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Prescribed burning in Australian forests: characteristics, impacts and effects

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Summary

- Two to seven per cent of the forests of southern Australia are prescribed burnt each year.
- Prescribed burning reduces the area burnt by wildfire by approximately 1 ha for every 3 ha treated, and other measures of wildfire are also reduced accordingly.
- At current levels, prescribed burning is reducing risk by a modest amount, but it is not causing substantial negative effects on biodiversity. However, there may be negative impacts in areas treated more frequently such as the interface with human populations.
- In the 2019–20 fires, recent prescribed burning within 500 m of houses reduced the rate of house loss such that areas where 50% had been treated in the last 5 years had only 41% of the loss rate of untreated areas.
- Under climate change, prescribed burning rates will need to increase markedly in order to keep wildfire risk at current levels. This is probably both impractical and detrimental to biodiversity.
- There are major knowledge gaps about the response of individual species to the full range of fire regime factors, about emissions and carbon storage under different regimes, and indirect effects of fire such as through increasing predator pressure, and interactions between prescribed burning and wildfire.

Introduction

Prescribed burning is one of the main wildfire risk reduction measures practised in Australian eucalypt forests and heathlands. But it is a contentious practice because there are concerns over its cost-effectiveness and that its widespread application reduces intervals between fires and thus may harm some components of biodiversity. Most major wildfire seasons spawn official inquiries and these have all investigated the role of prescribed burning (see Chapter 30). The modern fire management era began after the Stretton Inquiry into the 1939 wildfires in Victoria lamented that the rate of 'controlled burning' was 'ridiculously inadequate' (Stretton 1939). Of the subsequent inquiries, most have recommended improvements to the strategy and coordination of prescribed burning, but only two have recommended specific targets. These were the 2008 Victorian Parliamentary Inquiry into the management of wildfires on public land and the 2010 Victorian Royal Commission into the Black Saturday Fires (Anon 2008; Teague *et al*. 2010). The Black Saturday royal commission target that 5% of public land be prescribed burnt each year was adopted by the Victorian Government but abandoned in 2016 in favour of a more focused risk-based strategy.

Depending on where, when and how it is done prescribed burning can:

- Protect sensitive areas from burning in a wildfire. These areas may be houses or fire sensitive species or ecosystems.
- Reduce the severity of a wildfire. This will reduce the ecological impact of the wildfire, which will protect populations of some fire-sensitive species, but may be detrimental to populations of species that require high severity to complete their life cycle.
- Increase the frequency of burning (and thus decrease intervals between them). Because wildfires are rare, most prescribed burns never interact with one, and so act to increase fire frequency. This may be detrimental for fire-sensitive species or those that require long fire-free intervals to complete their life cycles.

Increases in prescribed burning are often called for after major wildfire seasons, and if prescribed burns are to be used to prevent the risk of future wildfires under climate change then the area treated will have to keep increasing (or become ineffective), so it is important to understand how prescribed burning, and increasing it, affects biodiversity.

What is prescribed burning?

Prescribed burning is the deliberate application of fire into the landscape. In contemporary times, most are 'hazard reduction burns': the removal of fuels to reduce risks to people and property (Fig. 21.1). The managers of conservation reserves may impose burns for

Fig. 21.1. A prescribed burn near houses, Stanwell Park, NSW, April 2021. (Photo: Owen Price)

ecological purposes, such as promoting the regeneration of a senescent seeding shrub species, or increasing the mix of post-fire ages within a reserve. Prescribed burning is most commonly applied in dry sclerophyll forests and heathland. Wet sclerophyll forests are more rarely treated because fire is more difficult to control there, and rainforests are generally never deliberately burnt. Sometimes dry sclerophyll forests are control burnt to protect other vegetation types.

Before European colonisation most fires were Indigenous burns or 'cultural burns' for a variety of purposes that can be grouped under the umbrella term 'caring for Country'. Colonisation brought a collapse of the practice, but there is now a resurgence across Australia, spearheaded in monsoonal Northern Territory where Indigenous savanna burning projects cover more than half of the land area (Russell-Smith *et al*. 2020). Indigenous land management is now expanding in south-eastern Australia (see Chapter 33).

