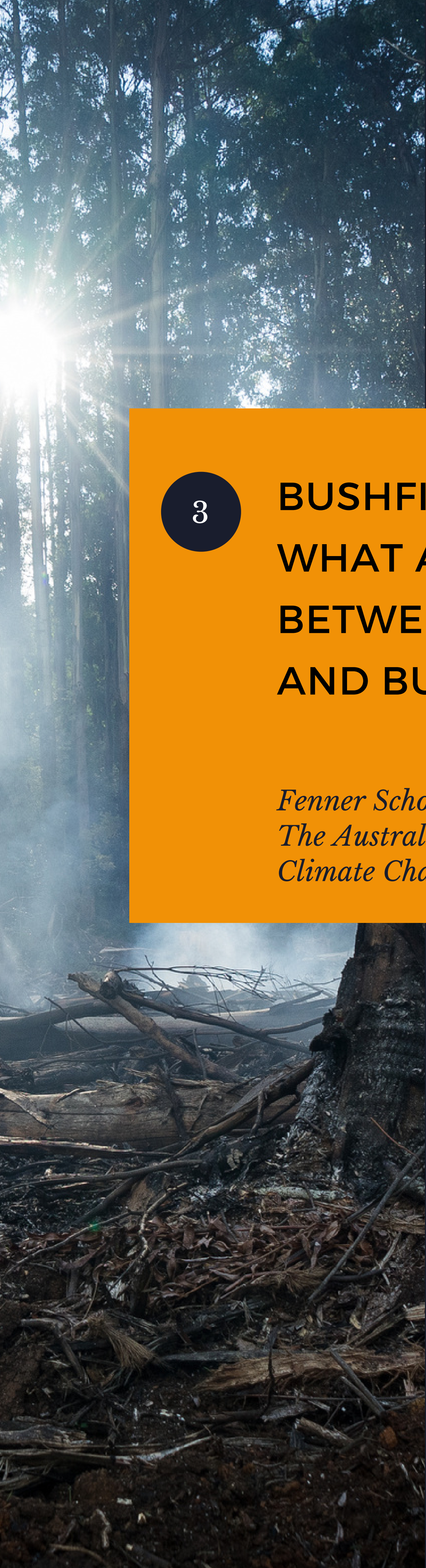

BUSHFIRE RECOVERY PROJECT

3

BUSHFIRE SCIENCE REPORT NO. 3: WHAT ARE THE RELATIONSHIPS BETWEEN NATIVE FOREST LOGGING AND BUSHFIRES ?

Fenner School of Environment & Society,
The Australian National University; and Griffith
Climate Change Response Program, Griffith University

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This report is one of a series of Bushfire Science Reports prepared by the Bushfire Recovery Project (see www.bushfirefacts.org). The reports aim to present the latest evidence from the peer-reviewed scientific literature about bushfires, climate change and the native forests of southern and eastern Australia.

Reports in the Bushfire Science series are:

No. 1 How does climate affect bushfire risks in the native forests of south-eastern Australia?

No. 2 How do the native forests of south-eastern Australia survive bushfires?

No. 3 What are the relationships between native forest logging and bushfires?

No. 4 What are the ecological consequences of post-fire logging in the native forests of south-eastern Australia?

No. 5 What is the role of prescribed burning of native forests in reducing the risk of infrastructure loss to bushfires?

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INTRODUCTION

As Australian communities, governments and businesses continue with the demanding task of planning for more resilient landscapes in light of the impacts of the 2019-2020 forest mega-fires, it is timely to review the scientific evidence underpinning forest management. Here we provide an update of the published scientific literature to address a critical forest management issue – the relationships between native forest logging and bushfires. We synthesise the relevant scientific literature in relation to four key questions with a focus on bushfire risk for the native eucalypt forests of eastern and southern Australia:

1. What drives the incidence of fire?

2. What drives the severity of fire?

3. How does logging affect the four fire switches?

4. Does logging affect fire severity?

KEY POINTS

- Climate, including fire weather, is the primary driver of the incidence and severity of fire.
- Native forest logging increases the severity at which forests burn. This is likely because such operations increase the volume of coarse woody debris, and the density of elevated and vertically oriented live fuels. In addition, by opening up the forest canopy, logging operations probably alter microclimate conditions, causing drying of soils and fuel.
- In Mountain Ash and Alpine Ash forests, high severity bushfires may be occurring at a frequency greater than the time it takes the canopy tree species to reproduce and this could cause demographic collapse, leading to a transition to a new ecosystem dominated by other species.

1.What drives the incidence of fire?

