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CSIRO Submission 16/558

Response to, and lessons learnt from, recent bushfires in remote Tasmanian wilderness

Senate Standing Committee on Environment and Communications

April 2016

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CSIRO response to the Terms of Reference (ToR)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) welcomes the opportunity to provide a submission to the *Senate Standing Committee on Environment and Communications inquiry into the response to, and lessons learnt from, recent bushfires in remote Tasmanian wilderness* in three of the six key areas identified by the Committee.

These are:

a) **the impact of global warming on fire frequency and magnitude;**
CSIRO provide an overview of the research conducted in Australia and around the world on the impacts of changing climate resulting from global warming on the increased occurrence of elevated fire weather conditions and the propensity for high intensity wildfires to breakout, spread and do damage.

c) **the adequacy of fire assessment and modelling capacity; and**
CSIRO provide an assessment of the adequacy of current Australian fire management knowledge and, more specifically, an analysis of fire behaviour models applicable to the remote Tasmanian wilderness areas affected by the fires.

f) **any related matter.**
CSIRO provide general comments about the increasingly pervasive reliance nationally on response rather than preparedness to deal with bushfire crises and the knowledge gaps that exist in fire behaviour, fire impacts and fire ecology for specific ecosystems such as found in the Tasmanian wilderness that make preparation problematic.

This response was prepared pursuant to a request by Ms Christine McDonald, Committee Secretary of the Environment and Communications References Committee, to Dr Larry Marshall, Chief Executive Officer of CSIRO.

Introduction

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national science agency and is an Australian Government corporate entity. CSIRO is an internationally recognised research and development provider in the fields of global climate modelling, climate change and bushfires. In the field of bushfires, CSIRO uniquely has a continuous history dating back to the 1950s and the early work that resulted in the grassland and forest fire danger rating systems currently used nationally (McArthur 1966, McArthur 1967) for determining fire danger warnings. CSIRO has conducted research relevant to this inquiry in areas including climate modelling and climate forecasting as well as bushfire fuel dynamics, fire weather, combustion dynamics, fire behaviour modelling, fire ecology and fire management.

Bushfires in Australia

Bushfires are an endemic part of the Australian landscape and their occurrence in any part of Australia is inevitable: the climate, topography and vegetation of the continent is such that bushfires will occur somewhere in the country at some time of the year. While bushfires are most common in the tropical savannas of the north, where some parts of the land burn on an annual basis, bushfires in the south-east of the continent, where the majority of the population resides, are less frequent but coincide with greater amounts of combustible vegetation and more difficult terrain, resulting in greater potential for high intensity wildfires that threaten life and property.

Bushfires are an endemic part of the Australian landscape

Most bushfires are relatively mild and frequently burn themselves out when they run out of fuel or the weather changes. However, when the outbreak of a bushfire coincides with hot strong winds that have been preceded by weather conditions that have left the vegetation across the landscape continuously dry and flammable (such as after an extended period of drought), bushfires have the potential to become widespread conflagrations that spread erratically and are essentially uncontrollable until the weather moderates. The fact that most locations do not experience fire very often means that their occurrence frequently comes as a complete surprise to those affected by them.

Relative to the mainland south-east of the continent, Tasmania generally experiences much less frequent occurrence of elevated fire weather and thus high intensity wildfire, predominantly due to its lower latitude. High intensity wildfires do occur, however, and these can have devastating social, economic and ecological impacts. The fire season in Tasmania generally occurs during summer and autumn, running from December to March (Luke and McArthur 1978). For the most part, eastern Tasmania is generally understood to have worse fire weather conditions than western Tasmania, primarily due to the latter's higher annual rainfall.

Tasmania's fires are generally less intense than those of the south-eastern mainland

In January 2013, south-eastern Tasmania experienced extreme heatwave conditions that led to the outbreak of more than forty fires that burnt out more than 20,000 hectares, impacting a large number of communities and resulting in the destruction of a large number of houses, including more than 60 in the town of Dunalley. Fortunately, there was no loss of life. The Hobart fires of 7 February 1967 occurred under very similar weather conditions before the introduction of fire restrictions, and resulted in the loss of 62 lives when more than 80 fires spread out of control, burning out more than 200,000 hectares in the afternoon.

Fire danger

The propensity for bushfires to break out, spread and do damage is described as fire danger (Chandler et al. 1983). Fire danger rating is a fire management system that integrates the facets of selected fire danger factors, primarily vegetation and weather conditions, into one or more qualitative or numerical indices of current protection needs (Chandler 1983). A variety of fire danger rating systems are used around the world (e.g. the National Fire Danger Rating System (Deeming et al. 1977) developed in the US, the Canadian Forest Fire Weather Index System (Van Wagner 1987, Stocks et al. 1991). Most operational fire danger rating systems are based upon the principle that fire danger is determined by the combination of wind speed, fuel moisture content, and fuel availability.

