Environment Protection and Biodiversity Conservation (National Recovery Plan for Leadbeater's Possum (*Gymnobelideus leadbeateri*)) Instrument 2024

We jointly make this recovery plan under subsection 269A(3) of the *Environment Protection and Biodiversity Conservation Act 1999*.

Dated 01/03/2024

Tanya Plibersek

Minister for the Environment and Water (Commonwealth)

Dated 22/01/2024

Steve Dimopoulos

Minister for Environment (Victoria)

Minister for Tourism, Sport and Major Events

Minister for Outdoor Recreation

2.1A Name

This instrument is the *Environment Protection and Biodiversity Conservation (National Recovery Plan for Leadbeater's Possum (Gymnobelideus leadbeateri)) Instrument 2024*.

2.1B Commencement

This instrument commences the day after it is registered.

2.1C Authority

This instrument is made under subsection 269A(3) of the *Environment Protection and Biodiversity Conservation Act 1999*.

Australian Government

Department of Climate Change, Energy, the Environment and Water

VICTORIA State Government

National Recovery Plan for Leadbeater's Possum

(Gymnobelideus leadbeateri)

Cataloguing data

This publication (and any material sourced from it) should be attributed as: DCCEEW 2024, National Recovery Plan for Leadbeater's Possum (*Gymnobelideus leadbeateri*), Department of Climate Change, Energy, the Environment and Water, Canberra. CC BY 4.0.

This publication is available at SPRAT EPBC Act Recovery Plans.

Department of Climate Change, Energy, the Environment and Water
GPO Box 3090 Canberra ACT 2601
Telephone 1800 900 090
Web dcceew.gov.au

Species Profile and Threats Database (SPRAT) pages for this species is available at Leadbeater's Possum (*Gymnobelideus leadbeateri*).

Disclaimer

The Australian Government acting through the Department of Climate Change, Energy, the Environment and Water has exercised due care and skill in preparing and compiling the information and data in this publication. Notwithstanding, the Department of Climate Change, Energy, the Environment and Water, its employees and advisers disclaim all liability, including liability for negligence and for any loss, damage, injury, expense or cost incurred by any person as a result of accessing, using or relying on any of the information or data in this publication to the maximum extent permitted by law.

The Australian Government, in partnership with the Victorian Department of Energy, Environment and Climate Change, facilitates the publication of recovery plans relevant to Victoria to detail the actions needed for the conservation of threatened native wildlife. This Recovery Plan has been developed with the involvement and cooperation of a range of stakeholders, but individual stakeholders have not necessarily committed to undertaking specific actions. The attainment of objectives and the provision of funds may be subject to budgetary and other constraints affecting the parties involved and may also be constrained by the need to address other conservation priorities. Approved recovery actions may be subject to modification due to changes in knowledge and changes in conservation status.

Acknowledgements

The Department of Climate Change, Energy, the Environment and Water would like to acknowledge the Leadbeater's Possum Drafting Group who contributed significantly to the development of this recovery plan. Maps were produced by the Arthur Rylah Institute and the Department of Climate Change, Energy, the Environment and Water.

Acknowledgement of Country

The Department of Climate Change, Energy, the Environment and Water recognises the First Peoples of this nation and their ongoing connection to culture and Country. We acknowledge Aboriginal and Torres Strait Islander Peoples as the Traditional Owners, Custodians and Lore Keepers of the world's oldest living culture and pay respects to their Elders past and present.

Image credits

Cover photo: © Tamara Leitch and Claire McCall 2019.

Contents

1 Summary

This plan was endorsed by the Threatened Species Scientific Committee (TSSC) in 2023, after the Victorian Government had announced that native timber harvesting would cease on public lands on 1 January 2024. Timber harvesting has been one of the major threats to Leadbeater's possum and the plan was initially drafted with a number of key objectives to ameliorate this threat, consistent with the 2019 Leadbeater's possum listing assessment and conservation advice. Although the direct threat from forestry will be largely removed, there are ongoing legacy impacts and future (interrelated) threats from fire, climate change as well as other challenges which will occur for many decades to come. This plan has been revised with the aim of meeting these priority challenges. Furthermore, management of forests in Victoria beyond 2023 is not yet finalised. This plan has therefore been developed in the context of the current circumstances and recognises that further revision may be required if circumstances change.

This Recovery Plan replaces the first (1997) Recovery Plan for Leadbeater's possum (*Gymnobelideus leadbeateri*). Leadbeater's possum is the only species in the genus *Gymnobelideus*, the only mammal endemic to Victoria and one of Victoria's two state terrestrial faunal emblems.

This Plan recognises that although substantial research and conservation achievements have been made associated with the previous Recovery Plan and other initiatives, the status of Leadbeater's possum has declined, such that it was up-listed to Critically Endangered under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in 2015, with this status re-confirmed in 2019.

The main threat to this species has been decline in the extent, quality and connectivity of suitable habitat, particularly the loss of hollow-bearing trees, due mostly to timber harvesting, which has occurred over many decades. Although timber harvesting will cease from 1 January 2024, the species will be subject to its impacts for many decades to come. This Plan therefore focuses on both the impacts of historical timber harvesting and the main current and ongoing threats, especially further decline in the extent, quality and connectivity of suitable habitat (and further loss of hollow-bearing trees) due to current and projected severe bushfire and changed fire regimes, all of which are and will be increasingly exacerbated by climate change. Leadbeater's possum occurs in a cool-climate region and may be susceptible to increasing temperatures and extreme heat events. Additional threats and actions to mitigate the known threats are described throughout this Plan.

Conservation planning for Leadbeater's possum is therefore a long-term proposition and commitment. Because of the legacy of historic fire and timber harvesting, the availability of suitable habitat is predicted to decline until at least 2065, such that it will be extremely challenging to achieve recovery of this species in the short term. Actions taken now to enhance its conservation status are unlikely to reverse the current decline over the 10-year period of this plan, but they will help to slow decline and are essential for future population recovery. Importantly, actions taken or not taken now will affect the likelihood of extinction of Leadbeater's possum over a 50–100 year timeframe.

1.1 Long-term recovery objective

The extent, quality and connectivity of current and future suitable habitat, and its occupancy by Leadbeater's possum, is increased, such that its probability of extinction over a 100-year period is less than 1%.

1.2 Recovery plan objectives

To progress the long-term recovery objective, eight objectives are set for the 10-year life of this plan. To achieve these objectives, and consistent with the requirements of the EPBC Act, the recovery plan sets out those research and management actions necessary to stop the decline of, and support the recovery of, Leadbeater's possum so that its chances of long-term survival in nature are maximised.

Objective 1: All relevant existing and future planning and policy settings are reviewed, and where required, refined and implemented in a manner that contributes appropriately to maximising the chances of long-term survival of Leadbeater's possum in nature.

Objective 2: A whole of landscape management regime is in place ensuring that all current and future suitable habitat across the species' known range is maintained, enhanced and effectively managed to maximise its suitability for Leadbeater's possum.

Objective 3: A range of ex-situ conservation strategies to support within range recovery are assessed, and where deemed there is a net long-term benefit (such as, likelihood of increase in overall population viability), implemented and evaluated.

Objective 4: Additional populations outside the core range of the Central Highlands are located, established and protected.

Objective 5: Targeted research addresses key knowledge gaps such that management options are better informed and management actions more effective.

Objective 6: An integrated monitoring program is effectively implemented (and maintained) that publicly reports in a timely manner on possum status, existing and future habitat extent, quality and connectivity, and effectiveness of management and research activities.

Objective 7: Stakeholders support and where relevant are involved in the implementation of the Plan.

Objective 8: Effective and adaptive implementation and management oversight of the Plan, including adequate resourcing, is in place.

