit on the day, and some resulted from the re-ignition of earlier fires in the extreme weather conditions (Chambers et al. 1967).

The impacts of Black Tuesday were due to unregulated ignitions (Bale 1993; Fahy 2005), and there had been minimal prescribed burning in and around Hobart for the protection of life and property, although somewhat uncontrolled 'prescribed' burning to create conditions for forest regeneration after timber harvesting was common. In response to the Black Tuesday fires, the *Tasmanian Bushfires Act 1967* established a statewide service of rural volunteer fire brigades to fight fires on private land, and the Forestry Commission had responsibility for public lands. The intention was that the two agencies would implement systematic and effective fire management. These changes did not result in increased prescribed burning for wildfire mitigation, although there was some prescribed burning near townships.

Significant wildfires have occurred episodically in Victoria (Fig. 4). One of the most severe was Ash Wednesday (16 February 1983), when 180 wildfires (mainly in South Australia and Victoria) resulted in 75 deaths and the destruction of 2500 homes on a single day. The average area of annual prescribed burning in Victoria in 1983 (based on a 10-year rolling average) comprised about 3% of the total forest area. This proved insufficient to prevent the severe impacts of the Ash Wednesday wildfires, although it may have been locally effective in some places (Billing 1981; Rawson et al. 1985).

After more than a decade of drought in south-eastern Australia in the 1990s and early 2000s, landscapes were dry and primed for burning. A dry lightning storm in January 2003 caused more than 100 wildfire ignitions across the ACT, New South Wales and Victoria. These fires ultimately burnt for two months (59 days) over about 1.6 million ha (see Fig. 4 and Table 3), and their impacts included the loss of over 500 houses in Canberra on one day (18 January 2003). Adams and Attiwill (2011) claimed that the 2003 wildfire in the ACT's Namadgi National Park burnt under higher intensities due to the preferences and attitudes of park rangers in not allowing prescribed burning at that time. Current managers have a different view on prescribed burning, and now there is support for the practice in the park.

Further significant forest fire events in the region occurred in 2005, 2006–2007, 2009, 2015 and 2016. The 2009 Black Saturday fires in Victoria were the most significant of these, not because of the extent of area burnt (430 000 ha) but because of the human impact, with 173 people killed and 2133 houses destroyed (Teague et al. 2009); this was the highest loss of life recorded in a wildfire event in Australia.

According to Styger et al. (2018), lightning-caused wildfire was rare before 2000 in the Tasmanian Wilderness World Heritage Area, but there has been an increase in the proportion of lightning strikes occurring there during dry conditions, resulting in large, damaging wildfires. In response, prescribed burning is being increasingly used to reduce the risk of loss of World Heritage values due to wildfire. Storms in Tasmania on 15 January 2019 resulted in approximately 2400 lightning strikes and caused over 60 new ignitions. Approximately 94 000 ha (about 6%) of the Tasmanian Wilderness World Heritage Area was burnt in very remote and rugged terrain (Parks and Wildlife Service Tasmania 2019). Early impact assessments indicate that prescribed burning for fuel reduction to mitigate the effects of wildfires on this land slowed the progress of the wildfire. The Tasmanian experience also showed that the

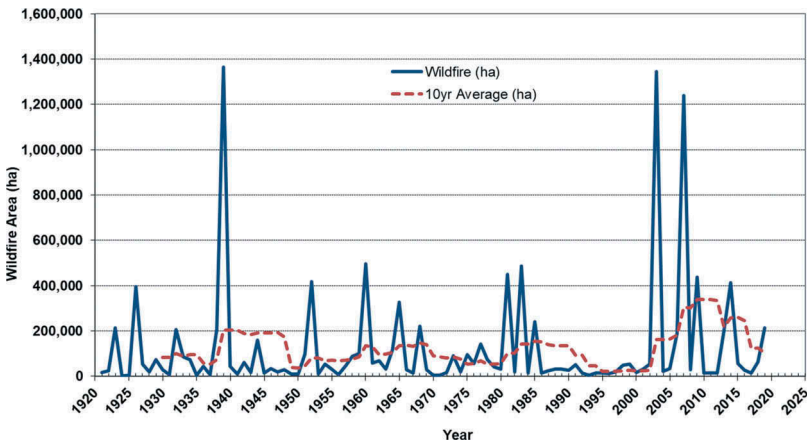

Figure 4. Annual extent of wildfires in Victoria since 1920. The solid line is the annual total area burnt by wildfire and the dashed line is the rolling 10-year average area burnt by wildfires (source: Annual reports and unpublished records from the Victorian Department of Land Environment Water and Planning)

Table 4. Bushfire inquiries and reviews in southern Australia, 1939–present

Year	Name/topic	Reference
1939	Royal Commission to Inquire into the Causes of and Measures Taken to Prevent the Bush Fires of January, 1939, and to Protect Life and Property (Victoria)	Stretton (1939)
1944	Royal Commission to Inquire into the Place of Origin and the Causes of the Fires which commenced at Yallourn on the 14th day of February, 1944 (Victoria)	Stretton (1944)
1961	Report of the Royal Commission Appointed to Enquire into and Report upon the Bush Fires of December 1960 and January, February and March 1961, Western Australia	Rodger (1961)
1967	The Bush Fire Disaster of 7th February, Tasmania 1967	Tasmania Office of the Solicitor-General (1967)
1977	Report of the Board of Inquiry into the Occurrence of Bush and Grass Fires in Victoria	Barber (1977)
1982	Fire Protection and Fuel Reduction Burning in Victoria. A Report to the Minister of Forests by a Task Force of Officers of the Forests Commission Victoria	Johnston et al. (1982)
1983	Report of the Bushfire Review Committee on Bushfire Disaster Preparedness and Response in Victoria, Australia, following the Ash Wednesday Fires of 16 February 1983	Miller et al. (1984)
1984	Bushfires and the Australian Environment	Milton (1984)
1994	Report of the Select Committee on Bushfires, Parliament of New South Wales, Legislative Assembly	NSW Parliament (1994)
1996	Inquiry into the Cause and Origin of the Bushfires occurring in New South Wales between 31 December 1993 and 14 January 1994 and Inquests into the Manner and Cause of Death of Norman John Anthes, Robert Eglinton Page, William John Roach and Pauline Mary O'Neil	Hiatt (1996)
1998	Report of the Investigation and Inquests into a Wildfire and the Deaths of Five Firefighters at Linton on 2 December 1998	Johnstone (2002)
1998	Performance Audit Report: Rural Fire Service—The Coordination of Bushfire Fighting Activities	NSW Audit Office (1998)
2000	Report on Inquiry into the NSW Rural Fire Service	Jones (2000)
2001	Inquest into the Deaths of Mark Douglas Cupit, Claire Wynne Dean, George Allan Fitzsimmons and Eric Furland and Inquiry into Fire at Mt Kuing-Gai National Park	Stevenson (2001)
2002	Report on the Inquiry into the 2001/2002 Bushfires (NSW)	Price (2002)
2003	Performance Audit Report on Fire Prevention and Preparedness (Victoria)	Cameron (2003)
2003	Report of the Inquiry into the 2002–2003 Victorian Bushfires	Esplin et al. (2003)
2003	Inquiry into the operational Response to the January 2003 Bushfires in the ACT	McLeod (2003)
2003	The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January 2003	Doogan (2006a, 2006b)
2003	A Nation Charred: Report on the Inquiry into Bushfires	Nairn (2003)
2004	National Inquiry on Bushfire Mitigation and Management	Ellis et al. (2004)
2004	Review of Fire Services Funding, NSW	Brown (2004)
2004	Performance Examination: Responding to Major Bushfires	Pearson (2004)
2005	Coronial Inquest into the Deaths associated with the Wangary Fire, Lower Eyre Peninsula, of 11 January 2005 (South Australia)	Schapel (2008)
2005	Examination of Prescribed Burning Practices, Victoria	Emergency Services Commissioner (2005)
2005	Eyre Peninsula Bushfire and Native Vegetation	Breuer (2005)
2005	Investigation Report: Planning and Implementation, Prescribed Burn Tidal Overlook, 21 March 2005	Van Rees (2005)
2006	Emergency Management Discussion Paper, Victoria	DOJ Victoria (2006)
2007	Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria	ENRC Victoria (2008)
2007	Ministerial Review of Bushfire Management in South Australia	Monterola (2007)
2007	Conserving Australia: Australia's National Parks, Conservation Reserves and Marine Protected Areas	Eggleston (2007)
2009	2009 Victorian Bushfires Royal Commission	Teague et al. (2009,2010)
2010	The Incidence and Severity of Bushfires across Australia	Heffernan (2010)
2010	A review of the Ability of the Department of Environment and Conservation, Western Australia, to Manage Major Fires	Ferguson (2010)
2011	Review of the Tostaree Fire Government Inquiry, Victoria	Buffone (2011)
2011	Management of Rural Fire Services in Queensland	Wendt (2011)
2011	Bushfire Management, Tasmania (audit)	Blake (2011)
2011	Bushfire Inquiry Final Report, Parliament of South Australia	Key (2011)
2011	A Shared Responsibility: The Report of the Perth Hills Bushfire, February 2011 Review	Keelty (2011)
2012	Appreciating the Risks: Report of the Special Inquiry into the November 2011 Margaret River bushfire, Western Australia	Keelty (2012)
2012	Major Incident Review for the Black Creek Fire, 12 October 2012	DFES Western Australia (2012)
2013	2013 Tasmanian Bushfires Inquiry	Hyde (2013)
2013	Performance Audit Report: ACT Bushfire Preparedness	Cooper (2013)
2013	The Malone Review into Rural Fire Services in Queensland	Malone (2013)
2014	Parkerville, Stoneville, Mt Helena Bushfire Review, Western Australia	SEMC (2014)
2015	Wambelong Fire (Parliamentary Inquiry, NSW)	Brown (2015)
2015	Independent Investigation of the Lancefield-Cobaw Fire (Government of Victoria)	Carter et al. (2015)
2015	Australasian Fire and Emergency Service Authorities Council (AFAC) Independent Operational Audit: South Australian fires of January 2015	AFAC (2015a)
2015	Review of Performance Targets for Bushfire Fuel Management on Public Land in Victoria	IGEM (2015)
2015	Review of the Initial Response to the 2015 Wye River-Jamieson Track Fire, Victoria	IGEM (2016)
2015	Bushfires Review—2015 O'Sullivan and Lower Hotham, WA	SEMC (2015)
2015	Major Incident Review of the Esperance District fires	Nous (2016)
2016	AFAC Independent Operational Review: A Review of the Management of the Tasmanian Fires of January 2016	AFAC (2016a)
2016	Reframing Rural Fire Management. Report of the Special Inquiry into the January 2016 Waroona Fire (WA)	Ferguson (2016)
2017	Inquiry into Fire Season Preparedness—Final Report. Parliament of Victoria	EPC Victoria (2017)
2018	NSW Bega Valley Fires—Independent Review	Keelty (2018)

strategic use of aerial suppression, including Large Air Tankers, can be worthwhile, with aerial suppression decreasing the intensity of a fire passing under the north–south electricity transmission lines and thereby preventing power disruption to the southern half of the state. While aircraft may not completely control wildfires, in

some circumstances they can slow the forward rate of spread sufficiently to allow ground crews to construct fuel breaks and backburns in accessible locations (S. Whight, pers. comm., January 2020).

Bushfire inquiries and their impacts on policy and management

Since 1939, there have been more than 50 systematic examinations of fire management in southern Australia (i.e. south-eastern Australia, plus Western Australia and the entire state of New South Wales; Table 4), including royal commissions, parliamentary, government, public and coronial inquiries and independent reviews. In addition, numerous legal claims have been made for damages related to prescribed burning and wildfire management. This intense scrutiny has consumed tens of millions of dollars and thousands of hours of fire management time and created a fire management approach that is now highly risk-averse and focused almost exclusively on the potential negative effects of wildfires and prescribed burning.

The Stretton Royal Commission into the 1939 wildfires in Victoria was the first systematic and comprehensive review of fire management in south-eastern Australia. The main fire management objective of the Government at that time was to prevent wildfires and to put them out if ignited. Stretton believed that the dominant policy of criminalising the unofficial lighting of fires had little effect in preventing the tradition of civilian burning and subsequent wildfires and therefore did not provide the public with adequate fire protection. He wrote that, '[t]hese fires were lit by the hand of Man' (Stretton 1939, p. 5). He criticised the Government's 'ridiculously inadequate' (Stretton 1939, p. 16) amount of prescribed burning for wildfire mitigation in state forests. In response to Stretton's report, the Victorian Government's policy shifted to a gradual increase in the area of prescribed burning for wildfire mitigation and silviculture on public land. Other jurisdictions eventually followed this policy.

The 2003 fires in the ACT, New South Wales and Victoria led to several inquiries (Table 4) that comprehensively reviewed all aspects of fire management, including the importance of prescribed fire for wildfire mitigation. Kanowski et al. (2005) provides a review of these inquiries. The inquiries resulted in many administrative changes and created momentum for a comprehensive national fire research program. In 2003, the Australian Government and the Australian and New Zealand fire and land management agencies and research partners committed to the formation of the Bushfire Cooperative Research Centre (CRC),[1] which directed a significant proportion of its funding to prescribed-burning research to better understand ecological processes associated with prescribed burning. It also researched physical, biological and social sciences relevant to bushfires and prescribed burning. Adams and Attiwill (2011) synthesised the research that ultimately arose from the CRC's work and other relevant research to assist both public debate and land managers in making judgements on the management of fire risks and environmental values.

The 2009 Black Saturday fires in Victoria resulted in the 2009 Victorian Bushfires Royal Commission (Teague et al. 2009), in which land and fuel management was an important issue. According to the Commission:

> 'Prescribed burning is one of the main tools for fire management on public land. It cannot prevent bushfire, but it decreases fuel loads and so reduces the spread and intensity of bushfires. By reducing the spread and intensity of bushfires, it also helps protect flora and fauna. Ironically, maintaining pristine forests untouched by fuel reduction can predispose those forests to greater destruction in the event of a bushfire.
>
> About 7.7 million hectares of public land in Victoria is managed by DSE.[2] This area includes national parks, state forests and reserves, of which a large portion is forested and prone to bushfire. DSE burns only 1.7 per cent (or 130,000 hectares) of this public land each year. This is well below the amount experts and previous inquiries have suggested is needed to reduce bushfire and environmental risks in the long term.
>
> The Commission recognises that prescribed burning is risky, resource intensive, available only in limited time frames, and can temporarily have adverse effects on local communities (e.g. reduced air quality). Nonetheless, it considers that the amount of prescribed burning occurring in Victoria is inadequate. It is concerned that the State has maintained a minimalist approach to prescribed burning despite recent official or independent reports and inquiries, all of which have recommended increasing the prescribed-burning program. The State has allowed the forests to continue accumulating excessive fuel loads, adding to the likelihood of more intense bushfires and thereby placing firefighters and communities at greater risk.
>
> The Commission proposes that the State make a commitment to fund a long-term program of prescribed burning, with an annual rolling target of a minimum of 5 per cent of public land each year, and that the State be held accountable for meeting this target. DSE should modify its Code of Practice for Fire management on Public Land so that it is clear that protecting human life is given highest priority, and should report annually on prescribed-burning outcomes.
>
> To ensure continuing environmental protection, the State needs to improve its understanding of the effects of different fire regimes on flora and fauna. The Commission proposes that DSE expand its data collection on the effects of prescribed burning and bushfire on biodiversity. Maintenance and extension of data collection on Victoria's flora and fauna assets has not been a high priority. It needs to be improved so that more informed and scientifically-based decision-making can accompany the development of prescribed-burning regimes that meet conservation objectives as well as accommodating bushfire safety considerations' (Teague et al. 2009, p. 15).