In Australia, two fire danger rating systems are employed - one for grasslands (McArthur 1966) and one for forests (McArthur 1967) - and are applied regionally. The key variables in each system are mean wind speed, relative humidity, air temperature, and a measure of longer term moisture deficit (such as recent rainfall in the forest system or curing state in the grassland system). Two systems are required because forest and grassland fuels, which represent the majority of vegetation types in Australia, have different burning characteristics and thus may represent very different levels of danger given the same conditions. For example, forest fuels can burn when grasslands are green and cannot burn. In other types of vegetation, such as heaths, shrubs or hummock grasses, different danger rating systems could be developed but, to date, have not.

Each system is represented by an index which is subdivided into rating classes: Low-Moderate, High, Very High, Severe, Extreme and Catastrophic. These ratings were revised following the Black Saturday bushfires in Victoria on 7 February 2009, in order to provide more precise levels of warnings under elevated fire weather conditions.

Under low fire danger indices (e.g. ‘Low-Moderate’ fire danger rating), fires either do not burn or spread so slowly that they are very easily extinguished. Under more elevated fire danger indices (e.g. ‘Severe’, ‘Extreme’ or ‘Catastrophic’ fire danger rating), fires start very easily from sources which, under milder conditions, normally do not start fires, (e.g. from the hot molten metal produced when powerlines clash together or from the incandescent carbon particles produced by faulty engine exhausts) and spread so rapidly and fiercely that they are virtually impossible to extinguish unless they are attacked within a few minutes of starting (Luke and McArthur 1978).

Australian fire danger rating systems are predominantly fire weather indices, based primarily on regional-scale weather forecasts with minimal fuel state information required. Most analytical studies of Australian fire danger utilise the forest fire danger index (FFDI) as this uses only weather variables or variables derived from weather (such as a soil dryness index). Few studies employ the grassland fire danger index (GFDI) as this requires information on the state of grassland curing which, while related to weather and time of year, varies by grass species and location (Sullivan 2010), and so is more difficult to acquire and apply.

Studies of the long-term fire weather climatology of Tasmania (Fox-Hughes 2008, Fox-Hughes 2012) identify a peak in forest fire danger in the spring in the eastern and south-eastern parts of the state. Due to the scarcity of automatic weather stations in the north-east of the state, little detailed analysis of the fire weather in this region has been published.

Eastern and south-eastern Tasmania’s forest fire danger reaches a peak in spring

While the fire danger index is useful for setting preparedness levels for firefighting, and alerting the public to the potential for dangerous fire conditions (e.g. Total Fire Bans), it provides little information about fire risk in general (i.e. the level of exposure of a particular location to damage by fire) and no information about the expected behaviour of a fire if one breaks out (Cheney and Gould 1995). For this a fire behaviour model is required.

Fire behaviour

The behaviour of a bushfire is influenced by three primary factors (Countryman 1966): the weather driving it, the vegetation (or fuel) through which it burns, and the topography across which it burns (Figure 1).

Each factor independently and interactively determines the speed and direction that the fire will spread. Additionally, the size and shape of the fire also plays a role in determining its behaviour (Cheney et al. 1993) - smaller fires will spread more slowly than larger fires.

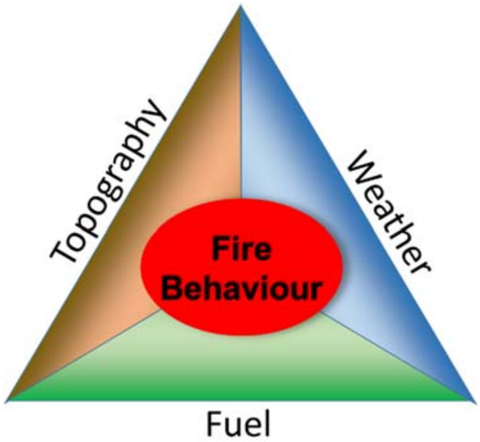

Figure 1. The fire behaviour triangle captures the elements that influence the behaviour and spread of a bushfire.

Of these factors, it is only the vegetation through which the fire burns that can be effectively modified in order to reduce the hazard inherent in the fuel and the risk represented by a bushfire. The management of fuels has thus become a primary tool in the fire manager's tool kit, in most instances in the form of prescribed burning. However, the limited options for reducing fuel hazard and thus improving the potential for managing the behaviour of high intensity fire has long passed by the time the fire arrives.