The distribution of fire activity across Australia is primarily driven by the seasonality of rainfall (Murphy et al., 2013) in combination with vegetation (and hence fuel) attributes (Russell-Smith et al., 2007). To understand the characteristics of bushfires in native forests, there is a need to view such environments as climate-vegetation-fire systems. For example, in the monsoonal tropics of northern Australia, rainfall is highly seasonal. Most of the rain falls in the warmer months and annual dry periods coincide with cooler conditions. In this system, annual grasses are the dominant fuel. The coincidence of abundant fine fuels and dry conditions on an annual basis permits high fire frequency over large areas. When combined with frequent early-mid dry season ignitions, this results in low intensity fires. Replacement of indigenous use of fire with contemporary land management is leading to altered timing of burning, and increasing fire intensities (Russell-Smith et al., 2003, 2007).

In contrast, the surface fuel that enables fires to spread in the eucalypt forests of southern Australia is sclerophyll litter and fire is concentrated primarily in the summer months. The seasonality of fire in the eucalypt forests of southern Australia is largely a result of the moisture content of the fuel (Gill and Zylstra, 2005; Murphy et al., 2013; Williamson et al., 2016). Bushfires in southern Australian eucalypt forests are generally much less frequent but more intense (and consequently more severe) than in other biomes in Australia (Table 1) (Murphy et al., 2013). They are usually associated with periods of extended drought, typically associated with El Niño and Indian Ocean Dipole events that dry out fuels that would normally be too moist to burn (Murphy et al., 2013; Boer et al., 2020). Infrequent days of extreme fire danger associated with high temperatures and strong, dry winds contribute to large areas of burnt vegetation in southern Australia (Williamson et al., 2016).

Forest type	Surface fuel type	NPP (t C/ha/year)	Crown fire propensity	Typical intensity (*extreme*) (kW/m)	Typical fire interval (*extreme*) (years)	Typical season of burning
Tropical rainforest	Rainforest litter	7.9	None	0 - 100 (5000 – 10000)	> 100	Spring
Temperate tall eucalypt forest	Sclerophyll litter	6.9	Facultative	5000 – 10000 (>50000)	20 – 100 *(> 100)*	Summer
Temperate eucalypt forest	Sclerophyll litter	5.5	Facultative	1000 – 5000 (10000 – 50000)	5 – 20 (20 – 100)	Spring - Summer
Temperate rainforest	Rainforest litter	4.4	None	0 - 100 (100 – 1000)	> 100	Autumn
Temperate heath	Sclerophyll litter	3.3	Facultative	1000 – 5000 (10000 – 50000)	20 -100 *(> 100)*	Autumn
Temperate eucalypt woodland	Tussock grass	2.2	None	100 – 1000 (1000 – 5000)	20 – 100 *(> 100)*	Summer
Tropical eucalypt woodland	Tussock grass + sclerophyll litter	2.1	None	1,000 – 5000 (5000 – 10000)	5 – 20 *(20 – 100)*	Spring
Brigalow	Perennial grass	1.7	Facultative	100 – 1000 (5000 – 10000)	20 – 100 *(> 100)*	Spring - Summer
Monsoonal tropical eucalypt savanna	Tussock grass + ephemeral grass	1.4	None	100 – 1000 (5000 – 10000)	2 – 5 (5 – 20)	Winter - Spring
Mallee	Sclerophyll litter	0.9	Facultative	1000 – 5000 (10000 – 50000)	20 - 100	Spring - Summer
Tropical semi-arid eucalypt woodland	Tussock grass	0.4	None	100 – 1000 (1000 – 5000)	5 – 20 (20 – 100)	Spring - Summer

Table 1. Major Australian fire regimes for forests and woodlands (modified from Murphy et al., 2013).

A useful model for understanding the incidence of landscape fire is the four switch model (Bradstock, 2010). The four "switches" are:

(1) sufficient fuel that is (2) dry enough to burn with (3) weather conducive to fire-spread, and (4) an ignition source.

Should any one of these switches be off, fire will not occur (Bradstock, 2010; Murphy et al., 2013; Williamson et al., 2016). Climate exerts strong control over all of these switches through a temporal hierarchy of biomass production to produce fuel (years to decades), drought cycles that dry out fuel (years), periods of severe fire weather (intra-annual or seasonal), to heat waves and lightning storms (daily and hourly) (Williamson et al., 2016).