While there is some degree of overlap among these three types of fires in terms of their ecological effect, they can be separated along a gradient of fire intensity. Many aspects of fire behaviour and impact are correlated: area, rate of spread, flame length, intensity and severity (the degree of impact on the vegetation). In general, cultural burns are mild, meaning all of those aspects are on the low end of the spectrum (small, trickling fire with short flames that only impact the ground and shrub layer). Wildfires are at the other extreme (severe) and hazard reduction burns are in the middle (moderate). In practice, this means that hazard reduction burns usually leave unburnt patches (ranging from 6–35% of the fire extent) (Penman *et al*. 2007; Volkova and Weston 2015; Duff *et al*. 2019). Cultural burns may leave most of the vegetation unburnt (Price *et al*. 2022). Across Australia there is a negative association between fire severity and fire frequency, which is a consequence of climate and the rate at which fuels accumulate. At one end of this gradient, tropical savannas experience high-frequency, low-severity fires and, at the other, south-eastern forests experience infrequent severe fires (Murphy *et al*. 2013). This means that the nature of both wildfire and prescribed fire varies across the nation.

Prescribed burning and wildfire risk to property

Protection of human life and property is the main purpose of hazard reduction burning. It is mostly focused on the interface between forest and houses, though there is considerable debate about the amount and locations that should be burnt. Victoria set targets of 5% of all public land from 2010–16, but shifted to a risk-based rather than area-based approach in 2016. NSW National Parks and Wildlife Service (NPWS) have targets of 135 000 ha per year (1.5% of the protected area estate and ~2.5% if only applied to forests). In Western Australia, the Department of Biodiversity, Conservation and Attractions (DBCA) aims to burn 7% of its forest estate each year (Bradshaw *et al*. 2018). In all states bar Western Australia, the annual treatment rate is much less than the area of wildfires, and has been relatively stable over recent decades (see Fig. 21.2 for trends in New South Wales).

Research evidence finds that prescribed burning reduces many aspects of wildfire risk. It reduces severity of a subsequent wildfire for ~5 years (Bradstock *et al*. 2010), but effectiveness reduces as fire weather increases. For example, recent prescribed burning had no effect under Catastrophic weather conditions in the 2009 Black Saturday fires (Price and Bradstock 2012). Under most conditions, there will be less impact on houses adjacent to the treated area and it is more likely that firefighters will be able to stop fire from reaching houses. The extent or proximity has been found to reduce wildfire impact in both the 2009 Black Saturday fires (Gibbons *et al*. 2012) and also in the 2019–20 megafires (Price and Haynes 2020). Prescribed burning also reduces the regional area burnt by wildfires by

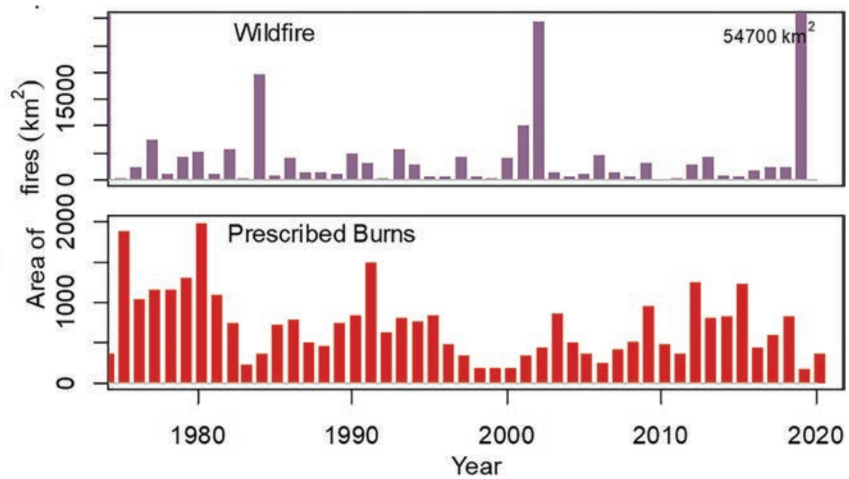

Fig. 21.2. Historical area burnt in New South Wales by wildfire and prescribed burns according to NSW DPIE fire history data (downloaded from SEED portal (https://www.seed.nsw.gov.au/). On average, wildfire area is 6.2 times prescribed burning area. Notice that the scales on the *y* axes differ.

