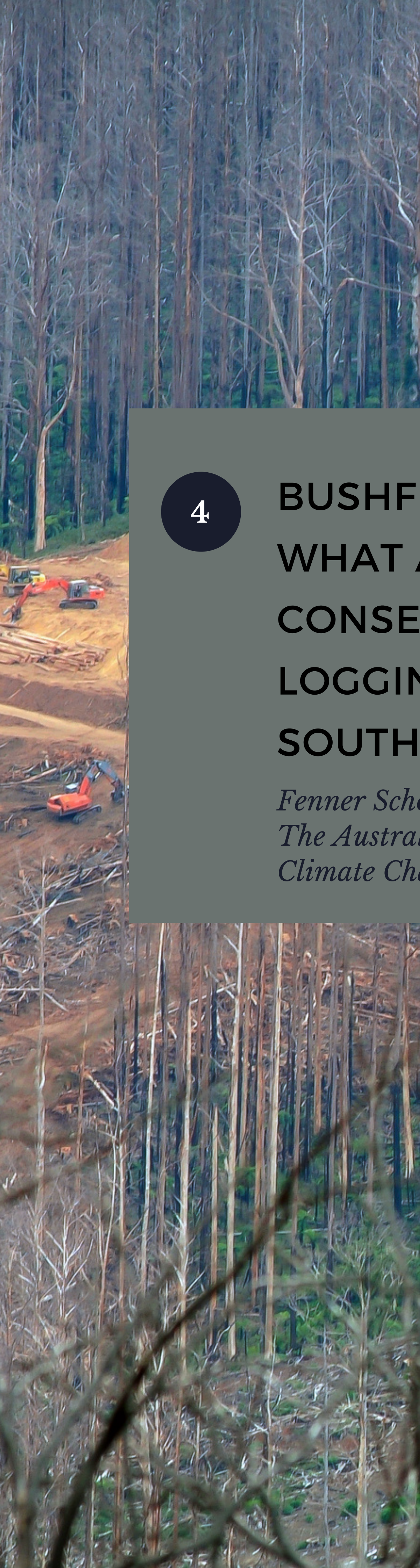

BUSHFIRE RECOVERY PROJECT

4

BUSHFIRE SCIENCE REPORT NO. 4: WHAT ARE THE ECOLOGICAL CONSEQUENCES OF POST-FIRE LOGGING IN THE NATIVE FORESTS OF SOUTH-EASTERN AUSTRALIA?

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

AUTHORS:

Professor David Lindenmayer
Professor Brendan Mackey
Dr Sue Gould
Dr Chris Taylor
Dr Pat Norman

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: Does prescribed burning of native forests reduce the risk to infrastructure from bushfires??

The Bushfire Recovery Project is a collaboration between the Fenner School of Environment & Society, The Australian National University, and Griffith Climate Change Response Program, Griffith University, 2020.

Acknowledgements: This research was supported by a grant from a charitable organisation which neither seeks nor permits publicity for its efforts.

'This report can be cited as: Lindenmayer D., Mackey, B., Gould S., Norman P. and Taylor C. (2021) How does climate affect bushfire risks in the native forests of south-eastern Australia? Bushfire Recovery Project Report No.1. Griffith University and The Australian National University, https://www.bushfirefacts.org/'.

Griffith UNIVERSITY Queensland, Australia

Australian National University

INTRODUCTION

An increasing proportion of the Earth's natural forests is subject to post-disturbance logging [*1*]. Post-disturbance logging, also referred to as salvage logging and post-fire logging, is conducted primarily for the purported aims of providing economic benefits [*2,3*] and reducing fuel loads [*4*] and is justified on the grounds that the impacts of logging are similar to the impacts of natural disturbance. The practice of post-fire logging originated in forests of the Northern Hemisphere where fire and other disturbances can cause high levels of tree mortality in some forest types. In Australia, total crown scorch can result in 100% mortality of canopy trees in ash-type forests [*3*]. However, most eucalypt forests and woodlands of southern Australia are dominated by fire tolerant resprouter tree species [*5*] and bushfires rarely cause high rates of tree mortality (see Bushfire Science Report No. 2). Furthermore, the benefits and ecological consequences of post fire logging are contested. Here, we present an assessment of the relevant scientific literature to address five key questions:

1. Are bushfires in the eucalypt forests of south-eastern Australia "stand-replacing"?
2. Are the impacts of logging the same as bushfire?
3. How does post-fire logging affect forest recovery and biodiversity?
4. What are the consequences for forest ecosystem services of post-fire logging?
5. Does post-fire logging reduce fire risk?

