REVIEW

Timber Harvesting Does Not Increase Fire Risk and Severity in Wet Eucalypt Forests of Southern Australia

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Abstract

Lindenmayer *et al*. proposed that logging makes "some kinds of forests more prone to increased probability of ignition and increased fire severity." The proposition was developed most strongly in relation to the wet eucalypt forests of south-eastern Australia. A key argument was that logging in wet forests results in drier forests that tend to be more fire-prone, and this argument has gained prominence both in the literature and in policy debate. We find no support for that argument from considerations of eucalypt stand development, and from reanalysis of the only Australian study cited by Lindenmayer *et al*. In addition, there is no evidence from recent megafires in Victoria that younger regrowth (<10 years) burnt with greater severity than older forest (>70 years); furthermore, forests in reserves (with no logging) did not burn with less severity than multiple-use forests (with some logging). The flammability of stands of different ages can be explained in terms of stand structure and fuel accumulation, rather than as a dichotomy of regrowth stands being highly flammable but mature and old-growth stands not highly flammable. Lack of management of fire-adapted ecosystems carries long-term social, economic, and environmental consequences.

Introduction

Lindenmayer *et al.* (2009) proposed that "logging can alter key attributes of forests." They stated that: "These changed attributes" (including microclimate, stand structure, and species composition) "may make some kinds of forests more prone to increased probability of ignition and increased fire severity."

The literature contains no definition of fire-prone and no methodology to define it. Rather, fire-proneness is a general term that encompasses factors such as climate (including amount and distribution of rainfall, drought frequency, temperature, and proportion of time when forest fuels are dry enough to burn), fuel characteristics (amount, structure), and ignition sources (especially lightning). Fire-proneness therefore most usually refers to location, as in "Australia is the most fire-prone continent and country on Earth" (Bryant 2008). If vegetation is to survive in fire-prone areas, a fire-prone site must support vegetation adapted to fire, as "in any 1 year numerous fires burn hundreds of thousands to millions of hectares of savannas, other grasslands, bushland, and forests . . . fire is an essential component of many ecosystems, a natural instrument for maintaining biodiversity and hence a tool that enables many species to survive" (Bryant 2008). In contrast, the view of Lindenmayer *et al.* (2009) is apparently that it is the vegetation that makes the site more fire-prone.

The review by Lindenmayer *et al.* (2009) was based on the authors' experience and a search of 650 published articles. However, they cite only one Australian study—Mueck & Peacock (1992)—on the basis of which they concluded that "logging in some moist forests in south eastern Australia has shifted the vegetation composition toward one more characteristic of drier forests that tend to be more fire prone." That conclusion was extended to management implications based on young forests being more fire-prone and burning at higher severity, than older forests (Lindenmayer *et al.* 2011); logging thereby creates "fire traps" (Lindenmayer 2010). These two themes are seen in the scientific literature (for example, Driscoll *et al.* 2010) and are vigorously debated by lobby groups concerned with forest management (for example, Poynter 2010; The Wilderness Society 2010).

Our contribution to this debate aims to improve the basis for management decisions affecting the wet eucalypt forests of southern Australia. First, we give a brief overview of the ecology and silviculture of these forests. We then address the following questions:

- Are there changes in key attributes (particularly vegetation characteristics) following timber harvesting that result in a shift to a more "fire-prone" vegetation, such as a vegetation type that is more typical of drier environments?
- Do younger forests (particularly those regenerated after logging) burn with greater severity than older forests?

Ecology and silviculture of wet forests of *Eucalyptus* in southern Australia

We focus on eucalypt forests described as "tall open-forests" (Specht 1970; mature height >30 meter and canopy cover of 30–70%). Other terms are "wet sclerophyll forests" (Beadle & Costin 1952), "eucalypt tall open forest" (National Forest Inventory 1998), and "wet eucalypt forests" or "tall wet forests" (particularly in Tasmania; Kirkpatrick *et al.* 1988). We use "wet eucalypt forests" to embrace all these terms.

These forests grow where annual precipitation exceeds 1,000 mm in temperate climates of southern New South Wales, Victoria, and Tasmania, and in the Mediterranean-type climate of south–west Western Australia. Winters are cool and moist, with occasional snow at elevations >800 m in south-eastern Australia, while summers are warm and dry. Extreme heat (>40°C) and dryness (relative humidity <10%) associated with strong winds blowing from the continental interior are common in summer. These forests across southern Australia are ecologically comparable in their structure, species composition and stand dynamics.

Wet eucalypt forests in Victoria

Two major species in Victoria's wet eucalypt forests are mountain ash (*Eucalyptus regnans* F. Muell.) and alpine ash (*Eucalyptus delegatensis* R.T. Baker) that together cover 561,000 hectares (Attiwill 2003) of Victoria's 7.8 million forested hectares. Infrequent high-intensity fires on a natural time scale of 75–150 years kill most of the trees in these forests (Ashton 1976, 1981; Mackey *et al.* 2002). The resultant seed fall from the canopy results in regeneration of predominantly even-aged stands. Lower intensity fires may lead to partial stand replacement and multiple age classes (Ashton 2000; Turner *et al.* 2009b).

Timber harvesting of alpine ash and mountain ash is permitted in State forest covering about half of the range of ash forest. Harvesting predominantly involves clear-felling in coupes averaging 16.5 hectares. Scattered trees or clumps of trees are retained for habitat. The debris (logging slash) is burnt to create an ash-bed on which seed is sown.

Wet eucalypt forests in Tasmania

Wet eucalypt forests occur extensively throughout Tasmania, from sea level to 900 meters, in areas of moderate to high rainfall and on most soils. They constitute about 25% of the State's forest (3.3 million hectares); 56% of the wet eucalypt forest is production forest, 28% is reserved, and 15% is privately owned (Tasmanian and Australian Governments 2007).

Wet eucalypt forests in Tasmania are dominated by *Eucalyptus obliqua* L'Hérit. and *E. delegatensis*, with smaller areas dominated by *E. regnans* and *E. nitida* Hook. f. The dense multilayered understoreys are dominated either by rainforest species ("mixed forests") or by a variety of broad-leaved tall shrubs and small trees ("wet eucalypt forests"). They have a distinct layered structure dominated by an open eucalypt canopy.