2. What drives the severity of fire?

Fire weather is the most important influence on fire behaviour, fire severity and the amount of area burned in a fire (Price and Bradstock, 2012; Penman et al., 2013b; Collins et al., 2019). In forests, fire spread requires a near-continuous layer of sufficiently dry fuel on the ground surface. In eucalypt forests, dead leaf litter performs this role. Flames burning dry leaf litter alone are rarely taller than approximately 1.5 m high and spread slowly even under the most severe conditions (Burrows, 1999; Cheney et al., 2012). Severe fire behaviour occurs only when standing vegetation ignites, and becomes the most severe when plants provide sufficient vertical continuity to conduct fire into the canopy and create a crown fire.

Vertical continuity of fuel is determined by the size of gaps between the plant strata, and by the flammability of the plants and plant strata (Zylstra et al., 2016). Large gaps, such as those often occurring in tall forests, act as barriers to vertical fire spread because air in the convective plume cools as it rises. Plant flammability varies with the density of plant crowns and the traits and moisture of their leaves, and larger gaps between strata can be crossed by larger flames, or when the plants above the gaps are more ignitable (Zylstra et al., 2016). The shrub or understorey layer is critical to this, as it is closer to the ground than the canopy, yet tall enough to produce large flames.

Larger flames are produced when larger shrubs or saplings burn, when the plants are more flammable, and when more plants contribute to the one flame (Cheney et al., 2012, Zylstra et al., 2016). More understorey plants burn together when they are close enough to ignite each other, and this arises from both understorey density and the angle of the flame. Steep slopes and strong winds cause flames to tilt and ignite neighbouring plants. The more open the overstorey, the less protection it provides from wind and the more likely it is that understorey plants can ignite neighbouring plants and produce a severe fire.

HOW?

Native forest logging increases the severity at which forests burn. This is likely because such operations increase the volume of coarse woody debris, and the density of elevated and vertically oriented live fuels. In addition, by opening up the forest canopy, logging operations alter microclimate conditions, causing drying of soils and fuel, and allowing stronger wind to affect fires on the forest floor.

3. How does logging affect fire switches?

Although there are well established empirical relationships between logging and fire severity, the mechanisms underlying such relationships are currently not well studied or understood. However, logging has the potential to alter fire activity through its impacts on three of the four switches in the model developed by Bradstock (2010): sufficient fuel, fuel moisture, and the prevalence of ignition points (Penman et al., 2013a).

Switch 1: Sufficient fuel

Fuel levels are rarely a factor limiting fire in eucalypt forests, as fire is able to spread through leaf litter on the ground when only 3 to 4 tonnes per ha is present (Burrows, 1999). If fuel is removed by fire, it can be quickly replenished (Sullivan et al., 2012). Rates of litter accumulation vary between eucalypt forest types and with seasonal conditions. In some types of eucalypt forest, fuel accumulates in as little as five months (Raison et al., 1983). Fuel is almost never limiting in wet sclerophyll forests (Cawson et al. 2018). The amount of litter generally reaches an equilibrium loading as a function of time since fire (Gill and Zylstra, 2005).

Fire weather, as measured by the Forest Fire Danger Index (FFDI) has been shown to be the best predictor of woody fuel consumption in Australian southern eucalypt forests (Hollis et al., 2011). Under extremely dry conditions, coarse woody debris can contribute substantially to the total heat released in a fire. It also increases the difficulty of suppressing and extinguishing a fire (Sullivan et al., 2012). Following logging of native forest, 20 to 80% of the biomass can remain in the forest as slash residues (the parts of trees left on site when timber is harvested) (Raison and Squire, 2008). Values for slash residue from logging in Australian eucalypt forests range from 20 tonnes per ha in selectively logged, dry forest to 500 tonnes per ha in clearfelled wet forest (Keith et al., 2014). Logging slash increases the risk of wildfire during the first few years after harvesting (Raison and Squire, 2008).

Thinnings logging operation before fire - Central Highlands

To minimise the risk of wildfire, slash burning is sometimes practiced, but is not universal. However, fuel in slash residue does not always completely combust, and 50% of woody debris can remain on site (Keith et al., 2014), increasing the difficulty of fire suppression.

A study of the impacts of forest thinning found that near surface and elevated shrub fuels re-established to levels comparable with unthinned forest within 6 to 10 years (Proctor and McCarthy, 2015). However, the levels of coarse woody debris increased and did not break down over 15 years. The re-arrangement of fine fuels may temporarily reduce the difficulty of fire suppression but the increase in coarse woody debris may increase the difficulty of extinguishing fires (Proctor and McCarthy, 2015). Another simulation modelling-based study of thinning in Alpine Ash forest in Victoria found that thinning decreased surface fuel hazard ratings but increased the amount of coarse woody debris by 50% and increased the density of saplings tenfold (Volkova et al., 2017), thereby increasing the vertical continuity of fuels. Vertically continuous fuels have a major influence on flame height (Cheney et al., 2012; Zylstra et al., 2016) and make fire suppression more difficult. Other studies suggest that mechanical thinning has limited effects on reducing fire severity and may even increase fire risk (Buckley and Cornish, 1991; La Sala, 2001). Work by Volkova and Weston (2019) showed that thinning alone had no net effect on fuel hazard measured directly afterward.

