Failing to conserve Leadbeater's Possum and its Mountain Ash forest habitat

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ABSTRACT

The conservation of the Critically Endangered Leadbeater's Possum *Gymnobelideus leadbeateri* in Victoria's Mountain Ash *Eucalyptus regnans* forests is one of the most controversial native mammal conservation issues in Australia. Much of the controversy results from long-running conflicts between the demands of the native forest logging industry and associated impacts on Leadbeater's Possum and its Mountain Ash forest habitat. Here we argue that despite a legislative obligation to protect Leadbeater's Possum and some limited recent improvements in management, conservation efforts for the species have gone backwards over the past decade. The key problems we identify include that the Victorian Government has: (1) maintained levels of wood production that are too high given the amount of the forest estate that was burned in 2009, (2) failed to substitute clearfell logging practices with more ecologically-sensitive Variable Retention Harvesting Systems, (3) ignored the science (including by its own researchers) on the need for a large protected area for Leadbeater's Possum, (4) altered key definitions such as those for mature trees and old growth that have substantially weakened the ability to protect Leadbeater's Possum, and (5) overlooked the array of forest values beyond timber production (such as water and tourism) and which make a greater contribution to the economy. Our analyses suggest that populations of Leadbeater's Possum are undergoing a substantial decline, as are other hollow-dependent species such as the Greater Glider *Petauroides volans*. In light of this, it is clear that Victoria needs to substantially change native forest timber harvesting practices as well as improve its efforts to conserve Leadbeater's Possum and the Mountain Ash forests in which it occurs.

Key words: Government policy, *Eucalyptus regnans*, Victoria, Central Highlands, timber harvesting, logging, wildfire, conservation principles, Gymnobelideus leadbeateri.

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Introduction

Australia leads the world in mammal extinctions with approximately 10% of the nation's native mammal species now extinct over the past 220 years (Woinarski *et al.* 2015) with additional species continuing to be lost (Woinarski *et al.* 2017). Cross-continent comparisons are telling, with the number of species lost in Australia 30 times greater than continental USA which is of a similar area (Woinarski *et al.* 2015). One of Australia's most controversial mammal species of conservation concern is the Critically Endangered Leadbeater's Possum *Gymnobelideus leadbeateri*. Much of the controversy over its conservation is underpinned by the fact that a substantial part of its distribution occurs in highly productive Mountain Ash *Eucalyptus regnans* forests in the Central Highlands of Victoria (Lindenmayer *et al.* 2015b), which are also an important source of pulp and timber for the native forest timber industry (Keith *et al.* 2017a).

Concerns about the conservation of Leadbeater's Possum date back over 40 years (Warneke 1968; Lindenmayer 1996; Lindenmayer *et al.* 2015c). Extensive scientific information is available to guide forest management and harvesting so as to conserve Leadbeater's Possum. While some improvements in the protection of Leadbeater's Possum have recently occurred, we argue that overall conservation efforts for this species have gone backwards in the past decade. In this paper, we review a series of decisions, policies and management actions that have undermined conservation actions for Leadbeater's Possum and the Mountain Ash habitat on which the species depends. The need for this review was brought about due to the increasing scientific evidence over 30 years that indicate Leadbeater's Possum populations continue to decline. Furthermore, policy implementation was of minor or even damaging reforms while necessary actions that address key habitat conservation were absent.

Examples of poor management of, and policies for, Leadbeater's Possum and its Mountain Ash habitat

We have selected seven examples to highlight how Leadbeater's Possum and the Mountain Ash forests are being poorly managed.