The dense understorey, often dense ground layer, and heavy litter loads in lowland wet eucalypt forests prevent continuous regeneration of shade-intolerant species, including eucalypts (Attiwill 1994). Because regeneration is usually initiated by wildfire, wet eucalypt forests in Tasmania are even-aged in that a cohort of regeneration arises from each disturbance event. As wildfires are rarely intense enough to kill all the overstorey trees (especially of *E. obliqua*), more than one age class of tree is usually present in the same stand (Turner *et al.* 2009a).

The dominant silvicultural system in wet eucalypt forest in Tasmania, as in Victoria, has been clear-fell, burn, and sow (Hickey & Wilkinson 1999). Increasingly, wet eucalypt forests are instead harvested to a variable retention prescription in which about 30% of the forest is retained within the coupe boundary to maintain late successional species and structures important for biodiversity (Baker & Read 2011).

Wet eucalypt forests in south-western Western Australia

Wet eucalypt forests occupy 190,000 hectares in south–west Western Australia (Bradshaw *et al.* 1997; Wardell-Johnson *et al.* 1997). Karri (*Eucalyptus diversicolor* F. Muell.) is the dominant overstorey tree and grows in pure stands or in association with other eucalypts. There is a dense midstorey of trees and woody shrubs which, if unburnt for several decades, attain a height >10 meters and accumulate a substantial layer of leaf litter, twigs, and small branches (Sneeuwjagt 1971; Christensen & Annels 1985; O'Connell 1987; McCaw *et al.* 2002). The effect of past bushfires is evident in the forest age-class distribution at the landscape scale, and in the structure of individual stands that may contain two or more cohorts of trees originating from separate regeneration events (Bradshaw & Rayner 1997; Wardell-Johnson 2000).

The area of wet eucalypt forest on public land that is available for timber harvesting is 60,000 hectares (Conservation Commission of Western Australia 2004). Timber production in mature stands is based on clear-felling with regeneration from retained seed trees or by planting seedlings (White & Underwood 1974; Bradshaw 1999). Prescribed fire is used at the landscape scale to reduce fuel loads and to achieve a variety of land management objectives including biodiversity conservation and forest regeneration.

Does timber harvesting change key attributes that result in regenerated forests becoming more "fire-prone"?

Changes in microclimate

There are changes in microclimate following both logging and wildfire. The trajectory of recovery toward mature forest reflects reestablishment of structural characteristics of the understorey, midstorey, and overstorey layers. Immediately following logging, and particularly after clear-felling and burning, increased solar radiation and wind dry the remaining fuels. With greatly reduced interception and evapotranspiration, however, the soil becomes wetter. As the regeneration grows, the soil becomes drier again. Experience in Western Australia and Victoria is that up to age 10 years, regenerating eucalypt stands do not burn readily (Figure 1, and our analysis of fire severities following recent wildfires in Victoria, presented later in this article). Dense regeneration less than 5 years old may not burn at all even under extreme conditions (Figure 1b). This can be attributed to the absence of a continuous layer of surface fuel, and the presence of dense understoreys that restrict the drying effects of solar radiation and wind on surface fuels.

McCaw *et al.* (2002) observed a rapid decline in shrub density during the first two to three decades of regeneration of karri after logging. Surface fuel in the youngest (11-year-old) regrowth with the densest shrub understorey was consistently moister than in older regrowth or mature forest. Days of very low fuel moisture content (<10%) were less frequent in regrowth stands than in mature forest.

Stand microclimate and fuel moisture regimes are also influenced by further fires as regrowth develops. Stands of *E. regnans, E. delegatensis*, and *E. obliqua* on moist, sheltered sites may develop to maturity over several centuries without fire, with a dense midstorey of shade-tolerant species and a mesic ground layer dominated by ferns and mosses (Gilbert 1959; Hickey 1994; Wells & Hickey 1999).

In the drier Mediterranean-type climate of south–west Western Australia, litter and understorey fuels in *E. diversicolor* forests are sufficiently dry to burn during summer in most years (McCaw & Hanstrum 2003; Matthews *et al.* 2006), predisposing the forest to fires at intervals of one to a few decades (Underwood 1978; Christensen & Annels 1985). There are no shade-tolerant midstorey species of sufficient longevity to replace the eucalypt overstorey, and coupling between understorey and overstorey structure in *E. diversicolor* forest is weak. Thus, stands having a mature overstorey above a recently burnt understorey are common. Conversely, active exclusion of fire from young regrowth stands of *E. diversicolor* has resulted in extensive areas of immature regrowth (20–80 years old) with understoreys unburnt for several decades and with attributes typical of older forest, including deep moss beds and epiphytic ferns (McCaw 2006).

Changes in fuel characteristics

Logging leaves behind all the materials that are not merchantable ("slash"). If slash is left unburned, then it creates an increased short-term fire hazard. Standard practice after harvesting in most wet eucalypt forests is to burn the slash, removing the hazard (Flint & Fagg 2007). Even in drier forests that can regenerate without fire, fire is commonly used to create a seed bed, enhance regeneration, and reduce fuels.