Thinnings logging operation after fire - Central Highlands

Notably, few studies have examined the long-term trajectory of shrub fuels. A study of the post-disturbance fuel trajectory in wet sclerophyll forests showed that the vertical distances between fuel strata in young forests are smaller than in older forests, and smaller in post-logging forests than in forests disturbed by fire (Cawson et al., 2018). An analysis of woodlands and open forest in south-eastern Australia found that across forest communities, forest stands dominated by larger trees had significantly lower cover of midstorey vegetation, significantly lower elevated fuel heights and significantly lower elevated fuel hazard scores (Wilson et al., 2018). A recent empirical analysis (Taylor et al., 2020) examined relationships between thinning and fire severity in different forest types burnt in the 2009 Black Saturday fires. The effectiveness of thinning varied depending on forest type and stand age. For crown burns, there were no thinning effects in ash-type eucalypt forests. For mixed species forests, thinning reduced the probability of crown burn in young stands but increased it in older stands. Data for the fire severity category of crown burn/crown scorch revealed that thinning generally elevated fire severity, irrespective of stand age, forest type or fire zone. This work indicates that except for 20-40 year old mixed species forest subject to a crown burn, proposals for thinning to reduce fire severity (such as those by AFPA (2020)) have limited support.

Switch 2: Fuel moisture

The moisture content of surface fuel has an important effect on the likelihood of ignition and the rate of spread of fire (Catchpole, 2002). In the southern eucalypt forests of Australia, litter fuels may often not be subject to burning because of their high moisture content. Eucalypt fuels with moisture contents higher than approximately 15% are difficult to ignite and fire spread is unlikely to be sustained if the moisture content of the surface litter exceeds 22% (Sullivan et al., 2012).

The moisture content of dead fuels lags behind changes in meteorological conditions. The lag time and the equilibrium moisture content of the fuel differs depending on the particle size, density and degree of decomposition. Under normal conditions, fine fuels may respond rapidly (1 to 2 hours) to changes in temperature and humidity, whereas large branches and logs may take hours to several days (Sullivan et al., 2012). Under conditions of extended drought, however, even heavy fuels can become very dry (Taylor and Webb, 2005).

Vegetation cover exerts strong control over fuel characteristics, especially fuel moisture, through its effects on sub-canopy environmental conditions (Bonan, 2008), including temperature, wind turbulence, and the amount of light. The effect of the canopy is most clearly demonstrated in closed forests. In the case of Mountain Ash forests, forest structure (and age) greatly influences water yield and the rate of evaporation from soil and leaf litter. Old growth Mountain Ash forests yield significantly more water (Vertessy et al., 2001), and have significantly lower evaporation rates from the forest floor (McJannet et al., 1996).

Loss or fragmentation of the vegetation canopy results in warmer and drier conditions which increase flammability (Miller et al., 2007). The abrupt forest edges created by vegetation clearing, whether for logging, road building or other purposes (see Figure 1) result in increased drying (Murcia, 1995, Briant et al., 2010) with fuels drying out faster than they otherwise would (Ray et al., 2005). In Australian forests, for the same ambient values of temperature and humidity, fuel moisture contents may be 2 to 3% lower in full sun than in shade (McArthur, cited in Catchpole, 2002).

Figure 1. Clearfell logging in Melbourne's water catchment in Gippsland, 2019.

Evidence from tropical forests suggests that these drying effects may increase over time and that drying effects become more severe as the amount of landscape-level forest fragmentation increases (Briant et al., 2010). At a larger scale, extensive vegetation clearing and tree thinning is an additional form of climate forcing that in Australia has made the climate of the southwest and southeast of the continent warmer and drier (Bonan, 2008).

Switch 4: Ignition

Human-caused ignitions, whether by arson or accident, are a common source of ignitions of bushfires in south-eastern Australia. Arsonists are most likely to light fires in easily accessible areas close to roads (Penman et al., 2013a), and most fires occurring close to roads are caused by human actions (Collins et al., 2015). The extensive road networks in wood production forests (Taylor and Lindenmayer, 2020) increase the potential for arson or unintentional fire ignitions, and this coincides with drier fuels on forest edges, adding further to fire risks.