2 Introduction

2.1 Conservation status of Leadbeater's possum

Leadbeater's possum is currently listed under the following legislation:

- *Environment Protection and Biodiversity Conservation Act 1999* (Cth): Critically Endangered
  - uplisted to Critically Endangered in 2015, previously listed as Endangered (since 2000); re-assessed in 2019 and maintained as Critically Endangered;
  - eligibility listing criterion 1A4(b) – a very severe (greater than 80%) decline in population size over a combination of the recent past and near future (that is, over a total of three possum generations (18 years) from 2006 to 2024) based on an appropriate index of abundance (abundance of hollow-bearing trees).
- *Flora and Fauna Guarantee Act 1988* (Vic): Critically Endangered.
- International Union for Conservation of Nature (IUCN) Red List of Threatened Species (2014): Critically Endangered.

2.2 About this recovery plan

This document constitutes the National Recovery Plan for Leadbeater's possum (*Gymnobelideus leadbeateri*). The plan considers the conservation requirements of the species across (and beyond) its range and identifies the actions to stop the decline, and support the recovery, of the species such that its chances of long-term survival in nature are maximised (EPBC Act s 270(1)).

This plan replaces the previous 'Leadbeater's possum (*Gymnobelideus leadbeateri*) Recovery Plan' (Macfarlane et al. 1997) in place since November 1997. A review of the previous Recovery Plan (available at Review of the 1997 Recovery Plan for Leadbeater's Possum) concluded that most recovery actions had been implemented to some extent over the life of the plan and a range of measures had been introduced to protect Leadbeater's possum habitat. Additionally, all 13 recommendations from the Leadbeater's Possum Advisory Group (LPAG), established in 2013, were implemented. Nevertheless, the species status continued to deteriorate such that in 2015 the TSSC increased its threatened status to Critically Endangered and reaffirmed this in 2019.

This new Recovery Plan has been developed in response to several key changes over the life of the previous Plan including:

- the continuing and projected decline in the species' population size and the extent and quality of its habitat (especially the abundance of large hollow-bearing trees);
- changed circumstances for population and habitat trajectories following the 2009 bushfires and the continuation of timber harvesting;
- new information on the species' ecology, distribution, habitat and management;
- a need to reassess some policies, management regulations and guidelines to improve the conservation prospects for the species;

- the Victorian Government's announcement in May 2023 that native timber harvesting will cease on 1 January 2024.

2.3 Urgent need and emergency response

All Recovery Plans describe priority management needs for species that are threatened with extinction. However, this Recovery Plan identifies a particular need for urgent conservation management responses.

In its assessment of the conservation status of this species, the TSSC (2019) concluded that the population of the species (explicitly as informed by data on the abundance of old or hollow-bearing trees) had declined and would continue to decline by more than 80% over three generations (18 years) spanning the recent past and near future, despite a suite of existing conservation planning and management actions.

In conducting its assessment, the TSSC used hollow-bearing trees as an index of abundance for Leadbeater's possum on the basis that they are the most limiting resource, have the longest renewal time after depletion, a decline in hollow-bearing trees should cause decline in Leadbeater's possum and that a projected decline in hollow-bearing trees indicates a future decline in Leadbeater's possum.

A range of assessments has consistently described severe and ongoing reduction in the abundance of hollow-bearing trees, projected until at least 2065 (Lindenmayer et al. 1990b; Lindenmayer et al. 2015b, Lindenmayer and Sato 2018). This decline is largely due to the ongoing collapse of large hollow-bearing trees killed in the extensive 1939 bushfires, reduction in the extent of mature ash forest, or areas that will become mature in the future, through historical timber harvesting, and the impacts of the 2009 bushfire. Any future extensive bushfire will further exacerbate this severe decline in available old hollow-bearing trees and impact future hollow recruitment. These declines will become more severe when climate change is considered, through direct effects on the possum and also the regeneration potential of mountain ash. Beyond 2065 Leadbeater's possum habitat extent may increase as new hollow-bearing trees recruit, but this will be contingent on the incidence and extent of future bushfires and the effects of climate change.

The total size of the 'lowland' subpopulation at Yellingbo has shown a severe and ongoing deterioration over recent years (from more than 110 individuals in 2003 to 23 individuals in 2022 D. Harley pers. comm.), notwithstanding a program of substantial and intensive research and conservation management actions (Harley 2012; Harley 2016; DELWP 2016).

The entire Lake Mountain plateau was burnt at high severity in the 2009 bushfires (Harley 2016) and there is little evidence of population recovery as at July 2019 (D. Harley pers. comm.). It is clear that rates of habitat recovery and recolonization are far slower in sub-alpine woodland relative to montane ash forest.

However, surveys in 2017 at sites selected randomly across the main range of the species (using randomised stratified sampling) detected Leadbeater's possums at 37% of these sites (ARI unpublished data). Recolonisation of the 2009 bushfire footprint commenced within 8 years, with 25–50% of a large sample of the fire-affected sites surveyed by the Arthur Rylah Institute (ARI) in 2017 to 2019 recording Leadbeater's possums, including at some burnt sites a considerable distance

from the nearest unburnt areas. There has also been a modest increase in the known range of the species, extending its confirmed distribution approximately 15 km to the east (McBride et al. 2019; Eyre et al. 2022). Additional lowland occurrences have been found in small patches of swamp forest at Murrindindi, Marysville and Buxton.

Despite these new records and insights, evidence of a more uniform distribution across a slightly increased range than was formerly known does not overcome the projected decline of the key limiting habitat element of old hollow-bearing trees. Prior management and protective mechanisms have not yet been sufficient to stop the decline and support the recovery of the species. A concerted long-term vision, commitment and management effort, with adequate resourcing and policy settings, is necessary to protect this species into the future.

2.4 Significance of Leadbeater's possum

Leadbeater's possum is the only species in the genus *Gymnobelideus*, which is most closely related to the tropical striped possums *Dactylopsila* (Edwards and Westerman 1992; Osborne and Christidis 2001; Cardillo et al. 2004). It is one of 21 Australian threatened mammal species accorded high priority in the Australian Government's Threatened Species Action Plan 2022-2032, and (its lowland subpopulation) is listed as one of the 27 priority threatened species in Zoos Victoria Fighting Extinction program.

Leadbeater's possum has great cultural significance, as one of Victoria's two state terrestrial faunal emblems, and is Victoria's only endemic mammal species. The species is the focus of an active and committed conservation group (Friends of the Leadbeater's Possum) and has substantial community profile.

The Wurundjeri, Taungurung and Gunaikurnai people are the traditional custodians of most of the land on which the Leadbeater's possum is found. This land is culturally significant for all these people who place a strong emphasis on the natural value of their unique environment and protecting the future of all species including the Leadbeater's possum.

Leadbeater's possum is also a 'flagship' species for the conservation of its montane ash forest environment and biodiversity more generally (Lindenmayer and Cunningham 1997; Lindenmayer et al. 2014b), because the main threats that affect this high-profile species are likely to affect many other less iconic species in this ecosystem. Hence, any conservation responses for Leadbeater's possum are likely to provide some benefit to many other species, particularly other hollow-dwelling mammals and birds, such as the sooty owl (*Tyto tenebricosa*), listed as Endangered under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act), and greater glider (southern and central) (*Petauroides volans*) listed as Endangered under the FFG Act and Endangered under the EPBC Act.

Conservation measures taken for the Leadbeater's possum may also be expected to benefit its main mountain ash forest habitat which was listed as a Critically Endangered ecosystem using IUCN criteria (Burns et al. 2015). The Yellingbo population has conservation significance as a relictual part of the distribution with importance for the longer-term evolutionary potential of the species, and because the small site at which it occurs (Yellingbo Nature Conservation Area) also supports the other Victorian faunal emblem, the helmeted honeyeater (*Lichenostomus melanops cassidix*) and has been the subject of substantial conservation effort extending over several decades.