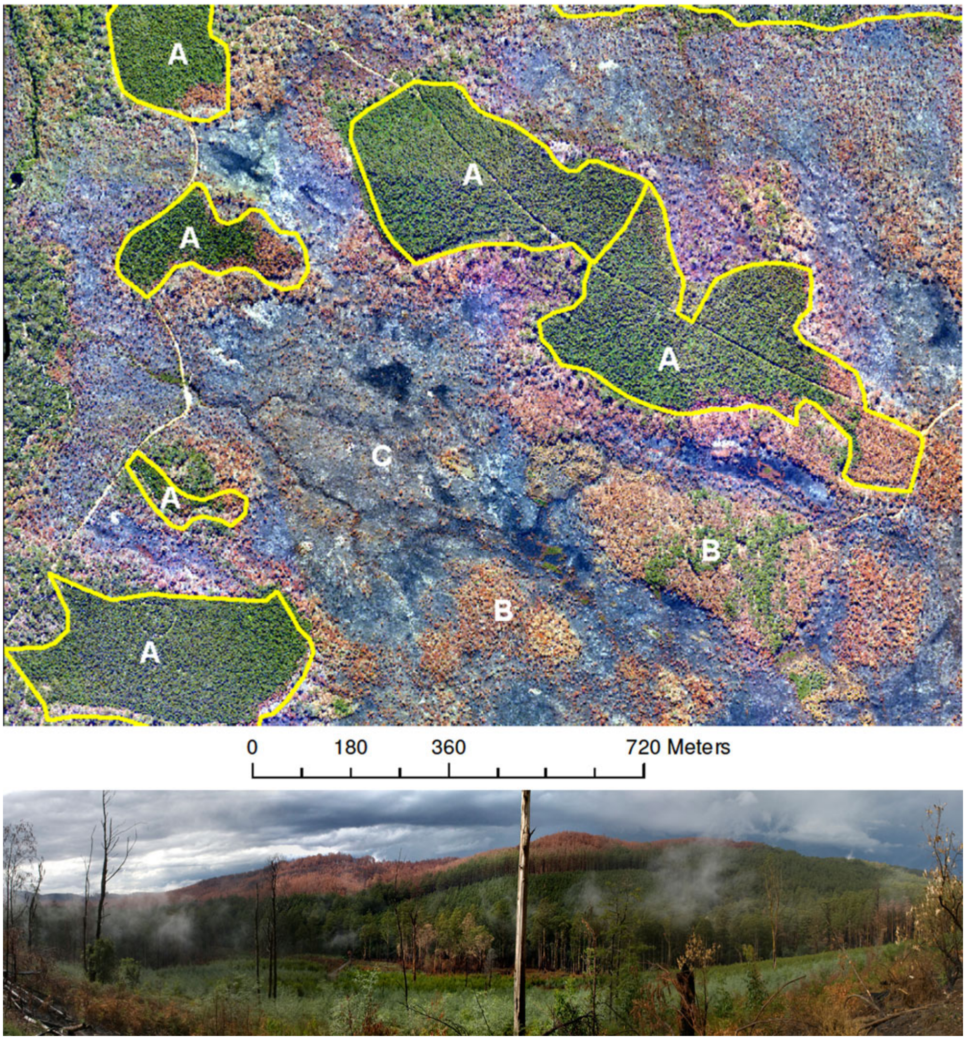


Figure 1 Regenerating forests may not burn. (a) Top: Aerial photograph of part of the area burnt by the Babbington bushfire in south–west Western Australia in February 2012 showing: (A) even-aged stands of *E. diversicolor* regenerated following timber harvesting in 2001 (outlined in yellow), (B) patches of mature *E. diversicolor* forest, and (C) shrubland with scattered *E. marginata*. Fire severity was greater in mature forest than in the regenerated forest, most of which did not burn at all. Some crown scorch is evident on the right-hand side of the regenerated forest patches that were directly in the path of the headfire. (b) Below: Young unburnt regeneration in the foreground and midground with burnt 70-year-old forest in background following 7 February 2009 bushfire in Victoria. The road from where the photo was taken acted as a firebreak preventing the further southerly spread of the fire. (Photo A. Leong, courtesy Victorian Association of Forest Industries).

Forest floor litter in even-aged stands of *E. diversicolor* accumulates for at least seven decades, and elevated dead fuels accumulate for at least three decades, following regeneration (McCaw *et al.* 2002). The longest unburnt wet eucalypt forest in south–west Western Australia on any significant scale (>100 ha) dates from extensive bushfires in February 1937. These stands have a deep, compact litter layer that includes substantial partially decomposed organic matter. Fires under dry conditions will nevertheless fully consume the litter layer down to the mineral soil.

Changes in stand structure and plant species composition

Wet eucalypt forests of south-eastern Australia

The part of the Lindenmayer *et al.* (2009) review with most relevance to Australia is the statement that: "*logging in some moist forests in south eastern Australia has shifted the vegetation composition toward one more characteristic of drier forests that tend to be more fire prone (Mueck & Peacock 1992)*." Mueck & Peacock (1992) is the only Australian study referred to by Lindenmayer *et al.* (2009), yet

Lindenmayer (2010) then restated the proposition as unequivocal and applicable to all moist forests of south-eastern Australia: "*logging has shifted the vegetation toward a composition that is more characteristic of drier forests that tend to be more fire-prone*."

Mueck and Peacock (1992) studied vegetation in chronosequences of "time since harvesting" in East Gippsland, Victoria. Sampling was intensive over three communities ("lowland sclerophyll forest," "damp sclerophyll forest," "wet sclerophyll forest," the latter synonymous with wet eucalypt forest), and five age classes since intensive harvesting with three replicates of each. In addition, there were six replicates of old-growth forest in each of the three communities giving a total of 63 sites. Cover abundance and species frequency data were analyzed by vector fitting and ordination.

Species richness over these communities was relatively low in the first years after harvesting, but equal to that in old-age forest after about 20 years. However, a key finding for wet sclerophyll forest was that the species in regrowth forest after harvesting were more typical of damp sclerophyll forest and occasionally of lowland sclerophyll forest, but not of wet sclerophyll forest.

Williams (1995) reanalyzed the sites and data of Mueck & Peacock (1992) by

- "Analyzing the floristic data collected from the Wet Forest chronosequence in 1991 using ordination and more rigorous statistical methods (including Non-Metric Multi-Dimensional Scaling).
- Comparing the classes of forest used in the chronosequence to the range of wet and damp forests in east Gippsland.
- Sampling the floristics of the chronosequence sites and analyzing the floristic change between 1991 (the date of the Mueck & Peacock sampling) and 1995."

Williams (1995) found that the Mueck & Peacock analysis was misleading. Floristic change between 1991 and 1995 was not *away from both wet and damp old-growth forest* as the 1991 data had indicated. In fact, "floristic change in the logging regrowth sites between 1991 and 1995 was *in the direction of old-growth wet forest*." Williams states: "As the . . . chronosequence demonstrates, without further analysis erroneous conclusions can be drawn."