4. Does logging affect fire severity?

A global review of the effects of logging on fire regimes in moist forests concluded that logging increases the risk of fire in a range of forest types. It found that the changes in conditions associated with logging (to microclimates, stand structure, fuel characteristics, the prevalence of ignition points and patterns of landscape cover) increased fire severity (Lindenmayer et al., 2009). Observations of the effects of logging on fire regimes in Australian forests come mostly from post-fire analysis of bushfire severity in Mountain Ash and Alpine Ash forests, although more recent work indicates that such patterns also extend to mixed species forests (Taylor et al., 2020). All studies have found that forest flammability is related to stand age (stand structure).

Four separate studies of fire severity following the February 2009 fire in Victoria found similar results. Price and Bradstock (2012) found that the probability of crown fire was significantly higher in recently logged areas than in areas logged decades earlier, therefore highlighting the likely ineffectiveness of logging as a fuel treatment. Similarly, Attiwill et al. (2014) showed that the likelihood of crown fire was 30 to 40% lower in long unlogged areas than in regrowth forest. They found that intermediate age classes (older than 10 years and younger than 80 years) experienced the greatest fire severity (Attiwill et al., 2014) and regrowth forests were twice as likely as old growth forests to burn at high severity. Taylor et al. (2014) also analysed fire severity following the 2009 fire in Victoria. After controlling for fire weather, they found a strong non-linear relationship between the age of a Mountain Ash forest and fire severity. High severity fire occurred more often in stands between the ages of 7 and 36 years. High severity fire almost never occurred in stands <7 years old and was also reduced in mature and old growth stands. The probability of crown consumption decreased with stand age and rarely occurred in forests aged >300 years. Young stands were seven times more likely to experience canopy-scorching bushfire than old growth stands (Taylor et al., 2014) (Figure 1). Further evidence of the left-skewed stand-age-fire severity relationships shown in Figures 1 and 2 has been found in more recent analyses (Taylor et al. 2020) and they extend beyond ash-type eucalypt forests to include drier, mixed species forest.

THE METRICS

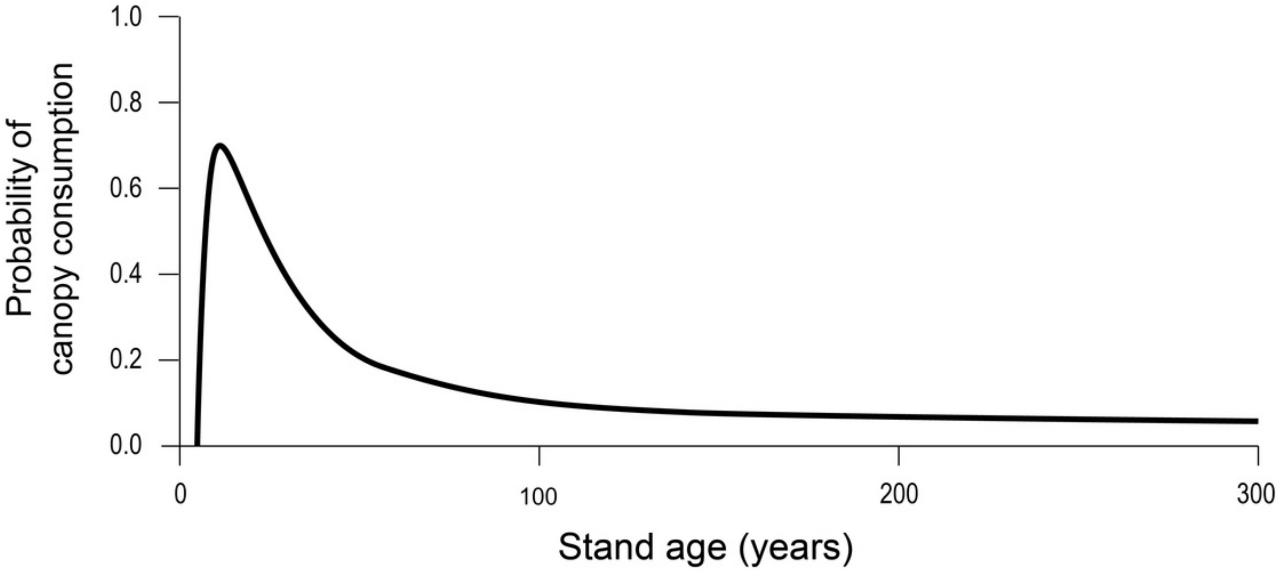

Figure 1. Relationships between stand age and the probability of canopy fire (modified from Taylor et al., 2014).

