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Interacting and compounding impacts: fire and forestry in the 2019–20 wildfires

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Summary

- Climate and weather are often the dominant drivers of fire behaviour, but the effects of forest management (including logging) also can be important and must not be ignored.
- An increasing body of evidence indicates that there is a significantly greater risk of high-severity fire in logged forests relative to undisturbed forest. This includes evidence from the 2019–20 wildfires.
- Elevated logging-induced forest flammability can last for several decades after cutting and is a particular concern in areas subject to prolonged and widespread industrial forestry.
- Logging prior to fire can simplify stand structure and reduce the potential for recovery following fire, an effect resulting from the limited prevalence for cutover areas to transmit biological legacies like large living and dead old trees from pre- to the post-fire stands.
- Logging soon after fires – sometimes termed 'salvage logging' – has negative effects on many elements of forests, from microbes and soils to plants and vertebrates.
- The 2019–20 wildfires left few and often small areas of unburnt refugia within the fire footprint. Some of these areas may be important for promoting post-fire biodiversity recovery. It will therefore be important to ensure that such areas are not further disturbed, such as by logging operations.
- The links between logging and fire and their combined effects on flammability, as well as on forest condition and biodiversity, suggest a need to cease widespread industrial logging in Australian native forests. This includes the cessation of post-fire (salvage) logging.
- Cessation of industrial logging is needed to reduce the number of stressors in many forest ecosystems which have been subject to frequent, widespread and severe wildfires in the past 25 years. Cessation of logging is also essential for

increasing the extent of old growth forest cover, where fire severity is lowest and post-fire ecological recovery is strongest.

- Protection from fire of the extensive areas of flammable forest created by past logging operations demands the development of new technologies such as drone fleets or satellite platforms, along with expanded capacity for proven techniques such as specialist remote-area fire-fighting crews for rapid detection and expeditious suppression of ignitions.

Introduction

The 2019–20 Australian wildfires had major impacts on forests (Collins *et al*. 2021), biodiversity (Ward *et al*. 2020), carbon emissions (van der Velde *et al*. 2021), human health and property (Inspector General for Emergency Management 2020). The extreme temperatures and prolonged drought, including climatic conditions associated with climate change, contributed to the extent and severity of the 2019–20 wildfires (van Oldenborgh *et al*. 2021; Mackey *et al*. 2021b). Indeed, climate and fire weather are major contributors to fire behaviour (Jones *et al*. 2020). Key attributes of the 2019–20 wildfires, such as severity, were strongly linked with fire weather (Collins *et al*. 2021; Lindenmayer *et al*. 2021). Beyond climate and weather as key drivers of fire, other factors that can influence fire behaviour include slope, aspect, fuel loads and fuel distribution (Catchpole 2002; Bradstock 2010; Sullivan *et al*. 2012). In addition, past disturbance, such as past fires and logging, can influence the severity of fire (Lindenmayer *et al*. 2020, 2021; Bowman *et al*. 2021; Taylor *et al*. 2021). Hence, how the forest is treated before the fire can have impacts on the fire itself (Lindenmayer *et al*. 2021) (see Box 19.1). Here, we briefly examine some of the evidence for the compounding and interacting effects of fire and logging, both in a pre-fire and post-fire (salvage) logging context. Many of these insights come from work in Victoria. The bulk of empirical work from which we draw examples has been conducted in the wet eucalypt forests of Victoria dominated by obligate seeder tree species such as mountain ash (*Eucalyptus regnans*) and alpine ash (*Eucalyptus delegatensis*), which are often killed by high-severity wildfires. However, some of the general patterns we have outlined are also found in drier mixed species forests (Taylor *et al*. 2020) and dry lowland forests (Lindenmayer *et al*. 2021; Taylor *et al*. 2021). We therefore suggest that some of the general principles derived from these bodies of work apply in other forest types, including those elsewhere in Australia and overseas.

Box 19.1. Does thinning reduce fire severity?