Vegetation management is the primary method for reducing the risk of bushfire occurrence. Reducing fuel hazard reduces the likelihood of a fire starting, increases the chances of a fire being successfully suppressed and reduces the chance of a fire becoming a large and potentially damaging fire.

a) The impact of global warming on fire frequency and magnitude

CSIRO has contributed to projections of climate change for Australia that generally indicate a warming climate with increases in extremely high temperatures, decreases in annual mean rainfall and relative humidity, and small changes in annual mean wind-speed (CSIRO and BoM 2007). Increases in the extent and frequency of droughts are likely in south-eastern Australia (Hennessy et al. 2008). There has been a 35 year trend of increasing annual total FFDI (the sum of daily maximum FFDI) for south-eastern Australia. Lucas et al. (2007) found that the annual total FFDI displays a rapid increase in the late-1990s to early-2000s at many locations. Increases of 10-40 per cent between the average level for 1980-2000 and the average level for 2001-2007 are evident at most sites. The increases are associated with an increase in the number of days of 'Very High' and greater fire danger rating. Large inter-decadal variations (increases and decreases) in fire danger were observed for most states during the period 1960-2010 (Stephenson et al. 2015).

Increases in the extent and frequency of droughts are likely in south-eastern Australia, and annual total forest fire danger index has increased 10-40 per cent in many locations in the last 35 years.

Just how changes to our climate will affect future fire risk (i.e. potential for, and level of, damage by bushfires), the behaviour and spread of bushfires and the difficulty of suppressing wildfires will depend on a number of factors, not the least of which is the projected changes in those weather and climate factors that affect both fire danger and fire behaviour - air temperature, relative humidity, rainfall and wind. These changes are first order effects (Figure 2) - changing climate directly results in changes in climate variables which may also include broader weather and climate factors such as propensity for dry lightning (a major cause of wildfire outbreaks in remote locations) (Dowdy and Mills 2012a) and changes to synoptic weather patterns associated with bad fire weather (Sullivan et al. 2012). The relationship between climate change, the occurrence of synoptic patterns conducive to elevated fire danger and the occurrence of bushfires in south-eastern Australia is complex, multi-faceted and only beginning to be understood.

The relationship between climate change, large weather patterns that increase immediate fire danger and bushfire occurrence has not been fully quantified.

However, future fire risk depends on a range of other indirect factors that may be affected by climate change, changes that may be described as second-order effects - climate change changes the weather or similar climatic variable, which subsequently changes other factors that influence fire risk or bushfire behaviour such as the fuel through which the fire burns and perhaps the physical processes that control the propagation and behaviour of fires in the landscape.

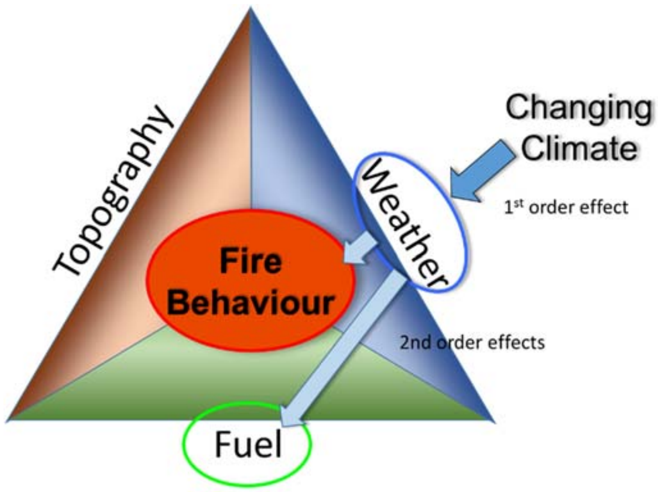

Figure 2. Changing climate can have direct (first order) effects on aspects of the local weather and climate but also indirect (second order) effects on other aspects that influence fire such as the fuels through which bushfires burn and perhaps also the behaviour of the fire itself.

First order impacts of climate change on fire danger

There have been a number of studies of climate change impacts on the weather factors of fire danger, particularly for eastern Australia, including two stations in Tasmania, the closest to north-west Tasmania being Launceston.

Hennessy et al. (2005) calculated the FFDI for a large number of weather stations in eastern Australia using historical weather records from 1974-2003, then applied the output of two climate models (each with two global warming scenarios) to these data to generate climate change weather scenarios for 2020 and 2050 which incorporated forecast changes in average climate and daily weather variability. For Launceston, they determined an increase from 1.5 days per year of 'Very High' or higher fire danger rating to 1.5-1.9 days per year by 2020, and 1.6-3.1 days per year by 2050. They found that the season length of monthly average FFDI greater than 10 currently ranges from late November to late March, and that this could extend from mid-November to late March by 2020 and early November to early April by 2050.