3 Background information informing recovery action

Leadbeater's possum has been the focus of substantial research effort extending for at least 30 years. This recovery plan does not attempt an exhaustive synthesis of this substantial literature, but rather aims to identify the key areas where it may inform the recovery effort, and the remaining gaps must be filled to optimise this effort. More detailed accounts of the species' biology are available elsewhere (Smith et al. 1985; Menkhorst and Lumsden 1995; Lindenmayer 1996a; Lindenmayer et al. 2015b; Harley 2016).

3.1 Description

Leadbeater's possum is a small (100–160 g), nocturnal, arboreal possum. It has some superficial resemblance to the far more abundant and widespread (but not closely related) sugar glider (*Petaurus breviceps*) but is notably distinct from that species in not possessing a gliding membrane and having a club-shaped tail.

3.2 Distribution

Leadbeater's possum is endemic to Victoria. Its former distribution is poorly resolved, with a sparse fossil and sub-fossil record, and uncertainty about the locations of some historic records (Harley 2004c). Its current habitat critical, montane ash forest, has had a very dynamic distribution over the last 20,000 years, including periods of very severe contraction in extent relative to its current range (McKenzie 2002; Worth et al. 2014).

3.2.1 Former distribution

Leadbeater's possum was formerly more widespread. Fossil deposits are known from near Buchan (in east Gippsland) and the Wombeyan Caves and Marble Arch in south-eastern New South Wales (Harley 2004c). Sub-fossil deposits (about 100–400 years before present) demonstrate that it formerly occurred in foothill and montane forests of south, central and east Gippsland (Bilney et al. 2006; Bilney et al. 2010; Bilney 2014). The species has not been reported as living individuals from these areas, however further surveys are warranted.

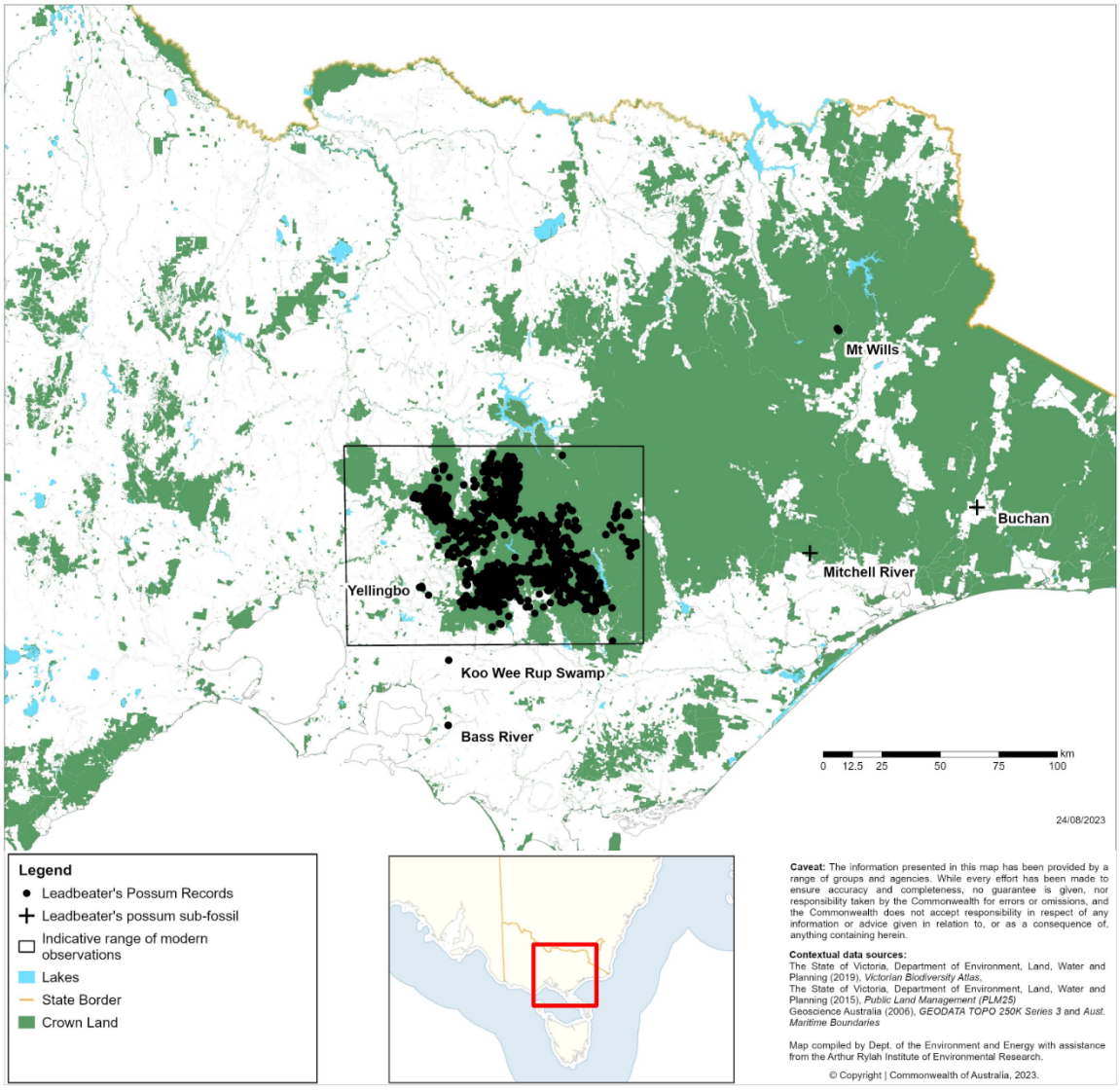
Of its known distribution since European settlement, there is a single isolated record from 1909 in north-eastern Victoria ('Sunnyside', Mt Wills) (Brazenor 1932), a specimen held at Beechworth museum but without locality data (Lindenmayer and Dixon 1992), and four records from south-western Gippsland (including Bass River and Koo Wee Rup swamp area near Tynong) collected between 1867 and 1915 (Myroniuk and Seebeck 1992; Menkhorst and Lumsden 1995; Figure 1). Harley (2004c) collated several other historic and recent records unsupported by confirmed specimens, beyond its currently known range. Subsequent sampling at most of these sites has failed to corroborate these records (Harley 2004a).

A substantial decline from the past to the current range is evident from the fossil record and from more recent historic habitat loss (especially in its former lowland swamp forest range). Distributional decline is also inferred from bioclimatic modelling, which suggests a range reduction of 88% over the last 250 years (Burgman and Lindenmayer 1998), and from genetic analyses (Hansen et al. 2009).

Priority research needs to enhance management

- A substantial survey effort incorporating new techniques should continue to be extended to more rigorously evaluate whether Leadbeater's possum occurs in potentially suitable areas (including sites of previous confirmed and plausible unconfirmed reports) outside the Central Highlands, and to evaluate the extent of current and future habitat availability across this larger range (see Section 3.2.6 Survey techniques and effort).