Thinning involves removing a proportion of the trees and hence some of the biomass in a forest and leaving a proportion of the overstorey intact (Helms 1998). There is some evidence that thinning has some effectiveness in North American forests and particularly when it is accompanied by prescribed burning (Kalies and Yocom Kent 2016). However, in an Australian context, thinning and prescribed burning are often not interlinked because of the damage done by the latter to sawlog value (Taylor *et al*. 2021). Indeed, empirical analyses after the 2009 wildfires and the 2019–20 wildfires have indicated that thinning often makes limited difference to subsequent fire severity and, in some cases, it can even elevate fire severity (Taylor *et al*. 2020, 2021).

We have structured our chapter around six key sections. We first outline evidence for relationships between logging and elevated fire severity. We then discuss how the post-fire recovery process can be impaired in previously logged forests (before they were then burnt). The third section of this chapter outlines evidence for yet other compounding interactions between logging and fire in a spatial and topographic context. Some of the impacts of post-fire logging are briefly described in the fourth section. Each of these negative impacts interacts with others, leading to major compounding negative effects on biodiversity and ecosystem condition. We present a new conceptual model to illustrate these effects and the overall disturbance burden faced by some forest landscapes. The final two sections focus on some overarching conclusions and associated general recommendations for forest management. We do not explore the direct effects of logging on biodiversity or key ecosystem processes, such as through the removal of key elements of stand structure (like large old trees) (Lindenmayer *et al*. 2016), altering plant species composition (which can influence animals such as through degrading foraging resources) (Au *et al*. 2019), or reducing the amount of old growth (Lindenmayer and Taylor 2020a) and other habitat attributes that provide critical habitat for a wide range of species (Lindenmayer *et al*. 1990, 2019a; Lefoe *et al*. 2022).

Key findings

Prior to the fire: logging makes forests more prone to high-severity wildfire

Several studies, encompassing a range of datasets in different jurisdictions, contain evidence that logged forests are at risk of an increased probability of high-severity wildfire (Attiwill *et al*. 2014; Bradstock and Price 2014; Taylor *et al*. 2014; Bowman *et al*. 2021; Lindenmayer *et al*. 2021). Some of these studies have found a non-linear relationship between stand age (which is often a measure of time since logging) and fire severity. This occurs because there is a very low probability of high-severity fire in very young forests soon after logging and in long-undisturbed forests (e.g. stands exceeding 100 years of age) (Taylor *et al*. 2014). However, stands aged between ~10 and 40 years of age had a seven times increased risk of high-severity wildfire relative to very young and long-undisturbed forest (Taylor *et al*. 2014) (Figs 19.1, 19.2).

Further analyses of a different dataset from the 2009 wildfires also revealed that the probability of a crown burn was significantly greater in young stands than older stands (Taylor *et al*. 2020). Evidence of such stand-age-fire-severity relationships were recently uncovered in analyses of the 2019–20 wildfires in north-eastern Victoria (Lindenmayer *et al*. 2021). Similarly, data in Bowman *et al*. (2021) show that logging has a marked effect on the probability of high-severity fire. Moreover, there was a broadly similar probability of high-severity fire in logged forests under the mildest conditions as in undisturbed forests under high and very high fire danger conditions (Bowman *et al*. 2021). Attiwill *et al*. (2014) suggested there was no relationship between logging and fire severity, but the data they presented actually showed that crown fires in the 2009 wildfires occurred twice as frequently in regrowth compared to old growth forests. The likelihood of crown fire was 30–40% lower in long-unlogged forests (exceeding 100 years old) than in regrowth forest (Attiwill *et al*. 2014). Attiwill *et al*. (2014) found that forests older than 10 years and younger than 80 years experienced the greatest fire severity. Yet other authors who have claimed there is no link between logging and fire severity (e.g. Tolhurst and McCarthy 2016) actually did not test for such effects.