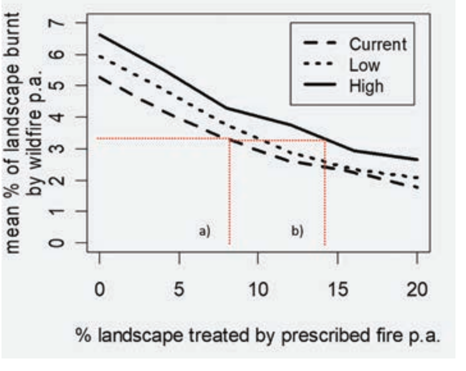

Fig. 21.3. Prescribed burning effect on the area of wildfire as predicted by fire simulations (from Bradstock *et al.* (2008)) for the Blue Mountains, showing (a) the annual treatment rate required to halve annual wildfire area and (b) the rate required under 2050 climate. (Image reproduced from Bradstock R, Davies I, Price OF, Cary G (2008) Effects of climate change on bushfire threats to biodiversity, ecosystem processes and people in the Sydney region: Final Report to the New South Wales Department of Environment and Climate Change. Centre for Environmental Risk Management of Bushfires, Faculty of Science, University of Wollongong, Wollongong)

~1 ha for every 3 ha treated over the long-term in forests (Fig. 21.3) (Bradstock *et al.* 2008, 2012b). However, prescribed burning rarely stops a fire unaided (without the addition of firefighters or a fire break such as a road) (Price and Bradstock 2010). Also, prescribed burns produce smoke, which can expose the local community and some land uses to poor air quality (up to ~5 km from the burn), and sometimes cause extensive exposure (Broome *et al.* 2016; Price and Forehead 2021).

Although protection of property is not the main reason for cultural burning, it can have that effect (Steffenson 2020), albeit to a lesser extent than hazard reduction burning due to the small scale and lower fuel reduction.

Prescribed burning and biodiversity

All Australian fauna and flora are adapted to fire to some extent, with specialised mechanisms to aid recovery. The way fire influences them depends on those adaptations and on the fire regime they experience (each individual fire, the sequence of fires, and the intervals between fires). The possible combinations are almost endless, so understanding these dynamics is complicated. For plants, there is a useful general division between species that recover from fire by surviving and resprouting (from the base, trunk or canopy depending on the severity of the fire) and those that are killed and regenerate from seeds: 'resprouters' (which include most eucalypts) and 'seeders' respectively (Keeley *et al*. 2011). Regular prescribed burning generally has the twin effects of reducing the interval between fires and their severity (because there is less time for fuel to build-up). Competition among plants is high after a mild fire because much of the vegetation is intact so those plants that survive (the resprouters) have the advantage. Seeders will decline if the interval between fires is less than the time required to mature and set another seed crop, and this effect has been shown to eliminate some plant species from certain places (Gill and Bradstock 1995). Resprouters can tolerate shorter intervals, but even they have limits (Enright *et al*. 2011): up to 5% of resprouting eucalypts are killed by low-severity fires typical of prescribed burns (Bennett *et al*. 2016; Etchells *et al*. 2020), and frequent prescribed burning may particularly impact larger trees (Watson *et al*. 2020). Also, many of the seeders require high temperatures to germinate their seeds, temperatures only experienced in severe fire (Liyanage and Ooi 2015). So generally, prescribed burning favours resprouters. This is a significant concern considering the large number of seeder species. For example, the NSW Flora Fire Response Database (V2.1, DPIE, unpublished data) lists 1113 plant species as seeders (36% of all species). Prescribed burns are usually conducted in spring or autumn, outside the typical summer wildfire season, and this will negatively affect species that are adapted to summer fires (Miller *et al*. 2019).

Set against these changes in interval, severity and season is the fact that prescribed burns tend to leave more unburnt patches than do wildfires. Estimates range from 22–35% unburnt (Penman *et al*. 2007; Volkova and Weston 2015), compared to < 5% in the 2019–20 wildfires (Price *et al*. 2022). This means that some sensitive plants will escape each prescribed burn, and the actual impacts of a regime of frequent prescribed burns may not emerge for many decades. It also means that concerns about the impact of reduced intervals may be overestimated if this patchiness is not factored into assessments. In general, the floristic composition, forest structure and carbon storage have been found to be resilient to a range of regimes (Knox and Clarke 2012; Gordon *et al*. 2018; Rahmani and Price 2021), although previously assumed resilience may be subverted by regimes characterised by an increasing extent and severity of wildfires.