Climate change is likely to increase both the frequency of Very High (and above) fire danger conditions and the length of season over which they occur.

Lucas et al. (2007) updated the findings of Hennessey et al. (2005) using a wider range of observations, extended to 2007 and using revised IPCC climate projections. They found that for a low rate of global warming the simulated annual-average number of days with 'Severe' fire danger rating or higher increased by 5-25 per cent by 2020 relative to 1990 levels. For a high rate of global warming, the number of 'Severe' or higher fire danger rating days increased by 15-65 per cent by 2020. By 2050, the number of 'Severe' or higher fire danger rating days increased by 10-50 per cent for low global warming and by 100-300 per cent for high global warming.

Only 12 of the 26 sites analysed in south-eastern Australia had recorded 'Catastrophic' fire danger rating days since 1973. By 2020, for high global warming rates, 'Catastrophic' fire-weather days were predicted to occur at 20 sites, 10 of which had return periods (average time between events of the same magnitude) of around 16 years or less. By 2050, for high global warming, 'Catastrophic' days occurred at 22 sites, 19 of which had return periods of around 8 years or less, while 7 sites had return periods of 3 years or less.

For Launceston, Lucas et al. (2007) found there had been a 6 per cent change in average cumulative FFDI between 1980-2000 and 2001-2007. Under climate change they forecast a 1-6 per cent change in average cumulative FFDI by 2020 and a 0-22 per cent change by 2050. The number of days of 'Very High' or greater fire danger rating would increase from 1.0 day per year to 1.0-1.2 days per year by 2020, and 1.0-2.2 days per year by 2050.

First and second order impacts on fire risk and fire behaviour

Changes to weather and climate will have second order effects on the type, nature and condition of bushfire fuels and perhaps also the factors that influence the behaviour of the fire, however these are very complex interactions that are yet to be understood in any detail and for which the science is in its early stages.

How the landscape and fuels respond to climate change depends on changes in growing conditions (rainfall, temperature), and interactions with fire regimes (i.e. the pattern of recurrence of fires across the landscape; Gill 1975, Bradstock et al. 2002), land management practices and the ecophysiology of bushfire fuel plant species. On the one hand, elevated carbon dioxide levels may enhance vegetation production and thereby increase fuel loads (Booth et al. 2008). On the other hand, drought may decrease long-term vegetation production (and fuels) and may decrease fuel moisture (thereby increasing potential rates of spread). The outcomes of these interacting processes on fire regimes will depend on whether factors act synergistically or antagonistically, are therefore highly uncertain, and require much further research (Williams et al. 2009, Williams et al. 2011).

Impacts of climate change on vegetation mass and condition, and their knock-on effects for fire risk, are yet to be quantified.

Matthews et al. (2012) investigated climate change impacts on the fuel loads, surface fuel moisture content and expected fire behaviour of dry eucalypt forest in Western Sydney. They found that fine surface fuel load (i.e. the amount of leaf litter, twigs and bark on the forest floor less than 6 mm in diameter) generally decreased as a result of general reducing trends in rainfall amount. However, the exact amount of fine fuel increased or decreased depending upon whether a given year in the future is dry and hot or wet and cool (temperature and rainfall deficit were highly correlated in climate forecasts). The number of years described as dry and hot increased under forecast climate change.

However, the impact of these reductions in surface fuel load on fire behaviour, which would be expected to reduce overall fire behaviour and fireline intensity, were ameliorated by reductions in surface fuel moisture. Reduced surface fuel moisture increases the combustibility and availability of this fuel, thus increasing potential fire behaviour. It was found through a sensitivity analysis, that these indirect climate change impacts on fire behaviour were of a similar order of magnitude of effect that could be expected from second order climate effects on vegetation, particularly the type, structure, continuity and distribution of all layers of fuels within the forest (captured in the concept of fuel hazard) (Matthews et al.

2012). There currently exists no method for determining what the changes in fuel hazard of forest fuels will be under climate change.

Thus, the implications for fire behaviour under climate change will be complex, since more frequent fires will affect ecosystem dynamics, plant ecophysiology and thus fuel hazard. Increased fire frequency may result in more frequent but less intense fires in a particular location, but may also increase the area burned in a given region. Such changes in fire regime may result in distinct changes in fuel type (e.g. frequently burnt forest may convert to open forest with a grassy understorey, or change completely to a shrubland).