The 2009 Victorian Bushfires Royal Commission made recommendations applying to the Victorian and Commonwealth governments, state agencies, councils and other bodies. Recommendations on land and fuel management (Recommendations 56–62) applied primarily to Victorian state agencies, but the issues raised are common to other states and territories. The Commission identified the importance and necessity of fire-related research and requested that, '[t]he Commonwealth establish a national centre for bushfire research in collaboration with other Australian jurisdictions to support pure, applied and long-term research in the physical, biological and social sciences relevant to bushfires and to promote continuing research and scholarship in related disciplines' (Recommendation 65). The Commonwealth Government

[1] www.bushfirecrc.com.
[2] DSE in this quote refers to the Victorian Department of Sustainability and Environment.

subsequently established the Bushfire and Natural Hazards CRC in July 2013 for eight years focusing research on physical and social sciences relevant to wildfire and prescribed burning. Research into ecological processes and biological sciences undertaken by the Bushfire CRC was discontinued.

Research and technological advances in prescribed burning

Technological advances in prescribed burning before 1980

Before 1980, one of the limitations on using prescribed burning was the lack of a sound scientific basis for applying fire predictably so that the fires could be controlled and the desired outcomes achieved. Alan McArthur began an experimental prescribed-burning program in the late 1950s in south-eastern Australia and south-west Western Australia, and there was a dramatic funding increase for prescribed-burning research and development across Australia following the disastrous Dwellingup fires in Western Australia in 1961 (Luke & McArthur 1978). McArthur published his landmark paper, 'Controlled burning in eucalypt forests', in the early 1960s (McArthur 1962).

There was a rapid uptake of prescribed burning thereafter (McArthur 1966; Hodgson 1967), including through the development of innovative and efficient burning techniques, such as the use of aircraft for extensive ignition operations. The ACT and New South Wales conducted large-scale trials with fixed-winged aircraft and CSIRO incendiary machines in 1967 (Packham & Peet 1967) to prescribe-burn mountainous areas. The aerial ignition of 4500 ha of rugged terrain on the western slopes of the Brindabella Ranges in the ACT demonstrated that low-intensity fire could be applied to steep terrain while keeping full crown scorch to an acceptable level of around 10% (P. Cheney, pers. comm., May 2019). Later research found that this level of scorch was unnecessarily restrictive and that burning could safely be carried out over a wider range of weather conditions than those defined in McArthur's burning guide (McArthur 1962). Over the next decade, several more similar-sized burns were conducted on the western slopes of the Brindabella Ranges, but these forests had no follow-up burns for the following 30 years and were burnt by wildfire in 2003.

In New South Wales in the autumns of 1967 and 1968, researchers from CSIRO and the Forest Research Institute[3] used fixed-wing aircraft to carry out low-intensity fuel-reduction prescribed burning in dry forests on vacant crown land (later to become Deua National Park) in rugged mountainous country on the New South Wales south coast (P. Cheney, pers. comm., May 2019). Extensive wildfires occurred on these lands in spring 1968 after a dry winter, from Bemboka in the south to Singleton in the north. The aerial prescribed burns conducted in the preceding years were credited with preventing these wildfires from burning in Moruya and Bega (D. Christopher, pers. comm., December 2019). Importantly, the prescribed burns demonstrated that the southern forests could be protected from wildfire. The New South Wales Forests Commission purchased a twin-engine aircraft dedicated primarily to aerial ignitions and set about an extensive program of prescribed burning for wildfire mitigation across the state.

Prescribed burning has been implemented widely in south-west Western Australia, where the relatively flat terrain and moderate fire climate allow for easier implementation across larger areas (Boer et al. 2009; Lin et al. 2013). Broadscale prescribed burning in Victoria and Tasmania is more difficult because of steep topography and variable and unpredictable weather conditions, particularly in spring, and consequently the uptake of prescribed burning was slower. In those states, early prescribed-burning efforts involved the use of handheld drip-torches. Victoria subsequently developed a helicopter system using delayed-action incendiary devices (DAIDs),[4] which was considered to offer a high degree of flexibility and accuracy for aerial ignitions, particularly when flying contour ignition lines (Rolland 1996; Underwood 2015). Tasmania also adopted this system, which proved successful in burning substantial areas within containment lines in rugged terrain under mild conditions before the onset of severe fire weather (Hodgson & Cheney 1969). However, a tragic helicopter crash in 1978 involving DAIDs, which killed two foresters and a pilot, ended the DAID program in both states (Elliott et al. 2008).

Seeking to continue aerial ignition in native forests in a safer manner, two officers in the Victoria Forests Commission, Barry Marsden and Bryan Rees, developed a system using 'ping pong ball' machines, which released polystyrene capsules containing potassium permanganate crystals injected with ethylene glycol, based on a Canadian system. The success of this led to improved prescribed-burning techniques and broadscale fuel-reduction prescribed burning for wildfire mitigation in forests in south-eastern Queensland, New South Wales, Tasmania and Victoria in the late 1970s and 1980s.

Technological advances in prescribed burning—1980s and 1990s

Fire research in dry eucalypt forests in the 1980s showed that the assessment of surface fine-fuel loads alone was not the best indicator of potential fire behaviour and that elevated (shrub) and bark fuels also needed to be considered (Tolhurst et al. 1992). A rapid visual fine-fuel assessment method was developed to assess fuel composition, structure and arrangement as well as fuel loads (Wilson 1992; McCarthy et al. 1999; Hines et al. 2010). This change in the method for assessing fuels also changed the focus of how wildfire-mitigation prescribed burning was used to most effectively reduce fire spread and intensity by mitigating the fire hazards associated with the various fuel components. The new fuel assessment method was used in Project VESTA (Gould et al. 2007) and proved effective; it is now the accepted method of fine-fuel assessment in south-eastern Australia.

Prescribed-burning prescriptions were produced in 1991 for wildfire-mitigation prescribed burning in thinning slash in Victorian coastal and foothill mixed-species eucalypt

[3]Before 1975, the Forest Research Institute was part of the Commonwealth Forestry and Timber Bureau. It was transferred to CSIRO in 1975 to become the Division of Forestry.

[4]A DAID resembles an elongated double-headed waterproof match. The short head is struck on a lighting pad, similar to the side of a match box, and the DAID is thrown by hand to the place of ignition, while the fuse between the two heads gradually burns and after a short period ignites the larger head, which ignites the dry vegetation.

regrowth forests (Buckley & Corkish 1991). Meanwhile, research in regrowth forests in southern New South Wales found that the moisture content of live and dead elevated fuels up to half a metre above the ground explained variations in observed fire behaviour (Cheney et al. 1992).

The Canadian development of an aerial drip-torch slung under a helicopter that dropped ignited petroleum gel opened up a new technique for conducting high-intensity burning of logging slash in Tasmania and Victoria in the 1990s. Before it was used operationally in Australia, the aerial drip-torch was modified to comply with Australian safety regulations and improve its ease of use. This technique enabled the ignition of moister fuels and more discontinuous fuels, expanding the range of fuel and weather conditions under which prescribed burning could be undertaken successfully.

In the 1980s, it became a standard procedure in Victoria's south-western plantations to burn dead needles suspended on standing *Pinus radiata* D.Don trees in closed-canopy plantations on days of very high relative humidity, replacing low pruning (Billing & Bywater 1982). The aim of this prescribed burning, using fuel-moisture differentials, was to restrict the movement of surface fires into tree crowns by breaking the vertical continuity of fine fuels. Tree breeding has now largely overcome the needle-retention problem.

In Tasmania, successful trials were conducted in the 1980s and prescriptions developed for wildfire-mitigation burning in dry forests and *P. radiata* plantations (Elliott et al. 2008). These prescriptions included tightly defined ranges of fine-fuel moisture contents measured in the field using the Speedy Moisture Meter (Dexter & Williams 1976) and later the Wiltronics TH Fine Fuel Moisture Meter (Chatto & Tolhurst 1997). Fine-fuel moisture content was known to be one of the most important factors affecting fire intensity and controllability. Other portable handheld devices were used to measure air temperature, relative humidity and wind speed. These in-field measurements were crucial for the successful use of burning guides (e.g. McArthur 1962).

Technological advances, 2000–2018

Since 2003, the question of how to record prescribed-burning treatments has arisen—should it be the total area treated, or only the actual area burnt? This question is important because burns can be conducted for multiple outcomes. In some cases, burning prescriptions may seek to achieve low coverage with significant patches of unburnt vegetation within the boundaries of a treated area to satisfy particular environmental requirements. In such cases, the operation would be considered successful if partial burning is achieved. A less-than-desirable outcome may have been achieved for wildfire mitigation, however, if large areas are recorded as treated but only patchy burning obtained.

MPIGA and NFISC (2018) reported on the extent of planned and unplanned fire in forests in Australia for the period 2011–2012 to 2015–2016. Ninety-four percent of planned fire was reported to have occurred in northern Australia (i.e. the Northern Territory, Queensland and north-western Australia) and 4% in south-eastern Australia. Research is underway on the use of satellite imagery, supported by ground-truthing, to establish a nationally consistent method for monitoring landscape burning (e.g. Leavesley et al. 2018). If such a method is developed, it would provide better data for 'state of Australia's forests' reporting undertaken in accordance with the Montreal Process (MPIGA & NFISC 2013).

The accurate reporting of prescribed-burning extent has become important in south-eastern Australia. Some lobby groups,[5] politicians[6] and others (Jurskis 2015; Poynter 2018; Underwood 2019) have attacked state governments for not achieving area-based targets, and some environmental activist groups have engaged in long-term campaigns to end broadscale prescribed burning in public forests (Poynter 2018; Underwood 2019). In addition, some ecologists and bushfire scientists have shown a lack of enthusiasm for broadscale prescribed burning. Such pressures have created doubts at the political level about whether broadscale prescribed burning should continue (Burrows 2018).

In Victoria by 2013, the public debate on how best to reduce wildfire risk, and the inability of agencies responsible to meet the prescribed-burning target for public land (390 000 ha per annum) recommended by the 2009 Victorian Bushfires Royal Commission (Teague et al. 2009), led the Victorian Bushfires Royal Commission Implementation Monitor (VBRCIM) to question whether an area-based performance measure achieved appropriate risk reduction and whether it was affordable and sustainable (Comrie 2013). Even though Victoria prescribed-burnt more than 250 000 ha in 2012–2013 (its highest annual burnt area since 1983), the VBRCIM recommended discarding the annual-area burning target in favour of a 'risk-based' approach. In 2015, Victoria's Inspector-General for Emergency Management recommended a risk-reduction target to protect life and property and to guide investments in wildfire-mitigation prescribed burning as an alternative to area-based burn targets (IGEM 2015).

A risk-reduction approach was introduced in Victoria on 1 July 2016 with the aim of prioritising the most at-risk areas for fuel-reduction operations (Department of Environment and Primary Industries 2013). Rather than an area-based target, Victoria aimed to maintain the wildfire risk at or below 70% of the state's maximum wildfire risk (Comrie 2013; Dexter & Macleod 2017). This has led to an associated drop in the annual area subject to prescribed burning (Fig. 4). There is ongoing debate on whether a 30% reduction in the wildfire risk is acceptable.[7]

In Tasmania, specific recommendations were made following the fires of January 2013 to implement a strategic fuel-management plan for the state that included measurable targets that would actively be monitored and reported to the community. A quantitative and qualitative analysis of the extent and effectiveness of fuel-reduction burning was undertaken, which included testing various scenarios for burning on both public and private land (State Fire Management Council 2014), building on the work pioneered by the then Victorian Department of Environment and Primary Industries. The report recommended the introduction of a whole-of-government, tenure-blind fuel-reduction

[5]Forest Fire Victoria. http://forestfirevictoria.org.au.
[6]Hon. E. G. Stoney (Central Highlands), 13 June 2006. http://forestfirevictoria.org.au/docs/StoneyHansard13Jun06.pd.
[7]To illustrate the concept, if a 30% risk reduction had been achieved in Victoria before 2009, it would be expected that about 1400 houses would have been lost, compared with the 2000 lost (K. Tolhurst, pers. comm., November 2019). Whether a 30% reduction in the wildfire risk is socially acceptable could be debated.

program using a risk-based approach for the prioritisation of implementation. Commencing in the 2014/15 financial year, the Tasmanian Government providing funding of AUD28.5 million over four years to implement the program with the aim of reducing risk to communities. Among other things, the program involved the establishment of a dedicated fuel-reduction unit in the Tasmania Fire Service and a targeted community engagement strategy seeking permission from private landowners to burn their lands as part of the annual program of burns. The funding also covered additional resources for both Sustainable Timber Tasmania (formerly Forestry Tasmania) and the Parks and Wildlife Service.

Before this program commenced, most prescribed burning was undertaken on public land at an average of 45 burns and about 16 000 ha per year (measured over five years, acknowledging that private burning is underreported). Between spring 2014, when the program commenced, and March 2019, more than 900 burns were completed and more than 100 000 ha burnt. Significantly, though, this burning was conducted on multiple tenures (private and public land), and there was an increase in the burning undertaken by local governments and private burning contractors as well as by the Tasmanian Fire Service. The ongoing efforts of the Parks and Wildlife Service and Sustainable Timber Tasmania have been essential for the successful implementation of the program. Program effectiveness is not just measured by the number of burns completed and area burnt, but also in changes to relative risk at different scales across the state (State Fire Management Council 2014), calculated annually and reported through the annual budget estimates process. The Government has now funded the program on an ongoing basis at AUD9 million per year.

Shifting to a strategically applied prescribed-burning program based on a risk-based target requires advanced risk assessment using robust fire-spread models. In south-eastern Australia, numerous models and simulators are used to predict the spread of prescribed fire across various vegetation types (Cruz et al. 2015a). In 2013, the Bushfire CRC commissioned CSIRO to produce a reference guide for fire managers to enable them to select appropriate models, relevant to specific vegetation types, in order to formulate more accurate predictions (Cruz et al. 2015b). Tasmania revised its planned burning prescriptions in 2009 (Marsden-Smedley 2009) after applying the most appropriate model for each fuel type, including the limited use of the Canadian Fire Danger Rating System (Stocks et al. 1989). The tool used most widely by fire-behaviour analysts in prescribed-burning operations in south-eastern Australia is, however, the PHOENIX RapidFire fire simulator (Tolhurst et al. 2008). This mechanistic fire-characterisation simulator uses computers to model fire in a way not possible with traditionally used linear fire-spread models (e.g. Cruz et al. 2015b). One of the unique aspects of PHOENIX RapidFire is how it dynamically incorporates local topographic effects on fine-fuel moisture and wind, different strata of fine fuels, and the effects of fire scale and spotting, into the fire-propagation process (Chong et al. 2012). Although PHOENIX RapidFire uses aspects of a range of fire-behaviour models, it represents a new, generic non-linear fire-behaviour model.

With the availability of a robust computational model that can provide local fire-behaviour predictions, several south-eastern Australian fire management agencies are developing economic models to examine the risk trade-offs, including in terms of potential house losses in wildfire (Tolhurst et al. 2008; Tolhurst & Chong 2011), and to compare the effectiveness of broadscale prescribed burning in and around townships with wildfire suppression. For example, Bentley and Penman (2017) used PHOENIX RapidFire to evaluate the change in wildfire risk to adjacent fire-sensitive populations of people and koalas in coastal New South Wales.

PHOENIX RapidFire has also been used to inform community engagement on prescribed-burning options in several townships in south-eastern Australia (Tolhurst et al. 2009; Ackland et al. 2010; State Fire Management Council 2014). It has enabled the objective quantification of the effects of different fire management strategies on mitigating potential wildfire losses and the demonstration of this to the public.