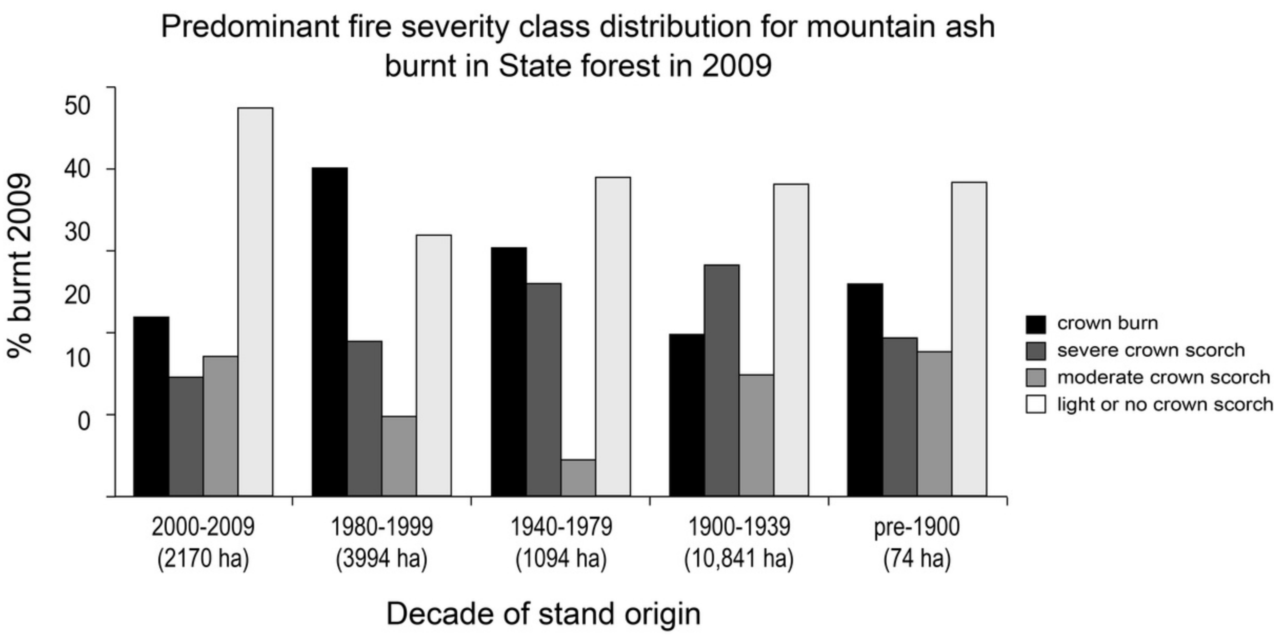

Figure 2. Relationship between stand age and the probability of canopy fire (Attiwill et al., 2014).

The empirically quantified relationships between logging and fire severity in the Mountain Ash forests of Victoria has led to the proposal that the interacting effects of wildfire and logging are creating a landscape trap in which dense regrowth stands of young forest are repeatedly burnt before they reach maturity (Lindenmayer et al., 2011). Zylstra (2018) found a highly significant positive feedback between fire and disturbance in forests of the Australian Alps with disturbed Alpine Ash forests (burnt rather than logged) eight times more likely to burn than undisturbed forest. The weakest feedback occurred in open forest but post-disturbance forests were still 1.5 times more likely to burn than mature forests. Crown fires were mostly confined to post-disturbance stands. A key issue is the spatial extent of logged areas and the potential for such changes in landscape cover to influence landscape-level contagion in wildfire. Figures 3 and 4 show the extent of logged areas in parts of the Central Highlands of Victoria where a predominance of young, logged and regenerated forest may be giving rise to more widespread, high severity wildfires than would historically have been the case.

While fire-atmosphere interactions will, of course, increase fire intensity and rate of spread, past forest disturbance also clearly impacts fire severity. The studies by Taylor et al. (2014 and 2020) and Attiwill et al. (2014) demonstrate that crown fire is significantly less likely to occur in older and unlogged forests. This includes under extreme conditions, such as the most extreme bushfire conditions recorded in Australia to date (i.e. those experienced during the 2009 Victorian 'Black Saturday' fires) (Taylor et al., 2014). In that case, when the rapidly spreading crown fire encountered mature and old Mountain Ash forest with no history of logging, it dropped dramatically in severity to a slow-spreading surface fire (Cruz et al., 2012).