Pathways to climate change adaptation for fire

The synergistic (where multiple changes work together) or antagonistic (where changes work against each other and may perhaps cancel each other out) and the complex mix of these means that understanding of potential impacts of climate change necessary to identify potential adaptation pathways is similarly complex.

Because the climate change factors influencing fire risk are complex, identifying pathways to adapt to them is also complex.

If we consider an abstraction of the concept of fire danger at a sub-regional scale that includes the factors important to fire behaviour as shown in Figure 1 (i.e. fire weather, fuel hazard and topography) we can begin to see how many of the factors interact. In this figure, fuel hazard incorporates those attributes of vegetation that promote the spread and intensity of a fire such as fuel availability, combustibility, structure and continuity, etc. Similarly, fire weather incorporates those aspects of the weather that promotes the spread and intensity of fire such as wind speed, turbulence, air temperature, relative humidity, atmospheric stability, presence of synoptic patterns that bring such weather, etc.

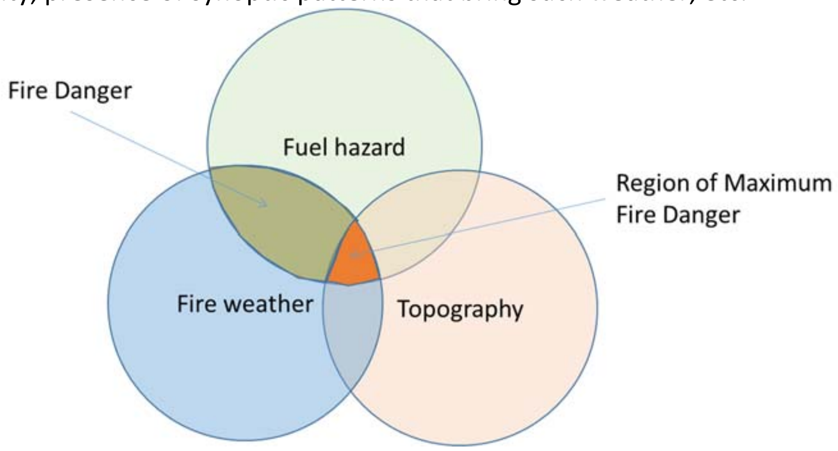

Figure 3. An abstraction of the concept of fire danger utilising local-scale factors that are important for determining potential fire behaviour.

From this figure, we can identify two important aspects: 1) that fire danger is the coincidence of fire weather and fuel hazard, regardless of topography; and 2) that where fire danger coincides with topography, the fire danger (and thus risk) will be at its maximum. Where fire weather is low or nil, fire danger is low or nil, regardless of fuel hazard. Where fuel hazard is low or nil, fire danger is low or nil, regardless of fire weather. Fire threat is the product of this abstracted fire danger and fire presence—no fire presence, no fire threat regardless of fire danger.

Under varying climate, only fire weather and fuel hazard are going to change—topography is assumed to be invariant to changes in climate. Whether these changing factors or increase may depend on the type of year (e.g. hot and dry or cool and wet), the general trend of preceding years, time of year, and even the weather of the day. Figure 4 illustrates how reducing the fuel hazard, such as through prescribed burning or mechanical treatment of the fuel, the fire danger posed in a particular location may be decreased. Such decreases in overall fire danger may be negated if there is a corresponding increase in the fire weather (antagonistic interaction), or alternatively, it may be amplified (synergistic interaction) if there is a decrease in the fire weather.

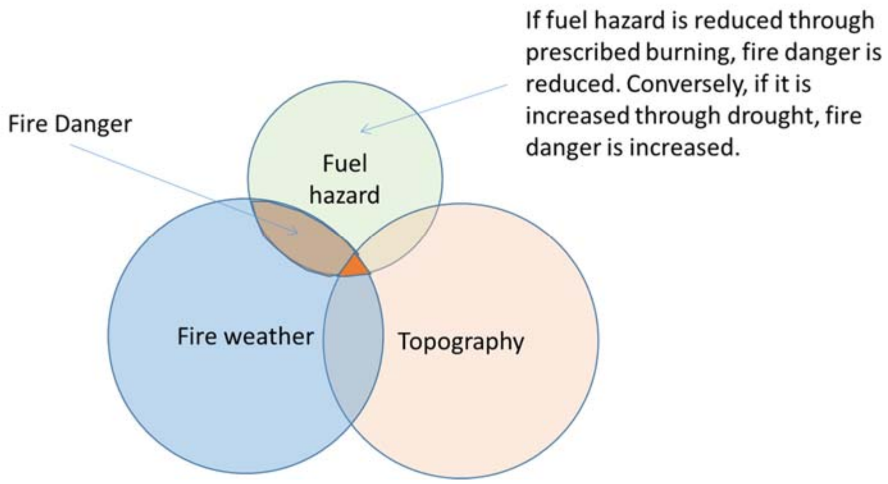

Figure 4. Reducing the hazard posed by fuel will reduce the overall danger posed by fire at a certain location which will reduce the threat posed by a fire if one breaks out and increase the chance of the fire be successfully suppressed on first attack.