KEY POINTS

- Post-fire logging is a forest management activity that originated in the Northern Hemisphere. It is designed to recover some of the economic value of disturbed forests by harvesting dead trees. However, the majority of Australian forests are dominated by eucalypt tree species that are not killed by fire.
- The ecological impacts of post-fire logging are different from the effects of bushfire. Post-fire logging results in the immediate loss of vital habitat resources. The mechanical disturbance of post-fire logging damages surviving plants, soil and seed banks, disrupting natural processes of post-fire recovery. It is a new type of disturbance that compounds the impacts of bushfire.
- In some forests, the combined impacts of logging and fire are causing a collapse in the availability of large, hollow-bearing trees, which are vital habitat to many forest animals, including threatened mammal and bird species.
- Post-fire logging damages important ecosystem services and the ecological damage caused by post-fire logging may outweigh short-term economic benefits
- Post-fire logging does not reduce subsequent fire risk and may increase fire risk over the short term.

1. Are bushfires in the eucalypt forests of south-eastern Australia "stand-replacing"?

A "stand-replacing" event is one in which 100% tree mortality is followed by the regeneration of a cohort that is all of the same size-class or age-class. Post-disturbance logging as a forest management practice originated in forests where disturbances can cause high levels of tree mortality. A key question then, is "to what extent do bushfires cause tree mortality in Australian native forests?".

In spite of the stark imagery of blackened landscapes and contrary to media reports, the ecological reality is that the eucalypt forests of southern Australia are not "destroyed" by bushfire [*6*]. In most of the eucalypt forests of southern Australia, the majority of tree species are able to tolerate fire [*5*] and have high survival rates [*7*], although mortality rates of small stems can be high [*8*]. As we discuss in Report No. 2 of this Bushfire Science Report series, fire has exerted a selective force on Australian vegetation for at least 60 million years [*9,10*] and Australia's plants and animals are adapted to the fire regimes [*11,12*]. Even large, infrequent disturbances do not override the biological legacies and "ecological memory" of pre-disturbance ecosystems. Rather, they result in landscape patterns and fire-generated legacies of physical and biological structures that form the template for subsequent ecosystem recovery [*13-15*]. Bushfires therefore do not cause high levels of mortality in the majority of the eucalypt forests of southern Australia.

In forests dominated by obligate-seeder tree species, such as the ash-type forests of the Australian Alps, Tasmania, and the Central Highlands of Victoria, high severity fire can cause high mortality rates. In Victoria, the area of ash forest amounts to approximately 7% of Victoria's total forest area [*16*]. In these ash-type forests, the trees are obligate seeder species that depend on high intensity fire to regenerate [*17,18*]. Fire stimulates the release of canopy-stored seed and regeneration of a new forest stand [*19*]. Even in the obligate seeder ash-type forests, the extent of mortality at the landscape level is highly variable [*20*].

Mortality rates of canopy trees in the ash-type forests vary depending on fire severity, the structure of the forest at the time of fire, topographic position, fire behaviour [20], and the composition of the understorey [21]. Survival of mature eucalypts, for example, is higher in wet eucalypt forests with a rainforest understorey [21]. Total crown burn or crown scorch typically results in 100% mortality of canopy trees of Mountain Ash (*Eucalyptus regnans*) and Alpine Ash (*Eucalyptus delegatensis*).

Nonetheless, there can be relatively high survival rates of canopy trees, even following moderate crown scorch [7] and up to up to four age classes can be present in an ash forest [19,22]. Thus, multi-aged stands are often prevalent (34% - 50% of stands), even in forests where the canopy is dominated by obligate seeder trees [20,21]. The presence of multi-aged stands challenges the assertion that fires cause 100% tree mortality that forms the justification for clearfelling and post-fire logging. Even at low stem densities, surviving trees are a critical resource for forest recovery.

Even in forests where the canopy tree species are obligate seeders, the understorey can be dominated by resprouter species [5,23-25]. Defining the age and mortality rate of these forests by the canopy species alone ignores the presence of long-lived, resprouting understorey species. Individual tree ferns and woody shrubs in the understorey can be hundreds of years old and have survived multiple fires [24,26].