Failure to respond to the need for reduced timber yields as a consequence of major natural disturbances

Mountain Ash forest in the Central Highlands of Victoria covers approximately 157 000 ha with an estimated 78 300 ha, or almost half, burned in the 2009 Black Saturday wildfires. These fires burned more than 40% of potentially suitable habitat for Leadbeater's Possum, with animals typically now absent from the vast majority of places where they formerly occurred (Lindenmayer *et al.* 2013). Remaining areas of unburned forest have therefore become critical for the continued persistence of Leadbeater's Possum. Despite this, and the loss of so much forest after the 2009 wildfires, the Victorian Government failed to reduce the harvest levels of timber and pulpwood from Mountain Ash forests. A year after the fires, senior government officials were provided with evidence of the rapid decline over the decade prior to the fires of the hollow-bearing tree resource (Lindenmayer and Wood 2010; Lindenmayer *et al.,* 2012). The scale of impact from the fires was known and further decline was predicted. Despite this, the perspective stated in the meeting was there would be "no net loss in timber supply to the forest industry". Without a reduction in overall harvested volumes, but with approximately half of the forest now unsuitable for logging due to the fires, the on-going harvesting was concentrated into a much smaller area which resulted in increasing the intensity of logging in important remaining habitat. The no-net loss approach essentially locked in over-cutting and left only a limited 'environmental margin' to enhance the conservation of Leadbeater's Possum. Harvest levels are now being reduced (VicForests 2017b), however, this is in response to a lack of available standing volume remaining in these forests due to losses from the fires and past rates of cutting, not as a conservation response. Despite sawlog extraction declining, the volume of pulp logs cut from the forests has not been reduced in line with the reduction in sawlog volume, with pulpwood harvesting forecast to continue at existing high levels until 2030 due to legislation enacted by the Victorian Government in 1996 (Victorian Government 1996; Victorian Environmental Assessment Council 2017).

Failure to adopt more environmentally-sensitive timber harvesting systems

Clearfell logging operations have been the conventional silvicultural system employed in Mountain Ash forests over the past 40 years (Flint and Fagg 2007). These operations are relatively efficient at producing pulpwood and sawlogs but have significant negative environmental impacts at a range of spatial scales and over prolonged periods (spanning centuries) (Lindenmayer 1994; Lindenmayer *et al.* 2015b), including impacts on Leadbeater's Possum.

A meeting of silvicultural scientists, representatives of industry groups, government officials and conservation biologists was held in 2002 to facilitate a move away from clearfelling toward more environmentally-sensitive harvesting methods such as the Variable Retention Harvest System (VRHS) (Lindenmayer and Franklin 2003). VRHS is a silvicultural system which retains islands of trees within a coupe with the goal of retaining habitat features, biological legacies and species diversity through into the regenerating stand Lindenmayer *et al.* 2012; Fedrowitz *et al.* 2014). A practical, on-the-ground VRHS experiment was established in 2003 with on-going monitoring, which we continue to carry out (Lindenmayer *et al.* 2015a). However, since the initial experiment, VRHS is rarely used in Victorian Mountain Ash forests. This is despite statements by the Victorian Government that VRHS would be implemented on a minimum of 50% of logging coupes with an aim of 100% application if found to be 'operationally achievable' (Leadbeater's Possum Advisory Group 2014a). VRHS has been found to be operationally achievable; and is applied around the world, including in Mountain Ash forests in Tasmania (Fedrowitz *et al.* 2014). Despite this, the timber release plan for the next five years of harvesting in the Central Highlands region has 402 coupes proposed for logging, with less than 5% of those designated for harvesting using VRHS (VicForests 2017a).

Failure to consider the key science on effective conservation strategies such as forest reservation

Recent initiatives to conserve Leadbeater's Possum have been constrained by prioritising the maintenance of harvesting levels for the native forest logging industry. For example, the package of conservation strategies in the Victorian Government's Leadbeater's Possum Advisory Group Technical Report was limited to a maximum combined reduction of 5% in sustained yield (Leadbeater's Possum Advisory Group 2014a). This automatically precluded the most effective strategy of establishing a large formally protected area (Todd *et al.* 2016; Taylor *et al.* 2017) where some of the key processes threatening Leadbeater's Possum could be excluded or their effects reduced. The effectiveness and necessity of an expanded ecological reserve system has been demonstrated through work led by Victorian Government scientists (Todd *et al.* 2016) and others (Taylor *et al.* 2017). Instead, several of the State Government's recommendations for conserving Leadbeater's Possum were actions that were unproven and high risk (such as translocation of animals), or were ineffective or difficult, and expensive to implement and maintain at a meaningful scale (nest boxes and artificial hollows), but which would have limited effect on the timber industry.

