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Logging elevated the probability of high-severity fire in the 2019–20 Australian forest fires

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In their recent article, D. Bowman et al.[1] analysed the severity of the 2019–20 Australian eucalypt forest fires. Their findings are consistent with those of our original article[2], that fires are more severe where logging operations take place. Indeed, their Fig. 3 (ref. [1]) showed that for a given Forest Fire Danger Index (FFDI), logged forests always burned with a higher probability of canopy damage than undisturbed forest (Fig. 1 in this article). Thus, they have demonstrated that logging increased the probability of canopy damage by 5–20% (Fig. 1). In general, the likelihood of canopy damage was similar for logged forests under the mildest conditions as they were for undisturbed forests under high and very high fire danger conditions (Fig. 1). In summary, data from ref. [1] indicate that fire weather had the greatest influence on fire severity over the broader landscape but such effects were amplified by management effects (namely, logging) where these occurred.

Beyond the work by Bowman et al.[1] empirically confirming our original conclusions that logging contributes to fire severity[2], we believe there are some substantial problems in their study that warrant further discussion.

Inappropriate combination of crown fire and canopy damage

Bowman et al.[1] examined canopy damage (sometimes termed crown scorch) rather than crown fire. For the purposes of their paper and this discussion, we believe that distinguishing between these categories of impact is crucial to quantifying relationships between logging and fire severity. Crown scorch affects foliage 8–16 times higher than the flames[3], so that scorch heights of 20–25 m have been recorded from low intensity (200–500 kW m^{-2}) prescribed burns[3]. These scorch heights exceed the canopy height of many dry sclerophyll forests[4] but resulted from flame heights small enough ($\leq$2 m) to be controllable using the most direct and effective means[5,6]. In contrast, crown fires are the most severe and uncontrollable kind of fire behaviour in which entire trees are burning[7], representing flame heights 8–16 times those in the crown scorch category.

Substantial research[8–12] demonstrates that crown fire is far less likely in older and unlogged forests. In logged forests, including those subject to intensive clearcutting, stand age can effectively be reduced to zero. For many forests studied to date, there is an initial (~10 yr) decline in high-severity fire after logging, followed by an extended period (of at least 40 yr) of increased probability of high-severity fire, particularly under extreme fire weather conditions[9,11]. The likelihood of crown fire then declines as forests further mature[13]. For example, a previous study[11] showed that in the 2009 fires in Central Victoria, crown fire was seven times more likely in young Mountain Ash regrowth forest (much of which was logged and subsequently regenerated) compared to unlogged old-growth forest.

In contrast to the strong trends quantified for crown fire in the broader scientific literature (for example, refs. [9,11]), there are weaker trends for canopy damage (which is a composite category of both canopy fire and canopy scorch)[8,9,11]. However, despite the problems in their overall methodology, the data presented in Bowman et al.[1] still show a significant relationship between logging and the probability of canopy damage (Fig. 1).

Logging and lag effects on flammability

A second problem in Bowman et al.[1] is their argument that the rate of native forest logging has declined in eastern mainland Australia and by implication was of limited importance relative to other factors. This ignores long-term lag effects on fire severity resulting from widespread past logging[11]. It also ignores the fact that current logging is concentrated within particular forest types which are often of high value for threatened forest-dependent species[14]. For example, 65% of clearcutting has occurred in wet and damp forest types across Victoria. The impacts of increased fire severity due to past logging can be significant for those localized areas and particular forest types.

Fire severity and plantations

Bowman et al.[1] argue that plantations are at risk of high-severity wildfire. This effect is unsurprising as trees in plantations are typically young (and usually harvested before they reach 25 years old). This places them within an age cohort where they are highly flammable and at risk of high-severity fire. In addition, they state that non-native conifer plantations in New South Wales suffered a greater proportion of area sustaining severe canopy damage (70%), compared with *Eucalyptus* plantations and native forests, where the proportion was similar (51% and 52%, respectively). Plantations are often subject to one or more thinning events which may elevate the risk of high-severity fire (as occurs after thinning in some Australian native forests)[10,15,16]. Despite the flammability of plantations, the time required for sawlog production from them is generally far shorter relative to most native forests. This means that even