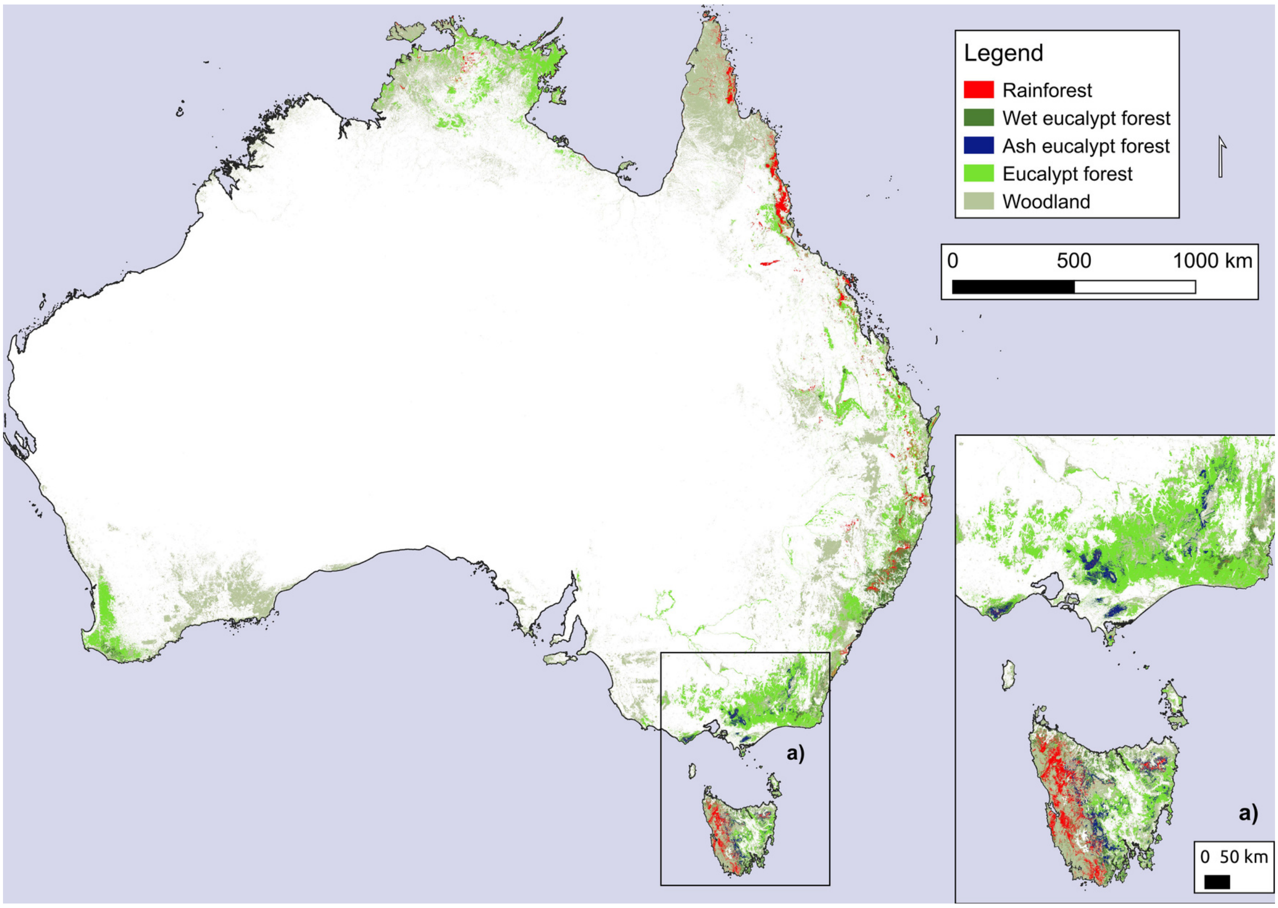

Figure 1 Forests and woodlands together cover 70,655,650 hectares of Australia. This is a huge area but still less than 10% of the land area. Of this, 4.7% is rainforest, 5.4% is wet eucalypt forest, 24.7% is eucalypt forest and 37.4% is eucalypt woodland. The remaining 27.8% is all other forests and woodlands including *Acacia*, *Callitris*, *Casuarina* and *Melaleuca* forests and woodlands. Obligate seeder ash-type forests are a formation within wet eucalypt forest that occurs in the Australian Alps, the Central Highlands of Victoria, and Tasmania. Note that our data are drawn from National Vegetation Information System (NVIS) [*27*] and state government vegetation datasets [*28-30*] and the Global forest change dataset in which forests are defined as tree cover < 5 metres tall [*31*].

Paradise Plains, Marysville

2. Are the impacts of logging the same as bushfire?

The fire ecology of the mountain ash forests has been used to justify both clear-fell logging and post-fire logging on the grounds that logging has similar impacts on this forest type as natural disturbance [32]. However, the impacts of logging on the forest are not the same as the impacts of high severity bushfire [33]. There are four important differences between the effects of fire and the effects of logging.