Figure 1: The distribution of Leadbeater's possum showing the historic records (prior to 1915) from Bass River, the edge of the Koo Wee Rup Swamp in the Western Port area, and Mt Wills in the north-east



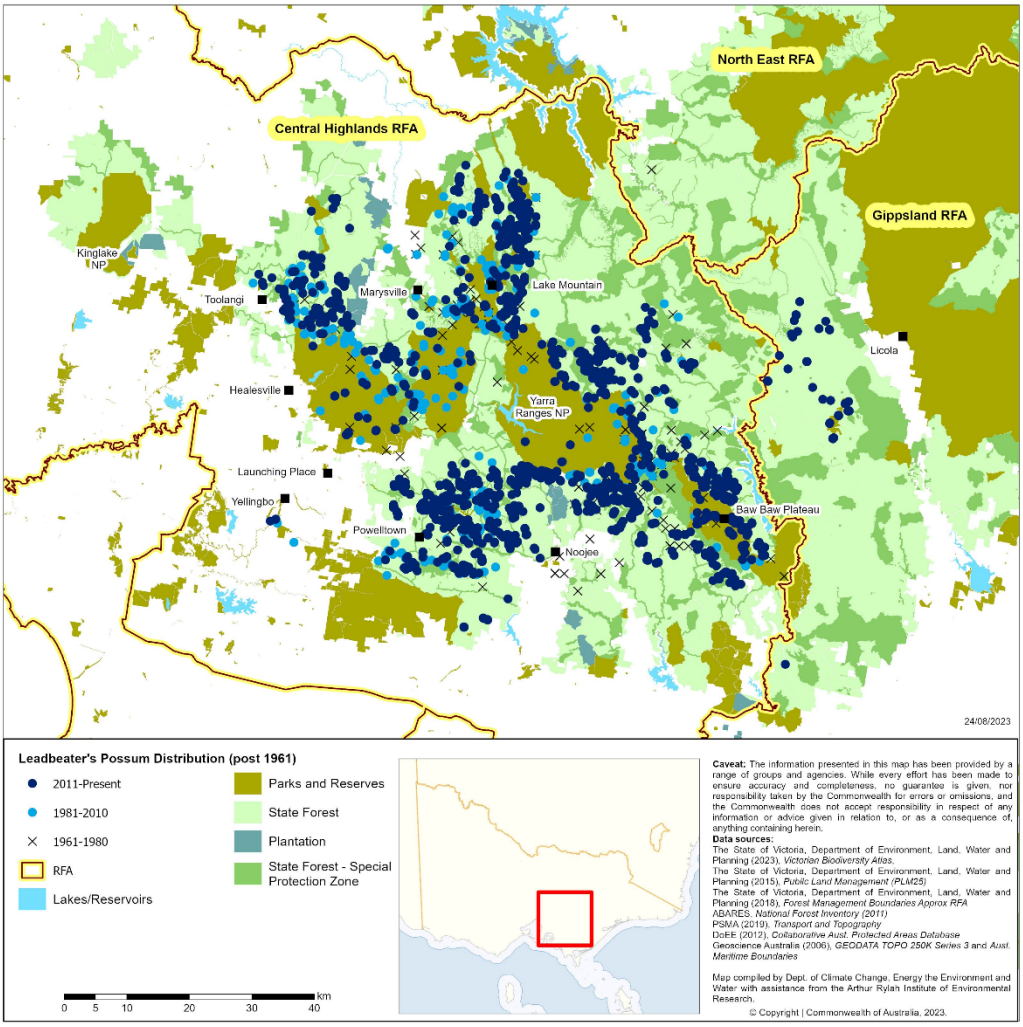
Note: Subfossil records from owl deposits at Mitchell River that are considered to be approximately 100 years before present are also shown (R. Bilney, pers. comm.).

3.2.2 Current distribution

Since its 'rediscovery' in 1961, almost all records of Leadbeater's possum have been in an area of approximately 70 km (north-south) by 100 km (east-west), in the Central Highlands, roughly bounded

by Toolangi in the west, Rubicon in the north, Mt Useful in the east and Beenak in the south (Figure 2). Recent discoveries have extended that range approximately 15 km eastwards, to the Mt Useful area and northwest of Licola (McBride et al. 2019; Eyre et al. 2020; ARI unpublished data). Although these new records are outside the Central Highlands Regional Forest Agreement (RFA) area, for simplicity in this Plan we continue to refer to the current distribution as occurring within the 'Central Highlands'. The exception to this core range is the isolated remnant subpopulation in lowland swamp forest at Yellingbo Nature Conservation Area, where the species occurs in an occupied area of less than 20 ha, along a 6 km riparian strip, approximately 16 km distant from the nearest montane ash forest population (Smales 1994; Harley 2002; Harley 2004c; Harley et al. 2005). Targeted camera trapping has recently detected additional lowland occurrences in small patches of swamp forest at Murrindindi, Marysville and Buxton within the highland range (presumably these individuals represent the highland genetics).

Figure 2: The distribution of Leadbeater's possum since its rediscovery in the Central Highlands in 1961



Note: The increase in number of records since 2011 largely reflects a marked increase in survey effort since this time.

Within its main range in the Central Highlands, it is patchily distributed, with distributional gaps due to areas of unsuitable vegetation types (typically those not dominated by montane ash forests or sub-alpine (snow gum) woodlands), or due to temporary or permanent loss of habitat critical because of loss of hollows due to fires or timber harvesting. Its actual current distribution is imprecisely known because not all habitat can be (or has been) surveyed, and because its persistence varies temporally due to hollow abundance, fire, timber harvesting, spatial context and other factors.

Recent extensive surveys are helping to increase knowledge of the distribution throughout the Central Highlands and have substantially expanded the number of records of the species within its central range (Lumsden et al. 2013; Nelson et al. 2015; Harley 2016; Nelson et al. 2017; McBride et al. 2019; Eyre et al. 2020, 2022; DEECA unpublished data; Zoos Victoria unpublished data). Despite this, in 2017 it was estimated that only approximately 6% of the montane ash forest within the range of the species in State forests had been surveyed (DELWP 2017).

A number of studies have used modern survey techniques in attempts to determine the full extent of the possum's range (i.e., identifying new locations beyond the previously known range), sampling widely across Victoria (McBride et al. 2019; Eyre et al. 2020, 2022; Zoos Victoria unpublished). The only detections have been 15 km east of the currently known range. Other studies using older techniques outside the Central Highlands, including north-eastern Victoria and southern New South Wales have not located any Leadbeater's possums (Lindenmayer et al. 1991d). Despite the lack of Leadbeater's possums recorded, further surveys are warranted given the large area over which the historic and subfossil records are distributed, much of which has not been sampled.

Modelling of the habitat distribution of Leadbeater's possum in 2022 (DEECA unpublished) using the additional recent records estimates the potential habitat to be likely less than 300,000 ha. This is a larger area than previous estimates such as that of the Victorian Leadbeater's Possum Advisory Group (2014b) which at the time considered there to be just over 200,000 ha of 'potential habitat' (defined as montane ash forest and snow gum woodland). 166,150 ha of the 300,000 ha has burnt since 2000 (DEECA unpublished). This includes 68,000 ha (34% of LPAG-defined area) burnt in 2009 that was not suitable for Leadbeater's possum for several years after the fires. Since then, some of the regrowth has been recolonised and some timber harvesting regrowth is also now being used as foraging habitat.

An occupancy model which factored in the impact of the 2009 bushfires suggested that the current 'strongholds' for the species are in the south of the Central Highlands, notably the Baw Baw Plateau and its southern slopes, the Toorongo Plateau south of the Upper Yarra Catchment, state forest near Powelltown, parts of Toolangi State Forest and southern parts of the Upper Yarra National Park (Lumsden et al. 2013). The model was not able to predict occupancy at a fine scale, partly because onsite habitat variables were not able to be incorporated (Nelson et al. 2017). Despite these limitations, it is useful to provide a general indication of the area that might have been occupied at the time: the total area with at least a 50% probability of occupancy by Leadbeater's possum was 35,764 ha; that with at least a 30% probability of occupancy was 93,825 ha.

The former Victorian government Department of Environment, Land, Water and Planning (DELWP) surveys in 2016 and 2017 at 149 sites, using a randomised sampling design across state forest and national parks, detected Leadbeater's possums at 37% of sites (ARI unpublished data). If these sites are representative of the whole area, it may suggest that 37% of the 300,000 ha of potential habitat

within the Central Highlands core area is occupied (no sampling was undertaken in the new extension area to the east), equivalent to 111,000 ha.