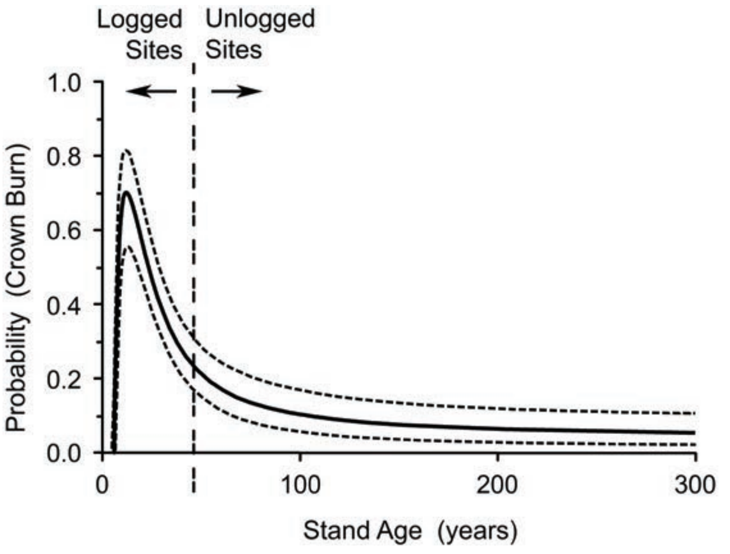

Fig. 19.1. The non-linear relationship between stand age and the probability of canopy fire or crown burn. The probability of crown burn peaks at ~40 years before declining as stands approach 80–100 years old. The solid line is the mean of the posterior prediction of the probit regression model fitted to a stratified sample of the data, and the dashed lines are 95% credible intervals. (Redrawn from Taylor *et al*. (2014))

Fig. 19.2. (A) Logged and regenerated mountain ash forests; and (B) logged and regenerated forest that was burnt at high severity in the 2009 wildfires. (Photos: Elle Bowd and David Lindenmayer)

There are several reasons why young logged and regenerated forests are at risk of elevated fire severity. These include (1) the additional volumes of logging slash that remain in cutover areas (and that are not consumed in regeneration burns), (2) the vertical structure of fuels that can move a surface fire to the canopy (Zylstra *et al*. 2016), (3) the loss of mesic elements such as the tree fern layer from logged forests (Blair *et al*. 2016), (4) the promotion of high-densities of flammable plant taxa in logged forest (Bowd *et al*. 2021), and (5) drying of soils (Bowd *et al*. 2019) as well as hotter microclimatic conditions in young logged and regenerated forests.

We argue that because forest management (including logging) is one of the factors contributing to fire severity, it is critical to mitigate that impact because it is one of the few drivers of fire severity over which we have direct control. This is especially important in areas like the Central Highlands of Victoria where there has been extensive disturbance as a result of past logging, and much of the landscape is dominated by highly flammable young and intermediate-aged forest (Taylor and Lindenmayer 2020).

Prior to the fire: logging impairs biological legacy effects and curtails post-fire recovery

There is a large body of work illustrating that disturbances such as wildfires leave behind many kinds of biological legacies (*sensu* Franklin *et al*. 2000) that can be incorporated into the regenerating forest and facilitate the recovery of biodiversity and the forest stand (Blackhall *et al*. 2017). Biological legacies include living and dead trees and other plants, carcasses, seeds, eggs and living animals. As an example of the role of biological legacies in burnt Australian forests, populations of small mammals that survived the 2009 wildfires were important for population recovery in burnt areas, including those burnt at very high severity (Banks *et al*. 2017).

The prevalence of many kinds of biological legacies after fire will be a function of forest condition at the time of a fire. Forests that are old growth at the time of a severe fire will produce many more large living and dead trees, and the regeneration of vegetation will be more advanced, than forests that are younger and previously logged at the time of a severe fire (Smith *et al*. 2014; Lindenmayer *et al*. 2019b; Bowd *et al*. 2021). For example, the multi-aged forests that are a key part of the habitat requirements of many species in Victorian mountain ash forests (Lindenmayer *et al*. 1990) can be produced where an old growth is burnt, but not when a young logged forest is burnt (Lindenmayer *et al*. 2019b).