Extensive research in Mountain Ash forests has highlighted the need to protect existing large old hollow-bearing trees with buffers of unlogged forest. This buffering of old trees is one of the highest priority actions that should be adopted (Lindenmayer 2017), especially given the prolonged time required to recruit new large old trees as

existing ones are lost (Lindenmayer *et al.* 2012). To date, this recommendation has largely been ignored, resulting in hundreds of large old hollow-bearing trees being badly damaged during logging operations or by fires lit to promote the regeneration of logged stands (Lindenmayer *et al.* 2016). We suggest that this recommendation was rejected by the Victorian Government because of its potential impacts on resource availability for the timber industry.

Retrogressive management zoning for forest protection

The Victorian Government has employed a range of strategies that has resulted in reduced levels of habitat protection for Leadbeater's Possum. For example, it has altered long-standing definitions of 'mature' trees and 'old growth'. Based on definitions developed in the 1950s (Jacobs 1955), mature trees were those that yielded sawlogs and, in Mountain Ash forests, were typically 60-80+ years old. The main way Leadbeater's Possum habitat is protected is through a zoning prescription underpinned by the density of 'mature' trees with hollows within a given area (Macfarlane *et al.* 1995; Victorian Government Department of Environment and Primary Industries 2014). By changing the previous definition to one that excludes trees younger than 120 years old, the vast majority of trees in logging coupes are no longer assessed. A number of additional changes to the methodology of calculating the habitat zones has meant it is now more difficult to find areas with the threshold density of hollow-bearing trees than it was when the original prescriptions were developed over 20 years ago (Blair *et al.* 2017).

There also have been definitional changes to 'old growth' trees and stands. Previously, old growth was deemed to occur when the senescence of Mountain Ash trees typically begins, especially the development of hollows (120-150 years old) (Lindenmayer *et al.* 2017a). However, trees must now be 250 years to be considered to be old growth (VicForests 2013; Victorian Government Department of Environment and Primary Industries 2013; Blair *et al.* 2017). The result of this change is less protection for old growth trees, which now have an additional century of growth required before prescriptions relating to their protection take effect (Blair *et al.* 2017). This significantly weakens the protection of large old trees and habitat for Leadbeater's Possum. To the best of our collective understanding, neither of these changes in definition of mature trees or old growth is based on credible empirical science.

Failure to recognize long-term declines in population and the continued threats to the conservation of the species

A critical part of the conservation of any species is to quantify temporal changes in populations. Due to a recent increase in the number of sightings of Leadbeater's Possum, some forest industry advocates claim that populations of Leadbeater's Possum are increasing and its Critically Endangered status should be downgraded (reviewed by Blair *et al.* 2017). These recent additional records of Leadbeater's Possum are most likely a function of a substantial increase in the amount of effort invested in trying to find animals after prescriptions changed to buffer known colonies with areas of unlogged forest (Leadbeater's Possum Advisory Group 2014a; b; Blair *et al.* 2017). Although buffering of known colonies of animals is an improvement in protection, recent work suggests that the size of the buffers may be inadequate (Lindenmayer *et al.* 2017b), and hence the effectiveness of long-term protection associated with this measure remains unclear.

The detection of more animals with greater search effort is a well-known phenomenon in studies of other animals but it does not mean populations are increasing (Harihar *et al.* 2017). Our large-scale, long-term monitoring work at over 160 field sites located throughout the distribution of Leadbeater's Possum indicates the species is in significant decline (Figure 1). Leadbeater's Possum is not the only species undergoing major decline; the Greater Glider *Petauroides volans* – which is classified as Vulnerable – was formerly found at 64% of our long-term sites (in 1997) and is now found at only 24% of sites; this is a highly statistically significant decline (Lindenmayer *et al.*, unpublished data).