Williams' explanation of the discrepancy was simple. The older regrowth sites (about 30 years old) were close to the sawmills at Orbost, at lower elevation and drier locations, while the younger regrowth sites were further from Orbost, at higher elevation and wetter locations (Figure 2). The chronosequence data of Mueck & Peacock (1992) were thus confounded by changes in elevation and rainfall between sites.

The detailed and rigorous reanalysis by Williams (1995) both of the original data and subsequent trends thus shows that the claim that the forests were drier and more fire-prone following logging (Lindenmayer *et al.* 2009) now lacks its key supporting evidence.

In fact, much of the literature for south-eastern Australia contains little evidence of marked change in understorey composition after clear-felling and burning in wet eucalypt forest (Cremer & Mount 1965; Ashton 1976; Wang *et al.* 1996; Wang 1997) or in open-forest (Loyn *et al.* 1983; Dickinson & Kirkpatrick 1987). Other studies in wet eucalypt forests have shown that

- Tree-ferns may be reduced in number after logging but not after bushfire (Mueck 1992; Mueck & Peacock 1992; Ough & Ross 1992). However, epiphytic fern species were much less abundant in silvicultural regeneration, and sedge species were more abundant in disturbed areas (Wapstra *et al.* 2003; Courtney *et al.* 2005).
- Most species common in old-growth mixed forest were represented in approximately similar frequencies in 20–30-year-old silvicultural regeneration and wildfire regeneration in wet eucalypt forests dominated by *E. obliqua, E. regnans*, or *E. delegatensis* in Tasmania (Hickey 1994). Hickey concluded that "after a single logging treatment, the vascular plant floristics of silvicultural regeneration were sufficiently similar to wildfire regeneration to assume that in the absence of further logging or fires, the silvicultural regeneration could become mature mixed forest and eventually rainforest." Similarly, Wapstra *et al.* (2003) concluded that "most native vascular species in lowland wet sclerophyll forests will either survive typical native forest silvicultural practices or recolonize harvested areas if suitable sources of propagules are available."
- In forests dominated by *E. regnans* in the Victorian Central Highlands, weed and sedge species occurred more frequently in approximately 10-year-old regeneration following clear-felling and burning than in similar-aged regeneration after bushfire (Ough 2001). Acacias were more abundant in regeneration after clear-felling, whereas resprouting shrubs, tree ferns and most ground-fern species were more abundant after wildfire.

Short-term (first decade) studies of floristic composition after disturbance are thus likely to be misleading, especially in studies where the so-called "control" is old-growth forest. Mueck & Peacock (1992) state that "the ordination suggests that site floristics will tend to revert back to the old growth condition," which accords both with Williams' subsequent resurvey of the wet forest

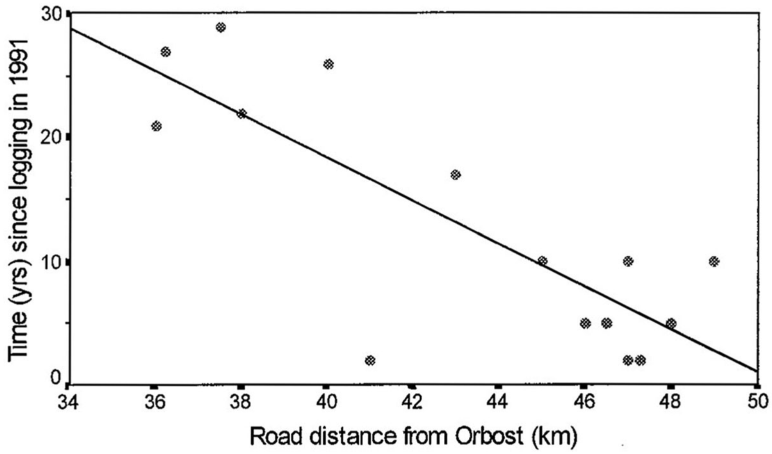


Figure 2 An analysis of the Mueck and Peacock (1992) chronosequence of regeneration following timber harvesting in wet eucalypt forest near Orbost, East Gippsland, Victoria (from Williams 1995). The chronosequence is compromised because the older logging coupes are closer to Orbost at a lower elevation and in drier forests than the younger coupes.

chronosequence which showed that "floristic change in the logging regrowth sites between 1991 and 1995 was in the direction of old-growth wet forest," and with other studies on the response of the vegetation in wet forests to harvesting in both Victoria and Tasmania (for example, Hickey 1994; Harris 2004; Neyland & Jarman 2011).

Wet eucalypt forests in south-western Australia

The understorey of karri (*E. diversicolor*) is highly resilient to disturbance by fire and by clear-felling and slash-burning (Wardell-Johnson *et al.* 2004, 2007). Wardell-Johnson *et al.* (2004) concluded that "despite the dramatic visual impacts of clear-fell and occasional high-intensity fires, recent management regimes in karri forest may have had less impact on floristic assemblages than commonly perceived." These studies cover four age classes from establishment (1–8 years), juvenile (9–30 years), and immature (31–120 years) to mature forest (>120 years). In recently disturbed sites, ephemerals (including introduced species) were common, but "do not remain at the site following the natural restoration of dense cover by native species" (Wardell-Johnson *et al.* 2007). Epiphytic ferns recolonize *E. diversicolor* forest within three decades of clear-felling and high-intensity postharvest burning (McCaw 2006). Wardell-Johnson *et al.* (2007) concluded that time-since-fire (and other disturbance) influenced species richness more than the number of recent past fires because of a high proportion of ephemerals associated with the immediate postfire period.

The peer-reviewed literature thus supports the view that the floristic composition of the wet eucalypt forests of southern Australia is highly resilient to irregular but intense disturbance.

Do younger forests (particularly those regenerated after logging) burn with greater severity than older forests?

First, we question whether an increase or decrease in local fire behavior has significant influence at the landscape level. Aerial imagery taken after the 2009 bushfires in Victoria shows that areas of young logging regeneration comprised some of the only areas unburnt during the high-intensity stages of the wildfire (Figures 3a and b). While these areas are significant in providing some "green" in a largely fire-killed landscape, they are only a small portion of the landscape. Young forests may not burn because the postharvesting regeneration burn removes fine fuels, and the reestablishing regeneration does not generate sufficient fine fuels to carry a fire until 5–10 years (Ferguson & Cheney 2011).