Reductions in fuel hazard not only reduce overall fuel hazard at a particular location but also increase the chances of a fire being successfully suppressed on first attack, increase the chances of aerial suppression being effective and also reduce the chance of a fire becoming a large and potentially damaging fire (Plucinski 2012, Plucinski et al. 2012).

c) The adequacy of fire assessment and modelling capacity

Fire behaviour is a collective descriptive term for a number of aspects of a bushfire. These include the rate of spread of the fire (i.e. the speed of the fire in the direction of the wind), the fireline intensity (i.e. the rate of energy release per unit length of fireline), flame height, angle and length, and spotting distance (the maximum distance firebrands will be cast by the fire and spot fires initiated). The fireline intensity of a bushfire is the product of the rate of spread of the fire, the amount of fuel consumed in the fire, and the heat yield (or energy available) of the fuel. The amount of fuel that is consumed in the fire is also a function of the intensity of the fire. A low intensity forest fire will burn only fuel that is on the ground (i.e. surface fuel). As the intensity increases, the fire will consume other (higher) strata of fuel, increasing the amount of fuel consumed and thus the intensity. An extremely intense forest fire may consume all fuel strata within the forest including the canopy.

Australia's approach to the prediction of the spread and behaviour of bushfires has historically been one focused on the development of specific fire models for each general class of vegetation in which bushfires occur. This approach is in contrast to that taken in other countries such as the USA, where a general fire spread model (known as the Rothermel model – Rothermel 1972) is applied to all fires and abstract models of fuels are employed to provide fuel specific attributes to the model in order to make predictions (Andrews 1986, Rothermel 1983).

The Australian approach has the advantage of enabling further development and refinement of a model for a specific fuel type without affecting the performance of fire spread predictions in other fuel types - although the Rothermel model is still in operational use, the Americans have been attempting to overcome deficiencies in its performance for some time with little success due to its complicated interrelations across the full range of different fuel types (Catchpole et al. 1998). The downside of the Australian approach is that separate knowledge on fire behaviour in a particular fuel type is required before a fire behaviour model for that fuel type can be developed.

Fire behaviour models can take a wide variety of forms (Sullivan 2009b, Sullivan 2009c, Sullivan 2009d) ranging from those that are based on fundamental considerations of combustion chemistry and physics, through to those that are based purely upon observation. In Australia, all operational fire spread models are of the latter variety (Sullivan 2009a), known as empirical models. These models are generally robust and provide high levels of reliability but are highly dependent on the science of the day when they are developed for their accuracy. However, as the science advances, improvements can be made, although generally new knowledge (i.e. new experiments) needs to be collected.

Cruz *et al.* (2015 a, b) recently analysed all fire behaviour models developed for Australian vegetation types. From these analyses, which included assessment of model applicability as well as prediction accuracy, bias and error, recommendations were made of those models appropriate for operational use and those models for which use should be discontinued.

A total of 24 models were identified, covering four major vegetation types (grasslands, forests, shrublands and plantations) and 13 fuel types for wildfire and some prescribed fire conditions. The fuel types covered are given in Table 1. A small number of these models are replacements that supersede earlier versions as a result of advances in fire science and methods for analysing fire behaviour data. Fuel types in bold are that are applicable to the north-west of Tasmania.

Table 1. Summary of the fuel and vegetation types for which fire behaviour models (rate of spread (ROS), flame height and maximum spotting distance) exist. Those in bold are applicable to Tasmanian fuels.