One of the important legacies remaining after wildfires is the presence of unburnt patches within the overall footprint of a fire. These patches can be valuable refugia for some species (Berry *et al*. 2015) and in some cases help speed post-fire species recovery (Lindenmayer *et al*. 2009). Spatial analyses of the 2019–20 wildfires indicate that, within the fire footprint, there were relatively few and typically very small patches of unburnt vegetation (Mackey *et al*. 2021a). Several studies have shown that long-unburnt refugia can be important for some elements of biota (Dixon *et al*. 2018) and we argue that such places should not be subject to yet further disturbances (like logging) wherever possible.

Other compounding effects: logging on steep slopes and 'downstreaming' effects

There may be additional compounding effects of logging on fire beyond those outlined above. First, fire burns more severely in forest on steep slopes (Catchpole 2002), and the 2019–20 wildfires were no exception (Lindenmayer *et al*. 2021). A spatial analysis of areas logged under past Victorian Government timber release plans has revealed that many stands on steep slopes (exceeding 30°C) have been cut (Taylor and Lindenmayer 2021). The combination of young, flammable regrowth forest on steep terrain means that such areas will be at risk of elevated severity wildfire for many years.

A second kind of compounding effect is the potential for high-severity fires to burn beyond logged forest into adjacent unlogged areas. That is, there is potential for spatial dependence in fire behaviour with close-by areas being more likely to suffer from similar levels of fire severity than forests located far apart. There is strong evidence of spatial dependence in high-severity fire following the 2009 fires (Taylor *et al*. 2020) and the 2019–20 fires (Taylor *et al*. 2020; Lindenmayer *et al*. 2021). In extensively logged areas, there is a risk of a landscape trap developing whereby widespread young, flammable forest promotes repeated high-severity wildfires and effectively precludes stand maturation. This positive feedback loop maintains ecosystems as young, flammable forest unable to grow to a less-flammable old growth state (Lindenmayer *et al*. 2011). That is, fire and logging 'beget more fire'. Without extensive and expensive management interventions, such a landscape trap can result in regeneration failure in dominant eucalypt species and replacement by non-forest vegetation, ultimately leading to ecosystem collapse. There is increasing evidence that a landscape trap is developing in the ash-type eucalypt forests across eastern Victoria, and in some other obligate-seeder dominated forests. For example, a recent paper from Tasmanian wet forests (Furlaud *et al*. 2021) concluded that:

> *the application of the moisture model flammability function, in which fire risk decreases with stand development … suggest[s] that widespread logging and wildfire can increase landscape-scale fire risk, as regenerating stands are more prone to high- severity fire than mature stands, which is consistent with the notion of a 'landscape trap'.*

After the fire: post-fire ('salvage') logging has major negative impacts

A controversial form of logging is post-fire logging, sometimes called 'salvage logging' (see Box 19.2). Under such operations, sawlogs and pulplogs are removed from burnt areas in an attempt to recover some of their economic value. Salvage logging is a double set of disturbances; a high-severity fire followed by intensive logging operations on the fire grounds.