The studies by Taylor et al. (2014) and Attiwill et al. (2014) demonstrate that crown fire is significantly less likely to occur in older and unlogged forests.

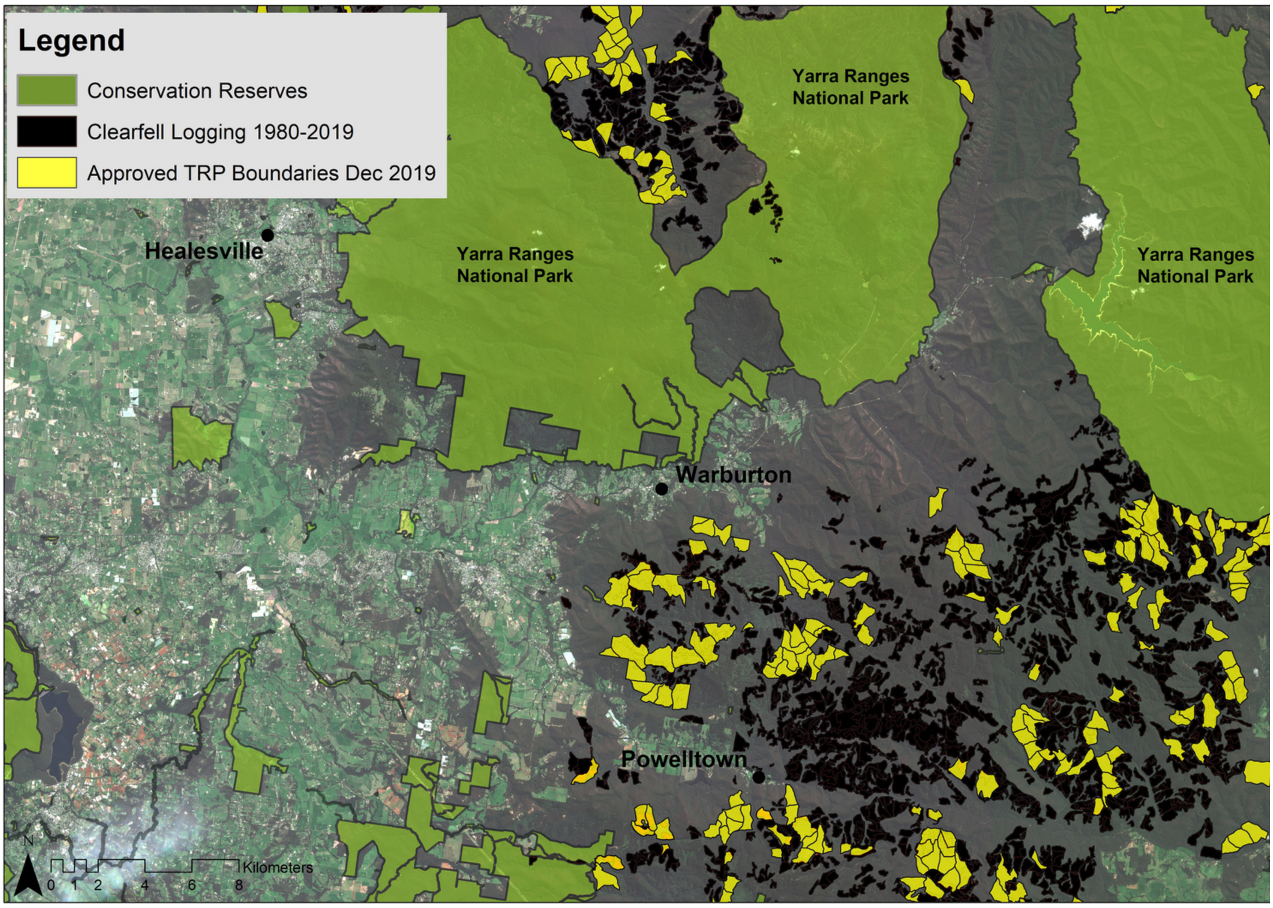

Figure 3. The spatial extent of logged areas and places proposed for logging under the Timber Release Plan (TRP) in part of the Central Highlands of Victoria.