Evidence to assess the propositions of Lindenmayer *et al.* (2009, 2011) that logging alters key attributes resulting in a forest characteristic of drier environments and one that burns with greater severity comes from an analysis of fire severity by age class. The recent, extensive fires in Victoria allow a broad test of these propositions.

The Eastern Victorian (Alpine) Fires, 2003, burnt some 1.07 million hectares; within 50% of the burnt area, the crowns of the trees were either completely burnt or severely scorched (Wareing & Flinn 2003). The Great Divide Fires, 2007, burnt some 1.1 million hectares, with almost 60% of tree crowns completely burnt or severely scorched (Flinn *et al.* 2008). The bushfires of Black Saturday, 7 February 2009, were the most devastating (in terms of loss of life) in Australia's history, and burnt 430,000 hectares, including 70 National Parks and Reserves. The largest was the Kilmore East—Murrindindi Fires that reached the urban–rural interface, 30–40

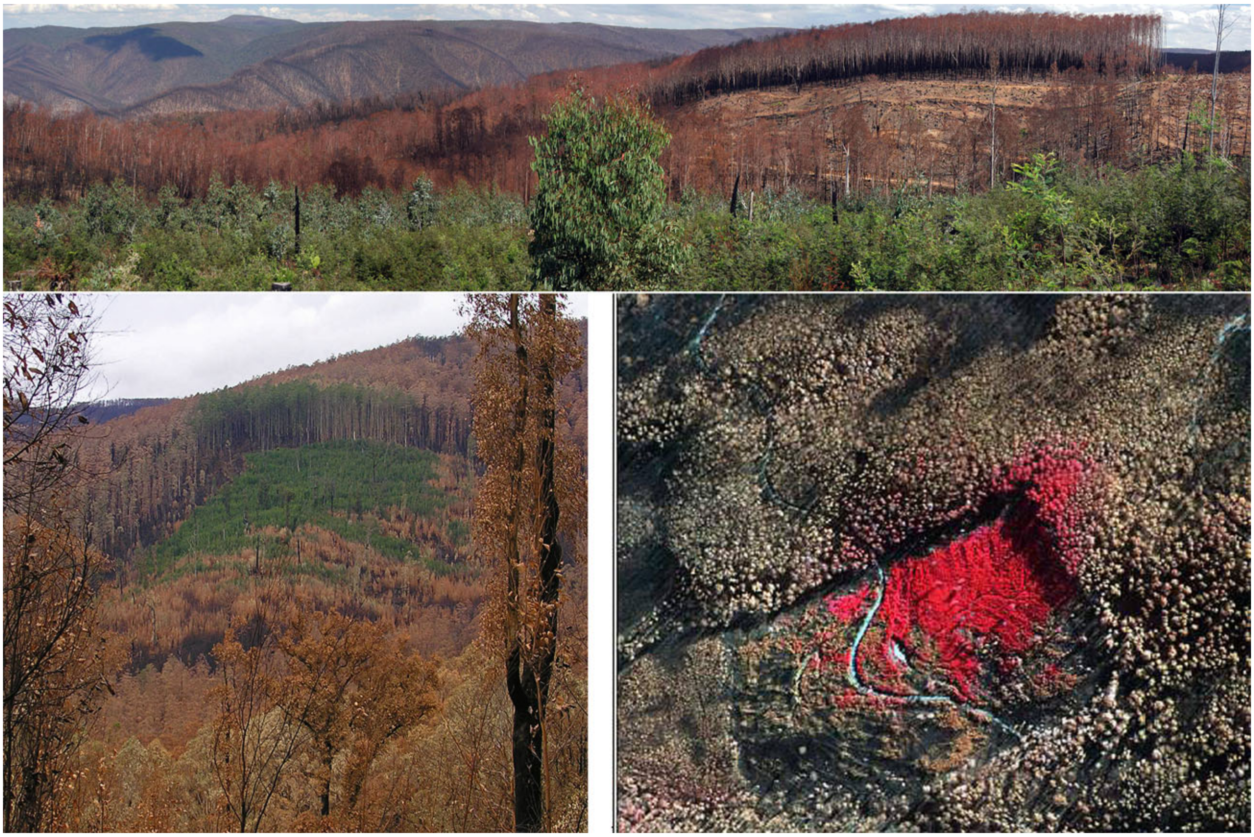


Figure 3 Further examples of young forests remaining unburnt while the surrounding older forest burnt at high intensity. (a) Top: Young alpine ash (*E. delegatensis*) Connors Plain, Victoria, unburnt following the 2007 Great Divide wildfire while the trees in surrounding 1960s regeneration and mature forest were killed (Photo M.F. Ryan). (b) Below: Photo (left) and near infrared image (right) of Keppel's Creek coupe (near Marysville, Victoria) that was harvested in 2003/2004 and burnt in the Black Saturday bushfire, February 2009. Much of the regeneration in the coupe did not burn, while trees in most of the surrounding forest were burnt at high intensity. The false-color red in the infrared image shows green, living canopy. (Photo L. Russell, near infrared imagery from LRI imagery VicForests).

kilometers north–east of Melbourne. The Kilmore East fire burnt 100,000 hectares in less than 12 hours under extreme weather conditions, most of it at the highest severities (Cruz *et al.* 2012).

Fire severity in the Kilmore East—Murrindindi Fires over the range of age classes of mountain ash was not consistently greater or lesser in older regeneration than in the most recent regeneration; the greatest fire severities as measured by crown burn were in the intermediate age classes (Figure 4). The predominant age class of mountain ash in State (production) forest in 2009 was 70 years (regenerated after the 1939 bushfires); 47% of the burnt area of forest in the age class 70–109 years burnt at the highest severities (tree crowns totally burnt or totally scorched), killing the trees and leading to stand replacement. Within the burnt area of forest that regenerated after logging or bushfire over the period 1940–1999, 58% burnt at the highest severities (Figure 4). Of the <10-year-old regeneration in the fire-burnt area, only 36% burnt at the highest severities.