The response of animals to fire is even more complicated than for plants because, depending on their size and mobility, they can escape the flames either *in situ* (in a burrow or hollow) or by fleeing. It follows that the most sensitive species are those that do not shelter (such as litter-dwelling lizards and insects or koalas (*Phascolarctos cinereus*)), have small home ranges, or both. Because prescribed burns are generally smaller, less severe and leave more internal unburnt patches than wildfires, the impact of any single prescribed fire on fauna is less than from wildfires. Most studies of animal responses to single fire events find either that populations are only slightly reduced (Jolly *et al*. 2022) by fire or that they recover to pre-fire levels in a few years, and this is especially the case for prescribed burns (Kuchinke *et al*. 2020; McHugh *et al*. 2020), although this finding is based on relatively few studies of impacts of high-severity fires. Many studies also find that the direct influence of fire is smaller than its indirect effect through modification of the habitat (such as temporarily removing the ground or shrub layer) (Monamy and Fox 2000; Swan *et al*. 2015). However, in contrast to wildfires and cultural burns, the ignition pattern often in hazard reduction burns involves a line of flame around the perimeter of the burn, spreading into the centre. This potentially leaves animals without easy escape routes, though the phenomenon has not been examined.

What we learned about prescribed burning from the 2019–20 wildfires

Previous prescribed burning affected the 2019–20 wildfires. The rates of house loss were ~30% lower where 50% of the area within 500 m of houses had been prescribed burnt within the past 5 years (Price and Haynes 2020). Fire severity was ~30% lower in areas burnt by recent prescribed burns (Hislop *et al*. 2020; Price *et al*. 2021). Of 1699 New South Wales prescribed burns in the five years before spring 2019, 30% were encountered by the wildfires, and of those 42% resulted in internal unburnt patches, and 13% were aligned with the wildfire boundary and so had a potential role in stopping the fire (Price *et al*. 2021). This shows that prescribed burning did reduce risks associated with property loss and can introduce refuges from wildfire and particularly from high-severity fire.

Prescribed burning and carbon storage

Prescribed burning in south-eastern forests decreases fire intervals. This is different to tropical savannas where spatially targeted treatments can slightly increase intervals (Evans and Russell-Smith 2020). Also, since one objective of prescribed burning programs is to keep fine fuel loads lower than they would otherwise be, a lower carbon stock may be expected under a regime dominated by prescribed burning. This means that prescribed burning may decrease forest carbon stocks. However, whether the total forest carbon stock falls depends on the comparative biomass consumption rates of prescribed and wildfires (Bradstock *et al*. 2012a), which in turn depends upon which fire type promotes the stocks of large trees where most of the carbon resides. This is a complicated and poorly understood issue, in large part because current estimates of rates of tree mortality and consumption are highly uncertain. On the one hand, a wildfire regime may kill many trees but provides the conditions for recruitment and regrowth. On the other a prescribed fire regime kills very few large trees, enabling them to grow to their maximum size, but the short inter-fire intervals may prevent recruitment when those trees senesce. The available field data suggest that differences in fire regime over several decades have a small effect on carbon stocks (Gordon *et al*. 2018) and that prescribed fires have little potential to increase carbon sequestration (Volkova *et al*. 2021).

Prescribed burning and climate change

Climate data suggest that the conditions conducive to wildfire have increased substantially over recent decades and are predicted to escalate further over coming decades (Clarke *et al*. 2013), and this is resulting in increased wildfire activity (Bradstock *et al*. 2014; Canadell *et al*. 2021). The 2019–20 wildfires were characterised by a clear climate change signal (Abram *et al*. 2021). Climate change will result in increased frequency and severity of wildfire, and this combined with probable poorer conditions for growth may lead to risk of loss of woody plants, and the ecological communities they comprise, through 'interval squeeze' (Enright *et al*. 2015). Should this occur, the reduction in biomass will eventually have a dampening effect on wildfire activity so that wildfire activity may increase over several decades, but then start to decline. Wildfire area and associated risk can be maintained at current levels by significantly increasing the annual amount of prescribed burning (probably to nearly 15% of the landscape by 2050 (Bradstock *et al.* 2012b; Fig. 21.3)), but this will be very costly; decrease inter-fire intervals even more; may be impossible to achieve; and the effectiveness of control burning in constraining wildfire may decrease under hotter, drier conditions forecast for the future, and may contribute to interval squeeze.

How much of a problem is prescribed burning?