A critical oversight on the part of all 'initiatives' to better conserve Leadbeater's Possum has been a failure to address one of the key processes threatening the

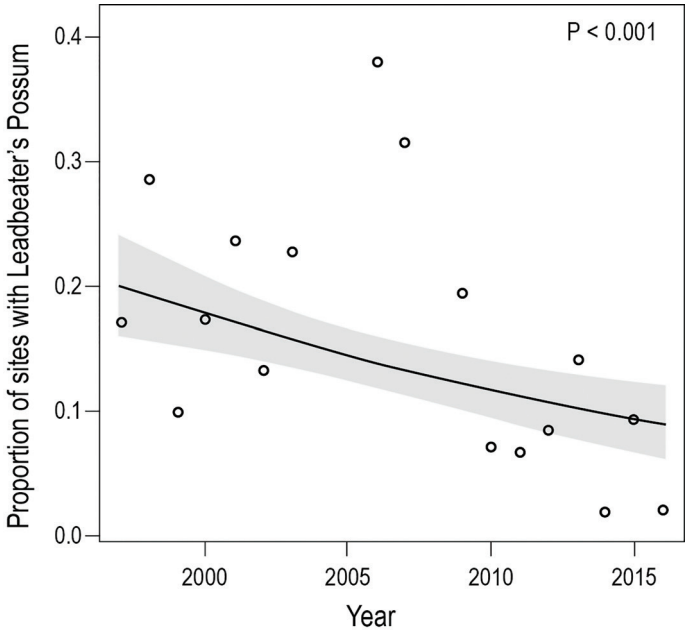

Figure 1. Temporal changes in the proportion of sites occupied by Leadbeater's Possum between 1997 and 2017. The curve is a multi-level logistic regression model for the presence/absence of a Leadbeater's Possum at the site level with site included as a random effect. The solid line represents the posterior mean and the shaded region indicate the 95% credible interval.

species – the rapid ongoing decline in large old trees. These trees are the sole form of natural nesting sites for the species, as well as the Greater Glider and other hollow tree dependent fauna in the Mountain Ash forests of Victoria) (Lindenmayer *et al.* 2016). Our most recent work suggests that by 2040, populations of large old trees will be less than 10% of what they were in 1997 (Burns *et al.* 2015). The paucity of large old trees and the significant risks including fire, climate change and on-going logging faced by the Mountain Ash forests in which Leadbeater's Possum lives has resulted in the forest ecosystem itself being classified as Critically Endangered under the IUCN formal process for assessment of Red Listed Ecosystems (Burns *et al.* 2015). It is unfortunate that no coherent policy or on-the-ground strategy has been developed (or implemented) to tackle the decline of large old hollow-bearing trees in Mountain Ash forests. Similarly, with logging planned in 5 yearly periods, the decision-making cycle is not sufficiently long-term to plan for the recruitment of new cohorts of hollow-bearing trees from stands that currently supply timber to sawmills and pulpmills.

Poor governance practices

The governance process for developing conservation measures for Leadbeater's Possum has changed markedly between 2012 and 2017. Prior to 2012, the government sought advice from expert ecologists on the most effective conservation measures. The government would subsequently try to balance these recommendations with their impacts on the timber industry and other stakeholders.

The current process appears to begin with input from the forest industry, which lacks conservation science credentials or expertise on Leadbeater's Possum. This precludes consideration of effective conservation measures that may affect the timber industry. Those with conservation management and forest ecology expertise (including those who study the species) have been largely excluded from input into the development of appropriate science-based recommendations. As a result, the most effective conservation options are not considered.

Failure to consider other forest values beyond timber harvesting

The Victorian Government currently has a limited view of the array of key values of Mountain Ash forests. Not only have there been substantial constraints on conservation efforts imposed by the desire to maintain the timber industry at current harvesting levels, but non-timber values are given secondary consideration. Economic and environmental accounting has been employed to quantify the relative contribution to the Victorian economy of different natural resource-based industries in the Central Highlands (Keith *et al.* 2017a; Keith *et al.* 2017b). This work shows that non-timber-based industries – water production and tourism – contribute significantly more (25.5 and 21.6 times, respectively) to the Victorian economy than the native forest logging industry. Moreover, native forest logging degrades water and tourism values as well as biodiversity and carbon storage values (Keith *et al.* 2017a). For example, intact ecologically mature forests generate in excess of 12 megalitres per ha per year more water than forests degraded by logging (Vertessy *et al.* 2001), and old forests on average store more than twice the carbon of young (30 year old) forest (Keith *et al.* 2014). Comparing the value of the timber industry to other forest values such as water, tourism and carbon storage that increase as the forest ages, the Victorian economy would be significantly better off if logging within the Mountain Ash forests ceased (Keith *et al.* 2017a; Keith *et al.* 2017b).