1. Even after high severity fire, large hollow-bearing trees remain standing [*33*]. Hollow-bearing trees, whether alive or dead, are particularly important for many species of arboreal mammals, birds, amphibians and reptiles [*34-37*]. Fifteen percent of known Australian terrestrial vertebrate species, including 27 amphibians, 79 reptiles, 114 birds and 83 mammals, use tree hollows [*37*]. Post-fire logging results in the immediate loss of these habitat structures [*38*] which are vital in the early stages of forest recovery [*39*]. Tree hollows suitable for vertebrate fauna do not typically develop in Mountain Ash trees until they are at least 120 years old [*33*] and for larger fauna species, suitable hollows may not develop until trees are at least 170-220 years old [*35,37*].

2. Post-fire logging reduces the amount of dead wood, including standing trees, logs and woody debris on the forest floor. Naturally disturbed forests are characterised by large volumes of dead wood which provide high structural diversity [*40-42*]. Deadwood has a number of important ecological roles in forests. It is important for biodiversity, nutrient cycling and forest regeneration. Logs for example, provide nest sites and shelter, facilitate animal movement and act as refuges during drought and fire [*42*]. Removing dead wood reduces the abundance and richness of species that depend on dead wood [*41,43*], including mosses, lichens, fungi, invertebrates, birds and mammals. In addition to its habitat value, the dead wood that remains after a wildfire has an important role in protecting a site from extreme environmental conditions [*23*]. Understorey cover, including logs, modify microclimatic conditions resulting in more shade, higher humidity and lower temperatures. These conditions protect new growth and newly established plants [*23*]. Thus, removing dead wood impacts on natural forest recovery processes.

3. **Post-fire logging is a physical disturbance to which forest plants and animals are not adapted [*44*].** The physical disturbance caused by mechanical logging damages or kills some understorey plant species including long-lived tree ferns and woody shrubs that can survive bushfire [*23*]. At the same time, the soil disturbance cause by logging increases opportunities for weed invasion [*23,25*]. Post-fire logging causes more changes in plant species composition than fire alone or clearfell logging [*45*].

4. The intensity, spatial scale and return interval of logging disturbance (whether logging live trees or post-fire) do not replicate the natural disturbance regime that leads to the development of multi-aged forests with hollow bearing trees [*20,33,35*]. Whereas bushfire varies in its intensity, killing all trees in some locations and leaving multi-aged stands elsewhere, post-fire logging removes virtually all standing trees in the [*15–40*] hectare area of each logging coupe. Such coupes can be aggregated up to 120 hectares and logged over a period of five years. The rotation time between clearfelling operations is nominally 80 years. Differences in the intensity, and spatial and temporal pattern of disturbances, including human and natural disturbances, over the last century have led to radical alteration of the structure and landscape composition of the Mountain Ash ecosystem [*46*]. This is important because the spatial distribution of multi-agedness and the ongoing development and replacement of large old trees is critical for the occurrence of a vital habitat resource, i.e., large, hollow-bearing trees.


Toolangi, post-fire logging in forests with a fire severity rating 4

3. How does post-fire logging affect forest recovery and biodiversity?

Post-fire logging disrupts natural processes of forest regeneration and reduces forest resilience. Plant communities that have survived fire or are in the process of regenerating following fire are impacted by the physical disturbance associated with mechanical logging [*4,23,25*]. For example, Mountain Ash forests that have been burnt and then logged have significantly lower abundances of long-lived, resprouting understorey species, especially tree ferns and shrubs [*3,45,47*] compared with sites that have been burnt but not logged. These impacts are reflected in the composition of the plant community. The compound disturbance of fire plus post-fire logging alters the trajectory of forest recovery and is likely to reduce the resilience of the plant community to future disturbance by fire [*14*]. Differences in the plant community are likely to be long term [*23*].

Post-fire logging has multiple impacts on forest animals. It has the potential to cause direct mortality of animals. A surprising number of animal species can survive even high intensity fire *in situ* by accessing fire refugia such as logs and hollows [*48-51*]. The animals that survive fire *in situ* are vitally important starting points for subsequent population recovery.

Post-fire logging removes habitat. The blackened post-fire forest retains habitat value for fauna surviving *in situ* as well as fauna immigrating from unburnt areas [*49*]. Hollow trees form the basis for the persistence and recovery of wildlife populations [*48,52*]. Several studies have shown that the loss of habitat caused by post-fire logging results in changes in the composition of animal communities including birds, mammals and invertebrates [*43,53-57*]. The impacts of post-fire logging on bird communities differ from severe bushfire and conventional logging, with lowest bird species richness in sites that have been logged following fire [*53*]. These effects can be very long term with some species occurring only in the remaining patches of forest that are older than 200 years [*58*].