Another approach for estimating the area of potential habitat has been undertaken by the University of Melbourne through detailed modelling of light detection and ranging (LiDAR) data to identify and map large old trees across the full extent of the Central Highlands (both montane ash forest and mixed species forest) and to model the understorey density and connectivity. This has identified a large number (over 1.6 million, with 95% confidence intervals from 1.2–2 million) of large hollow-bearing trees across this area, comprising 819,000 live and 822,000 dead hollow-bearing trees. Incorporating these data with presence and absence records of Leadbeater's possums suggests there are currently 28,000 ha (95% confidence interval of 17,000–40,000 ha) of potential Leadbeater's possum habitat across the Central Highlands (R. Jiang, C. Nitschke and P. Baker, pers. comm.).

The divergence between estimates of potential habitat and currently occupied habitat, and variability in both, are indicative of the specialised habitat requirements of Leadbeater's possums and the complex dynamics of tree hollow development and decay and midstorey growth and senescence (see Section 3.4 Habitat). Any such estimates will vary in response to disturbance events (such as fires) and ongoing pressures such as climate change.

Implications for conservation management

- Given the current state and prognosis of Leadbeater's possum, all sites at which the species has recently been recorded are important and merit protection; as do all areas at which there is a reasonable likelihood of its occurrence as indicated by occupancy and population viability analysis (PVA) modelling.

Priority research needs to enhance management

- Precision in local and regional scale conservation planning will be enhanced with evidence from additional distributional surveys and analysis to further improve the refinement, resolution, complementarity and testing of occupancy and other distributional modelling, predictions of the area of suitable habitat, and improved understanding of why different modelling provides markedly different estimates.

3.2.3 Tenure and land use of the current distribution

Native timber harvesting will cease on 1 January 2024 but it is yet to be determined how that will affect the reserve system or other subsequent land use or tenure changes. Habitat modelling that currently captures tenure breakdown will need to respond to any proposed changes so current analyses will need updating to potentially inform any differing management intent.

As part of the transition, the Victorian government will be required to deliver a program of land management works to manage the 1.8 million ha of public land currently subject to the timber harvesting allocation order. Currently, the Victorian government proposes to establish an advisory panel to consider and make recommendations to Government on the areas of forests that qualify for protection as National Parks, the areas of forests that would be suitable for recreation opportunities, and opportunities for management of public land by Traditional Owners.

A specific 'Leadbeater's Possum reserve system' (see Section 10.2 Definitions) was established in 2008, but analysis concluded that it was insufficient to ensure the long-term persistence of the

species under scenarios incorporating future fires (Lumsden et al. 2013, Todd et al. 2016). However, this modelling was undertaken prior to the dramatic increase in survey effort described earlier and does not reflect the cessation of native timber harvesting. No modelling has yet been done of population viability to reflect the current circumstances.

Implications for conservation management

- Previous arrangements suggested that reserved areas were insufficient for conservation of the species. However, the circumstances have since changed substantially and there is considerable uncertainty what that means for Leadbeater's possum conservation.

Priority research needs to enhance management

- Updated population viability and distributional modelling followed by additional surveys should be undertaken to determine the arrangements required to significantly reduce the risk of extinction of Leadbeater's possum over the next 100-year period. Such analysis will need to reflect new understanding of the distribution and dynamics of the possum and its habitat and incorporate projected changes in land use and climate including those parts of the landscape likely to provide climate refugia.

3.2.4 Recent decline in distribution

The 2009 bushfires burnt 68,000 ha of the montane ash forest and sub-alpine (snow gum) woodland potential habitat, apparently eliminating possums from those areas (Lindenmayer et al. 2013c; Lumsden et al. 2013). In recent years, however, recolonisation has commenced, with Leadbeater's possum detected at between 25% and 50% of 2009-burnt sites that have been sampled since 2016. This includes sites in montane ash habitats (ARI unpublished data), areas of snow gum at Lake Mountain (ZoosVic and Parks Victoria unpublished data) and in the Buxton Silver Gum Nature Conservation Reserve northeast of Toolangi (which contains habitat more similar to Yellingbo lowland swamp habitats). Post-fire recolonisation rates in different forest types appear to be variable, with longer periods required in subalpine woodland (Zoos Victoria, unpublished data), presumably related to the slower rate of vegetation regeneration.

Habitat loss is not only sudden and episodic – there is also an ongoing, more gradual decline. Based on assessments of decline in the abundance of hollow-bearing trees (Lindenmayer et al. 2015b), the TSSC described an ongoing decline in the extent and quality of suitable habitat based on the collapse of large hollow-bearing trees, fire and timber harvesting, with such decline causing a projected decrease of 83% (confidence range of 78–88%) in population size of Leadbeater's possum, over the period between 2006 and 2024 (i.e. three possum generations) (TSSC 2019; See Section 3.4.3 Decline in habitat extent, suitability and connectivity: montane ash forest).

3.2.5 Future range

Regardless of habitat loss due to fire or other disturbance, bioclimatic modelling incorporating projected climate change predicts considerable ongoing diminution of the range of the Leadbeater's possum and of its principal habitat, montane ash forest (Lindenmayer et al. 1991d; Burns et al. 2015), and the likely increase in fire severity and frequency (Keenan and Nitschke 2016). Recent climate modelling by researchers at Deakin University in collaboration with Zoos Victoria predict a significant contraction in the suitable climate space in the Central Highlands by 2090 due to climate change (Archibald et al. 2023). Other climate change effects may include reduced productivity and

recruitment of mountain ash. Forest stand density is predicted to be reduced by approximately 15% by 2080 and the area of the Central Highlands suitable for natural regeneration may be reduced by up to 80% over this timeframe (Baker et al. 2017).

3.2.6 Survey techniques and effort

Conservation planning and management will be most effective when there is a high degree of confidence in known and prospective distribution, and the determinants of that distribution. There has been substantial investigation of, and refinement in, targeted survey techniques allowing for rapid and comprehensive sampling, although all sampling procedures have some interpretational and other constraints.

The longest-used monitoring method is 'stag-watching', which involves a set of observers positioned under large hollow-bearing trees on dusk to observe possums emerging from tree hollows (Seebeck et al. 1983; Smith et al. 1989). It is a generally reliable, but resource-intensive method (Lindenmayer 2009). It is important in the context of the long-standing research and monitoring program run by Professor David Lindenmayer of the Australian National University (ANU). Importantly, it specifically evaluates hollow-bearing tree occupation.

More recently, some surveys have successfully used call playback or imitation to lure the possums towards observers, with detection in dense vegetation further improved by the use of thermal cameras (Lumsden et al. 2013; Harley 2015b). There may be some caveats with interpretations of results from this method including uncertainty about the distance that responding possums may move to the playback (Harley 2015b) and variability in response rates relating to wind or rain, and to habituation (Lindenmayer et al. 2014a), or seasonal or site-specific variation.

Fixed remote (motion-sensing) cameras, directed at bait stations ('camera traps'), are a cost-effective and efficient survey tool for determining occupancy at a site (Harley et al. 2014). This technique has been shown to have a greater than 85% likelihood of detecting the species where it is present when using three cameras deployed for four weeks (Nelson et al. 2017). Camera traps are now routinely used in surveys by the Department of Energy, Environment and Climate Action (DEECA), Zoos Victoria, Parks Victoria and University of Melbourne. Harley and Eyre (in press) discuss the benefits and limitations of camera trapping surveys for Leadbeater's possum.