Since 2003, there has been a renewed push to better understand the landscape-scale effects of fire. A multi-institutional research effort was initiated in Victoria to investigate the effects of different landscape fire patterns on flora and fauna (Leonard et al. 2016). This research provides a complementary view of fire to that simulated by PHOENIX RapidFire for wildfire risk analysis.

Agencies have also used PHOENIX RapidFire to help evaluate various scenarios, such as comparing options to maximise community or asset protection, determining tolerable fire intervals and protecting ecosystem services such as water quality and quantity. Various fire management strategies can be compared visually to show how given options might be modified to reduce impacts on other values (Ackland et al. 2010).

The ACT, New South Wales, Tasmania and Victoria now routinely use PHOENIX RapidFire to model where fires may start, spread and affect assets in a landscape as part of risk-assessment processes and to guide where best to conduct prescribed burning. This is a major part of the Victorian fire monitoring, evaluation and reporting framework (DELWP Victoria 2015a).

The commercial plantation industry is also increasing its use of PHOENIX RapidFire. HVP Plantations, for example, is using it to assess wildfire risk to its plantation assets and the potential role of fuel management programs within and in the vicinity of the plantations to reduce the risk. HVP Plantations has become involved with various non-governmental organisations and government agencies in workshops and surveys to influence landscape-scale fuel management programs. HVP Plantations firefighters have assisted in prescribed-burning operations on a tenure-blind basis.

The ACT released its territory-wide risk-assessment report into natural hazards in 2014 (ACT Emergency Services Agency 2014). The threat posed by wildfire was one of three hazards rated as extreme among the 23 identified hazards facing the ACT. Prescribed burning is widely acknowledged as a legitimate mitigation strategy for reducing the risk of wildfire in the ACT (ACT Emergency Services Agency 2014). The ACT and New South Wales are using PHOENIX RapidFire in joint research into risk modelling to measure the effectiveness of prescribed burning on the reduction of wildfire risk.

The Bushfire and Natural Hazards CRC and the Australasian Fire and Emergency Service Authorities Council (AFAC) are conducting further research into fire-spread models to improve predictive capabilities for fire behaviour and spread. A CRC[8] project is building an improved predictive model and

[8]https://www.bnhcrc.com.au/research/understanding-mitigating-hazards/262.

framework for the planning of prescribed burns and for benefit–cost modelling to assess the economic value of prescribed burning (Florec et al. 2017; Florec & Pannell 2017). Other research[9] is using satellites to detect soil dryness and flammability and developing an online mapping tool to help fire managers decide where and when to conduct prescribed burning (Dharssi & Kumar 2017; Yebra et al. 2018).

Alternatives to wildfire prevention not using prescribed burning are being investigated. In 2015, the Australian Government provided AUD1.5 million, in a 'national partnership' with the government of New South Wales, to undertake trials aimed at establishing whether the mechanical thinning of forests can reduce bushfire risk in an economically viable, socially acceptable and environmentally sound manner around key assets, such as conservation areas and townships, where prescribed burning may be undesirable for a range of reasons.

Modelling smoke and smoke drift

Smoke from prescribed burning may affect urban areas and other infrastructure, such as airports, and may cause impacts on human respiratory health. The impacts of smoke from prescribed burning on scenic quality and human health became a political issue towards the end of the twentieth century (e.g. Meyer et al. 2011), although fire researchers had been investigating this issue from the 1970s (Vines et al. 1971; Evans et al. 1976; Packham & Vines 1978). The increased political attention resulted in the application of restrictions aimed at maintaining smoke-free airsheds for popular tourist destinations and urban areas, particularly in autumn. Land managers recognise the potential impacts of smoke and seek to schedule prescribed burning to coincide with wind conditions that move smoke away from sensitive areas. No process exists in government, however, to balance concern about respiratory health from prescribed burning with the need to protect the public and assets from the adverse effects of wildfires (which themselves can have severe impacts on human respiratory health).

The ACT recently developed the Prescribed Burn Decision Support Tool, which could be applied nationally, to better assist fire managers in implementing burns (Levine et al. 2017). It includes a 'smoke module' designed to assist planners in identifying the risk of smoke to communities; it includes the consistent documentation of decision-making based on the best available information.

Recognising the need to better manage smoke drift, the Australian Forest Fire Management Group (FFMG)[10] supported research by the Bureau of Meteorology in the late 1990s into smoke-plume modelling with the aim of producing smoke-spread prediction models (Valianatos et al. 2003). This research, which was continued by the Bushfire CRC, led to predictive models that continue to be refined today through research and operational practice in south-eastern Australia (Cope 2017; Long et al. 2017). As a result, the ACT, New South Wales, Tasmania and Victoria all now have procedures for minimising the nuisance and human-health impacts of smoke arising from prescribed burning geared to maintaining acceptable air quality over (and in) towns and settlements. These procedures have the effect of restricting the periods within which prescribed burning may be conducted. During the 2006 Commonwealth Games in Melbourne, smoke-prediction modelling was used successfully to allow prescribed-burning operations to continue in Victoria without causing a smoke nuisance in Melbourne.

Ecological burning and impacts

Research into the ecological effects of fire has been conducted in Victoria since the 1920s (Tolhurst & Flinn 1992). By the mid-1970s, there was a strong understanding among scientists that fire was a natural environmental component of the state's landscapes (Gill 1975). At the third Fire Ecology Symposium, held at Monash University in 1974 (Ealey 1974), Emeritus Professor Turner from the University of Melbourne called for more ecological research into the effects of fire on mammals, birds and ground flora. While noting the need for more knowledge on the effects of prescribed burning, he encouraged the Victorian National Parks Service to start prescribed burning in forested parks and reserves rather than waiting for research outputs, which might take decades to appear.

A long-term fire ecology research study was initiated in 1984 in Victoria's Wombat State Forest with the aim of gathering scientific data on the ecological impacts of prescribed burning for wildfire mitigation (Tolhurst & Flinn 1992). Significantly, this multidisciplinary research examined the effects on flora, fauna, fuels and soils of repeated low-intensity prescribed burning (rather than the impact of single fire events) in spring and autumn and at various frequencies. Similar but less-comprehensive studies were conducted at Eden (Binns & Bridges 2003) and Bulls Ground (York 1996, 2000) in southern New South Wales.

Not all agencies had trained professionals to conduct ecologically focused prescribed burning. Tolhurst and Cheney (1999) provided a synopsis of the current (at that time) understanding of fire behaviour used in prescribed burning based on the fire science literature. A group of ecologists, fire-behaviour specialists, researchers and fire and ecology managers (Kevin Tolhurst, Malcolm Gill, Gordon Friend and Mike Leonard) conducted fire ecology workshops in Victoria in 1999 and 2000 (Fire Ecology Working Group 1999, 2000) to assist land managers, park rangers and fire managers to deliver on the legislated requirement of fire protection for human life and property through burning designed to modify fire behaviour and improve the probability of controlling wildfires while considering the effects on biodiversity and the landscape (Gill 2008).

Existing knowledge on fire ecology was codified in interim guidelines and procedures for ecological burning on public land in Victoria, published in 1999 following initial trialling and finalised in 2004 (Fire Ecology Working Group 2004). Concurrently, considerable effort was made to improve the quality of information in the state's flora and fauna databases. Knowledge accrued in other parts of Australia was also used and extrapolated for the south-eastern Australian environment (Burrows & Friend 1998; Gill et al. 1999).

Using the 1998 Victorian Department of Natural Resources and Parks Victoria databases of plant species' 'vital attributes', a subsequent analysis of 'disturbance' by fire on public land in that state found that the major threat to species composition and vegetation community conservation on most Victorian

[9]https://www.bnhcrc.com.au/research/understanding-mitigating-hazards/255.
[10]The FFMG is a subgroup of the Forestry and Forest Products Committee under the Agriculture Senior Officials' Committee and Agriculture Ministers Forum.

public lands at that time was under-exposure to fire (Department of Natural Resources and Environment 2002).

Concerns that too-frequent and too-infrequent burning of the native vegetation was adversely effecting biodiversity were increasing, indicating a need for more high-quality research and the application of existing research knowledge to support management decisions on prescribed burning. The intervals between fires necessary for the persistence of a species, known as 'tolerable limits' (Wouters et al. 2002) or 'critical domains' (Bradstock & Kenny 2003), were identified for a number of species. Considerable other data were obtained by researchers on the effects of fire on biodiversity, enabling land managers to better appreciate the impacts of prescribed burning (Bradstock et al. 2002).

By 2002, the New South Wales National Parks and Wildlife Service had developed the Flora Fire Response Database (Adams & Attiwill 2011). In South Australia, workshops held in 2002 developed interim prescribed-burning prescriptions. These were reviewed in 2009 to incorporate experience using the principles of adaptive management (DENR South Australia 2009).

Protocols were formally put in place in Victoria in 2008 to measure changes in flora following vegetation fires (Tolhurst & Friend 2001). These were based on flora 'vital attributes' methods used in fire ecology management (Cawson & Muir 2008a, 2008b) to integrate human and ecological needs in fire management.

Similarly, the Queensland Parks and Wildlife Service published a series of 'planned burn guidelines' in 2013 to assist burning for a range of purposes in each bioregion, including the South-east and New England Tableland bioregions.[11]

Gill (1975) discusses the adaptive traits of Australia's flora and vegetation communities, highlighting that knowledge of species adaptation is necessary to predict species behaviour under natural and imposed fire regimes. This will be the case under environmental changes caused by climate change. Fire (presence and absence) is crucial in assisting many plant species to move across landscapes (thus potentially finding better habitats as the climate changes) and respond to environmental change by providing them with opportunities to regenerate and to use more climate-tolerant parts of their gene pool.

Prescribed burning extent and management practice

Prescribed burning to reduce wildfire risk and intensity

Little prescribed burning to reduce wildfire risks or impacts was carried out in south-eastern Australia before the disastrous 1939 fires. 'Burning off' was mainly to remove rubbish, improve grazing and clear vegetation for agriculture, and forest-fuel hazard reduction was not planned or strategic. To George S. Perrin, Victoria's first Conservator of Forests, those who lit fires seemed 'careless of the consequences'. In 1890, he described the 'universal carelessness with regard to fire' as 'culpable negligence' (Hansen & Griffiths 2012).

By the 1920s, two schools of thought had developed about the use of fire as a forest management tool. Pyne (1991) noted that, at that time, most field-based forestry personnel believed regularly using fire to 'clean up' the forest floor and maintain a light fuel load was the key to controlling wildfires. This was heresy, however, to the more academic professional foresters—particularly those trained at Britain's Oxford University—who believed that wildfires would largely vanish as tangled wilderness was converted to organised, tended forest (Pyne 2006).

As early as 1923, Victoria's Forests Commission warned the State Government that wildfire would continue to be a major threat and was 'a tragedy waiting to happen'. Major efforts were made to exclude fire from forests and to educate the public in its safe use on adjacent lands, but with only moderate success. Meanwhile, small advances were being made in fire management, but these were focused on improving the capability to locate fires (including from the air) and developing effective firefighting tactics which were nevertheless primitive by today's standards (Moulds 1991).

Progress was initially slow in increasing the area subject to prescribed burning in Victoria following the 1939 Stretton Royal Commission, but there was a steady increase from 1962 to about 1986. The increasing use of fire was driven primarily by a desire to reduce the risk of wildfire to human life and property, in accordance with the Commission's recommendations. Nevertheless, the extent of prescribed burning in Victoria declined from 1986 until the 2009 Victorian Bushfires Royal Commission (Fig. 5).

Fire management followed a similar pattern in south-eastern Queensland. The Queensland Department of Forestry applied a policy of total fire exclusion until the early 1960s. With the expansion of softwood plantations and treated native forests, fire exclusion was no longer a tenable aim and extensive prescribed burning was adopted (Department of Forestry Queensland 1984), including the encouragement of burning by grazing lessees for pasture management in state forests to increase burning capability.

Prescribed burning was generally standard practice for wildfire mitigation among government land management agencies in South Australia, Tasmania and Victoria and in New South Wales state forests by the end of the twentieth century. Published independent observations recorded that the frequency and extent of major forest fires had declined dramatically in Australia where extensive prescribed burning and improved suppression techniques were deployed (Cheney 1976; Boer et al. 2009). Nevertheless, and despite knowledge of the interdependence of eucalypt forests on fire for their survival, health and distribution (Mount 1964), national parks agencies were generally reluctant to use fire as an ecological process. This was particularly so in New South Wales (Jurskis et al. 2003), where demonstrably larger areas were being burnt by wildfire in national parks than on similar lands managed by the New South Wales Forestry Corporation, which used prescribed burning on a higher percentage of the land under its control. The application of prescribed burning in New South Wales nature conservation reserves has changed since 2003, however: 622 000 ha of planned fire (prescribed burning) occurred in these reserves in forest communities during the period 2011/12–2015/16 (11% by forest area in nature conservation reserves, MPIGA & NFISC 2018).

Victoria prepared fire management plans for public lands in 2002 with a collective annual prescribed-burning target of

[11] https://parks.des.qld.gov.au/managing/planned-burn-guidelines.html.

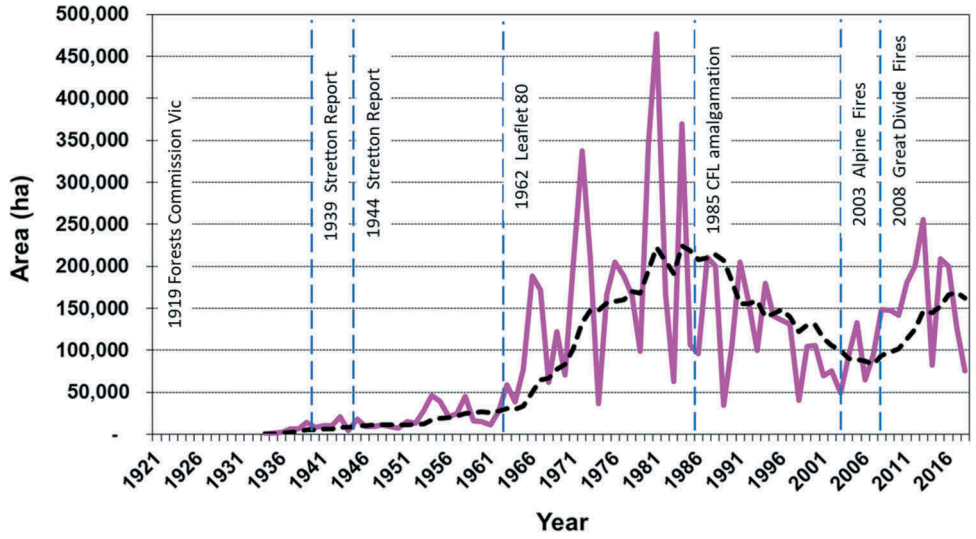

Figure 5. Annual extent of prescribed burning in Victoria, 1921–2016. The solid line is the annual area burnt with prescribed fire and the dashed line is the 10-year rolling average area (source: Annual reports and unpublished records from the Victorian Department of Land Environment Water and Planning)

228 899 ha (M. Leonard, pers. comm., April 2018)—the area that, according to Victoria's forest and fire management agency, was required to address the state's wildfire risk. The target was increased following the 2009 Victorian Bushfires Royal Commission, which considered, '… that a target of 5 to 8 per cent prescribed burning of public land is necessary for community safety and would not pose unacceptable environmental risks, particularly if priority is given to the dry eucalypt forests referred to by the expert panel' (Teague et al. 2010, vol. 2, p. 295). Some other states also adopted prescribed-burning targets, with all state and territory governments in south-eastern Australia increasing their budgetary allocations for wildfire-mitigation prescribed burning after the 2003 wildfires. Achieving these targets proved difficult, however.