Box 19.2. The effects of post-fire 'salvage' logging

Post-fire logging is occurring in southern New South Wales and north-eastern Victoria following the 2019–20 wildfires. Approximately 3500 ha of forest in Victoria will be subject to post-fire logging (VicForests 2020). The extent of post-fire logging in New South Wales remains unclear, but it is occurring in native forests in many regions throughout the state (Fig. 19.3). Post-fire logging occurred in Victoria following wildfires in 1939, 1983 and 2009 and is a form of logging that is widely practised globally, not only after fires but also after windstorms and insect attack (Thorn *et al.* 2018). There have been numerous studies of post-fire logging globally and almost all of them highlight the negative ecological effects of such operations (Thorn *et al.* 2018). In an Australian context, salvage logging has been shown to (1) deplete populations of hollow-bearing trees that are critical habitat for cavity-dependent wildlife (Lindenmayer and Ought 2006), (2) reduce bird species richness (Lindenmayer *et al.* 2018), (3) alter plant species composition and deplete populations of resprouting taxa like tree ferns and promote flammable plant species (Bowd *et al.* 2018), and (4) deplete soil organic carbon and plant-available nutrients including nitrate and phosphorus, and change the structural composition of soil (e.g. an increased sand fraction) (Bowd *et al.* 2019). Where areas subject to post-fire logging are then regenerated, the subsequent young stands are characterised by a prolonged period of elevated risk of high-severity wildfire.

Fig. 19.3. Post-fire logging following the 2019–20 fires in the Eden region of southern New South Wales. (Photo: Nina Lindenmayer)

The majority of post-fire logging operations (and associated studies) in Australian forests have been conducted in wet ash-type eucalypt ecosystems where the dominant tree species are obligate seeders that are killed by wildfires. Following the 2019–20 wildfires, other kinds of burnt ecosystems also were targeted for post-fire logging, such as those dominated by drier lowland forest in southern New South Wales. Post-fire logging operations are inappropriate in such environments because most of overstorey trees in such forests were not killed by the fires, but rather resprouted and were recovering naturally before being cut down.

Does it matter if logged forests are more flammable?

Some authors have argued that because logging occurs in limited parts of the forest estate, then relationships between logging and fire are trivial (Bowman *et al*. 2021). This argument does not hold for those forest types, landscapes and regions where logging operations are concentrated. For example, 65% of all native forest clearcut logging in Victoria occurs in Wet and Damp forest types (Taylor and Lindenmayer 2019). The elevated flammability of numerous cutblocks throughout these forest types in such regions is therefore of concern, both for the long-term persistence of the forest and its associated biota, but also for the ability to limit the spread of high-severity fires in these environments.

Lack of congruence between the impacts of logging and fire

There is an extensive literature that pivots around the hypothesis that if logging 'mimics' the impacts of wildfires, then there will be limited effects of logging on biodiversity and ecological recovery (Florence 1994). This is, in part, because species will have co-evolved with high-intensity disturbances. Such thinking has, at times, been used to justify the widespread use of silvicultural systems like clearcutting in ecosystems where the natural fire regime is high-severity, stand-replacing wildfire (Attiwill *et al*. 1994). However, a substantial body of work shows that logging and fire have markedly different impacts on many elements of biodiversity and on ecosystem structure and condition. For example, unlike logging, wildfires leave behind numerous living and dead biological legacies. These differences influence the structure and species composition of forest stands recovering after disturbance (Lindenmayer *et al*. 2019b). Indeed, studies comparing the impacts of the 2009 wildfires and ongoing clearcutting in the montane ash forests of the Central Highlands of Victoria, showed major differences in responses of birds to the two kinds of disturbance (Lindenmayer *et al*. 2019a). Moreover, the high-intensity, mechanical nature of logging operations can compact soils and destroy subterranean plant propagules, including the root systems of tree-ferns and broadleaved shrubs, which would otherwise survive and resprout under natural fire regimes (Blair *et al*. 2016; Bowd *et al*. 2018). Natural and human disturbances in these ecosystems are therefore not ecologically congruent.

Perhaps what is more important than the clear difference in the effects of fire and logging is that ecosystems and the species they contain must now deal not with one form of disturbance or the other, but with both – and, as indicated throughout this chapter, the compounding and interactive effects of both. This problem is perhaps best illustrated by the parlous state of the mountain ash forests of the Central Highlands of Victoria in which the legacy of wildfires and logging (as well as past widespread post-fire logging) has resulted in less than 1.16% of the ecosystem being old growth forest – between 1/30th and 1/60th of what it was historically (Lindenmayer and Taylor 2020a). The paucity of old growth forest resulting from both fire and logging (and their interaction such as salvage logging) matters for many species and species assemblages in these forests (Lindenmayer *et al*. 2019a).