The establishment and regular checking of nest boxes has also progressed recently as a survey and monitoring tool, with particular applicability in sub-alpine woodland and lowland swamp forest habitats (Harley 2006b; Harley et al. 2014) and varying success in montane ash forests (Lindenmayer et al. 2003b; Lindenmayer et al. 2009; Harley 2016). The entire lowland population at Yellingbo is provisioned with nest boxes so that den availability does not constrain the subpopulation size (Zoos Victoria unpublished data). In the Central Highlands there are currently more than 750 nest boxes installed for the species, with new designs being developed and tested (Harley 2023). In addition, there are 132 manually excavated chainsaw hollows, of which 62% have been used by Leadbeater's possums as at August 2023 (ARI unpublished).

There have been substantial targeted surveys for Leadbeater's possum in recent years. The number of sites with confirmed records for this species has increased very markedly in recent years, and for many of these the detection rates have been fairly high. These surveys have shown that the species is more widespread than previously recognised and may be more numerous than once thought.

However, except where there is recolonisation of the 2009 bushfire area, it is unlikely that the actual number of animals is increasing. While the expanded (known) distribution and higher numbers are encouraging, there is still a declining trend based on habitat condition and trajectory, reflecting the disturbance history of sites.

3.3 Population size

3.3.1 Estimates of current population size

There is no precise and robust estimate of the total population size for Leadbeater's possum. An exception is for the very small and disjunct subpopulation at Yellingbo, where censuses of all individuals have been undertaken since 1996 (Harley 2015a) – its subpopulation in 2023 was reliably estimated to be 34 individuals (D. Harley pers. comm.).

The TSSC (2019) estimated that the population of possums may have exceeded 10,000 mature individuals, but was more likely in the range 2,500–10,000. However, that estimate used a conservative value of three possums per colony and was based on the earlier estimate of approximately 200,000 ha of potential habitat. Given that potential habitat is now estimated to be approximately 300,000 ha, and new records continue to accumulate, the previous estimate is likely lower than the actual population size.

It is useful to attempt to derive an accurate estimate of population size, to better resolve population viability modelling and assessment of conservation status but the actual population size is a less important parameter for conservation management than the population trend, in particular the current and projected rate of population decline.

Priority research needs to enhance management

- Further investigations to provide a robust and reliable estimate of current total population size, and that of discrete subpopulations.

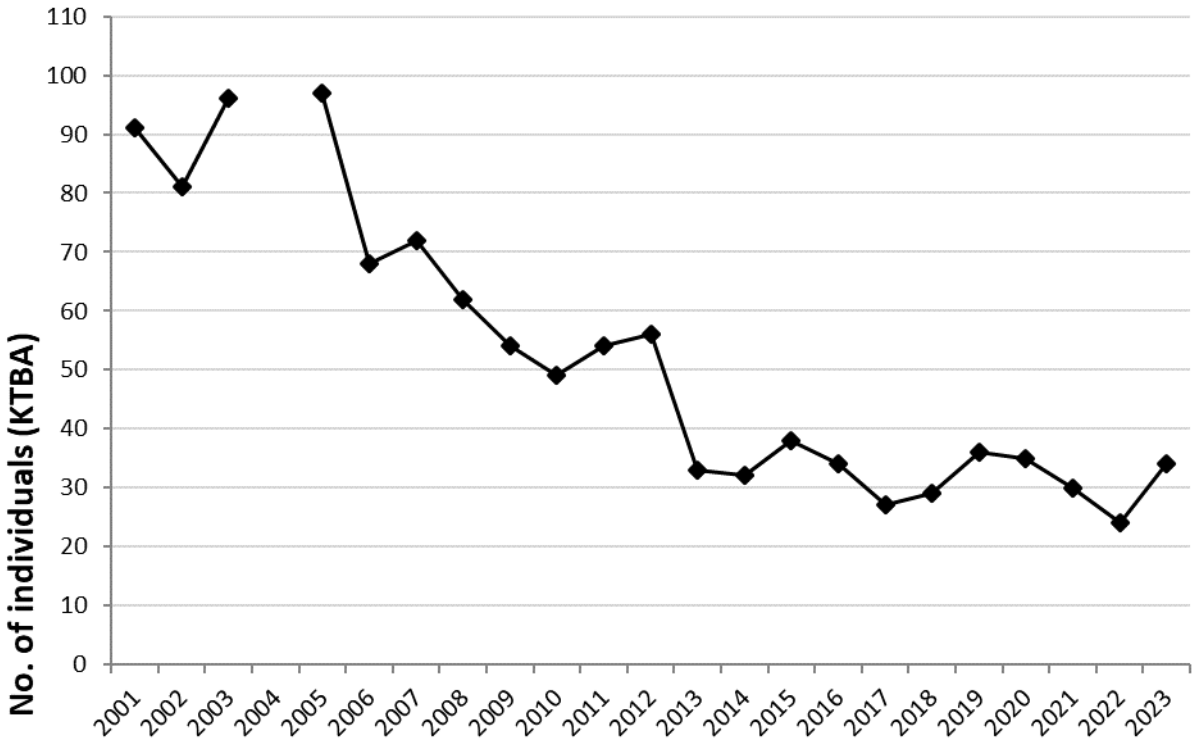
3.3.2 Rates of current and projected population decline

Population trends are largely influenced by changes in the extent, quality and connectivity of suitable habitat, and such changes are considered in more detail in Section 3.4 Habitat.

Population trends have been described based on population monitoring at some sites, and – more broadly – on population projections based on models of the variation over time in the extent of suitable habitat.

Regular, detailed monitoring of the subpopulation at Yellingbo since 2001 has demonstrated a largely continuous downward trajectory, with total decline over this period of approximately 80% (Harley 2015a, 2023; Figure 3). In 2023, the total subpopulation size was estimated to be 34 individuals (Zoos Victoria, unpublished data). Despite evidence of inbreeding depression in the lowland subpopulation (Zilko et al. 2020), reproductive rates in the wild remain within an acceptable range, with at least 54 young produced at Yellingbo Conservation Area during the past 5 years (since 2018) indicating that the population retains the capacity to increase in size. However, the critically small size of this subpopulation, places it at extremely high risk of local extinction.

Figure 3: Leadbeater's possum subpopulation trend based on estimates of 'Known to be Alive' (KTBA) from long-term nest box monitoring and camera trapping at Yellingbo Nature Conservation Area (lowland habitat)



Source: Harley (2023)

Population counts were made at several sub-alpine woodland sites prior to the 2009 bushfires, and repeated after those fires. For the Lake Mountain area, an estimated subpopulation of 200–300 individuals, based on survey results prior to the fire, was reduced to just six individuals following the bushfire, indicating that the fire resulted in greater than 95% mortality at that locality (Harley 2016). The monitoring data collected between 2010 and 2021 indicate that the subpopulation has yet to show any significant signs of recovery, with the plateau estimated to support fewer than 10 individuals throughout most of this period (Zoos Victoria, unpublished data).

Leadbeater's possums have recently been detected at three lowland areas within the Central Highlands, all severely burnt in the 2009 bushfires, the Buxton Silver Gum Nature Conservation Reserve, Murrindindi Scenic Reserve and Marysville Sate Forest. These areas are notable as they support lowland swamp forest with Mountain Swamp Gum (*Eucalyptus camphora*) and share habitat affinities with that occupied by Leadbeater's possums at Yellingbo. The recent detections were in habitat with dense, post-fire regeneration (D. Harley, pers. comm).

The most substantial monitoring program reporting on changes in the abundance or incidence of Leadbeater's possum was established in 1983 (and subsequently expanded) for the montane ash forests. The most recent analysis reported a 50% decline in the number of sites occupied since 1987, from approximately 20% of sites occupied to less than 10% in 2017 (Lindenmayer and Sato 2018).