The area-based performance targets proposed by the 2009 Victorian Bushfires Royal Commission were criticised (IGEM 2015, 2017), reflecting the public policy challenge of achieving a desired area of prescribed burning. Johnston et al. (1982) found that government agencies often reported actual areas burnt that were less than planned, mainly because obtaining the required alignment of favourable weather, fuel conditions and resourcing often proved difficult, combined with factors such as conflicts with neighbouring landholders and with community and environmental groups over issues such as smoke, visual amenity, and flora and fauna.

Prescribed burning has only been encouraged on private land in a tenure-blind approach in the last decade or so through programs such as Hotspots in New South Wales, the South-East Queensland Fire and Biodiversity Consortium and Safer Together in Victoria (e.g. Lloyd 2011; Edwards 2014; State Fire Management Council 2014; DELWP Victoria 2015b).

Prescribed-burning techniques

Prescribed burning in south-eastern Australia has been used not only to reduce forest fuels for wildfire mitigation but also for environmental and silvicultural goals; the removal of plantation thinning slash to reduce wildfire hazard (Thomson 1978; Woodman & Rawson 1982); post-harvesting in native forests to improve regeneration by creating nutrient-rich ash seedbeds; and the removal of windrow and logging slash before plantation establishment.

High-intensity slash burning following logging has been conducted in the wet forests of Tasmania and Victoria from the 1950s and 1960s, respectively (Cunningham 1960; Grose 1963). However, it took time to develop prescriptions based on experience for successful burning within containment lines to regenerate high-elevation native forest; remove pine plantation logging slash (Thomson 1978; Woodman & Rawson 1982); and dispose of windrows created when clearing native forest for pine plantation establishment.

Two related, but distinct, approaches have been used for prescribed burning in Australia. One has been to use burning guides such as McArthur's Leaflet 80 (McArthur 1962) and the regrowth eucalypt forest burning guide (Cheney et al. 1992). These burning guides focus on achieving prescribed fire behaviour for a given set of fuel, weather and topographic conditions.

The second approach, which is deployed widely in south-eastern Australia, is to use fire, under prescribed conditions, to achieve a defined set of land management, fire-behaviour and fire-safety objectives. Prescribed conditions might include ranges of air temperature, relative humidity, wind speed and fine-fuel moisture content, and the level of the drought index (e.g. Billing & Bywater 1982; Buckley & Corkish 1991; Marsden-Smedley 2011). In the latter approach, burn officers are given greater flexibility to achieve the stated objectives while still ensuring that fires are controllable. The widespread use of burning within prescribed conditions has been favoured for dealing with the broad range of variability and complexity in the burning and management environments.

The two prescribed-burning approaches have advantages and disadvantages. The choice of approach must consider the level of skill and knowledge of burn officers and crews and the historical effectiveness of the approach.

ACT Forests (the ACT's forest management agency) has a long history of successfully conducting prescribed burning and working with fire researchers from CSIRO (O'Keefe 2017). Following the disastrous 2003 wildfires (McLeod 2003), and in acknowledgement of the importance of prescribed burning, the *Emergency Management Act 2004* was passed, requiring the development of the Strategic Bushfire Management Plan

(SBMP) to detail, to the territory's parliament, fuel management and access works (ACT Government 2014). The SBMP and its associated bushfire operational plan system remains in place today; it exemplifies the diligent process, documentation and assessment of prescribed-burning operations required to balance fire protection and conservation objectives in what is a complex and politically sensitive working environment (ACT Government 2017).

Current fire management policy

By 1995, following extensive criticism of broadscale prescribed burning by some environmental groups, Australia's first code of practice for fire management on public lands (DNRE Victoria 1995) was introduced in Victoria, providing a comprehensive framework for fire management procedures and practices. This code conveyed a balance of community views, fire-behaviour science, and fire ecology, integrated with practical wildfire-mitigation measures. It was updated in 2006 (DSE Victoria 2006) and revised again in 2012 (DSE Victoria 2012) to reflect the recommendations of the 2009 Victorian Bushfires Royal Commission. The 2012 version provides greater recognition of the role of fuel management in reducing wildfire risk over broad areas and risk-based planning with the primacy of human life (DSE Victoria 2012).

South Australia has its Code of Practice for Fire Management on Public Land (DEWNR South Australia 2012), and the ACT is developing a code of practice (N. Cooper, pers. comm., November 2017).

In 2011, the FFMG and rural fire agencies developed the National Bushfire Management Policy Statement for Forests and Rangelands (Forest Fire Management Group 2014) under the auspices of two Australian ministerial councils.[12] This statement, which was endorsed by all members of the Council of Australian Governments, including the Australian Local Government Association, in late 2011 and early 2012, acknowledges that the principles contained therein will be reflected in all operational codes of practice used by the nation's land management jurisdictions.

The National Bushfire Management Policy Statement for Forests and Rangelands identifies 14 national goals, including that land managers use prescribed burning to maintain appropriate fire regimes, balance the environmental impacts of fire, promote Indigenous Australians' use of fire and mitigate the risk of wildfire risk and manage risk.

In 2012, Australia's land management agencies initiated the National Burning Project (AFAC 2014) to produce best-practice national guidelines for prescribed burning and to ensure greater interoperability between fire management agencies by developing common standards and approaches to prescribed burning. Specifically, the project aims 'to provide a national approach to reduce the bushfire risk to the Australian and New Zealand communities by the comprehensive management of prescribed burning at a landscape level that balances operational, ecological and community health' (AFAC 2014, p. 5). Among other things, the National Burning Project has made a wealth of usable information and tools available for use by land managers to responsibly conduct prescribed burning in south-eastern Australia (Forest Fire Management Group 2014; AFAC 2015b, 2016b, 2016c, 2016d, 2017a, 2017b).

Consistent with the National Bushfire Management Policy Statement for Forests and Rangelands, AFAC issued a National Position Statement on prescribed burning in conjunction with the FFMG in 2014. This statement provides a consensus view of the underlying principles of prescribed burning among the Australian fire and land management agencies (AFAC 2016b). At the 2017 Prescribed Burning Forum in Western Australia, Australia's land managers reaffirmed their commitment to a collaborative approach to managing the inherent uncertainty in prescribed-burning operations, as well as their support for ongoing research and the application of research outputs.

Burning practice and clearing controls

In the 1950s and 1960s, South Australia, which had little remnant native forest, mainly conducted prescribed burning to protect plantations and townships (Richards 2006). The South Australian Woods and Forests Department (now Forestry SA) burnt areas to specified control lines, rather than burning to prescriptions, to achieve management objectives for a given area. Later (i.e. in the late 1980s and early 1990s), Forestry SA, the National Parks and Wildlife Service SA and the Country Fire Service formed the Prescribed Burning Working Group to improve the use of prescribed burning for fire protection and biodiversity.

Because of the significant level of land clearing that had occurred in South Australia up to the 1980s, planning regulations were introduced in 1983 to require permits for clearing native vegetation. Burning was included in the definition of 'clearing' to prevent further land clearing using quick successive burns. These regulations were introduced without public warning (to prevent further clearing), resulting in considerable protest from landowners and Forestry SA. Nevertheless, the South Australian Government stood firm, passing the *Native Vegetation Management Act 1985* to enshrine clearance controls in law. After a review in 1991, the Act was amended to the *Native Vegetation Act 1991*, with a stronger focus on native vegetation management (including some exemptions for fire/asset protection). The effect of these clearance controls has been that private burning (other than stubble burning) has virtually ceased in South Australia since the mid-1980s; land management agencies have continued to conduct burns on public lands via a significant administrative approvals process.

Discussion

Various fire inquiries have created pressure to restrict prescribed-burning operations. For example, there were seven inquiries after the 2003 wildfires in the ACT, New South Wales and Victoria (Poynter 2007), and more have followed after subsequent fires. In the view of the authors, most of these inquiries have looked for scapegoats rather than sought to identify the systemic issues that have created the problems. Hence, operational personnel have felt unduly criticised for their actions, and situations have been created in which personnel who didn't meet prescribed-burning targets have not been penalised, even though their actions meant an increase in the risk to lives and property posed by wildfire.

[12]The Primary Industries Ministerial Council and the Natural Resource Management Ministerial Council.

Personnel with responsibility for prescribed burns that escaped planned boundaries or created smoke hazes in politically sensitive airsheds have, however, been criticised within their institutions and often even publicly. This has led to an environment in which, for the sake of an individual's career, 'matches are best kept in the pocket', thereby further discouraging prescribed burning (e.g. Carter et al. 2015).

Organisational changes in land management agencies and periodic fire inquiries have had adverse impacts on prescribed burning. In the view of the authors, this is due mainly to a lack of appetite for risk among politicians and senior public servants typically with no operational land management or fire experience. In Victoria, for example, the area of public land subject to prescribed burning increased through the 1970s and 1980s (Fig. 4) during a period of relative organisational stability. Much of the rapid decline in the use of prescribed burning since the mid-1980s can be attributed to the Victorian Government's multiple organisational changes of amalgamation, disaggregation and privatisation. There were eight such changes in the 21 years from 1983 to 2004, with an associated reduction of prescribed burning (Doolan 2015). A further two departmental changes followed, with associated staff movements, continuing the disruption. Over time, many experienced foresters resigned or were transferred from dispersed smaller townships to major regional centres. In the period 1982–1995, for example, there was a 44% reduction of field-based personnel with native forest management skills (Poynter 2007). Coinciding with this period was the transfer of public production forest (state forest) to national parks and reserves, and significant reductions in the public land management workforce, equipment and skills available for forest firefighting and fire management (Auditor-General Victoria 2003; Morgan et al. 2007).

The debate on where best to burn has played out in the public arena in south-eastern Australia, the region in which the majority of wildfire-related deaths and property damage have occurred since European settlement (e.g. Cary et al. 2003; Gibbons et al. 2012). No one wants the loss of life or property; nor, however, does everyone want to see forests burnt, even by low-intensity prescribed fires. Experience has shown that a focus on 'fence-line' burning adjacent to specific assets, although beneficial for those assets, does not provide sufficient protection for the whole community and allows the build-up of dangerous levels of fuel over landscapes, exacerbating the risk of large, damaging, high-intensity fires (Poynter 2010; Tolhurst et al. 2013). There are both positive and negative impacts associated with any form of prescribed burning, and these need to be considered alongside other options for meeting land management objectives and the positive and negative economic, social and environmental impacts of no action. Risk-weighted decisions need to be made between the costs and benefits of not deploying prescribed burning to mitigate wildfire, and the impacts and likelihood of high-intensity wildfire.

The effectiveness of landscape-scale prescribed burning in reducing risk to assets (biodiversity and human assets) through fuel reduction was an important consideration in the inquiries of 2002–2004 (i.e. those of the governments of the ACT and Victoria, the federal House of Representatives and the Council of Australian Governments; Kanowski et al. 2005). Research has also determined that prescribed burning is effective in reducing fire intensity and aiding fire suppression (Billing 1981; Grant & Wouters 1993; McCarthy & Tolhurst 1998, 2001; Tolhurst & McCarthy 2016). Prescribed burning for wildfire mitigation has the primary role of reducing the intensity of wildfires to enable firefighters to control them faster. It widens the range of weather and other conditions under which a wildfire may be controlled, and potentially allows firefighters to break the run of large fires (McCaw 2013). Even under extreme fire weather, reduced fuel levels may enable firefighters to suppress a wildfire's flanks, thus limiting the area burnt. Reduced fuel levels also reduce the number of wildfires ignited through lightning, and those that are ignited burn with lower intensity and severity, reducing impacts on wildlife, soil and water values compared with wildfires burning in high-fuel-load forests.

Some researchers (as well as some environmental groups), however, advocate the cessation of widespread prescribed burning in large areas of south-eastern Australian forests and call, rather, for a focus on 'fence-line' burning adjoining built assets to reduce community fire risk (Bradstock & Price 2010; Gibbons et al. 2012; Price et al. 2015). Some researchers indicate concern that prescribed burning for forest-fire reduction in south-eastern Australia actually increases the total area burnt (Price 2012), although this argument does not consider the severity of wildfire versus prescribed fire and the ability of ecosystems to recover (Tolhurst 2012). Others strongly advocate for more broadscale burning in fire-evolved forested landscapes (Cheney 2008; Adams & Attiwill 2011), as do professional bodies representing practising forest and fire managers—such as the FFMG (Forest Fire Management Group 2014), the Institute of Foresters of Australia (IFA 2018) and the AFAC (AFAC 2015b). Jurskis (2005) advocated a regime of more frequent, low-intensity fire using prescribed burning across landscapes to reverse the declining ecological health of eucalypt forests in New South Wales.

Some of the conflicts in the use of fire between maintaining ecosystem processes and reducing wildfire risk would be better addressed through improved land-use planning and urban development (e.g. Standards Australia 2009). As a community living in a highly fire-prone environment, there is also an imperative to address where and how homes are built and to accept that we must live with fire in our landscapes (e.g. NSW RFS 2018).

Reintroducing Aboriginal burning culture

It took a long time for government agencies in south-eastern Australia to appreciate the importance of working with Aboriginal communities in managing public land, but all relevant agencies now involve Aborigines to some extent in prescribed burning (Forest Fire Management Group 2014). Most commence prescribed-burning seasons with the ceremonial lighting of fires by Aboriginal elders. Some employ Aboriginal rangers, many of whom are actively involved in prescribed-burning programs. New South Wales has developed a policy to support Aboriginal community aspirations to connect to and care for country through cultural fire management in parks (OEH NSW 2016). The south-eastern Australia Aboriginal Fire Forum held in Canberra in May 2018 brought together 130 local and interstate Aboriginal and Torres Strait Islander people and non-Indigenous fire managers to share their knowledge and experiences of cultural burning (Smith et al. 2018).

We anticipate that Aboriginal involvement will increase in all jurisdictions in the future. This will require that land managers (public and private) go beyond a normal understanding of external relationship management and adopt new methods of engagement to create enduring personal and professional relationships (Falconer 2017). An example of the latter is a fire management plan recently prepared for Cape Barren Island in Tasmania—*truwana patrula nayri* ('Cape Barren Island Good Fire'). Undertaken as collaborations using a shared-learning approach, engagements of this nature have the potential to create a lasting legacy for safeguarding Australia's environmental and cultural environments (Maclean et al. 2018).

Ongoing debate and future directions

Why is prescribed burning in south-eastern Australia considered, in some quarters, as destructive, unnecessary and unwanted? The view that fire can only be destructive rather than an essential part of enhancing biodiversity and conserving ecosystems drives ongoing public debate over prescribed burning (Clarke 2008; Dixon 2019), exacerbated by an absence of shared objectives and a lack of appreciation of the best available scientific knowledge, particularly as Australia's population becomes increasingly urbanised and affluent. The politically charged nature of the debate, and a lack of performance measures for biodiversity conservation in land management agencies, hinders the application of proper fire regimes in Australian fire-adapted ecological communities (Thornton 2015), and it may seem easier to take a 'do nothing' approach to fire management. The risk of prescribed burning must be weighed against the risks associated with uncontrolled wildfires that have much greater impacts on biodiversity than low-intensity prescribed burning in the same areas. Risk-averse decision-makers may invoke the precautionary principle to defer decisions on prescribed burning until everything is known, but this could have devastating consequences for human and ecological communities. Gill (2008) proposes an adaptive management approach to fire management for biodiversity conservation using prescribed burning rather than invoking the precautionary principle to defer decisions on prescribed burning.