Finally, some of the issues around the interrelationships between fire and logging have major consequences for the sustainability of timber yields from the forest industry *per se*. Notably, ~30% of the forest that was planned for logging in Victoria in the five years from 2019 under that state's Timber Release Program was burnt in the 2019–20 fires; this number approached almost 60% for individual regions such as East Gippsland (Lindenmayer and Taylor 2020b). Figures from southern New South Wales are even higher and vary from 74–80% in the Southern and Eden Regional Forest Agreement areas, respectively (Forestry Corporation 2020). The frequency of high-severity fire in several parts of Victoria means that there is a high probability (~80%) that some forest types (like those dominated by ash-type eucalypts) will be burnt before the trees reach an age where they are suitable for sawlog production (Cary *et al*. 2021). This has economic and ecological ramifications as it indicates there is both declining certainty in future sawlog supply and potentially increasing pressure to log remaining unburnt forest (which often has high conservation value for threatened forest-dependent species (Taylor and Lindenmayer 2019)) – thereby adding to the overall extent of disturbed forest in the landscape. Indeed, recent analyses (Mackey *et al*. 2021b) showed that unburnt refugia within the footprint of the 2019–20 wildfire were both rare and typically small (1–3 ha in size). Further disturbance of these areas, such as through logging operations, may well exacerbate the problems for species persistence created by the widespread, high-severity wildfires that characterised the 2019–20 fire season.

Responses to long-term elevated flammability

The evidence that logging contributes to elevated fire severity is compelling. These effects can last for several decades after forests have been cut and then regenerated, leaving a prolonged flammability risk (Taylor *et al*. 2014). What can be done to counter such problems in flammable forest environments? One step is to expand the old growth forest estate as this is where fire severity is typically lowest. Another, interrelated, approach is to invest in new technologies for early detection and rapid suppression of fires, thereby increasing the chances of forest maturing to an old growth stage. These technologies include the development or enhanced use of (1) drone fleets and satellites to quickly detect ignitions like those triggered by lightning strikes, and (2) aerial assets to dispatch targeted water bombing or specialist remote-area fire-fighting crews to rapidly suppress ignitions and limit fire spread in highly flammable environments.

Conclusions

Climate and weather are typically the dominant drivers of fire behaviour including key aspects of fire regimes such as fire severity. However, other factors contribute to fire severity, and forest management is one of them. Although its effects are generally less pronounced than those of climate and weather, that does not mean we can ignore the potential benefits of changing forest management to reduce fire severity and promote forest conservation.

The amount of disturbance in some forest types in south-eastern Australia is very high and is likely increasing because of climate change. The persistence of biodiversity and the maintenance of ecosystem condition in these environments is likely to depend on attempts to reduce the overall disturbance burden and reduce the number of drivers of decline. Removing industrial logging from threatened forest communities is a key way to reduce the number of drivers.

Logging elevates the probability of subsequent high-severity wildfire, an effect that lasts for up to 40 years after cutover stands have been regenerated. Logging simplifies stand structure and when regenerating stands are then burnt, biotic recovery is impaired. Logging and fire may interact at large spatial scales (and well beyond a logged area),