Vegetation	Fuel type	Models and references
Grassland	**Continuous open**	ROS: Cheney et al. (1998) Flame height: Cheney and Sullivan (2008)
	Woodlands	ROS: Cheney et al. (1998) Flame height: Cheney and Sullivan (2008)
	Open grassy forest (Northern Australia)	ROS: Cheney et al. (1998) Flame height: Cheney and Sullivan (2008)
	Spinifex	ROS: Burrows et al. (2009)
	Buttongrass	ROS and flame height: Marsden-Smedley and Catchpole (1995)
Native Forest	**Dry eucalypt** (*wildfire conditions*)	ROS and flame height: Cheney et al. (2012) Maximum spotting distance: Gould et al. (2007)
	Dry eucalypt (*prescribed fire conditions*)	ROS and flame height: Gould's (1994) equations for McArthur (1962), Cheney et al. (1992) for *Eucalyptus sieberi.*
	Tall wet eucalypt (*prescribed fire conditions*)	ROS: Sneeuwjagt and Peet (1985)

Shrubland	**Temperate shrubland**	ROS: Anderson et al. (2015)
	Semi-arid heath	ROS: Cruz et al. (2010)
	Semi-arid mallee-heath	ROS and flame height: Cruz et al (2013)
Plantations	**Radiata pine** (wildfire conditions)	ROS and flame height: Cruz et al. (2008)
	Maritime pine (wildfire conditions)	ROS and flame height: Cruz et al. (2008)
	Short rotation eucalypt (wildfire conditions)	Grass dominated- ROS: Cheney et al. (1998) is used (with a user-defined wind correction factor), Flame height: Cheney and Sullivan (2008) Litter dominated- ROS and flame height: Cheney et al. (2012); Maximum spotting distance: Gould et al. (2007)

While for the most part many models in Table 1 may directly applicable to Tasmanian fuels, there are a couple of fuel types found in Tasmania for which either no fire rate of spread model exists or no suitable model for wildfire conditions exists. These include peat, rainforest, wet heath, alpine forest, alpine scrub and wet eucalypt forest, which represent many of the predominant fuel types found in sensitive and Tasmanian Wilderness Heritage Areas. The only fire behaviour model that has been developed specifically for a Tasmanian fuel type is the Buttongrass model of Marsden-Smedley and Catchpole (1995). The applicability of existing wildfire behaviour models to other Tasmanian fuel types in unknown.

Reliable methods for predicting fire spread do not exist for many of the vegetation types found in the Tasmanian Wilderness.

Similarly, the applicability of rate of spread models for prescribed fire conditions for the fuel types of north-west Tasmania is uncertain. The tall wet eucalypt prescribed burn model of Table 1 is designed for the karri forest of south-west Western Australia and its performance in the wet eucalypt forest types in Tasmania is unknown. Likewise, prescribed burning models for dry eucalypt were developed for mainland forests and there performance under Tasmanian conditions is uncertain.

Nationally, the rate of development of fire spread models developed for new fuel types has decreased over the years. In the last decade only one model has been developed for a fuel type that did not previously have a fire spread model. While fire behaviour research continues on a number of fronts at various institutions, nationally there has been reducing support for the development of operational fire spread models critical to the effective management of fire in less mainstream or high impact vegetation, which leaves crucial gaps in fire management knowledge in increasingly sensitive locales.

This is particularly evident in the development of prescribed burning models. In Australia, there are only three prescribed burning models—all for eucalypt forests, one for use in Western Australia (dry and wet forest, Sneeujagt and Peet (1985)), one for use in eastern Australia (dry forest, McArthur (1962)), and one for *Eucalyptus sieberi* forest of southern NSW (Cheney et al. 1992). These (mainly McArthur (1962), which is a relatively simple model that is often used well beyond its intended domain) are used to varying levels of success in all native forests as well as other fuel types for want of alternatives. Their performance in fuel types other than for that which they were designed is poor.

Despite the recognition of, and recommendations for, (see outcomes of the Royal Commission into the 2009 Victorian Bushfires, (Teague et al. 2010)) increased prescribed burning for hazard reduction and bushfire risk mitigation, it has been more than 20 years since the last prescribed burn model was developed.

f) Any related matter - The future of fire management in Australia

Fuel management

Australia has a long history of using fire to manage fuel hazard in the form of prescribed burning (see Control Burning Guide by Alan McArthur (McArthur 1962)). This generally consists of intentionally lighting fires under relatively mild conditions to consume surface and near surface fuels while minimising the risk of damage to trees or the fire escaping. Some land management burns (e.g. regeneration burns) require higher intensity fires carried out under more severe conditions to achieve desired objective such as the reduction of bark fuels, which is critical to reducing the propensity for spotting. Prescribed burning is the most cost effective way of reducing fuel hazard at landscape scales (Rawson et al. 1985) and in many native ecosystems that are fire-adapted are necessary to ensure long term ecosystem health.

Prescribed burning is the most cost-effective method for reducing fire risk and can in some circumstances facilitate ecosystem health. Effective application requires experience, and fear of causing damage to ecosystems and property encourages a conservative approach to prescribed burning.