Prescribed burning can help to protect areas from high-severity fire so it is beneficial for species whose survival is a function of severity. However, the dominant effect is to decrease intervals between fires and this is likely to be detrimental to many plant and animal species, and some ecological communities. The extent to which this is a problem depends on how much the average inter-fire interval is reduced. Current fire management policies in national parks rely on thresholds of potential concern (Kenny *et al.* 2004), which define minimum and maximum fire intervals for vegetation formations or individual species. Analysis of these threshold status in New South Wales shows that only a small area was burnt too frequently before the 2019–20 wildfires, and even those massive fires caused only a modest increase of 25% in that area burnt below threshold from 800 000 ha to 1 million ha (Williamson 2020) (Fig. 21.4). However, the entire burnt area (of 550 million ha) is now vulnerable to falling below threshold should another wildfire occur in the next 5–10 years. Prescribed burning rates are much lower than wildfire rates (< 3% of the landscape per year) so it is unlikely that they will cause significant shortening of intervals. For example, on average, a prescribed fire regime that burns 3% of forests on average each year overlaid on a 5% annual wildfire rate will reduce inter-fire intervals from ~20 years to 14 years, still considerably higher than thresholds of potential concern for most species.

However, there are some causes for concern. Prescribed burning treatments may be increased to counter increased risk from wildfires under climate change. Simulation studies suggest that if treatment rates are increased to 10% per annum in Tasmania or the Australian Capital Territory, then the area of forests burnt below thresholds of potential concern will increase by 15% relative to current levels (Cirulis *et al.* 2019). These kinds of treatment levels have been proposed to be needed to keep wildfire area constant in the future. Current treatments are unevenly distributed across the forests, and are focused at the interface between forests and human settlements (Price and Bradstock 2013). These areas may well be burnt below threshold of potential concern (i.e. leaving inter-fire intervals too short to maintain some species) and this is also likely to worsen under climate change. In some respects, these are areas managed by frequent prescribed fires as sacrificial areas, but there has been no assessment of the area involved either as hectares or as a proportion of the total forest. While a modest increase in fire frequency will have a small effect on biodiversity overall, the impact on particular threatened species and ecological communities may be much more significant. Changed fire regime is a listed threatening process for 66% of threatened species in Australia (Kearney *et al.* unpublished), and many of these will be interval sensitive. Considering that many of these species have small populations that may be completely burnt in a single fire, close attention should be paid to applying prescribed burns to threatened species habitat.

Prescribed burning may have some detrimental impacts on biodiversity through demographic factors influenced by the inter-fire interval, but it also may have more indirect impacts such as through increasing the risk and impact of compounding threats. For example, many native plants and animals may survive any fire event, but those