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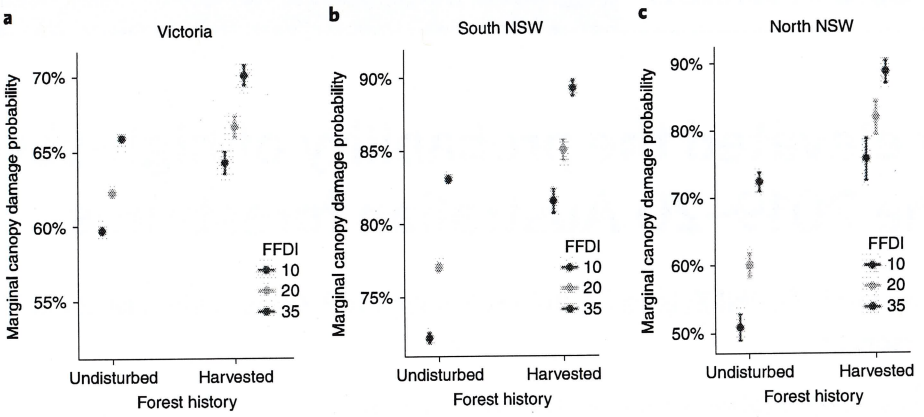

Fig. 1 | Revised version of Fig. 3 from Bowman et al.[1]. The figure has been simplified to show the comparison raised by ref. [2], which is the influence of logging on fire severity. FFDI shows higher values corresponding to extreme conditions (red) with high conditions (yellow) and moderate conditions (green). **a**–**c**, Victoria (**a**), South New South Wales (NSW) (**b**) and North NSW (**c**).

under high fire frequency regimes, there is a greater chance that plantations can generate a sawlog crop relative to native forests[17].

Potential 'downstream effects' of logging on spatial patterns of high-severity fire

A key area for future work is to quantify the effects of logging and other forest management regimes beyond site scales to include landscape and regional scales[18]. This is important given the finding of Bowman et al.[1] that spatial relationships were a key driver of high-severity fire. As these authors proposed this was a result of fire runs, the factors that initiate such runs warrant examination. High-severity fire spread may lead to problems such as mass spotting as well as the formation of pyrocumulonimbus events and associated dry lightning strikes, triggering further ignitions[7]. It is likely that spotting and pyrocumulonimbus events are among the factors contributing to high fire severity runs (together with terrain and wind speeds). If that is the case, then factors such as widespread historical logging, which has occurred in eastern Australia (and which increase the likelihood of high-severity fires; Fig. 1) will probably exert influence in a 'downstream' area (along the direction of fire spread) beyond the logged sites[12]. Indeed, a recent paper from Tasmanian wet forests[12] 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'..."[19]. A 'landscape trap' can occur where natural and human disturbances produce young, flammable vegetation that is at increased risk of repeated re-burning at high severity, thereby precluding it from growing to older, less flammable vegetation[19].

Concluding comments

We fully agree with Bowman et al.[1] that climate and weather are key drivers of fire behaviour. However, it is critical not to ignore the influence of practices like logging for which we have direct agency. This concern was validated by Bowman et al.[1] in their analysis of canopy damage (Fig. 1). Their data clearly show the effect of logging on the probability of high-severity fire[1] and such findings, coupled with the results of other empirical analyses (for example, refs. [9,11]), indicate that forest management can lead to long-term elevated risks of high-severity fire. Even in mild fire weather, logged forests were more likely to suffer high-severity fire than undisturbed forests under more severe fire weather conditions (Fig. 1). If rates of disturbance by logging are minimized, canopy damage can be mitigated and the risk of uncontrollable high-severity fires that endanger humans and biodiversity can be reduced.

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Author contributions

D.B.L. and P.Z. jointly conceived the concept for the paper. D.B.L. drafted an initial manuscript. R.K., C.T., M.W., J.E.M.W. and P.Z. provided extensive review.

Competing interests

The authors declare no competing interests.

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