Expanding the range of values considered in debates over the fate of Leadbeater's Possum and the industry gives a broader perspective on rational economic use and protection of forest resources in the Central Highlands region (Keith *et al.* 2017b). To date, the Victorian Government has not been receptive to the results of economic and environmental accounting, despite it having an entire section of its administration dedicated to the application of such methods and advocating the use of the same approaches employed by Keith *et al.* (2017a, b) (and which are also used in 54 other countries worldwide).

Discussion

Leadbeater's Possum is arguably one of the best studied Critically Endangered species worldwide. Legislation to protect the species obliges the Victorian Government to guarantee the species is able to 'survive, flourish and retain their potential for evolutionary development in the wild', and to 'manage potentially threatening processes' (Victorian Government Department of Environment and Primary Industries 2014). There is no shortage of scientific evidence to guide best practice conservation management and evidence-based policy, and the government is regularly updated as new information becomes available. Indeed, there is a broad consensus among experts on the most appropriate and ecologically-effective strategies for the conservation of the species – that is, the establishment of a large protected area (Todd *et al.* 2016; Taylor *et al.* 2017). However, policies and practices for the conservation of Leadbeater's Possum do not reflect current scientific knowledge, but show a lack of political will to make rational decisions and a position that continues to favour one stakeholder (the timber industry) to the detriment of all others. This is underscored by recent analyses showing the substantial economic benefits that accrue from a change in land tenure from extensive and intensive wood production to conservation (Keith *et al.* 2017a, b).

The best way to resolve the current impasse on the conservation of Leadbeater's Possum remains unclear.

The Government's Forest Industry Taskforce released a Statement of Intent in 2016, collaboratively written by timber industry and conservation groups, which stated "*the current 'business-as-usual' response to the many complex issues facing Victoria's forests is insufficient, and that to continue in this way will be of detriment to all stakeholders and the broader community*." (Forest Industry Taskforce 2016). Despite recognition of the unsustainable nature of current management for industry and conservation, demonstrable positive change is yet to occur. Considerable time has been spent in the past decade outlining the need for policy and forest management reform. Communication efforts have engaged politicians (during which time there has been several changes in government), resource managers and the general public with literally thousands of hours dedicated to highlighting key and salient points arising from the intensive scientific research and monitoring programs (and more recently economic studies). Whether these efforts will eventually catalyse change in management or whether the status quo continues to be maintained and with it, the ongoing demise of Leadbeater's Possum and possibly other charismatic faunal icons like the Greater Glider remains to be seen.

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References

Blair, D., McBurney, L., Lindenmayer, D. B., Banks, S. and Blanchard, W., 2017. *The Leadbeater's Possum Review*. The Australian National University, Canberra. Available at: https://fennerschool-associated.anu.edu.au/documents/Leadbeater_Pos_Rev_Aug_2017.pdf.

Burns, E. L., Lindenmayer, D. B., Stein, J., Blanchard, W., McBurney, L., Blair, D. and Banks, S. C., 2015. Ecosystem assessment of mountain ash forest in the Central Highlands of Victoria, south-eastern Australia. *Austral Ecology* **40:** 386-399. doi:10.1111/aec.12200

Fedrowitz, K. F., Koricheva, J., Baker, S. C., Lindenmayer, D. B., Palik, B., Rosenvald, R., Beese, W., Franklin, J. F., Kouki, J., Macdonald, E., Messier, C., Sverdrup-Thygeson, A. and Gustafsson, L., 2014. Can retention forestry help conserve biodiversity? A meta-analysis. *Journal of Applied Ecology* **51:** 1669-1679. doi:10/1111/1365-2664.12289

Flint, A. and Fagg, P., 2007. *Mountain Ash in Victoria's State Forests. Silviculture reference manual No. 1*. Department of Sustainability and Environment, Melbourne.