Post-fire logging represents an additional threat to wildlife populations that are already under significant stress from multiple pressures [*59*]. Although the impacts of the loss of forest fauna have not been quantified, their loss is expected, in turn, to result in a cascade of adverse impacts. For example, the loss of digging mammals is thought to exacerbate the effects of drought [*60*] and can alter natural processes of post-fire regeneration [*54*].

Post-fire logging also reduces the future availability of hollow trees [*61*]. The impacts of the loss of tree hollows on fauna populations are therefore long term. The impacts of post-fire logging are not confined to the immediate area logged, as there are impacts on populations of hollow-using animals at landscape scales. The declining abundance of large, hollow-bearing trees is leading to population declines in hollow-dependent species [*62*] including the vulnerable Greater Glider and the critically endangered Leadbeater’s Possum. Without intervention, the ongoing loss of hollow-bearing trees will increase the extinction risk of other hollow-dependent animals.

Post-fire logging also impacts on forest structure even in adjacent unlogged sites. Interactions between logging, climate change and fire, accelerate the rate of loss of existing hollow-bearing trees in unlogged sites probably due to increased wind exposure [*63*]. The rate of loss of existing hollow-bearing trees is also faster in more recently logged forest than in old-growth forest [*64*].

Logging, climate change and fire also interact to reduce the rate of development of future hollow-bearing trees. This because these combined factors are leading to increased fire frequency and severity in predominantly young Mountain Ash forests [*65*]. Fires burn young, logged forest more severely than older forest [*66*], leading to high rates of tree fall. Furthermore, small diameter Mountain Ash trees killed by fire will be unlikely to form hollows because they lack internal decay [*22,46*]. This is resulting in a collapse in populations of hollow-bearing trees [*62*]. Given that it may take at least 120 years for Mountain Ash trees to develop hollows, there is the real possibility that almost all of the existing population of large hollow-bearing trees may be lost from the Mountain Ash forests before replacement hollow-bearing trees can develop [*64*].

Water run-off after fire and logging, Central Highlands, Victoria

4. What are the consequences for forest ecosystem services of post-fire logging?

Post-fire logging occurs at a time when forest landscapes are most vulnerable to increased run-off, erosion and impacts on downstream water quality [*67*]. A global review found that post-fire logging has a negative effect on regulating ecosystem services [*68*]. For example, compared to long-undisturbed sites, Mountain Ash sites subject to compound disturbances consistently had the lowest values of a wide range of soil measures which affect ecosystem function and forest productivity [*69*].

The time taken for catchment water yield to recover increases when post-fire logging occurs [*70*]. In the case of mountain ash forests, logging causes long term reductions in water yield (< 25 years and up to 150 years to recover fully) [*71*]. The combined effects of fire and post-fire logging can also cause large increases in run-off, erosion and nutrient loss compared to burnt unlogged forest [*67*].

The ecological damage caused by post-fire logging may outweigh short-term economic benefits [*44*]. It also undermines potential alternative high value uses for the forest. Ecosystem accounting has shown that native forests would provide greater benefits from their ecosystem services of carbon sequestration, water yield, habitat provisioning and recreational amenity if harvesting for timber production ceased, thus allowing forest to continue growing to older ages [*72*].

5. Does post-fire logging reduce fire risk?

One of the justifications given for post-fire logging is that reducing the volume of coarse woody debris reduces the risk of subsequent fire [*68,73*]. However, several studies have shown that post-fire logging does not reduce subsequent fire hazard and can increase fire hazard over the short term by leaving large quantities of fine fuels on the ground that are easy to ignite and cause rapid fire spread [*4,68,73,74*].

References:

1. Müller, J. et al. Increasing disturbance demands new policies to conserve intact forest. *Conservation Letters* 12, doi:10.1111/conl.12449 (2019).

2. Thorn, S. et al. Estimating retention benchmarks for salvage logging to protect biodiversity. *Nature Communications* 11, 4762, doi:10.1038/s41467-020-18612-4 (2020).

3. Lindenmayer, D. B. & Ough, K. Salvage logging in the montane ash eucalypt forests of the Central Highlands of Victoria and its potential impacts on biodiversity. *Conservation Biology* 20, 1005-1015, doi:10.1111/j.1523-1739.2006.00501.x (2006).

4. Donato, D. C. et al. Post-wildfire logging hinders regeneration and increases fire risk. *Science* 311, 352, doi:10.1126/science.1122855 (2006).

5. Clarke, P. J. et al. A synthesis of postfire recovery traits of woody plants in Australian ecosystems. *Science of the Total Environment* 534, 31-42, doi:10.1016/j.scitotenv.2015.04.002 (2015).