Importantly, while monitoring of possums directly is valuable, it is the availability of hollow bearing trees, as the most limiting resource for Leadbeater's possum, that is the key variable in all attempts

to assess or model the population trend of the possum into the future (Lumsden et al. 2013; LPAG 2014b; Todd et al. 2016; TSSC 2019). The dynamics of the trees are quite well understood and it is widely accepted that their availability will continue to decline until approximately 2065 (Lindenmayer and Sato 2018). It also generally accepted that subsequent fires will exacerbate the decline of both hollow-bearing trees and possums. There is also a developing understanding of the interplay between the dynamics of hollow-bearing trees and of the growth and senescence of midstorey trees essential for foraging and movement (Baker et al. 2022). Recent advances in forest dynamics modelling could be incorporated into future PVA to improve these aspects of the model (Baker et al. 2017; Trouvé et al. 2019; Nitschke et al. 2020), albeit they are unlikely to alter the overall trends that reflect forest condition.

Implications for conservation management

- Population and habitat monitoring has provided a vital contribution to understanding this complex system, and existing monitoring programs should be retained and expanded to including all relevant habitat types, forest ages and throughout all of the species' range. Existing monitoring also provides information on responses to some management, but further enhancements to more comprehensively assess management effectiveness are required.

3.3.3 Subpopulation structure and genetic variation

Leadbeater's possum comprises two distinct genetic groups, with marked and long-standing distinction in genetic composition between the small lowland subpopulation at Yellingbo and all other (montane ash forest and sub-alpine (snow gum) woodland) subpopulations (Hansen et al. 2005; Hansen and Taylor 2008; Zilko 2021). The former is considered an evolutionarily significant unit (ESU) as it is the last surviving remnant (relict) of an otherwise extinct genetic unit, that has historically been, and remains, isolated from others (Hansen and Taylor 2008).

Genetic sampling has been more limited across the highland range. The only location with substantial sampling effort is Lake Mountain, where samples were collected from 159 individuals in 2006 to 2007 (Hansen and Taylor 2008; Hansen et al. 2009). However, small numbers of samples are available from most parts of the species' range following field sampling undertaken by Zoos Victoria in 2018 and 2019 (Zilko 2021).

The Yellingbo population is inbred (Hansen et al. 2009; Zilko et al. 2020), with recent analyses revealing inbreeding depression (Zilko et al. 2020, 2021). Sub-structuring has also been reported indicating that this can occur over small spatial scales and the species may be highly sensitive to habitat fragmentation (Hansen et al. 2009; Zilko et al. 2020). A genetic rescue strategy has been devised and is being implemented based on managed levels of gene-pool mixing between lowland and highland Leadbeater's possums.

Previous research indicated that in the Central Highlands populations are 'remarkably genetically diverse', with evidence of ongoing gene flow (indicating effective dispersal) across much of this range, although with some contrary evidence of recent disruption of gene flow for some sites (for example, Powelltown), probably due to habitat fragmentation (Hansen et al. 2009). Subpopulation structuring has recently been re-examined in the Central Highlands (Zilko 2021) and revealed four distinct genetic groups in the highlands: Northern (encompassing Snob's Creek, Mt Bullfight, Lake Mountain, Arnold Gap, and Marysville), Central (Warburton, Donna Buang, and Ben Cairn), Southern (Powelltown), and Eastern (Baw Baw National Park and Toorongo Plateau). This suggests

contemporary isolation of the four groups, highlighting the need to reconnect populations to avoid further erosion of genetic diversity and fitness decline (as has been documented for the lowland population).

The southern genetic group (Powelltown population) appears to be most vulnerable based on its size. It also was inferred to have had the most recent gene flow with extinct Bass River population, which in turn shared genes with the lowland population (Hansen et al. 2009). This suggests mixing lowland possums with those of the southern groups should replicate past gene flow and thus be of low risk of outbreeding depression.

Small and isolated subpopulations may be particularly at risk from genetic, stochastic and other factors: for example, even a relatively small bushfire may destroy all habitat in the Yellingbo area (Harley 2015a). PVA has indicated that discrete subpopulations need to be larger than a threshold of 200 individuals to have at least a 90% chance of persistence over a 100-year period (Lindenmayer and Lacy 1995b; Lindenmayer 2000).

Implications for conservation management

- Populations in the highland tall forests and the lowland swamp forest must be maintained. Given the parlous status of the lowland subpopulation, there may be a need to enhance its genetic stock through careful gene-pool mixing (i.e., outbreeding with highland animals).
- Management should aim to increase the population size and geographical extent of the lowland swamp forest subpopulation.
- Management should seek to actively retain or enhance adequate habitat connectivity within the montane forest habitat through linking reserves and wildlife corridors and artificial connectivity over roads, or if necessary to augment such connectivity through careful translocation.

Priority research needs to enhance management

- Use the results of monitoring of genetic diversity within highland subpopulations to (1) detect fragmentation and isolation effects and (2) inform appropriate ongoing management strategies that maintain genetic diversity. Greater sampling across highland populations is required, including:
  - increasing the number of samples across some previously under-sampled locations (those fewer than 10 samples), and
  - obtaining samples from some localities with occupied lowland habitat within the highland range.
- Assess the risks, costs and benefits, and likelihood of success of options for genetic rescue of the lowland swamp forest subpopulation, including gene pool mixing between the lowland swamp forest subpopulation and other subpopulations.
- Validate harmful and climate-adaptive genetic variants as predictors of individual fitness in the inbred lowland populations using genomic data. This will allow targeting best quality individuals for genetic rescue and population management.
- Collect and biobank sperm and somatic tissues from at risk populations (for example, lowland) for restoring genetic diversity in the future.

3.4 Habitat

3.4.1 Key habitat features

Broadly, the key habitat features required by Leadbeater's possum are (1) suitable (large) hollows for denning and breeding, at a density that allows for multiple den sites within any single colony home range; (2) vegetation structure in the form of a sub-canopy or midstorey layer of more of less continuous or interconnecting foliage cover (to facilitate the possum's movement and foraging) (Lindenmayer 1996b); and (3) forest composition that includes dominance of smooth-barked eucalypts (especially species with some loose or decorticating bark that provides shelter for invertebrate prey) (Lindenmayer 1996b; Harley 2004a,c), often with a midstorey of gum-producing wattle (*Acacia* spp.) species in montane ash (Smith et al. 1985; Smith and Lindenmayer 1988; Lindenmayer et al. 1991b).

In subalpine woodland the presence of mountain tea tree (*Leptospermum grandifolium*) is a key feature of suitable habitat, as is the presence of *Melaleuca* spp. or *Leptospermum* spp. in lowland swamp forest. Additionally, Leadbeater's possums construct a large nest (inside hollows) made of shredded fibrous bark from eucalypts or paperbark, and the occurrence of trees with such fibrous bark in the home range is also required (Smith and Lindenmayer 1988; Harley 2004b).

Suitable hollows are closely associated with tree age and size. Hollows used typically have large internal dimensions (approximately 30 cm diameter) (Smith and Lindenmayer 1988) and occur almost exclusively in large old trees (Lindenmayer et al. 2013b; Lindenmayer et al. 2013c), that are 190–450 years old (Smith and Lindenmayer 1988; Lindenmayer et al. 2015a). In contrast, the dense midstorey preferred by Leadbeater's possum often occurs in young regenerating forests and optimal habitat occurs in multi-aged forest where the large trees, dead or living, provide hollows, and regenerating vegetation provides food and movement pathways (Lindenmayer et al. 1990b).