Forest Industry Taskforce., 2016. *Statement of Intent*. Available at: http://forestindustrytaskforce.com.au/?page_id=435, accessed 19 October 2017.

Harihar, A., Chanchani, P., Pariwakam, M., Noon, B. R. and Goodrich, J., 2017. Defensible inference: questioning global trends in tiger populations. *Consevation Letters* **10:** 502-505. doi:10.1111.conl.12406

Jacobs, M. R., 1955. *Growth Habits of the Eucalypts*. Forestry and Timber Bureau, Department of the Interior, Canberra.

Keith, H., Lindenmayer, D., Mackey, B., Blair, D., Carter, L., McBurney, L., Okada, S. and Konishi-Nagano, T., 2014. Managing temperate forests for carbon storage: impacts of logging versus forest protection on carbon stocks. *Ecosphere* **5:** art75. doi:10.1890/es14-00051.1

Keith, H., Vardon, M., Stein, J., Stein, J. and Lindenmayer, D. B., 2017a. *Experimental Ecosystem Accounts for the Central Highlands of Victoria*. The Australian National University and the Threatened Species Recovery Hub, Canberra, Australia.

Keith, H., Vardon, M., Stein, J., Stein, J. and Lindenmayer, D. B., 2017b. 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

Leadbeater's Possum Advisory Group. 2014a. *Leadbeater's Possum Technical Report*. Report to the Minister for Environment and Climate Change and the Minister for Agriculture and Food Security, Melbourne.

Leadbeater's Possum Advisory Group. 2014b. *Leadbeater's Possum Recommendations*. Report to the Minister for Environment and Climate Change and Minister for Agriculture and Food Security, Melbourne.

Lindenmayer, D., Wood, J., McBurney, L., Blair, D. and Banks, S. C., 2015a. Single large versus several small: The SLOSS debate in the context of bird responses to a variable retention logging experiment. *Forest Ecology and Management* **339:** 1-10. doi:10.1016/j.foreco.2014.11.027

Lindenmayer, D. B., 1994. Timber harvesting in the montane ash forests of the Central Highlands of Victoria: impacts at different spatial scales on arboreal marsupials and the implications for ecologically sustainable forest use. Pp. 31-50 *in* Ecology and Sustainability of Southern Temperate Ecosystems ed by T. W. Norton and S. R. Dovers. CSIRO Publications,

Lindenmayer, D. B., 1996. *Wildlife and Woodchips: Leadbeater's Possum, a Testcase of Sustainable Forestry*. UNSW Press, Sydney.

Lindenmayer, D. B. and Franklin, J. F., Editors, 2003. *Towards forest sustainability*. CSIRO Publishing, Melbourne.

Lindenmayer, D.B. and Wood, J.T., 2012. Long-term patterns in the decay, collapse, and abundance of trees with hollows in the mountain ash (Eucalyptus regnans) forests of Victoria, southeastern Australia. *Canadian Journal of Forest Research* **40**: 48-54.

Lindenmayer, D. B., Blanchard, W., McBurney, L., Blair, D., Banks, S., Likens, G. E., Franklin, J. F., Laurance, W. F., Stein, J. A. and Gibbons, P., 2012. Interacting factors driving a major loss of large trees with cavities in a forest ecosystem. *PLOS One* **7:** e41864. doi:10.1371/journal.pone.0041864

Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Martínez Pastur, G., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J., Wayne, A. and Gustafsson, L., 2012. A major shift to retention forestry can help resolve global forest sustainability issues. *Conservation Letters* **5**: 421-431.

Lindenmayer, D. B., Blanchard, W., McBurney, L., Blair, D., Banks, S. C., Driscoll, D., Smith, A. and Gill, A. M., 2013. Fire severity and landscape context effects on arboreal marsupials. *Biological Conservation* **167:** 137-148. doi:10.1016/j.biocon.2013.07.028

Lindenmayer, D. B., Blair, D., McBurney, L. and Banks, S., 2015b. *Mountain Ash. Fire, Logging and the Future of Victoria's Giant Forests*. CSIRO Publishing, Melbourne.