6. Bradstock, R. A. Effects of large fires on biodiversity in south-eastern Australia: disaster or template for biodiversity. *International Journal of Wildland Fire* 17, 809-822 (2008).

7. Benyon, R. G. & Lane, P. N. J. Ground and satellite-based assessments of wet eucalypt forest survival and regeneration for predicting long-term hydrological responses to a large wildfire. *Forest Ecology and Management* 294, 197-207, doi:10.1016/j.foreco.2012.04.003 (2013).

8. Bennett, L. T. et al. Mortality and recruitment of fire-tolerant eucalypts as influenced by wildfire severity and recent prescribed fire. *Forest Ecology and Management* 380, 107-117, doi:10.1016/j.foreco.2016.08.047 (2016).

9. He, T., Lamont, B. B. & Downes, K. S. Banksia born to burn. *The New Phytologist* 191, 184-196, doi:10.1111/j.1469-8137.2011.03663.x (2011).

10. Crisp, M. D., et al. Flammable biomes dominated by eucalypts originated at the Cretaceous-Palaeogene boundary. *Nature Communications* 2, 193, doi:10.1038/ncomms1191 (2011).

11. Gill, A. M. in *Fire and the Australian Biota* (eds A. M. Gill, R. H. Groves, & I. R. Noble) 243-272 (1981).

12. Pausas, J. G. & Keeley, J. E. A burning story: The role of fire in the history of life. *BioScience* 59, 593-601, doi:10.1525/bio.2009.59.7.10 (2009).

13. Foster, D. R., Knight, D. H. & Franklin, J. F. Landscape patterns and legacies resulting from large, infrequent forest disturbances. *Ecosystems* 1, 497-510 (1998).

14. Johnstone, J. F. et al. Changing disturbance regimes, ecological memory, and forest resilience. *Frontiers in Ecology and the Environment* 14, 369-378, doi:10.1002/fee.1311 (2016).

15. Burton, P. J., Jentsch, A. & Walker, L. R. The Ecology of Disturbance Interactions. *BioScience* 70, 854-870, doi:10.1093/biosci/biaa088 (2020).

16. Victorian Government. *Sustainable Forests (Timber) Act 2004 Section 13 Allocation Order 2013, No. S 343*. Victorian Government Gazette (2013).

17. Smith, A. L. et al. Dominant Drivers of Seedling Establishment in a Fire-Dependent Obligate Seeder: Climate or Fire Regimes? *Ecosystems* 17, 258-270, doi:10.1007/s10021-013-9721-9 (2014).

18. Smith, A. L. et al. The dynamic regneration niche of a forest following a rare disturbance event. *Diversity and Distributions* 22, 457-467, doi:10.1111/ddi (2016).

19. Ashton, D. H. & Attiwill, P. M. in *Australian Vegetation*. Second Edition (ed R. H. Groves) (Cambridge University Press, 1994).

20. McCarthy, M. A. & Lindenmayer, D. B. Multi-aged mountain ash forest, wildlife conservation and timber harvesting. *Forest Ecology and Management* 104, 43-56 (1998).

21. Turner, P. A. M., Balmer, J. & Kirkpatrick, J. B. Stand-replacing wildfires? The incidence of multi-cohort and single cohort Eucalypts regnans and E. obliqua forests in southern Tasmania. *Forest Ecology and Management* 258, 366-375, doi:10.1016/j.foreco.2009.04.021 (2009).

22. Lindenmayer, D. B. et al. Predicting the abundance of hollow-bearing trees in montane forest of southeastern Australia. *Australian Journal of Ecology* 16, 91-98 (1991).

23. Ough, K. Regeneration of wet forest flora a decade after clear-felling or wildfire - is there a difference? *Australian Journal of Botany* 49, 645-664 (2001).

24. Mueck, S. G., Ough, K. & Banks, J. C. G. How old are wet forest understories. Australian *Journal of Ecology* 21, 345-348 (1996).

25. Murphy, A. & Ough, K. Regenerative strategies of understorey flora following clearfell logging in the Central Highlands, Victoria. *Australian Forestry* 60, 90-98, doi:10.1080/00049158.1997.10674703 (1997).

26. Blair, D. P. et al. Non-linear growth in tree ferns, *Dicksonia antarctica* and *Cyathea australis. PLoS One* 12, e0176908, doi:10.1371/journal.pone.0176908 (2017).

27. Australian Government. *Native Vegetation Information System (NVIS) 5.1 Australia - Extant vegetation.* (2018).

28. Victorian Government. *Native Vegetation - Modelled 2005 Ecological Vegetation Class (with Bioregional Conservation Status).* (2005).