The interactions between fire and the people and landscapes of south-eastern Australia are complex. Nuanced, informed debate, therefore, is essential, and considerable scientific knowledge is publicly available to enable this (Tolhurst & Cheney 1999; Gill 2008; Marsden-Smedley 2009; AFAC 2015b). There is a need, however, to counter the view—still held strongly in some quarters—that prescribed burning is unnecessary or potentially even worse than 'doing nothing'. Given the devastating impacts that high-intensity wildfires can have on communities and the environment, and the increasing threat of climate change, we believe that a non-interventionist approach to landscape fire management will result in higher numbers of human deaths and greater impacts on wildlife and ecosystems than approaches involving the prescribed use of fire.

The best available assessments indicate that the climate in south-eastern Australia is warming and drying, and this will increase the frequency, intensity and size of wildfires in some of the continent's most densely populated regions (Hughes & Steffen 2014; Dowdy 2018; Steffen et al. 2019). The Climate Council of Australia (Hughes & Alexander 2017, p. 2) noted in 2017 that, '[d]eclining cool season rainfall has had a significant impact on increasing bushfire risk. Since the mid-1990s, southeast Australia has experienced a 15% decline in late autumn and early winter rainfall and a 25% decline in average rainfall in April and May. The fire season in southeast Australia has lengthened, reducing opportunities for fuel reduction burning and increasing the resource needs of firefighting services'. Changes in weather conditions in south-eastern Australia (Lucas et al. 2007; Clarke et al. 2013) are significantly increasing McArthur Forest Fire Danger Index ratings in the ACT, New South Wales, South Australia, Tasmania and Victoria. Thus, global climate change will increase the wildfire threat, with adverse impacts on the natural environment.

Critics of prescribed burning have drawn attention to the potential contributions of prescribed burning to increasing atmospheric greenhouse gases that drive climate change. Research has shown, however, that prescribed burning for wildfire-mitigation purposes produces fewer greenhouse gas emissions than do wildfires (Australian Human Rights Commission 2007; Volkova et al. 2014).

The wider use of prescribed burning is essential for managing escalating wildfire risks to human lives and property and to biodiversity and other environmental values. The increasing extent and occurrence of wildfire disasters in south-eastern Australia indicates that current fire management will not sustain the full range of ecosystem processes and biodiversity, nor reduce to an acceptable level the impact of wildfires on human lives and property.

Concerns have been raised (Pyne 2009; Poynter 2018) that the expenditure on aircraft for effective first-attack suppression could, ironically, reduce the resources available for the necessary follow-up ground-level fire suppression. Similarly, aircraft expenditure may reduce the resources available for prescribed burning to reduce forest fuels for wildfire-mitigation purposes.

Much has been learnt in the last 50 years or so about the application and effects of prescribed burning through a significant amount of applied and academic research. The more that is learnt, the more clearly it is seen that there is more to learn. An adaptive management approach is crucial for fire management (Gill 2008; Campbell et al. 2010). The Aborigines increased fire in the environment and shaped today's fire-adapted forests. To discontinue prescribed burning in forests would change the current forest ecosystems. Burning without constraints is not possible if property and lives are to be protected. But utilising the principles of Aborigine burning will allow fire-adapted forest ecosystems to thrive.

A clearly structured process of prescribed-burning planning, implementation, monitoring, evaluation, review and adaptation would appear best able to ensure appropriate decision-making in a quickly changing and highly complex environment in which knowledge will always be incomplete. This structured process needs to be applied at the landscape scale across tenures.

Conclusions

Wildfires will always be a part of the ecology of south-eastern Australia, given the highly fire-prone natural environment, the common occurrence of lightning ignitions in drier months, and human activities that can cause ignition

at any time of year (Davies 1997). In the extreme weather conditions that occur in spring to late summer, wildfires can reach such high intensities that they are unstoppable until weather conditions ameliorate, no matter how many firefighting resources are available (Tolhurst & McCarthy 2016).

It is also clear that attempts to exclude fire from forests and rangelands in south-eastern Australia can have catastrophic consequences, including the loss of human lives (McLeod 2003; Teague et al. 2009), reductions in biodiversity (Morgan & Lunt 1999; Jurskis 2005), soil erosion and reductions in water quality and quantity (Worthy & Wasson 2004; Nyman et al. 2011). Some ecosystems are not fire-dependent or fire-adapted, and these may benefit from fire suppression and exclusion, but such ecosystems are relatively few in south-eastern Australia. However, policies of fire exclusion will change the dynamics of fire-adapted communities and ecosystems.

There is a strong need to manage fire in the region. Prescribed burning is and remains an important land and fire management tool for meeting land management objectives related to, for example, wildfire mitigation, forest silviculture, certain agricultural practices, water and soil management, greenhouse gas emission reductions, ecologically sustainable processes and biodiversity conservation.

Measures for tackling the increasing threat of wildfire must include reducing the risk of wildfires spreading from adjoining lands. This will drive wildfire-mitigation efforts at the whole-of-landscape scale, rather than on the basis of land tenure. Considerable information is available and frameworks are in use for the adaptive management of the natural environment (Campbell et al. 2010).

As the climate in south-eastern Australia becomes warmer and drier (Hughes & Steffen 2014), it is more urgent than ever that appropriate strategies are in place, with a strong emphasis on prescribed burning, for the year-round management of fire-prone forests on public and private lands. Such strategies could create a mosaic forest estate ranging from recently burnt to long unburnt, thereby providing the greatest chance of maintaining biodiversity while simultaneously reducing risks to lives and property and the costs of emergency and disaster relief.

Acknowledgements

The authors acknowledge the valuable contributions made to this paper by Phil Cheney (CSIRO), who reviewed the draft and contributed personal communications, Paul DeMar (GHD Consulting) for his constructive criticism, Adam Leavesley (ACT Parks) for reviewing and editing an earlier draft, and the members of the Institute of Foresters of Australia's Forest Fire Management Committee for the provision of previously unpublished material. Alastair Sarre and two anonymous reviewers provided valuable comments on earlier versions of the manuscript.

Disclosure Statement

No potential conflict of interest was reported by the authors.

ORCID

M. W. Poynter http://orcid.org/0000-0002-0641-1578

References

ABS. 2004. Year Book Australia, 2004. Canberra (Australia): Australian Bureau of Statistics.

Ackland A, Salkin O, Blackett A, Friend G, Fogarty L. 2010. Future Fire Management Project – defining and evaluating alternative fire management options to achieve improved outcomes for community protection, biodiversity and ecosystem services. Otway Pilot Study – Interim Report. Melbourne (Australia): Department of Sustainability and Environment.

ACT Emergency Services Agency. 2014. Territory-wide risk assessment report. Canberra (Australia): ACT Emergency Services Agency. [accessed 2018 May 7]. Available from: http://cdn.esa.act.gov.au/wp-content/uploads/Territory-Wide-Risk-Assessment-Report.pdf

ACT Government. 2014. ACT strategic bushfire management plan, version 3. Canberra (Australia): ACT Government.

ACT Government. 2017. 2017/18 Bushfire operations plan. Canberra (Australia): Environment, Planning and Sustainable Development Directorate.

Adams MA, Attiwill PM. 2011. Burning issues – sustainability and management of Australia's southern forests. Melbourne (Australia): CSIRO Publishing.

AFAC. 2012. Bushfire glossary. Melbourne (Australia): Australasian Fire and Emergency Service Authorities Limited.

AFAC. 2014. Review of best practice for prescribed burning: national burning project. Melbourne (Australia): Australasian Fire and Emergency Service Authorities Council Limited. [accessed 2018 Oct 11]. Available from: https://knowledge.aidr.org.au/media/4864/review-of-best-practice-for-prescribed-burning.pdf

AFAC. 2015a. AFAC independent operational audit: South Australian fire of January 2015. Melbourne (Australia): Australasian Fire and Emergency Services Authorities Limited.

AFAC. 2015b. Overview of prescribed burning in Australasia. Report for the national burning project – subproject 1. [accessed 2018 Oct 11]. Melbourne (Australia): Australasian Fire and Emergency Service Authories Council Limited. Available from: https://knowledge.aidr.org.au/media/4893/overview-of-prescribed-burning-in-australasia.pdf

AFAC. 2016a. Independent operational review: a review of the management of the Tasmanian fires of January 2016. Melbourne (Australia): Australasian Fire and Emergency Services Authorities Limited.

AFAC. 2016b. National position on prescribed burning. Melbourne (Australia): Australasian Fire and Emergency Service Authorities Council Limited. [accessed 2018 Oct 11]. National Burning Project. Available from: https://knowledge.aidr.org.au/media/4869/national-position-on-prescribed-burning.pdf

AFAC. 2016c. A risk framework for ecological risks associated with prescribed burning. Melbourne (Australia): Australasian Fire and Emergency Service Agencies Council Limited. National Burning Project: Sub-Project 3. [accessed 2018 Oct 11]. Available from: https://knowledge.aidr.org.au/media/4865/a-risk-framework-for-ecological-risks-associated-with-prescribed-burning.pdf

AFAC. 2016d. A risk framework for operational risks associated with prescribed burning. Melbourne (Australia): Australasia Fire and Emergency Service Authorities Council Limited. National Burning Project: Sub-project 3. [accessed 2018 Oct 11]. Available from: https://knowledge.aidr.org.au/media/4891/a-risk-framework-for-operational-risks-associated-with-prescribed-burning.pdf

AFAC. 2017a. Best practice principles for prescribed burning. Melbourne (Australia): Australasian Fire and Emergency Service Authorities Council. National Burning Project No. 8. [accessed 2018 Oct 11]. Available from: https://knowledge.aidr.org.au/media/4899/best-practice-principles-for-prescribed-burning.pdf

AFAC. 2017b. Program logic for prescribed burning: charting the rationale underpinning prescribed burning. Melbourne (Australia): Australasian Fire and Emergency Service Authorities Council. National Burning Project No. 8. [accessed 2018 Oct 11]. Available from: https://knowledge.aidr.org.au/media/4905/program-logic-for-prescribed-burning.pdf

AIDR. 2018. Australian Disaster Resilience Knowledge Hub: Victoria (February 1851, Black Thursday). [accessed 2019 Apr 26]. Available from: https://knowledge.aidr.org.au/resources/bushfire-black-thursday-1851/

Anon. 1884. Report of the secretary for the Department of Agriculture 1883. Melbourne (Australia): Parliament of Victoria.

Auditor-General Victoria. 2003. Fire prevention and preparedness. Report No. 15. Melbourne (Australia): Office of the Victorian Auditor-General.
Australian Human Rights Commission. 2007. Western Arnhem Land fire management. Canberra (Australia): Australian Human Rights Commission. Native Title Report 2007, Chapter 12.
Bale WRC. 1993. Review of vegetation-based fire in Tasmania. Report of the Tasmanian Fire Review Committee. Hobart (Tasmania).
Barber EHE. 1977. Report of the board of inquiry into the occurrence of bush and grass fires in Victoria. Melbourne (Australia): Legislative Assembly, Government of Victoria. Parliamentary Paper No. 91.
Bartlett T, Leonard M, Morgan G. 2007. The mega-fire phenomenon: some Australian perspectives. In: The 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference: Programme, Abstracts and Papers; 2007 Jun 3–7; Coffs Harbour. Canberra (Australia): Institute of Foresters of Australia.
Beard JS. 1977. Tertiary evolution of the Australian flora in the light of latitudinal movements of the continent. Journal of Biogeography. 4:111–118. doi:10.2307/3038133.
Bentley PD, Penman TD. 2017. Is there an inherent conflict in managing fire for people and conservation? International Journal of Wildland Fire. 26:455–468. doi:10.1071/wf16150.
Billing P. 1981. Effectiveness of fuel-reduction burning: five case histories. Melbourne (Australia): Forests Commission, Victoria. Fire Management Research Report No. 10.
Billing PR, Bywater JV. 1982. Using fire to reduce aerial fuels in first thinned radiata pine. Melbourne (Australia): Forests Commission, Victoria. Fire Management Research Report No. 16.
Bindon SH. 1871. Royal commission on foreign industries and forests, progress report. Melbourne (Australia): Parliament of Victoria.
Binns DL, Bridges RG. 2003. Establishment and progress of the Eden burning study. Sydney (Australia): Research and Development Division, State Forests of New South Wales. Technical Paper No. 67. [accessed 2018 Nov 22]. Available from: https://www.dpi.nsw.gov.au/content/research/areas/resources-research/forest-resources/pubs/Ecological-Impacts-and-Sustainability-of-Timber-Harvesting-and-Burning-in-Coastal-Forests-on-the-Eden-Area-Establishment-and-Progress-of-the-Eden-Burning-Study.pdf
Bird MI, Turney CSM, Fifield LK, Jones R, Ayliffe LK, Palmer A, Cresswell R, Robertson S. 2002. Radiocarbon analysis of the early archaeological site of Nauwalabila I, Arnhem Land, Australia: implications for sample suitability and stratigraphic integrity. Quaternary Science Reviews. 21:1061–1075. doi:10.1016/s0277-3791(01)00058-0.
Blake HMAG. 2011. Bushfire management. Hobart (Australia): Auditor General's Department, Tasmanian Government. Special Report No. 99.
Blanchi R, Leonard JE, Haynes K, Opie K, James M, Kilinc M, De Oliveira FD, van Den Honert R. 2012. Life and house loss database description and analysis – final report. CSIRO, Bushfire CRC report to Attorney-General's Department. CSIRO EP-129645.
Boer MM, Sadler RJ, Wittkuhn RS, McCaw L, Grierson PF. 2009. Long-term impacts of prescribed burning on regional extent and incidence of wildfires: evidence from 50 years of active fire management in SW Australian forests. Forest Ecology and Management. 259:132–142. doi:10.1016/j.foreco.2009.10.005.
Bowler JM. 2002. Lake Mungo: window to Australia's past. [CR-ROM]. Melbourne (Australia): School of Earth Sciences, University of Melbourne.
Bowler JM, Johnston H, Olley JM, Prescott JR, Roberts RG, Shawcross W, Spooner NA. 2003. New ages for human occupation and climatic change at Lake Mungo, Australia. Nature. 421:837–840. doi:10.1038/nature01383.
Bowman DMJS. 1998. Tansley review No. 101 – The impact of aboriginal landscape burning on the Australian biota. New Phytologist. 140:385–410. doi:10.1046/j.1469-8137.1998.00289.x.
Bradstock RA, Kenny BJ. 2003. An application of plant functional types to fire management in a conservation reserve in South Eastern Australia. Journal of Vegetation Science. 14:345–354. doi:10.1111/j.1654-1103.2003.tb02160.x.
Bradstock RA, Price OF. 2010. The effect of fuel age on the spread of fire in sclerophyll forest in the Sydney region of Australia. International Journal of Wildland Fire. 19:35–45. doi:10.1071/wf08167
Bradstock RA, Williams JE, Gill AM. 2002. Flammable Australia: the fire regimes and biodiveristy of a continent. Cambridge (UK): Cambridge University Press.
Breuer LPM. 2005. Eyre Peninsula bushfire and native vegetation. Adelaide (Australia): Parliament of South Australia, Environment, Resources and Development Committee. Parliamentary Paper No. 242.
Brown MC. 2004. Review of fire services funding. Sydney (Australia): Legislative Assembly Public Accounts Committee, Parliament of NSW. Report No. 148.
Brown R. 2015. Wambelong fire. General Purpose Standing Committee No. 5. Sydney (Australia): Legislative Council, Parliament of NSW. Report No. 41.
Buckley AJ, Corkish NJ. 1991. Fire hazard and prescribed burning of thinning slash in eucalypt regrowth forest. Melbourne (Australia): Department of Conservation and Environment. Fire Management Research Report No. 29.
Buffone J. 2011. Review of the Tostaree fire. Melbourne (Australia): Emergency Services Commissioner. Report No. 25, July 2011.
Burrows ND. 2018. Conflicting evidence: prescribed burning – when 'evidence' is not the reality. keynote address. In: Australiasian Fire and Emergency Services Authorities Council (AFAC) Conference; 2018 Sep 5; Perth. Melbourne (Australia): Bushfire and Natural Hazards CRC. [accessed 2020 Jan 13]. Available from: https://www.bnhcrc.com.au/resources/presentation-slideshow/4953
Burrows ND, Friend G. 1998. Biological indicators of appropriate fire regimes in southwest Australian ecosystems. In: Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings; 1996 May 7-10, Boise (ID). Tallahasse (FL): Tall Timbers Research Station. Vol. 20. p. 413–421.
Cameron JWAG. 2003. Performance audit report on fire prevention and preparedness. Melbourne (Australia): Auditor General Victoria. Audit Report No. 15.
Campbell C, Blair S, Wilson A. 2010. Adaptive management of fire: the role of a learning network. Melbourne (Australia): Department of Sustainability and Environment. Fire Research Report No. 76.
Carron LT. 1985. A history of forestry in Australia. Rushcutters Bay (Australia): Australian National University Press, Pergamon Press.
Carter M, Howard T, Haylock K, Philpotts V, Richards J. 2015. Independent investigation of the Lancefield-Cobaw fire. Brunswick (Australia): Department of Environment, Land, Water and Planning, Victoria. Report of the Independent Lancefield-Cobaw Fire Investigation Team.
Cary GJ, Lindenmayer DB, Dovers S. 2003. Australia burning: fire ecology, policy and management issues. Collingwood (Australia): CSIRO Publishing.
Cawson J, Muir A. 2008a. Fire and biodiversity monitoring protocols for flora: rationale report. Melbourne (Australia): Department of Sustainability and Environment. Fire Management Research Report No. 75.
Cawson J, Muir A. 2008b. Fire and biodiversity monitoring protocols for flora: users guide. Melbourne (Australia): Department of Sustainability and Environment. Fire Management Research Report No. 74.
Chambers DM, Sinclair GG, McArthur AG, Burbury DL. 1967. Fire prevention and suppression: bushfire disaster of February 1967. Hobart (Australia): Parliament of Tasmania. Parliamentary Report No. 8.
Chatto K, Tolhurst KG. 1997. The development and testing of the wiltronics T-H fine fuel moisture meter. Melbourne (Australia): Department of Natural Resources and Environment. Fire Management Research Report No. 46.
Cheney NP. 1976. Bushfire disasters in Australia, 1945–1975. Australian Forestry. 39:245–268. doi:10.1080/00049158.1976.10675654.
Cheney NP. 2008. Can forestry manage bushfires in the future? Australian Forestry. 71:1–2. doi:10.1080/00049158.2020.12089339.
Cheney NP, Gould JS, Knight I. 1992. A prescribed burning guide for young eucalypt regrowth forests of Silvertop Ash. Sydney (Australia): Forestry Commission of NSW.
Chong DM, Duff TJ, Tolhurst KG. 2012. Evaluation of weather data at different spatial and temporal scales on fire behaviour prediction using PHOENIX RapidFire 4.0 – kilmore case study. Melbourne (Australia). University of Melbourne/Bushfire CRC. Technical Report No. 19.
Clarke H, Lucas C, Smith P. 2013. Changes in Australian fire weather between 1973 and 2010. International Journal of Climatology. 33:931–944. doi:10.1002/joc.3480.
Clarke MF. 2008. Catering for the needs of fauna in fire management: science or just wishful thinking? Wildlife Research. 35:385–394. doi:10.1071/wr07137.