Analysis of recent fire history in Victoria demonstrates that fires are recurring at shorter intervals than natural return intervals. There has been a significant increase in the annual area burnt in the last 17 years (2003-2020) compared to the preceding 52 years (1950-2002) (Lindenmayer and Taylor, 2020) with many areas experiencing multiple wildfires within short timeframes (5 to 6 years). An earlier analysis of fires in the Australian Alps produced similar results. Since 2002, 85% of the Australian Alps bioregion has been burnt by large wildfires, with 12% being burnt twice or more in that time (Bowman et al., 2014). The short return interval of fire poses the risk of demographic collapse in forest ecosystems dominated by long-lived obligate seeders (e.g. Mountain Ash and Alpine Ash) (Burns et al., 2015, Lindenmayer and Sato, 2018). These systems should burn no more frequently than every 75 to 150 years (McCarthy et al., 1999) and can persist without fire for 500 years or longer (Wood et al., 2010). Fuel moisture is a key constraint on fire in Mountain Ash forests. As fuels become drier under climate change, managing fire will become a major challenge (Cawson et al. 2018).

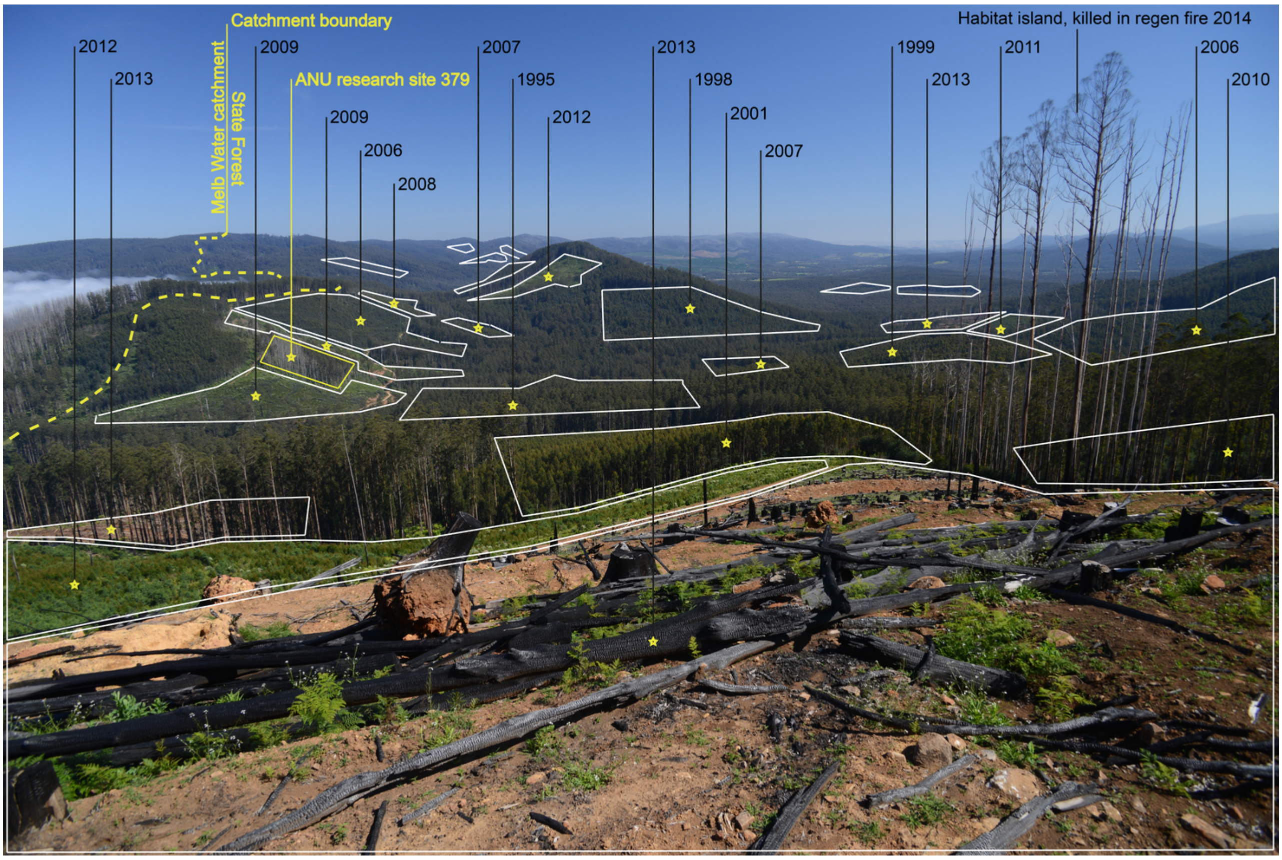

Figure 4. Wood production landscape in the Central Highlands of Victoria showing the location of multiple cutblocks. Photo taken in 2014.

Clearfell and burn practice used in native forests.

"The high frequency of fires means that tree species like Mountain Ash and Alpine Ash do not reach an age where they produce viable seed before being burnt. This greatly increases the risk that the forest ecosystem will collapse."

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