29. Tasmanian Government. *TASVEG 4.0.* (2014).

30. ACT Government. *ACT Vegetation Map.* (2018).

31. Hansen, M. C. et al. High-resolution global maps of 21st century forest cover change. *Science* 342, 850-853 (2013).

32. Attiwill, P. M. The disturbance of forest ecosystems: the ecological basis for conservative management. *Forest Ecology and Management* 63, 247-300 (1994).

33. Lindenmayer, D. & McCarthy, M. A. Congruence between natural and human forest disturbance: a case study from Australian montane ash forests. *Forest Ecology and Management* 155, 319-335 (2002).

34. McElhinny, C. et al. Fauna-habitat relationships: a basis for identifying key stand structural attributes in temperate Australian eucalypt forests and woodlands. *Pacific Conservation Biology* 12, 89-110 (2006).

35. Lindenmayer, D. B. et al. Relationships between tree size and occupancy by cavity-dependent arboreal marsupials. *Forest Ecology and Management* 391, 221-229, doi:10.1016/j.foreco.2017.02.014 (2017).

36. Loyn, R. H. & Kennedy, S. J. Designing old forest for the future: Old trees as habitat for birds in forests of Mountain Ash *Eucalyptus regnans*. *Forest Ecology and Management* 258, 504-515, doi:10.1016/j.foreco.2009.01.005 (2009).

37. Gibbons, P. & Lindenmayer, D. *Tree hollows and wildlife conservation in Australia*. (CSIRO Publishing, 2002).

38. Lindenmayer, D. B. & Sato, C. Hidden collapse is driven by fire and logging in a socioecological forest ecosystem. *Proceedings of the National Academy of Sciences USA* 115, 5181-5186, doi:10.1073/pnas.1721738115 (2018).

39. Lindenmayer, D. B., et al. Key perspectives on early successional forests subject to stand-replacing disturbances. *Forest Ecology and Management* 454, doi:10.1016/j.foreco.2019.117656 (2019).

40. Swanson, M. E. et al. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Frontiers in Ecology and the Environment* 9, 117-125, doi:10.1890/090157 (2010).

41. Thorn, S. et al. The living dead: acknowledging life after tree death to stop forest degradation. *Frontiers in Ecology and the Environment*, doi:10.1002/fee.2252 (2020).

42. Lindenmayer, D. B. et al. The ecological role of logs in Australian forests and the potential impacts of harvesting intensification on log-using biota. *Pacific Conservation Biology* 8, 121-140 (2002).

43. Thorn, S. et al. Impacts of salvage logging on biodiversity: a meta-analysis. *Journal of Applied Ecology 55*, 279-289, doi:10.1111/1365-2664.12945 (2018).

44. Dellasala, D. A. et al. Post-fire logging debate ignores many issues. *Science* 314, 51-52 (2006).

45. Blair, D. P. et al. Disturbance gradient shows logging affects plant functional groups more than fire. *Ecological Applications* 26, 2280-2301 (2016).

46. Lindenmayer, D. et al. Ten years on - a decade of intensive biodiversity research afer the 2009 Black Saturday wildfires in Victoria's Mountain Ash forest. *Australian Zoologist* (2019).

47. Bowd, E. J. et al. Logging and fire regimes alter plant communities. *Ecological Applications* 28 (2018).

48. Banks, S. C. et al. The effects of wildfire on mortality and resources for an arboreal marsupial: resilience to fire events but susceptibility to fire regime change. *PLoS One* 6, e22952, doi:10.1371/journal.pone.0022952 (2011).

49. Banks, S. C. et al. Starting points for small mammal population recovery after wildfire: recolonisation or residual populations? *Oikos* 120, 26-37, doi:10.1111/j.1600-0706.2010.18765.x (2011).

50. Lunney, D., Lunney, H. W. M. & Recher, H. F. Bushfire and the Malthusian guillotine: survival of small mammals in a refuge in Nadgee Nature Reserve, south-eastern New South Wales. *Pacific Conservation Biology* 14, 263-278 (2008).

51. Sutherland, E. F. & Dickman, C. R. Mechanisms of recovery after fire by rodents in the Australian environment. *Wildlife Research* 26, 405-419 (1999).

52. Leverkus, A. B. et al. Salvage logging effects on regulating and supporting ecosystem services — a systematic map. *Canadian Journal of Forest Research* 48, 983-1000, doi:10.1139/cjfr-2018-0114 (2018).

53. Lindenmayer, D. B. et al. From unburnt to salvage logged: Quantifying bird responses to different levels of disturbance severity. *Journal of Applied Ecology* 55, 1626-1636, doi:10.1111/1365-2664.13137 (2018).