Comrie N. 2013. Bushfires Royal Commission Implementation Monitor, 2013 annual report. Melbourne (Australia): Inspector General for Emergency Management, Department of Justice and Regulation. [accessed 2018 Oct 16]. Available from: https://www.igem.vic.gov.au/sites/default/files/embridge_cache/emshare/original/public/2017/07/6e/7ad4d3119/Publication%20-%20brcim_annual_report_July%202013.PDF

Cooper MAG. 2013. Performance Audit Report: bushfire preparedness. Canberra (Australia): ACT Legislative Assembly, Auditor General. Report No. 5/2013.

Cope ME. 2017. Smoke emission and transport modelling – final report. Melbourne (Australia): Department of Environment, Land, Water and Planning, and CSIRO Oceans & Atmosphere. Available from: https://hpc.csiro.au/users/69785/projects/aqfx/Draft%20Final%20Report_17Feb2017.pdf

Cruz MG, Gould JS, Alexander ME, Sullivan AL, McCaw WL, Matthews S. 2015a. Empirical-based models for predicting head-fire rate of spread in Australian fuel types. Australian Forestry. 78:118–158. doi:10.1080/00049158.2015.1055063.

Cruz MG, Gould JS, Alexander ME, Sullivan AL, McCaw WL, Matthews S. 2015b. A guide to rate of fire spread models for Australian vegetation. Melbourne (Australia): CSIRO Publishing.

Cunningham TM. 1960. The natural regeneration of *Eucalyptus regnans*. Melbourne (Australia): University of Melbourne.

Davey SM. 2018. Regional forest agreements: origins, development, contributions. Australian Forestry. 81:64–88. doi:10.1080/00049158.2018.1458701.

David B, Delannoy J-J, Mialanes J, Clarkson C, Petchey F, Geneste J-M, Manne T, Bird MI, Barker B, Richards T, et al. 2019. 45,610–52,160 years of site and landscape occupation at Nawarla Gabarnmang, Arnhem Land plateau (northern Australia). Quaternary Science Reviews. 215:64–85. doi:10.1016/j.quascirev.2019.04.027

Davies C. 1997. Analysis of fire causes on or threathening public land in Victoria, 1977–1996. Melbourne (Australia): Fire Management Branch, Department of Natural Resources and Environment. Fire Research Report No. 49.

DELWP Victoria. 2015a. Monitoring, evaluation and reporting framework for bushfire management on public land. Melbourne (Australia): Department of Environment, Land, Water and Planning.

DELWP Victoria. 2015b. Safer together – a new approach to reducing the risk of bushfire in Victoria. Melbourne (Australia): Department of Environment, Land, Water and Planning. [accessed 2018 Oct 11]. Available from: https://www.safertogether.vic.gov.au/

DENR South Australia. 2009. Prescribed burning in South Australia: a review of operational practices. Adelaide (Australia): Department of Environment and Natural Resources, South Australia.

Department of Environment and Primary Industries. 2013. Victorian bushfire risk profiles – a foundational framework for strategic bushfire risk assessment. Melbourne (Australia): epartment of Environment and Primary Industries.

Department of Forestry Queensland. 1984. Forest management in Queensland Part II. Detailed departmental forest management functions and aims (objectives, policies and strategies). Brisbane (Queensland): Department of Forestry, Queensland. Unpublished document.

Department of Natural Resources and Environment. 2002. Analysis of disturbance by fire on public land in Victoria, 2002 workshop proceedings. Melbourne (Australia): Department of Natural Resources and Environment. Workshop Proceedings No. 1.3.

DEWNR South Australia. 2012. Code of practice for fire management on public land in South Australia 2012–2016. Adelaide (Australia): Department of Environment, Water and Natural Resources, South Australia, Country Fire Service (CFS), SA Water, Forestry SA.

Dexter B, Macleod D. 2017 What is the true cost of forest fire management on public lands in Victoria. Melbourne (Australia): Forest Fire Victoria. [accessed 2019 Mar 29]. Available from: http://forestfirevictoria.org.au/docs/What%20is%20true%20cost%20FFM%20PL%20Vic%20Nov%202017%20.pdf

Dexter BD, Williams DF. 1976. Direct field estimation of fine fuel moisture content. Australian Forestry. 39(2):140–144. doi:10.1080/00049158.1976.10675649.

DFES Western Australia. 2012. Major incident review for the Black Cat Creek Fire, 12 October 2012. Perth (Australia): Department of Fire and Emergency Services, Government of Western Australia.

Dharssi I, Kumar V. 2017. JASMIN: a prototype high-resolution soil moisture analysis system for Australia. Melbourne (Australia): Bureau of Meteorology. Research Report No. 026.

Dixon KW. 2019. Controlled burns destroy ecosystems and may not reduce fire risk. The Science Show. [accessed 2020 Jan 13]. Available from: https://www.abc.net.au/radionational/programs/scienceshow/controlled-burns-destroy-ecosystems-and-may-not-reduce-fire-risk/11774496

DNRE Victoria. 1995. Code of Practice for fire management on public land. Melbourne (Australia): Department of Natural Resources and Environment.

DOJ Victoria. 2006. Emergency management discussion paper. Melbourne (Australia): Department of Justice.

Doogan M. 2006a. The Canberra firestorm: inquests and inquiry into four deaths and four fires between 8 and 18 January 2003. Volume I. Canberra (Australia). ACT Coroners Court Report No. 1.

Doogan M. 2006b. The Canberra firestorm: inquests and inquiry into four deaths and four fires between 8 and 18 January 2003. Volume II. Canberra (Australia). ACT Coroners Court Report No. 2.

Doolan BV. 2015. Institutional continuity and change in Victoria's forests and parks 1900–2010 [master's thesis]. Clayton (Australia): Faculty of Arts, Monash Univeristy.

Dowdy AJ. 2018. Climatological variability of fire weather in Australia. Journal of Applied Meteorology and Climatology. 57(2):221–234. doi:10.1175/JAMC-D-17-0167.1.

DSE Victoria. 2006. Code of Practice for fire management on public land. Melbourne (Australia): Department of Sustainability and Environment.

DSE Victoria. 2012. Code of Practice for bushfire management on public land. Melbourne (Australia): Department of Sustainability and Environment.

Ealey EHM. 1974. In: Ealey EHM, editor. Fire in the forest environment, Third Fire Ecology Symposium, Forests Commission, Victoria in conjunction with Monash University Environmental Studies, Monash University, Clayton, 1974 Mar 23. Clayton (Australia): Monash University.

Edwards A. 2014. Evaluation of the hotspots fire project. Australian Centre for Cultural Environmental Research, University of Wollongong, NSW. [accessed 2018 Oct 11]. Available from: http://hotspotsfireproject.org.au/resources-materials.

Eggleston A. 2007. Conserving Australia: Australia's national parks, conservation reserves and marine protected areas. Standing committee on environment, communications, information technology and the arts. Canberra (Australia): Commonwealth of Australia.

Elliott H, Felton K, Jarman J, Stone M. 2008. A history of innovation: eighty-five years of research and development at Forestry Tasmania. Hobart (Tasmania): Forestry Tasmania.

Ellis S, Kanowski P, Whelan R. 2004. National inquiry on bushfire mitigation and management. Canberra (Australia): Council of Australian Governments, Commonwealth of Australia.

Emergency Services Commissioner. 2005. Examination of prescribed burning practices. Melbourne (Australia): Emergency Services Commissioner, Department of Justice.

ENRC Victoria. 2008. Report of the Environment and Natural Resources Committee (ENRC) on the inquiry into the impact of public land management practices on bushfires in Victoria. Parliament of Victoria. Parliamentary Paper No. 116. Melbourne (Australia): Victorian Public Printer.

EPC Victoria. 2017. Inquiry into fire season preparedness – final report. Melbourne (Australia): Environment and Planning Committee (EPC), Legislative Council, Parliament of Victoria. Parliamentary Paper No. 295.

Esplin B, Gill AM, Enright NJ. 2003. Report of the inquiry into the 2002–2003 Victorian bushfires. Abbotsford (Australia): Department of Premier and Cabinet, State Government of Victoria.

Evans LF, King NK, MacArthur DA, Packham DR, Stephens ET. 1976. Further studies of the nature of bushfire smoke. Melbourne (Australia): Division of Applied Organic Chemistry. CSIRO Technical Paper No. 2.

Fahy M. 2005. Black Tuesday: 1967 Tasmania Bushfires. [DVD]. Melbourne (Australia): Bushfire CRC. 1 DVD, 29 mins.

Falconer S. 2017. The Lord Mayor's Bushfire Appeal Chruchill Fellowship to create close partnerships with the jobs for traditional owners in fire and land management – USA, Canada. Canberra (Australia): The Winston Churchill Memorial Trust. [accessed 2018 Oct 11]. Available