Price & Bradstock (2012) found that the effects of forest type and aspect on the probabilities of crown and understorey fires were relatively strong. Their study was based on a 500-meter grid in burnt areas of the Kilmore East—Murrindindi Fires and two other large fires that burnt during 2009 in Victoria. Their study ranged over three forest types (broadly classed as "dry," "damp," and "ash"). They found that the "effects of logging age and topographic position were weak" except in dry eucalypt forest where the probability of crown fire in dry eucalypt forest decreased with time since logging. Our data (Figure 4) are restricted to mountain ash in State forest (where age class is known) but they cover the entire area that was burnt in the East Kilmore—Murrindindi fires, rather than being based on sample points. In this extreme fire, there was an apparent *increase* in the severity of crown fire with

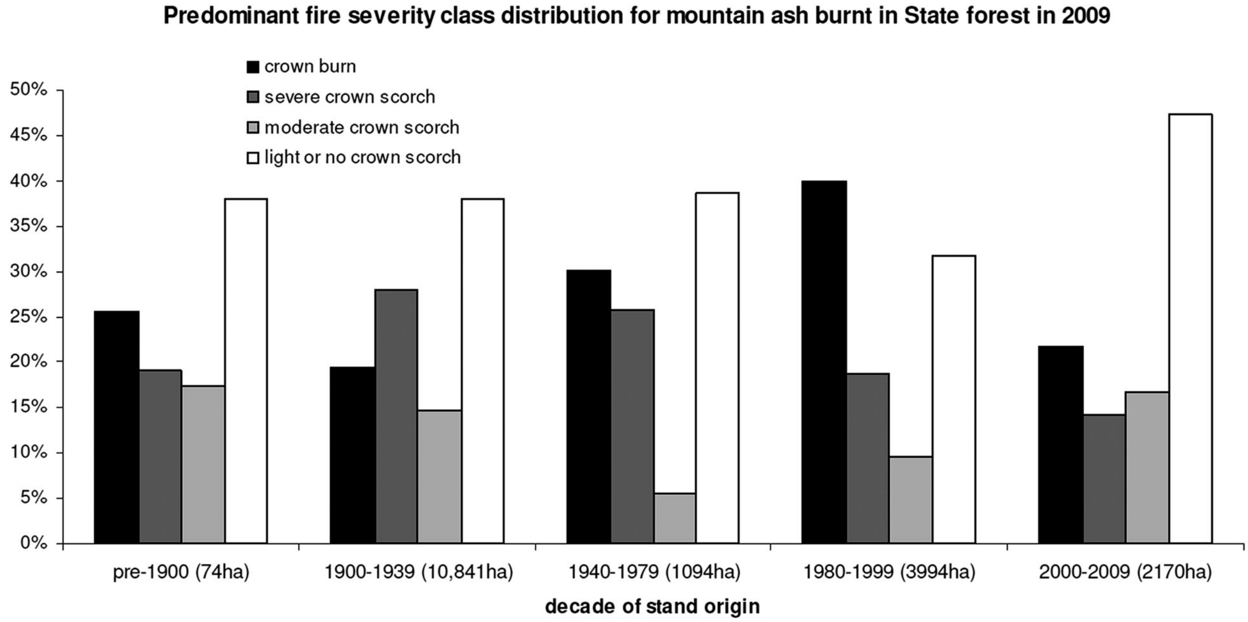


Figure 4 Fire severity classes over the predominant age-class range of burnt mountain ash (*Eucalyptus regnans*) in State forest; the Kilmore East and Murrindindi fires, 7 February 2009. (Data from Department of Sustainability and Environment, 2009.)

time since logging or bushfire up to about age 30 years (Figure 4), rather than a decrease as shown by Price and Bradstock (2012, their Figure 6) for "dry forest." Since the number of grid points falling in mountain ash forest in Price & Bradstock (2012) is not known, the two studies are not directly comparable.

Fire severity in the Alpine Fires 2003 and the Great Divide Fires 2007 was not consistently greater or lesser in parks and reserves protected from timber harvesting than in State Forest where there has been timber harvesting over the years (Figure 5). The only consistent differences in fire severity in the Alpine Fires 2003 and the Great Divide Fires 2007 were for forest type. Severity in wet ash eucalypt forests was generally less than in drier, mixed-species eucalypt forests—an entirely expected result (Figure 6).

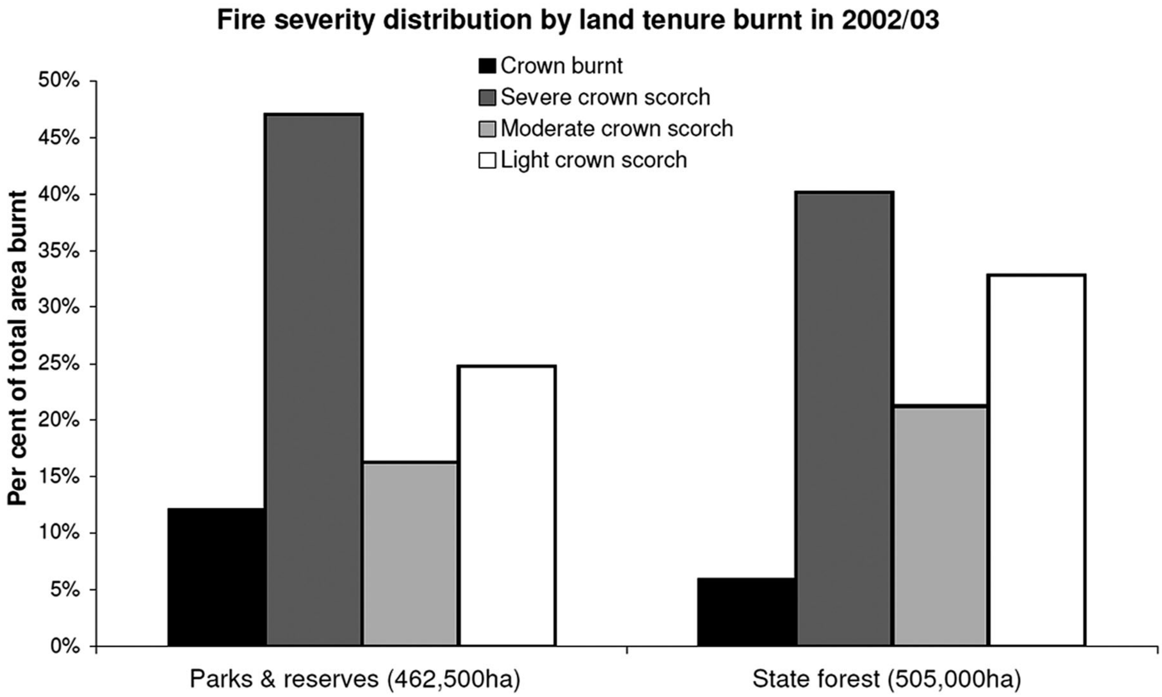
These various observations (Figures 4–6) support the proposition that the flammability of stands of different ages can be explained in terms of stand structure and fuel accumulation, rather than as a dichotomy of regrowth stands (whether as the result of logging or bushfire) being highly flammable but mature- and old-growth stands not highly flammable. They do not support the propositions that "logging results in drier, more fire-prone forests" and that "old-age eucalypt forests develop fire-resistant characteristics" (Lindenmayer *et al.* 2009).