Lindenmayer, D. B., Blair, D., McBurney, L. and Banks, S. C., 2015c. Ignoring the science in failing to conserve a faunal icon – major political, policy and management problems in preventing the extinction of Leadbeater's possum. *Pacific Conservation Biology* **21:** 257-265. doi:10.1071/PC15022

Lindenmayer, D. B., Blanchard, W., Blair, D., McBurney, L. and Banks, S. C., 2016. Environmental and human drivers of large old tree abundance in Australian wet forests *Forest Ecology and Management* **372:** 266-235. doi:10.1016/j.foreco.2016.04.017

Lindenmayer, D. B., 2017. Conserving large old trees as small natural features. *Biological Conservation* **211:** 51-59. doi:10.1016/j.biocon.2016.11.012

Lindenmayer, D. B., Blanchard, W., Blair, D., McBurney, L. and Banks, S. C., 2017a. 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

Lindenmayer, D. B., McBurney, L., Blair, D. P. and Banks, S. C., 2017b. Inter-den tree movements by Leadbeater's Possum. *Australian Zoologist* doi:10.7882/AZ.2017.028

Macfarlane, M., Lowe, K. and Smith, J., 1995. *Action Statement No. 62: Leadbeater's Possum Gymnobelideus leadbeateri*. Victorian Government, Melbourne.

Taylor, C., Cadenhead, N., Lindenmayer, D. B. and Wintle, B. A., 2017. Improving the design of a conservation reserve for a critically endangered species. *PLOS One* **12:** e0169629. doi:10.1371/journal.pone.0169629

Todd, C. R., Lindenmayer, D. B., Stamation, K., Acevedo-Cattaneo, S., Smith, S. and Lumsden, L. F., 2016. Assessing reserve effectiveness: Application to a threatened species in a dynamic fire prone forest landscape. *Ecological Modelling* **338** 90-100. doi:10.1016/j.ecolmodel.2016.07.021

Vertessy, R. A., Watson, F. G. R. and O'Sullivan, S. K., 2001. Factors determining relations between stand age and catchment water balance in mountain ash forests. *Forest Ecology and Management* **143:** 13-26. doi:10.1016/S0378-1127(00)00501-6

VicForests., 2013. *Growth Stages of Ash Eucalypts*. VicForests, Melbourne.

VicForests., 2017a. *Timber Release Plan (including Approved Changes) - January 2017*. VicForests, Melbourne.

VicForests., 2017b. *Resource Outlook 2016-2017*. VicForests, Melbourne.

Victorian Environmental Assessment Council., 2017. *Fibre and Wood Supply Assessment Report*. Victorian Environmental Assessment Council, East Melbourne.

Victorian Government., 1996. *Forest (Wood Pulp Agreement) Act 1996*.

Victorian Government Department of Environment and Primary Industries., 2013. *Maturity Assessment of Mountain Ash, Alpine Ash and Shining Gum*. Department of Environment and Primary Industries, Melbourne.

Victorian Government Department of Environment and Primary Industries., 2014. *Action Statement No. 62: Leadbeater's Possum Gymnobelideus leadbeateri, Flora and Fauna Guarantee Act 1988*. Department of Environment and Primary Industries, Melbourne.

Warneke, R. M., 1968. Leadbeater's Possum. Pp. 23-28 *in* Wildlife in South-eastern Australia ed by K. Dempster. Australian Broadcasting Commission, Sydney.

Woinarski, J. C., Burbidge, A. A. and Harrison, P. L., 2015. Ongoing unraveling of a continental fauna: Decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences of the USA* **112:** 4531-4540. doi:10.1073/pnas.1417301112

Woinarski, J. C. Z., Garnett, S. T., Legge, S. M. and Lindenmayer, D. B., 2017. The contribution of policy, law, management, research and advocacy failings to the recent extinctions of three Australian vertebrate species. *Conservation Biology* **31:** 13-23. doi:10.1111/cobi.12852