from: https://www.churchilltrust.com.au/fellows/detail/4233/Scott%20+Falconer.
Ferguson E. 2010. A review of the ability of the department of environment and conservation Western Australia to manage major fires. Perth (Australia): Minister for Environment, Parliament of Western Australia.
Ferguson E. 2016. Reframing rural fire management. Report of the Special Inquiry into the January 2016 Waroona fire. Perth (Australia): Public Sector Commission, Government of Western Australia.
Fire Ecology Working Group. 1999. Management of fire for the conservation of biodiversity. editors, Friend G, Leonard M, Maclean A, Sieler I. Melbourne (Australia): Department of Natural Resources and Environment, Victoria & Parks Victoria.
Fire Ecology Working Group. 2000. Management of fire for the conservation of biodiversity, Workshop 2. Melbourne (Australia): Department of Natural Resources & Environment, Parks Victoria.
Fire Ecology Working Group. 2004. Guidelines and procedures for ecological burning on public land in Victoria. Melbourne (Australia): Department of Natural Resources and Environment.
Florec V, Chalak M, Hailu A. 2017. Integrating intangible values in economic analyses of flood mitigation: a case study of the Brown Hill and Keswick creeks catchment in Adelaide. Australian Journal of Emergency Management. 32:30–36.
Florec V, Pannell DJ. 2017. Where do we put our dollars? Economic analysis of different bushfire management options in Western Australia. In: AFAC17, Australasian Fire and Emergency Service Authorities Council and Bushfire and Natural Hazards Cooperative Research Centre Annual Conference, Sydney. Sydney (Australia): Bushfire and Natural Hazards CRC.
Foley JC. 1947. A study of meteorological conditions associated with bush and grass fires and protection strategy in Australia. Australian Department for the Interior. Meteorological Branch Bulletin No. 38, Melbourne, Australia.
Forest Fire Management Group. 2014. National bushfire management policy statement for forests and rangelands. [accessed 2018 Oct 11]. Canberra (Australia): Commonwealth Government Printer. Available from: http://www.sfmc.tas.gov.au/sites/sfmc.tas.gov.au/files/NationalBushfireManagementPolicy_2014.pdf.
Gammage W. 2011. The biggest estate on earth: how Aborigines made Australia. Sydney (Australia): Allen & Unwin.
Gibbons P, Van Bommel L, Gill AM, Cary GJ, Driscoll DA, Bradstock RA, Knight E, Moritz MA, Stephens SL, Lindenmayer DB. 2012. Land management practices associated with house loss in wildfires. PloS One. 7 (1):e29212. doi:10.1371/journal.pone.0029212.
Gill AM. 1975. Fire and the Australian flora: a review. Australian Forestry. 38(1):4–25. doi:10.1080/00049158.1975.10675618.
Gill AM. 2008. Underpinnings of fire management for biodiversity conservation in reserves. Melbourne (Australia). Department of Sustainability and Environment. Fire Management Research Report No. 73. [accessed 2018 Nov 22]. Available from: https://www.ffm.vic.gov.au/__data/assets/pdf_file/0012/21090/Underpinnings-of-fire-management.pdf
Gill AM, Groves RH, Noble IR. editors. 1981. Fire and the Australian biota. Canberra (Australia): Australian Academy of Science.
Gill AM, Woinarski JCZ, York A. 1999. Australia's biodiversity: responses to fire. Canberra (Australia): Department of Environment and Heritage. Biodiversity Technical Paper No. 1.
Gott B. 2005. Aboriginal fire management in south-eastern Australia: aims and frequency. Journal of Biogeography. 32(7f):1203. doi:10.1111/j.1365-2699.2004.01233.x.
Gould JS, McCaw WL, Cheney NP, Ellis P, Matthews S. 2007. Project Vesta: fire in dry Eucalypt forest: fuel structure, fuel dynamics and fire behaviour. Canberra (Australia): Ensis-CSIRO and Perth (Australia): WA Department of Environment and Conservation.
Grant S, Wouters M. 1993. The effect of fuel reduction burning on the suppression of four wildfires in Western Victoria. Melbourne (Australia): Department of Conservation and Natural Resources. Fire Research Report No. 41.
Grose RJ. 1963. The silvicultural design of *Eucalyptus delegatensis*: Part 1: germination and seed dormancy. Melbourne (Australia): University of Melbourne.
Hansen C, Griffiths T. 2012. Living with fire: people, nature and history in Steels Creek. Melbourne (Australia): CSIRO Publishing.
Heffernan BC. 2010. The incidence and severity of bushfires across Australia. Canberra (Australia): Parliament of Australia, Senate Select Committee on Agriculture and Related Industries.
Hiatt JWC. 1996. Inquiry into the cause and origin of the bushfire occurring in New South Wales between 31st December, 1993 and 14th January, 1994 and Inquests into the manner and cause of death of Norman John Anthes, Robert Eglinton Page, William John Roach and Pauline Mary O'Neil. Sydney (Australia): Coroner of NSW.
Hines F, Tolhurst KG, Wilson AAG, McCarthy GJ. 2010. Overall fuel hazard assessment guide, 4th ed. Melbourne (Australia): Department of Sustainability and Environment. Research Report series No. 82.
Hodgson A. 1967. Fire management in eucalypt forest. Proceedings of the 6th Tall Timbers Fire Ecology Conference 1967 Mar 6-7; Tallahassee (FL): Tall Timbers Research Station. [accessed 2019 Aug 23]. Available from: http://talltimbers.org/wp-content/uploads/2014/03/Hodgson1967_op.pdf
Hodgson A, Cheney NP. 1969. Aerial ignition for backburning. Australian Forestry. 33(4):268–274. [accessed 2019 Aug 23]. 10.1080/00049158.1969.10675500.
Howitt AW. 1890. The Eucalypts of Victoria. Transactions of the Royal Society of Victoria. 1890:82–120.
Hughes L, Alexander D. 2017. Earlier, more frequent, more dangerous: bushfires in New South Wales. Sydney (Australia): Climate Council of Australia Ltd. [accessed 2019 Aug 23]. Available from: https://www.climatecouncil.org.au/uploads/02401b8a369a37c7763b3c2b4171a517.pdf
Hughes L, Steffen W. 2014. Be prepared: climate change and the ACT bushfire threat. Sydney (Australia): Climate Council of Australia.
Hyde M. 2013. 2013 Tasmanian bushfires inquiry. Hobart (Australia): Tasmanian Government.
IFA. 2018. The role of fire and its management in Australian forests and woodlands. Canberra (Australia). Institute of Foresters, Australia. IFA Forestry Policy Statement 3.1 No. 3.
IGEM. 2015. Review of performance targets for bushfire fuel management on public land. Melbourne (Australia): Inspector General for Emergency Management, Department of Justice and Regulation. [accessed 2018 Oct 11]. Available from: https://www.igem.vic.gov.au/sites/default/files/embridge_cache/emshare/original/public/2017/07/d7/24d0ede21/Reviewofperformancetargetsforbushfirefuelmanagementonpublicland.pdf
IGEM. 2016. Review of the initial response to the 2015 Wye River-Jamieson Track fire. Melbourne (Australia): Inspector General for Emergency Management, Department of Justice.
IGEM. 2017. Annual Report: implementation of recommendations on bushfire fuel management. Melbourne (Australia): Inspector General for Emergency Management, Department of Justice and Regulation.
Johnston JB, McKittrick DJ, Flinn DW, Brown HG. 1982. Fire protection and fuel reduction burning in Victoria. A report to the Minister of Forests by a Task Force of Officers of the Forests Commission Victoria. Melbourne (Australia): Forests Commission Victoria.
Johnstone GC. 2002. Report of the investigation and inquests into a wildfire and the deaths of five firefighters at Linton on 2 December 1998. Melbourne (Australia): State Coroner's Office.
Jones RC. 2000. Report on inquiry into the NSW Rural Fire Service. Sydney (Australia): NSW Legislative Council, General Purpose Standing Committee No. 5. Parliamentary Paper No. 358.
Jurskis V. 2005. Decline of eucalypt forests as a consequence of unnatural fire regimes. Australian Forestry. 68:257–262. doi:10.1080/00049158.2005.10674974.
Jurskis V. 2015. Firestick ecology fairdinkum science in plain English. Ballarat (Australia): Connor Court Publishing.
Jurskis V, Bridges B, de Mar P. 2003. Fire management in Australia: the lessons of 200 years. Joint Australia and New Zealand Institute of Forestry Conference; 2003 Apr 27–May 1; Queenstown, New Zealand. Wellington (NZ): Ministry of Agriculture and Forestry.
Kanowski PJ, Whelan RJ, Ellis S. 2005. Inquiries following the 2002–2003 Australian bushfires: common themes and future directions for Australian bushfire mitigation and management. Australian Forestry. 68:76–86. doi:10.1080/00049158.2005.10674950.
Keelty MJ. 2011. A shared responsibility: the report of the Perth Hills Bushfire, February 2011 Review. Perth (Australia): Public Sector Commissioner, Government of Western Australia.
Keelty MJ. 2012. Appreciating the risks. Report of the Special Inquiry into the November 2011 Margaret River bushfire. Perth (Australia): Public Sector Commissioner, Government of Western Australia.
Keelty MJ. 2018. Bega Valley fires – independent review. Sydney (Australia): Department of Justice, Government of NSW.

Kershaw AP, Clark JS, Gill AM, D'Costa DM. 2002. A history of fire in Australia. Bradstock RA, Williams JE, Gill AM. Flammable Australia – the fire regimes and biodiversity of a continent Cambridge (UK): Cambridge University Press.

Key SPM. 2011. Bushfire Inquiry Final Report. Adelaide (Australia): South Australian Parliament, Natural Resources Committee.

Lahmeyer J. 2003. Australia: historical demographical data of the whole country. [accessed 2019 Nov 6]. Available from: http://www.populstat.info/Oceania/australc.htm

Leavesley A, Van Dijk A, Yebra M. 2018. A LIDAR-derived fuel map for the ACT. In: Proceedings of the Bushfire and Natural Hazards CRC and AFAC Conference; 2018 Sep; Perth. Melbourne (Australia): Bushfire and Natural Hazards CRC.

Leonard S, Bruce M, Christie F, Di Stefano J, Haslem A, Holland G, Kelly L, Loyn R, MacHunter J, Rumpff L, et al. 2016. Foothills fire and biota. Melbourne (Australia): Department of Environment, Land, Water and Planning. Fire and Adaptive Management Report No. 96. [accessed 2019 Nov 6]. Available from: https://www.ffm.vic.gov.au/__data/assets/pdf_file/0007/21121/Report-96-Foothills-fire-and-biota-report.pdf.

Levine B, Hemer S, Denman T, Farquhar S. 2017. Prescribed Burn Decision Support Tool. An essential process to support your decision-making. In: Proceedings of the 2017 Bushfire and Natural Hazards CRC & AFAC Conference; 2017 Sep 4–6; Sydney. Melbourne (Australia): Bushfire and Natural Hazards CRC.

Lin XG, Sullivan AL, Stephenson AG, Dunstall S. 2013. Initial analysis of fire weather characteristics between south-east Australia and south-west of Western Australia. In: 20th International Congress on Modelling and Simulation, MODSIM2013; 2013 Dec 1–6; Adelaide. Canberra (Australia): Modelling and Simulation Society of Australia and New Zealand. p. 2054–2060.

Lloyd S. 2011. South East Queensland Fire and Biodiversity Consortium – terms of reference. Brisbane (Australia): SEQ Fire & Biodiversity Consortium. [accessed 2019 Nov 6]. Available from: http://www.fireandbiodiversity.org.au/.

Long M, Wain AG, Cope ME, Ebert EE, Carroll M, Parkyn K, Tostovrsnik N 2017. A new quantitative smoke forecasting system for Victoria. In: Proceedings from the Bushfire and Natural Hazards CRC & AFAC Conference; 2017 Sep 4–6; Sydney. Melbourne (Australia): Bushfire and Natural Hazards CRC.

Lucas C, Hennessy K, Mills GA, Bathols J. 2007. Bushfire weather in south-east Australia: recent trends and projected climate change impacts. Melbourne (Australia): Bushfire CRC. Consultancy Report prepared for The Climate Institute of Australia No. 84.

Luke RH, McArthur AG. 1978. Bushfires in Australia. Canberra (Australia): CSIRO Division of Forest Research, Australian Government Publishing Service.

Maclean K, Robinson C, Costello O. 2018. A national framework to report on the benefits of Indigenous cultural fire management. National Landcare Program. Canberra (Australia): CSIRO, Land and Water.

Malone T. 2013. The Malone Review into rural fire services in Queensland. Brisbane (Australia): Queensland Government.

Marsden-Smedley J. 2009. Planned burning in Tasmania: operational guidelines and review of current knowledge. Hobart (Australia): Tasmania Department of Primary Industries, Parks, Water and the Environment – Parks and Wildlife Service; [accessed 2018 May 14]. Available from: http://www.fire.tas.gov.au/userfiles/stuartp/file/Publications/PlannedBurningInTasmania.pdf.

Marsden-Smedley JB. 2011. Planned burning in Tasmania. III. Revised guidelines for conducting planned burning. Tasforests. 19:122–134.

McArthur AG 1962. Control burning in eucalypt forests. Canberra (Australia): Forestry and Timber Bureau, Commonwealth of Australia. Leaflet No. 80.

McArthur AG. 1966. Prescribed burning in Australian fire control. Australian Forestry. 30:4–11. doi:10.1080/00049158.1966.10675391.

McCarthy GJ, Tolhurst KG. 1998. Effectiveness of firefighting first attack operations by the department of natural resources and environment from 1991/92–1994/95. Melbourne (Australia): Department of Natural Resources and Environment. Fire Management Research Report No. 45.

McCarthy GJ, Tolhurst KG. 2001. Effectiveness of broadscale fuel reduction burning in assisting with wildfire control in parks and forests in Victoria. Melbourne (Australia): Department of Natural Resources and Environment. Fire Management Research Report No. 51.

McCarthy GJ, Tolhurst KG, Chatto K. 1999. Overall fuel hazard guide. Melbourne (Australia): Department of Sustainability and Environment. Fire Management Research Report No. 47.

McCaw WL. 2013. Managing forest fuels using prescribed fire – A perspective from southern Australia. Forest Ecology and Management. 294:217–224. doi:10.1016/j.foreco.2012.09.012.

McLeod RN. 2003. Inquiry into the operational response to the January 2003 bushfires in the ACT. Canberra (Australia): Department of Urban Services, ACT Government.

Meyer CP, Reisen F, Keywood M, Crumeyrolle S. 2011. Impacts of smoke from regeneration burning on air quality in the Huon Valley, Tasmania. Aspendale (Australia): The Centre for Australian Weather and Climate Research, CSIRO and Bureau of Meteorology.

Miller SI, Carter W, Stephens RG. 1984. Report of the bushfire review committee on bushfire disaster preparedness and response in Victoria, Australia, following the Ash Wednesday Fires of 16 February, 1983. Melbourne (Australia): Parliament of Victoria.

Milton PC. 1984. Bushfires and the Australian Environment. Canberra (Australia): House of Representatives Standing Committee on Environment and Conservation, Parliament of Australia.

Monterola VC. 2007. Ministerial review of bushfire management in South Australia. Adelaide (Australia): Minister for Emergency Services, Government of South Australia.

Montoya D. 2014. Bushfires in NSW: timelines and key sources. Issues backgrounder No. 6/June 2014. Sydney (Australia): NSW Parliamentary Research Service. [accessed 2019 Nov 22]. Available from: https://www.parliament.nsw.gov.au/researchpapers/Documents/bushfires-in-nsw-timelines-and-key-sources/Bushfires%20in%20NSW%20-%20timelines%20and%20key%20sources.pdf

Mooney SD, Harrison SP, Bartlein PJ, Daniau AL, Stevenson J, Brownlie KC, Buckman S, Cupper M, Luly J, Black M, et al. 2011. Late quaternary fire regimes of Australasia. Quaternary Science Reviews. 30:28–46. doi:10.1016/j.quascirev.2010.10.010.

Morgan G, Bartlett T, Leonard M. 2007. Fire management and the bush – from an ad hoc seasonal pre-occupation to 'policy centre-stage'. In: Bushfire CRC/AFAC 2007 Conference; 2007 Sep 19–21; Hobart. Melbourne (Australia): Bushfire and Natural Hazards CRC.

Morgan JG, Lunt ID. 1999. Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland. Biological Conservation. 88:379–386. doi:10.1016/s0006-3207(98)00112-8.

Moulds FR. 1991. The dynamic forest – a history of forestry and forest industries in Victoria. Richmond (Australia): Lynedoch Publications.

Mount AB. 1964. The interdependence of the eucalypts on forest fires in southern Australia. Australian Forestry. 28:166–172. doi:10.1080/00049158.1964.10675366.

MPIGA, NFISC. 2013. Australia's state of the forests report 2013. Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee. Canberra (Australia): Australian Bureau of Rural Sciences. [accessed 2019 Nov 22]. Available from: http://www.agriculture.gov.au/abares/forestsaustralia/sofr/sofr-2013

MPIGA, NFISC. 2018. Australia's state of the forests report 2018. Montreal Process IMplementation Group for Australia and National Forest Inventory Steering Committee. Canberra (Australia): [accessed 2019 Nov 22]. Available from: https://www.agriculture.gov.au/abares/forestsaustralia/sofr/sofr-2018

Nairn G. 2003. A nation charred: report on the inquiry into bushfires. Canberra (Australia): House of Representatives Select Committee into the recent Australian bushfires, Parliament of Australia.

NFI. 1998. Australia's state of the forests report (1998). Canberra (Australia): National Forest Inventory, Bureau of Rural Sciences. [accessed 2019 Nov 22]. Available from: https://www.agriculture.gov.au/sites/default/files/documents/Australia%27s_State_of_the_Forests_Report_1998_v1.0.0.pdf

Nous. 2016. Major incident review of the Esperence District fires. Perth (Australia): Department of Fire and Emergency Services, Government of Western Australia.

NSW Audit Office. 1998. Performance audit report: rural fire service – the coordination of bushfire fighting activities. Sydney (Australia): The Audit Office of New South Wales.

NSW Parliament. 1994. Report of the select committee on bushfires. Sydney (Australia): Joint Select Committee on Bushfires, Parliament NSW, Legislative Assembly.