Our data support the conclusion of Ferguson & Cheney (2011) who responded to the proposition of Lindenmayer *et al.* (2011) that regrowth from timber harvesting produces "landscape traps" where landscapes are shifted into, and then "trapped" in a highly compromised functional state. Ferguson & Cheney (2011) conclude that "the domination of (the wet eucalypt forest landscape) by younger-aged stands . . . . is the outcome of a very productive ecosystem carrying very high fuel loads that will support landscape-level wildfires of high fire intensity under drought and extreme weather conditions, regardless of age (if over about 5 years) and/or logging . . . . What matters for potential landscape traps is the adequacy of seeding after an extensive wildfire, the scale and intensity of a subsequent fire within (about) the next 20 years and the management response to it."

Management intervention has proved an important tool to prevent landscape traps by actively seeding forest areas resulting from either logging or wildfire that are at risk of not self-regenerating due to inadequate seed crops. Indeed, in some areas of the conservation reserve system where there has been no management intervention, landscape traps eventuated when areas of regeneration from the 2003 Alpine Fire were subsequently killed in fires in the 2007 Great Divide Fires (Figure 7; Flinn *et al.* 2008; Ferguson 2011).

Conclusion: management of fire-dependent ecosystems

The evidence we have presented here gives little support for the argument that logging in the wet eucalypt forests across southern Australia results in forests that are drier



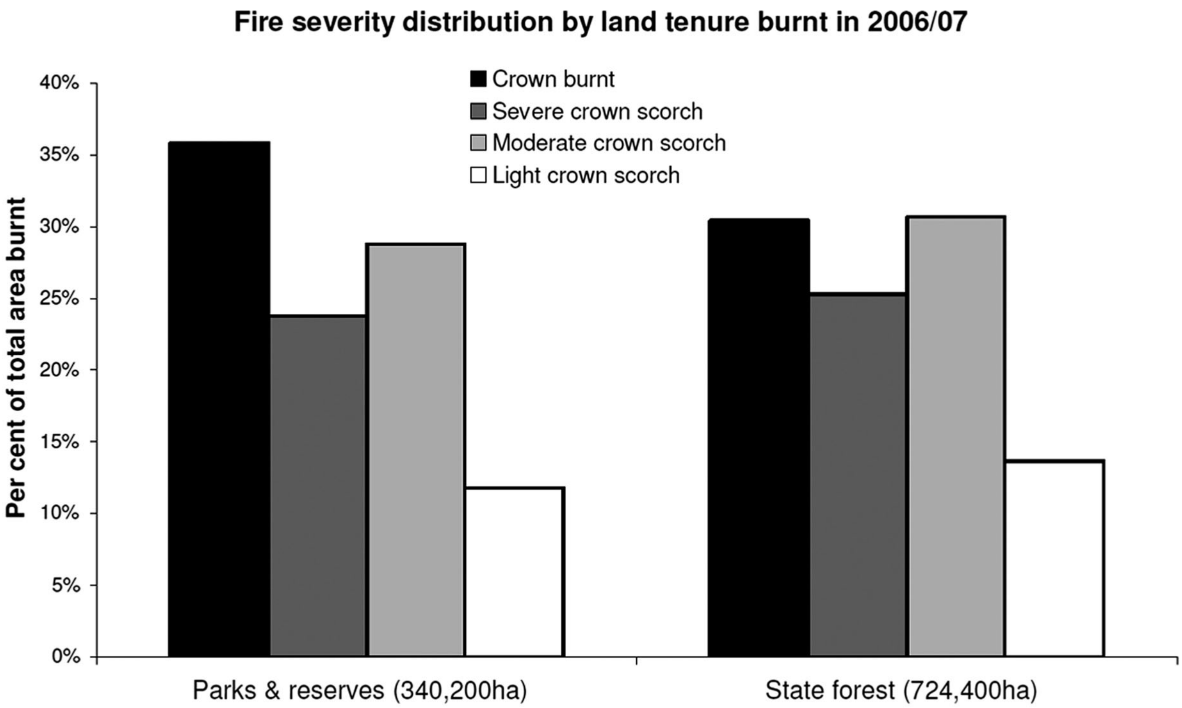


Figure 5 Fire severity by land tenure (conservation parks and reserves vs. State multiple-use forest) in the 2003 Alpine fires (top) and the 2007 Great Divide fires (bottom). The data for the 2003 Alpine fires come from "Victorian Alpine Fires 2003—Area Statements," Department of Sustainability and Environment, Victoria, http://www.dse.vic.gov.au/__data/assets/pdf_file/0006/101796/Alpine_Fires_Area_Statment.pdf. The data for the 2007 Great Divide fires are from Jewell *et al.* (2008) based on fire severity data from Department of Sustainability and Environment (2007).