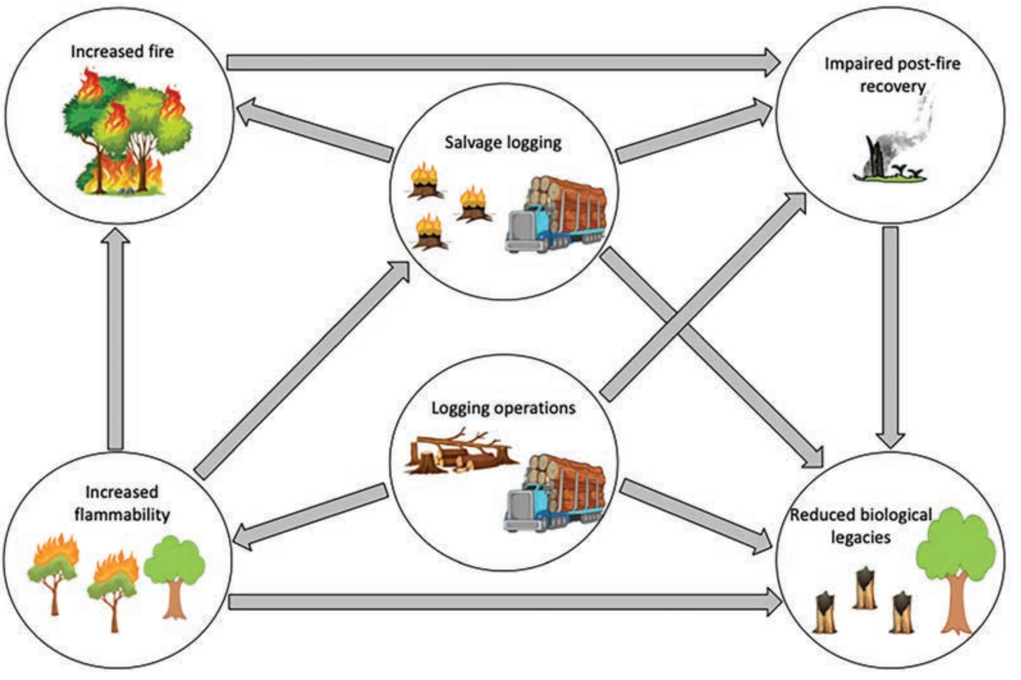

Fig. 19.4. Conceptual model showing compounding and interacting fire and logging effects in native forests. The model relates primarily to wet montane ash-type eucalypt forests where the dominant trees are obligate seeders and typically killed by high-severity stand-replacing wildfires.

potentially leading to more extensively burnt areas than would occur in the absence of logging. Post-fire logging has significant negative impacts on ecosystem condition and ecological recovery – from microbes and soils to plants and vertebrate groups such as birds and arboreal marsupials. The interactions and compounding impacts of forestry and fire described in this chapter are summarised in Fig. 19.4.

Recommendations

- The cessation of industrial logging from native forests is one of the key steps governments can take to reduce the problem of high fire severity. States such as Western Australia have begun to do this, and Victoria plans to do the same by the end of this decade (2030). This transition in Victoria should be brought forward and the exit from the native forest logging industry made far earlier, given the extent of repeated fires that have already occurred in that state over the past 25 years (Lindenmayer and Taylor 2020b), coupled with the fact that logging adds to the fire proneness of native forests.
- Forest management policies and practices should aim to ensure that as much of the forest estate is as old as possible. This is because old growth forests are where fire severity is lowest (Attiwill *et al.* 2014; Taylor *et al.* 2014; Lindenmayer *et al.* 2021) and value for many elements of biodiversity is often highest (Lindenmayer *et al.* 1990, 1999, 2019a). Efforts to boost the amount of old growth forest also will be important in the event of future fires, as such areas will more likely support more of the key kinds of

biological legacies that make regenerating stands more suitable for species to persist in and/or eventually recolonise burnt forests (Lindenmayer *et al*. 2019b).

- Land managers should focus on protecting and conserving fire refugia and limiting any additional disturbances in unburnt patches within already extensively disturbed landscapes.
- There should be a ban on all post-fire logging in native forest (i.e. no more salvage logging). The impacts of such practices are substantial, and inconsistent with principles of ecological sustainability. Hence, no resource management agency or government should countenance such destructive practices.
- The elevated levels of forest flammability that are a legacy of past widespread logging practices demand new technologies for the detection and suppression of wildfires in young forests.
- Much of the work on interactions between logging and fire severity has been in tall, wet ash-type eucalypt forests and additional research in other forest types is warranted.

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