NSW RFS. 2018. Planning for bush fire protection: a guide for councils, planners, fire authorities and developers. Granville (Australia): NSW Rural Fire Service.
Nyman P, Sheridan GJ, Smith HG, Lane PNJ. 2011. Evidence of debris flow occurrence after wildfire in upland catchments of south-east Australia. Geomorphology. 125:383–401. doi:10.1016/j.geomorph.2010.10.016.
O'Keefe B. 2017. Forest capital: Canberra foresters and forestry workers tell their stories. Canberra (Australia): ACT Parks and Conservation Service, Department of Environment, Planning and Sustainable Development Directorate.
OEH NSW. 2016. NPWS cultural fire management policy. Sydney (Australia): Office of Environment and Heritage; [accessed 2019 Jul 25]. Available from. https://www.environment.nsw.gov.au/~/media/7072F25BE42D4194BA1D7D3ED73570B5.ashx
Packham DR, Peet GB. 1967. Developments in controlled burning from aircraft. Melbourne (Australia): CSIRO Chemical Research Laboratories.
Packham DR, Vines RG. 1978. Properties of bushfire smoke:the reduction in visibility resulting from prescribed fires in forests. Journal of the Air Pollution Control Association. 28:790–795. doi:10.1080/00022470.1978.10470661.
Parks and Wildlife Service Tasmania. 2019. Fires update (1 Mar 2019). [accessed 2019 Mar 1]. Available from: https://www.parks.tas.gov.au/?base=50500
Parliament of Victoria. 1869. The Land Act 1869. Melbourne (Australia): George Robertson.
Pascoe B. 2018. Dark Emu: Aboriginal Australia and the birth of agriculture. Broome (Australia): Magabela Books.
Pearson DDR. 2004. Performance examination: responding to major bushfires. Perth (Australia): Auditor General for Western Australia. Report No. 7.
Poynter M. 2007. Saving Australia's forests and its implications. East Ivanhoe (Australia): M. Poynter.
Poynter M. 2018. Going 'green': forests, fire and a flawed conservation culture. Redland Bay (Australia): Connor Court Publishing.
Price JC. 2002. Report on the Inquiry into the 2001/2002 Bushfires. Sydney (Australia): Joint Select Committee on Bushfires, Parliament NSW, Legislative Assembly.
Price O, Borah R, Bradstock R, Penman T. 2015. An empirical wildfire risk analysis: the probability of a fire spreading to the urban interface in Sydney, Australia. International Journal of Wildland Fire. 24:597–606. doi:10.1071/wf14160.
Price OF. 2012. The drivers of effectiveness of prescribed fire treatment. Forest Science. 58:606–617. doi:10.5849/forsci.11-002.
Pyne SJ. 1991. Burning bush – a fire history of Australia. Seattle (WA) and London (UK): University of Washington Press.
Pyne SJ. 2006. The still-burning bush. Carlton North (Australia): Scribe.
Pyne SJ. 2009. Black Saturday: the sequel. Peeling back the bark (blog). Forest History Society. [accessed 2019 Mar 9]. Available from: https://foresthistory.org/blog/
Rawson R, Billing P, Rees B 1985. Effectiveness of fuel reduction burning: ten case histories. Melbourne (Australia): Forests Commission. Fire Research Report No. 10.
Recher HF, Christensen P. 1981. Fire and the evolution of the Australian biota. In: Keast A editor. Ecological biogeography of Australia. The Hague (Netherlands): Dr W Junk Publishers;p. 1761–1797.
Resource Assessment Commission. 1992. Forest and Timber Inquiry: final report, Volume 1. Canberra (Australia): Australian Government Publishing Service.
Richards N. 2006. History of prescribed burning in high-rainfall areas of South Australia from the 1960s through to 2000. Brian Gepp and Simon Lewis oral history interview, State Library of South Australia. J.D. Somerville Oral History Collection, Interview OH806. [CD]. Adelaide (Australia): State Library of South Australia. [accessed 2019 Dec 31]. Available from: https://archival.collections.slsa.sa.gov.au/oh/OH806.pdf.
Rodger GJ. 1961. Royal Commission Report of Evidence – bush fires in Western Australia (Dwellingup, Karridale, Gidgegannup, Chittering). Perth (Australia): Government Printer.
Rolland D. 1996. Aerial agriculture in Australia: a history of the use of aircraft in agriculture and forestry. Sydney (Australia): Aerial Association of Australia, Ltd.
Schapel AE. 2008. Inquest into the deaths of Star Ellen Borlase, Jack Moreley Borlase, Helen Kald Castle, Judith Maud Griffith, Jody Maria Kay, Graham Joseph Russell, Zoe Russel-Kay, Trent Alan Murnane and Neil George Richardson. Adelaide (Australia): Coroner's Court of South Australia.
SEMC. 2014. Parkerville, Stoneville, Mt Helena Bushfire Review. Perth (Australia): State Emergency Management Committee, Government of Western Australia.
SEMC. 2015. Bushfire review, 2015 O'Sullivan and Lower Hotham Bushfires. Perth (Australia): State Emergency Management Committee, Government of Western Australia.
Smith W, Weir JK, Neale T. 2018. Southeast Australia Aboriginal Fire Forum: an independent research report. Melbourne (Australia): Bushfire and Natural Hazards CRC.
Standards Australia. 2009. Construction of buildings in bushfire-prone areas. AS 3959-2009 (Amend 1, 2, 3) Sydney (Australia): SAI Global Limited.
State Fire Management Council. 2014. Bushfire in Tasmania: a new approach to reducing our statewide relative risk. Hobart (Australia): State Fire Management Fire Unit, Tasmania Fire Service. [accessed 2019 Mar 2019]. Available from: http://www.sfmc.tas.gov.au/sites/sfmc.tas.gov.au/files/Bushfire_In_Tasmania%20V1.2%20pdf%20web%20version_0_0.pdf.
Steffen W, Dean A, Rice M, Mullins G. 2019. The angriest summer. Sydney (Australia): Climate Council of Australia Ltd. [accessed 2019 Oct 29]. Available from: https://www.climatecouncil.org.au/resources/angriest-summer/.
Stevenson JC. 2001. Inquest into the deaths of Mark Douglas Cupit, Claire Wynne Dean, George Allan Fitzsimmons and Eric Furland and Inquiry into fire at Mt Kuing-Gai National Park. Sydney (Australia): Coroner's Court.
Stocks BJ, Lawson BD, Alexander ME, Van Wagner CE, McAlpine RS, Lynham TJ, Dube DE. 1989. The Canadian forest fire danger rating system: an overview. Forestry Chronicle. 65:450–457. doi:10.5558/tfc65450-6.
Stretton LEB. 1939. Report of the Royal Commission to inquire into the causes of and measures taken to prevent the bush fires of January, 1939, and to protect life and property. Melbourne (Australia): Victorian Government.
Stretton LEB. 1944. Report of the Royal Commission to inquire into the place of origin and the causes of the fires which commenced at Yallourn on the 14th day of February, 1944. Melbourne (Australia): Victorian Government.
Styger J, Marsden-Smedley J, Kirkpatrick JB. 2018. Changes in lightning fire incidence in the Tasmanian wilderness World Heritage Area, 1980-2016. Fire. 1:38. doi:10.3390/fire1030038.
Tasmania Office of the Solicitor-General. 1967. The bush fire disaster of 7th February, 1967: report and summary of evidence (excluding appendicies) by the Solicitor-General (D.M. Chambers) and the Master and Registrar of the Supreme Court (C.G. Brettingham-Moore). Tasmania. Supreme Court. Parliamentary Paper No. 16 of 1967. Hobart (Australia): Government Printer.
Teague B, Macleod R, Pascoe S. 2009. The 2009 Victorian Bushfires Royal Commission Interim Report. Melbourne (Australia): Parliament of Victoria. 359.
Teague B, McLeod R, Pascoe S. 2010. The 2009 Victorian Bushfires Royal Commission final report (volume II fire preparation, response and recovery). Melbourne (Australia): Parliament of Victoria. Parliamentary Paper No. 332.
Thomson D. 1978. Low intensity prescribed burning in three *Pinus radiata* stand types. Melbourne (Australia): Forest Commision Victoria. Fire Management Research Report No. 2.
Thornton RP. 2015. After action: to burn or not to burn. Wildfire Magazine April 24. [accessed 2019 Nov 22]. Available from: http://wildfiremagazine.org/article/to-burn-or-not-to-burn/
Tindale NB. 1981. Prehistory of the Aborigines: some interesting considerations. In: Keast A, editor. Ecological biogeography of Australia. The Hague: Dr W Junk Publishers; p. 135–162.
Tolhurst KG, Kellas JD, Wilson AAG. 1992. Low intensity fire behaviour and fuel dynamics in dry sclerophyll forest, Wombat State Forest. In: Tolhurst KG, Flinn DW, editors. Ecological impacts of fuel reduction burning in dry sclerophyll forest. Forest Research Report No. 349. Melbourne (Australia): Forest Research, Department of Conservation and Natural Resources.
Tolhurst KG. 2003. Prescribed burning in Victoria: policy and practice. In: Bushfire prevention: are we doing enough? Melbourne (Australia): Institute of Public Affairs.
Tolhurst KG, Chong DM. 2011. Assessing potential house losses using PHOENIX RapidFire. In: Thornton RP, editor. Proceedings of Bushfire CRC & AFAC 2011 Conference; 2011 Sep 1; Sydney.

Melbourne (Australia): Bushfire CRC. p. 74–86. [accessed 2018 Mar 12]. Available from: www.bushfirecrc.com/sites/default/files/managed/resource/74-86_assessing_potential_house_losses.pdf

Tolhurst KG. 2012. Fire severity and ecosystem resilience – lessons from the Wombat Fire Effects Study (1984–2003). Proceedings of the Royal Society of Victoria. 124:30–37. doi:10.1071/rs12030.

Tolhurst KG, Cheney NP. 1999. Synopsis of the knowledge used in prescribed burning in Victoria. Melbourne (Australia): Department of Natural Resources and Environment.

Tolhurst KG, Chong DMO, Ackland A. 2009. Assessing and evaluating bushfire management options in the rural-urban interface using PHOENIX RapidFire. Melbourne (Australia): Bushfire CRC Victoria. [accessed 2018 Mar 12]. Available from: https://www.mssanz.org.au/modsim2013.A3/tolhurst.pdf

Tolhurst KG, Duff TJ, Chong DM. 2013. From "Wildland-Urban Interface" to "Wildfire Interface Zone" using dynamic fire modelling. In: 20th International Congress on Modelling and Simulation, MODSIM2013; Adelaide: Modelling and Simulation Society of Australia and New Zealand. p. 290–296. [accessed 2018 Mar 12]. Available from: https://www.academia.edu/30317129/From_Wildland-Urban_Interface_to_Wildfire_Interface_Zone_using_dynamic_fire_modelling

Tolhurst KG, Flinn DW. 1992. Ecological impacts of fuel reduction burning in dry sclerophyll forest: first progress report. Melbourne (Australia): Department of Conservation and Environment, Victoria. Forest Research Report No. 349.

Tolhurst KG, Friend G. 2001. An objective basis for ecological fire management in Victoria. In: Australian Bushfire Conference; 2001 Jul; Christchurch, New Zealand. Rotorua (NZ): New Zealand Forests Research Institute. p. 220–228.

Tolhurst KG, McCarthy GJ. 2016. Effect of prescribed burning on wildfire severity: a landscape-scale case study from the 2003 fires in Victoria. Australian Forestry. 79:1–14. doi:10.1080/00049158.2015.1127197.

Tolhurst KG, Shields B, Chong DMO. 2008. PHOENIX: development and application of a bushfire risk management tool. Australian Journal of Emergency Management. 23:47–54. Available from: https://search.informit.com.au/documentSummary;dn=609496843850011;res=IELHSS.

Tucker AL. 1898a. Progress report of the Royal Commission on State forests and timber reserves: sleeper hewing in forest reserves and on Crown lands. Melbourne (Australia): Parliament of Victoria.

Tucker AL. 1898b. Progress report of the Royal Commission on State forests and timber reserves: the Victorian Forest; its resources, management and control. Melbourne (Australia): Parliament of Victoria.

Tucker AL. 1899. Fourth progress report of the Royal Commission on State forests and timber reserves 1899: Wombat Forest; its resources, management and control. Melbourne (Australia): Parliament of Victoria.

Tucker AL. 1900a. Eleventh progress report of the Royal Commission on State forests and timber reserves: fire-protection in country districts; being a report on the measures necessary to prevent the careless use of fire, or the spread of bush and grass fires on public and private lands. Melbourne (Australia): Parliament of Victoria.

Tucker AL. 1900b. Twelfth progress report of the Royal Commission on State forests and timber reserves 1900: the Pyrenees and minor Kara Kara reserves, north western district and Tambo reserve East Gippsland; with a short review of the work by the Commission. Melbourne (Australia): Parliament of Victoria.

Tucker AL. 1901. Fourteenth report of the Royal Commission on State forests and timber reserves: forestry in Victoria, Australia: the legislation, control and management requisite. Melbourne (Australia): Parliament of Victoria.

Underwood R. 2015. Fire from the sky. Perth (Australia): York Gum Publishing.

Underwood R. 2019. Bushfire management: wisdom versus folly quadrant online, 10 February 2019, [accessed 2019 Nov 22]. Available from: https://quadrant.org.au/opinion/doomed-planet/2019/02/bushfire-management-wisdom-versus-folly/

Valianatos OD, Tolhurst KG, Siems S, Tapper N. 2003. Modelling transport, dispersion and secondary pollutant formation of emissions from buring vegetation using air quality dispersion models. Melbourne (Australia): Department of Sustainability and Environment. Fire Management Research Report No. 53.

Van Rees M. 2005. Investigation Report: planning and implementation, prescribed burn Tidal Overlook, 21 March 2005. Melbourne (Australia): Department of Sustainability and Environment.

Victorian Lands Alliance, Poynter M. 2010. Fuel reduction burning in southern Australia's forests: are view of its effectiveness as a bushfire management tool. Melbourne (Australia): Forest Fire Victoria Inc. [accessed 2018 Mar 9]. Available from: https://webcache.googleusercontent.com/search?q=cache:15LH5Aib-TMJ:https://www.aph.gov.au/DocumentStore.ashx%3Fid%3D3d358fcd-bf85-4a5d-9daa-2f3628a55ba7+&cd=11&hl=en&ct=clnk&gl=au&client=firefox-b-d.

Vines RG, Gibson LA, Hatch AB, King NK, MacArthur DA, Packham DR, Taylor RJ. 1971. On the nature, properties and behaviour of bushfire smoke. Canberra: CSIRO Australian Division of Applied Chemistry Technical Paper No. 1.

Volkova L, Meyer CP, Murphy S, Fairman T, Reisen F, Weston C. 2014. Fuel reduction burning mitigates wildfire effects on forest carbon and greenhouse gas emission. International Journal of Wildland Fire. 23:771–780. doi:10.1071/WF14009.

Wendt WC. 2011. Management of rural fire services in Queensland. Brisbane (Australia): Public Accounts and Public Works Committee, Legislative Assembly of Queensland. Report No. 11.

Wilson AAG. 1992. Assessing fire hazard on public lands in Victoria: fire management needs and practical research objectives. Melbourne (Australia): Department of Conservation and Environment. Fire Management Research Report No. 31.

Woodman M, Rawson R. 1982. Fuel reduction burning in radiata pine plantations. Melbourne (Australia): Forests Commission Victoria. Fire Management Research Report No. 14.

Worthy M, Wasson R. 2004. Fire as an agent of geomorphic change in southeastern Australia: implications for water quality in the Australian Capital Territory. In: Roach IC, editor. Brisbane (Australia): CRC Landscape Environments and Mineral Exploration. Regolith 2004.

Wouters M, Tolhurst KG, Troy S, Friend G. 2002. Analysis of distribution by fire on public land in Victoria. Fire Ecology Working Group. East Melbourne (Australia): Victoria, Department of Natural Resources and Environment.

Yebra M, Quan X, Riano D, Rozas Larraondo P, van Dijk A, Cary GJ. 2018. A fuel moisture content and flammability monitoring methodology for continental Australia based on optical remote sensing. Remote Sensing of Environment. 212:260–272. doi:10.1016/j.rse.2018.04.053

York A. 1996. Long-term effects of fuel reduction burning on invertebrates in a dry sclerophyll forest. Canberra (Australia): Biodiversity Unit, Department of Environment, Sport and Territories. Fire and Biodiversity. The Effects and Effectiveness of Fire Management. Biodiversity Series, Paper No. 8. p. 163–181.

York A. 2000. Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests of southeastern Australia. Austral Ecology. 25:83–98. doi:10.1046/j.1442-9993.2000.01014.x.