54. Castro, J. et al. Post-fire salvage logging alters a key plant-animal interaction for forest regeneration. *Ecosphere* 3, doi:10.1890/es12-00089.1 (2012).

55. Hutto, R. L. The effects of postfire salvage logging on cavity-nesting birds. *The Condor* 108, 817-831 (2006).

56. Cahall, R. E. & Hayes, J. P. Influences of postfire salvage logging on forest birds in the Eastern Cascades, Oregon, USA. *Forest Ecology and Management* 257, 1119-1128, doi:10.1016/j.foreco.2008.11.019 (2009).

57. Kelly, A. J. & Hodges, K. E. Post-fire salvage logging reduces snowshoe hare and red squirrel densities in early seral stages. *Forest Ecology and Management* 473, doi:10.1016/j.foreco.2020.118272 (2020).

58. Loyn, R. H. Bird populations in successional forests of Mountain Ash *Eucalyptus regnans* in Central Victoria. *The Emu* 85, 213-230 (1985).

59. Cresswell, I. D. & Murphy, H. T. Australia: *State of the Environment 2016: Biodiversity*. (Canberra, 2017).

60. Fleming, P. A. et al. Is the loss of Australian digging mammals contributing to a deterioration in ecosystem function? *Mammal Review* 44, 94-108, doi:10.1111/mam.12014 (2014).

61. Lindenmayer, D. B. Environmental and human drivers influencing large old tree abundance in Australian wet forests. *Forest Ecology and Management* 372, 226-235, doi:10.1016/j.foreco.2016.04.017 (2016).

62. Lindenmayer, D. B. et al. The response of arboreal marsupials to long-term changes in forest disturbance. *Animal Conservation*, doi:10.1111/acv.12634 (2020).

63. Lindenmayer, D. B. et al. Empirical relationships between tree fall and landscape-level amounts of logging and fire. *PLoS One* 13, e0193132, doi:10.1371/journal.pone.0193132 (2018).

64. Lindenmayer, D. B. et al. The road to oblivion – Quantifying pathways in the decline of large old trees. *Forest Ecology and Management* 430, 259-264, doi:10.1016/j.foreco.2018.08.013 (2018).

65. Lindenmayer, D. B., et al. Newly discovered landscape traps produce regime shifts in wet forests. *Proceedings of the National Academy of Sciences USA* 108, 15887-15891, doi:10.1073/pnas.1110245108 (2011).

66. Taylor, C., McCarthy, M. A. & Lindenmayer, D. B. Nonlinear Effects of Stand Age on Fire Severity. *Conservation Letters* 7, 355-370, doi:10.1111/conl.12122 (2014).

67. Smith, H. G. et al.. Wildfire and salvage harvesting effects on runoff generation and sediment exports from radiata pine and eucalypt forest catchments, south-eastern Australia. *Forest Ecology and Management* 261, 570-581, doi:10.1016/j.foreco.2010.11.009 (2011).

68. Leverkus, A. B. et al. Salvage logging effects on regulating ecosystem services and fuel loads. *Frontiers in Ecology and the Environment* 18, 391-400, doi:10.1002/fee.2219 (2020).

69. Bowd, E. J. et al. Long-term impacts of wildfire and logging on forest soils. *Nature Geoscience* 12, 113-118, doi:10.1038/s41561-018-0294-2 (2019).

70. Webb, A. A. & Jarrett, B. W. Hydrological response to wildfire, integrated logging and dry mixed species eucalypt forest regeneration: The Yambulla experiment. *Forest Ecology and Management* 306, 107-117, doi:10.1016/j.foreco.2013.06.020 (2013).

71. Vertessy, R. A., Watson, F. G. R. & O'Sullivan, S. K. Factors determining relations between stand age and catchment water balance in mountain ash forests. *Forest Ecology and Management* 143, 13-26 (2001).

72. Keith, H. et al. Ecosystem accounts define explicit and spatial trade-offs for managing natural resources. *Nature Ecology and Evolution* 1, 1683-1692, doi:10.1038/s41559-017-0309-1 (2017).

73. Johnson, M. C. et al. Effects of post-fire management on dead woody fuel dynamics and stand structure in a severely burned mixed-conifer forest, in northeastern Washington State, USA. *Forest Ecology and Management* 470-471, doi:10.1016/j.foreco.2020.118190 (2020).

74. Leverkus, A. B. et al. Tamm review: Does salvage logging mitigate subsequent forest disturbances? *Forest Ecology and Management* 481, doi:10.1016/j.foreco.2020.118721 (2021).