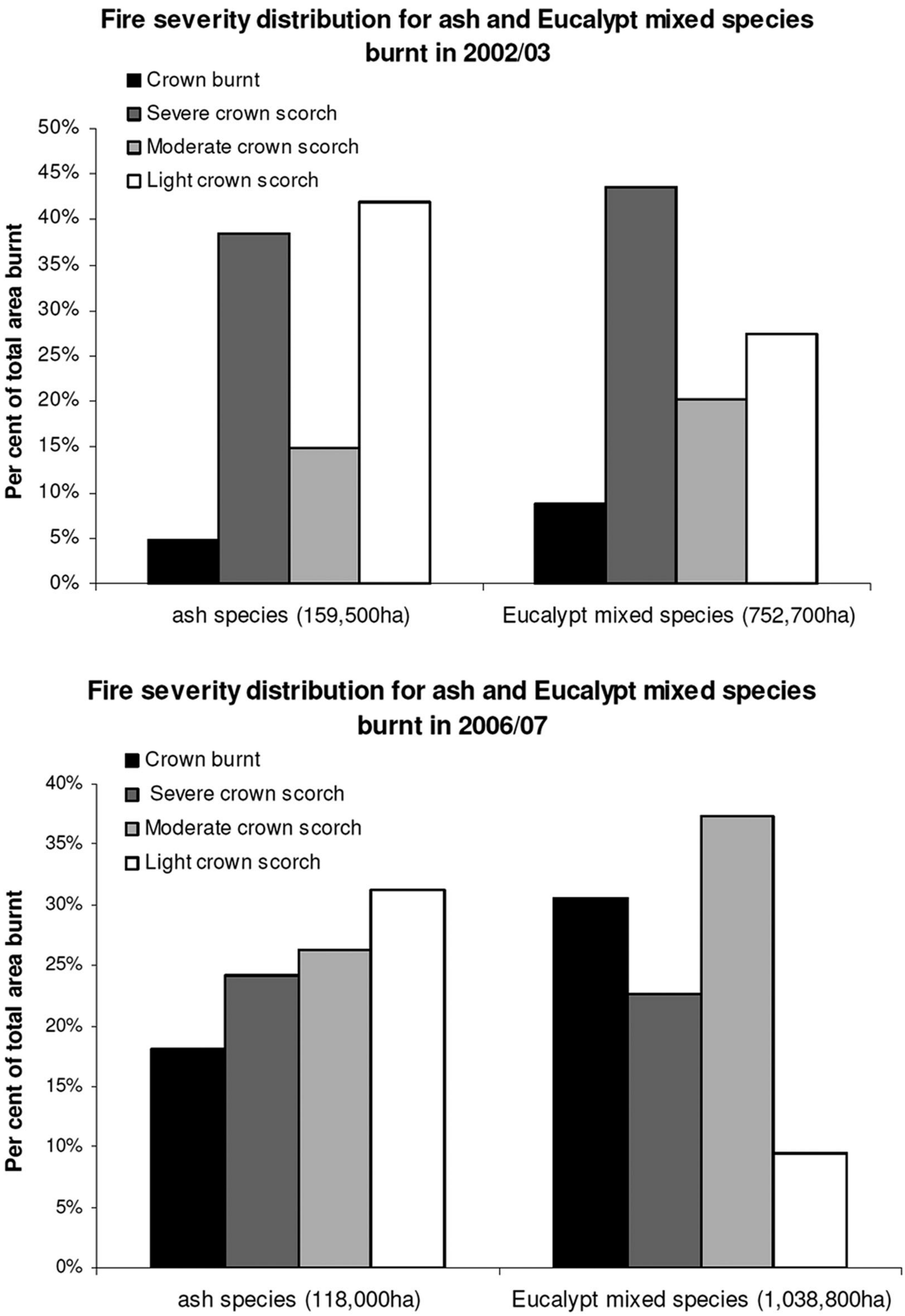


Figure 6 Fire severity by forest type (ash eucalypt forest vs. Drier-mixed-species eucalypt forest) in the 2003 Alpine fires (top) and the 2007 Great Divide fires (bottom). The data for the 2003 Alpine fires come from "Victorian Alpine Fires 2003—Area Statements," Department of Sustainability and Environment, Victoria, http://www.dse.vic.gov.au/__data/assets/pdf_file/0006/101796/Alpine_Fires_Area_Statment.pdf. The data for the 2007 Great Divide fires are from Jewell *et al.* (2008) based on fire severity data from Department of Sustainability and Environment (2007).

Figure 7 Left side of track: alpine ash near Mount Hotham, Victoria, in the Alpine National Park burnt and regenerated from natural seed fall in 2003 and then reburnt and killed 2007. The alpine ash on the right side of track carried a partial-stand replacement fire in 2003 but did not burn in the 2007 wildfires due to the break of fuel by the track. No active regeneration efforts were undertaken in the national parks. Areas burnt twice will therefore revert to a treeless vegetation except where there are living seed-bearing trees such as immediately adjacent to this track (Photo MF Ryan).

and more fire-prone. Victoria is one of the three areas on earth most prone to bushfires, and fire has been a major force in the evolution of Victoria's native flora. For the mountain ash forests of Victoria, "that they need to be burned down at some time in their seed-bearing life (if they are to be perpetuated) is axiomatic" (Ashton & Attiwill 1994).

We have shown that whether or not forests are harvested is not the critical question. The wet eucalypt forests of southern Australia build up huge amounts of fuel. The critical question therefore remains: how are we to manage for fire? If we are to control bushfire (including those caused by lightning), then we must extinguish summer fires rapidly and manage fuel accumulation by fuel-reduction burning in autumn and spring (Attiwill and Adams 2013). Since this is not practical in the wet eucalypt forests of eastern Australia, fuel-reduction must concentrate on the surrounding drier forests. In Western Australia, broad-scale prescribed fire is practical due to the Mediterranean climate and the fire tolerance of karri and associated eucalypts. While that will enable control of most bushfires, fires of stand-replacing severity are inevitable. Logging will neither increase nor decrease that inevitability. We must grasp the fact that lack of management of fire-adapted ecosystems carries long-term social, economic, and environmental consequences.

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