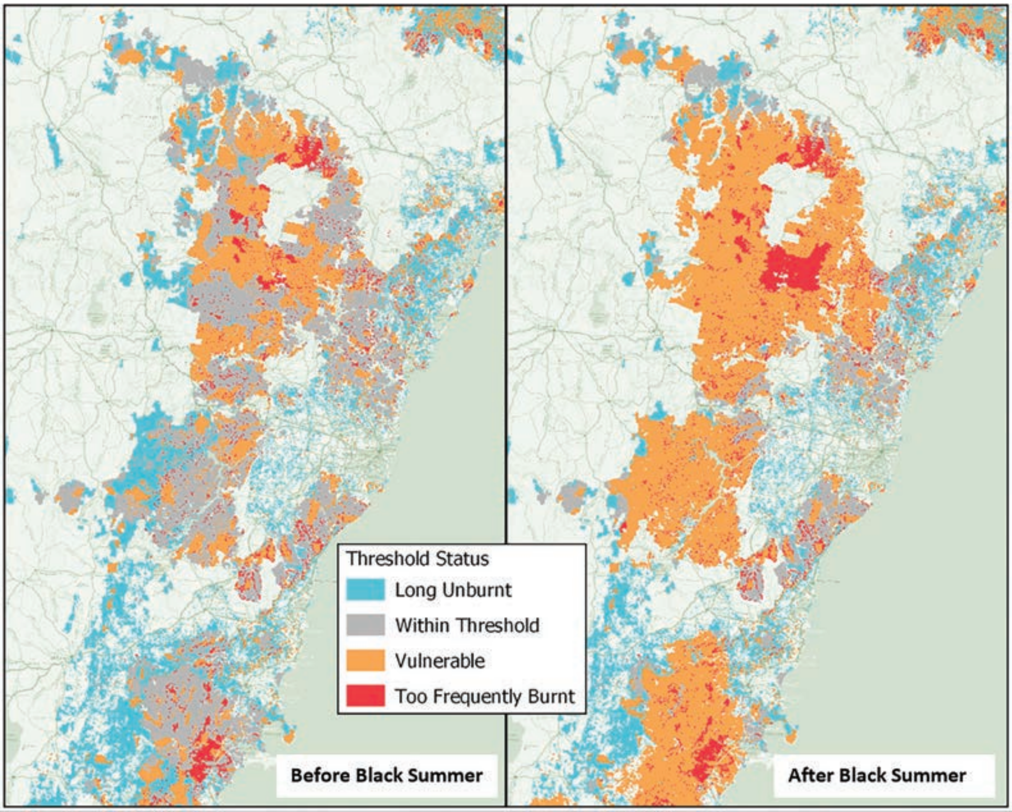

Fig. 21.4. Firetools analysis of thresholds of potential concern before and after the Black Summer fires (from Williamson (2020)) for vegetation formations in the Sydney region. The main effect has been to shift a large area into the vulnerable class (83% increase across New South Wales), with more modest 21% increase in area burnt too frequently and 30% decrease in the area long unburnt. Vulnerable means an area that would be burnt too frequently if another fire occurred within 5–7 years. (Image: Grant Williamson)

survivors may then be exposed to increased rates of consumption by introduced herbivores and predators (e.g. Hradsky 2020; Chapter 17), and these compounding impacts may escalate and become more extensive with increased application of prescribed burning.

Prescribed burns can also escape their proposed boundaries and cause damage. A notable example was the 2011 Ellenbrook burn near Margaret River, Western Australia, which destroyed 32 homes (Keelty 2012).

Knowledge gaps

Prescribed burning involves winners and losers, and finding the best settings to balance the trade-off between these, and with property risk reduction, is a very complex problem. Some issues are noted below:

- There is still a basic need to understand species-level responses to elements of the fire regime. There is a reasonable knowledge base for plant species in respect to interval thresholds, but very little in respect to severity, seasonality and long-term regimes, and the knowledge base is notably flimsier for animals. Prescribed burning impacts can be interpreted in this context via a species' minimum interval requirement for low-severity fire. To illustrate the scale of the problem, the NSW Flora Fire Response Database (DPIE, unpublished data) has a defined fire response (seeder, sprouter, etc.) for 3086 plant species, but an estimated primary juvenile period (minimum threshold) for only 474 of these, and no information about responses to fire of different severity or season. There is no equivalent database for animals. These gaps can only be filled by field work targeting a range of species and fire regime conditions, most practically via natural experiments such as chrono-sequences (Driscoll *et al*. 2010). Studies collecting this information are ongoing, spawned in part by the opportunity presented by the 2019–20 wildfires.

- The response of trees is a high priority because they contribute significantly to carbon storage and ecosystem health. The main questions here are rates of mortality and recruitment under different combinations of fire frequency and severity and drought.
- The extent of internal patchiness of fires and its effect on survival of plants and animals, and the viability of their populations, needs much more attention, especially in the context of prescribed burns because they are patchier than wildfires.
- Fire interacts with many other processes that potentially can have synergistic impacts on biodiversity. Drought is probably the most significant because it is always associated with major wildfire seasons, but post-fire impacts of feral herbivores and predators, and of weeds, have all been identified as problems for certain species (see Chapters 17, 18). Much more needs to be understood about these effects: how pervasive they are, how they play out and how to ameliorate them (Driscoll *et al*. 2010).
- There is a need to compare different types or methods of prescribed burning. In particular, hazard reduction burns are likely to cause different effects to cultural burns because they are generally larger, more severe and are lit around the perimeter of the treated area. One knowledge gap here is the extent to which the conventional practice of hazard reduction burning can incorporate and adopt cultural burning principles and practice, and the extent to which such modification may maintain the benefits of hazard reduction burning but reduce its risks and detriments.
- Alternatives to frequent prescribed burning applications should be explored. This includes the potential that fire risk may be reduced when forests are left long unburnt, and that more focus should be placed on the human dimensions of wildfire risk, such as ignitions, property preparedness, defence and evacuation and wildfire suppression.

Recommendations

- There is much still to understand about the influence of fire regime factors on species survival, growth and reproduction, emissions and carbon. Prescribed burning and cultural burning are two of those factors that need more research.
- Climate change will squeeze species through drought and decreased fire intervals. Prescribed burning should not be applied in a way that makes this worse.
- All aspects of wildfire risk (to human, economic and environmental values) and all mitigation strategies (prescribe burning, suppression, town planning) need to be evaluated holistically to identify optimum, cost-effective strategies.

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