However, understanding the conditions required to achieve the desired management objective (e.g. reducing fuel hazard) without inflicting detrimental impacts upon the vegetation community and others (such as smoke impacts, or assets) is not simple. As mentioned above, there are only a small handful of guides available for managers to follow and these are often for specific vegetation types or specific management objectives. More frequently managers rely upon experience in order to achieve their objectives and thus their knowledge base is limited to their personal exposure to fire behaviour and impacts. The fear of causing damage means that managers often err on the side of caution when it comes to implementing fire in the landscape and as such may miss critical opportunities to achieve the planned burn or light it in such mild conditions that objectives are not met (very often fires burning under such conditions do not sustain active spread and thus do not burn any fuel).

In many vegetation types in Australia, particularly those described as ‘wet’, fuels will only be dry enough to burn very rarely—so rarely that being able to conduct effective hazard reduction through prescribed burning will only happen when the potential for high intensity wildfire is high. Inaccurate or misapplied use of fire in such fuel types can be very risky with great potential for wide-spread damaging fire.

The management of fuels in this way is fraught with complex issues, such as the potential for fundamental changes to fire regimes if fire is implemented too often for a particular ecosystem that may result in irreversible changes to vegetation composition. Understanding precisely the role of fire in a particular ecosystem and the response of that ecosystem to fire is essential to optimising both the hazard represented by the fuel in that ecosystem and that health of that ecosystem.

There are currently very few ecosystems in Australia for which this information exists, with perhaps only the Buttongrass moorlands representing that set of knowledge in Tasmania. It is critical that further research into these aspects is carried out for the optimal management of sensitive and valuable ecosystems in Tasmania and the mainland.

Without this information, appropriate and effective management of many ecosystems, particularly those in close proximity to built-up areas and people, will not be achievable. With changes to fire weather conditions happening due to the effects of climate change, windows of opportunity for carrying out effective, meaningful and safe hazard reduction are reducing in many locations. Maximising these reducing opportunities is critical to ensuring the health of natural heritage areas.

Climate change is likely to simultaneously increase the potential benefits of prescribed burning whilst reducing the set of conditions under which it will be successful. Only further research will break this nexus.

Fire management

The last two or three decades has seen a dramatic shift in the focus of fire management in Australia. During the 1960s and 1970s, fire management was closely related to fuel management - reducing risk through reducing fuel hazard, the primary agencies dealing with bushfires were State land management agencies such as National Parks services or primary industry agencies. Australia led the world in the application of fire in this way. Western Australia, in the form of the Department of Conservation and Land Management (now Department of Parks and Wildlife), was a key leader in this.

However, in the 1980s and 1990s there was a subtle shift in the focus of fire management at a State level from managing the fuel to reduce risk to an emergency response perspective (Cheney 2008). Rural fire agencies (very often predominantly staffed with volunteers) now are often the primary fire management agency. These agencies may have hazard reduction responsibility on private land and possibly some public land but they generally do not have critical extensive experience in undertaking prescribed burning in the range of fuel types and ecosystems they are charged with managing or at the scales required to make the hazard reduction cost-effective. Furthermore, their reliance upon a predominantly volunteer workforce restricts their ability to take advantage of suitable weather for prescribed burning, reducing further the windows of opportunity for hazard reduction.

Rather, rural fire agencies and their volunteer forces focus their planning on emergency response - responding to and fighting fires, either directly using road-based tankers or aerial suppression or indirectly with backburning or burning out operations. Their effort is less about reducing risk through reducing the potential for fire spread, and more about reducing risk by trying to restrict the actual spread by suppression. However, under high intensity fire conditions, the effectiveness of suppression efforts is very much reduced until the burning conditions moderate. Firefighting efforts refocus to property protection rather than actual firefighting.

The focus of Australian fire management has, over the last 30 years, changed from prevention to emergency response and from landscape scale suppression to localised property protection. This simultaneously increases the risk of fires that damage ecosystems and reduces the likelihood of their being controlled.

For fires in remote locations, firefighting activity is very often dependent upon aerial suppression as it often takes too long to get ground crews to the fire (if access is at all possible). Aerial suppression, however, will not be effective at controlling a fire in many fuel types without support from ground crews.

Increases in potential ignition sources resulting from increased dry lightning (the cause of many of the recent fires in Tasmania) expected under climate change will mean that these sorts of fire events are going to become increasingly common (Dowdy and Mills 2012a,b). Reliance upon bigger and better technological solutions (such as very large aircraft) to fight future fires under changed climate will not adequately ensure the effective and safe protection of sensitive and heritage listed ecosystems such as found in north-west Tasmania.

Comprehensive and fundamental research into these ecosystems is required to develop effective plans for managing the risk of fire.

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