Habitat suitability and occupancy is also influenced by broader spatial landscape context, around individual nest trees (Lindenmayer et al. 1990a) and around a forest site. The likelihood of persistence of Leadbeater's possum in any habitat patch increases substantially with increasing patch area (McCarthy and Lindenmayer 2000; Lindenmayer and McCarthy 2006). At least in montane ash habitat, there is little use of narrow habitat strips through recently harvested areas (Lindenmayer et al. 1993b). Three years after the 2009 bushfires, Leadbeater's possums were detected in 16% of isolated unburnt mountain ash forest patches with the smallest occupied patch being 10 ha (Lumsden et al. 2013). Small numbers of individuals also persisted in unburnt linear refuges of sub-alpine woodland at Lake Mountain and Mt Bullfight (D. Harley and J. Antrobus, pers. comm.). While the pattern of recolonisation is still not fully understood, the rapid recolonisation throughout some of the severely burnt areas suggests that colonies were able to persist. Furthermore, sampling soon after the 2009 bushfires found that Leadbeater's possum were significantly less abundant in unburnt sites where fire had approached within 500–1000 m (in comparison to unburnt areas without such proximity to recently burnt areas), suggesting that the detrimental short-term impacts of fire are greater than simply the proportion of the landscape that has been burnt (Lindenmayer et al. 2013c).

Most of the core habitat requirements are consistent across the three broad habitat types in which the species occurs: montane ash forest (comprising about 96% of suitable habitat), sub-alpine (snow gum) woodland (about 4%) and lowland swamp forest (less than 1%) (Department of Environment

and Primary Industries 2014a). However, there are additional specific factors characteristic of each of these habitat types, as described below.

A small number of records in 'mixed species' forests had smooth-barked eucalypt species present other than mountain ash, such as manna gum (*E. viminalis*) or mountain gum (*E. dalrympleana*) (McBride et al. 2019) which might have provided the same habitat resources, but these have mostly been close to areas of montane ash forest. Other surveys sampling marginal habitat, to reduce uncertainty in the Habitat Distribution Models, have not detected the species within these drier forest types (ARI unpublished data), and so the extent to which mixed species forest is used by Leadbeater's possum is unclear.

Implications for conservation management

- The extent, quality and connectivity of suitable habitat is the critical factor for conservation of Leadbeater's possum, and conservation management actions should focus primarily on factors and actions that serve to increase (or most effectively reduce the rate of decline in) the current and future habitat extent, quality and connectivity.

Priority research needs to enhance management

- Undertake further surveys in mixed species forest and lowland habitats dominated by smooth-barked eucalypts to determine how widespread the species is in these more marginal habitat types.

3.4.2 Montane ash forest habitat

The vast majority of the Leadbeater's possum population occurs in montane ash forest, dominated by mountain ash (*E. regnans*), alpine ash (*E. delegatensis*) or shining gum (*E. nitens*), at altitudes from 400–1,200 m above sea level (Lindenmayer 1989; Lindenmayer et al. 1989). In montane ash forest, Leadbeater's possum occurs at highest densities in multi-aged forest containing several age classes of eucalypts, including live and dead hollow-bearing trees, together with a dense midstorey of wattles (notably *A. dealbata*, *A. obliquinervia*, *A. melanoxylon* or *A. frigescens*) (Lindenmayer et al. 1990a; Lindenmayer et al. 1991b; Smith and Lindenmayer 1992; Lindenmayer et al. 1994b). They also regularly occur at the eucalypt forest – rainforest ecotone and in montane riparian thickets along gullies embedded within montane ash forests (D. Harley unpublished data; DEECA unpublished data).

In these tall forests, the occurrence and density of Leadbeater's possum is strongly associated with hollow availability. There is a significant correlation between the incidence and abundance of Leadbeater's possum and the density of hollow-bearing trees on a site (Lindenmayer et al. 1991b; Lindenmayer et al. 1994b), although this relationship is less pronounced in reporting of results from recent years (Lindenmayer et al. 2011b; Lindenmayer et al. 2014b). The absence or low abundance of resident Leadbeater's possums on sites with few potential nest trees is thought to be due to competition for hollows from other species, a requirement by individual colonies of Leadbeater's possum to use more than one nest tree and because of their specific hollow requirements (Smith and Lindenmayer 1988; Lindenmayer and Meggs 1996; Lindenmayer et al. 2018). However, the species may show some flexibility in its selection of nesting sites where there are low numbers of hollow-bearing trees by using a wider variety of types of hollow-bearing trees (Lindenmayer et al. 2011b).

In the montane ash forests, the abundance of suitable nest trees is tightly correlated with disturbance history (Lindenmayer et al. 1990b; Lindenmayer et al. 1990c; Lindenmayer et al. 1991a;

Smith and Lindenmayer 1992; Lindenmayer et al. 2016). For the dominant mountain ash trees, hollow formation does not start until the trees are about 120 years old, and the hollows with large internal cavities that are preferred by Leadbeater's possum typically do not form until the trees reach 190–220 years old (Smith and Lindenmayer 1988; Lindenmayer et al. 1991c).

Peak densities of Leadbeater's possum occur in regrowth forests (15–50 years after bushfire), in which stags may supply abundant tree hollows (depending upon the age of the forest at the time of disturbance), and there is a high biomass of wattles (20–50% of stand basal area) and eucalypt regrowth (Smith and Lindenmayer 1988; Lindenmayer et al. 1990a; Lindenmayer et al. 1991b; Lindenmayer et al. 2000). Dense regrowth after timber harvesting can also provide suitable foraging habitat if there are sufficient suitable nesting sites within the regrowth or in adjacent areas (Smith et al. 1985; Nelson et al. 2015; Keith et al. 2016; Nelson et al. 2017). A recent study reported that the abundance of Leadbeater's possum in a set of sites with large hollow-bearing trees retained within timber harvesting regrowth from the 1960 to the 1980s (prior to the commencement of clear felling) was significantly higher than their abundance in 1939 regrowth or mixed aged forest, and not significantly different from the abundance in old growth (Keith et al. 2016). Similarly, surveys of younger timber harvesting regrowth (1978 to 2000) showed high detection rates of Leadbeater's possum compared to older age classes (Nelson et al. 2015; Nelson et al. 2017).

In the post-fire (bushfire or regeneration burns after harvesting) successional cycle, the biomass of wattles increases, peaks and then declines as they senesce and die (typically 60–100 years after disturbance), and stags gradually collapse (Lindenmayer et al. 2012). Habitat may then be of diminishing suitability to provide for all Leadbeater's possum habitat requirements, until the regrowth cohort of eucalypts becomes old enough to form suitable hollows for Leadbeater's possum (typically well over 100 years), however, by that time since disturbance, the forest lacks the dense wattle midstorey component required by Leadbeater's possum (Baker et al. 2022).

Bushfire is a key driver of habitat suitability in montane ash forests (and in other habitats used by Leadbeater's possum with the exception of sub-alpine woodland). Frequent, high intensity or extensive fires may reduce the availability of hollow trees. Recent estimates indicate that the extent of mountain ash forest that is 'old-growth' has declined from an estimated minimum 47,000 ha at the time of European settlement to approximately 1700 ha now, mostly in very small fragments (Lindenmayer et al. 2014a; Burns et al. 2015; Lindenmayer et al. 2015a). The extent of old-growth in alpine ash forests is even less (0.37% of its extent) (Lindenmayer et al. 2014a).

Habitat suitability at any site is typically related to the co-occurrence at that site of sufficient hollows (for nesting) and adequate midstorey cover (for movements and feeding), but these attributes may not always co-occur at the site itself – Leadbeater's possums can occur in an area in which there is a close juxtaposition of habitat that provides nesting hollows but not suitable foraging habitat with habitat that provides suitable foraging habitat but few nesting hollows (Lumsden et al. 2013; Nelson et al. 2017). However, further research is required to understand the extent to which Leadbeater's possum can use such spatial variation, and if there are negative consequences from using separate foraging and nesting areas. In lowland swamp forest at Yellingbo, spatial separation between foraging habitat (within the swamp) and den trees (distributed along the swamp margins) has been observed (Harley et al. 2005). Despite these observations, it is reasonable to conclude that the best quality habitat has overlapping foraging and denning resources.

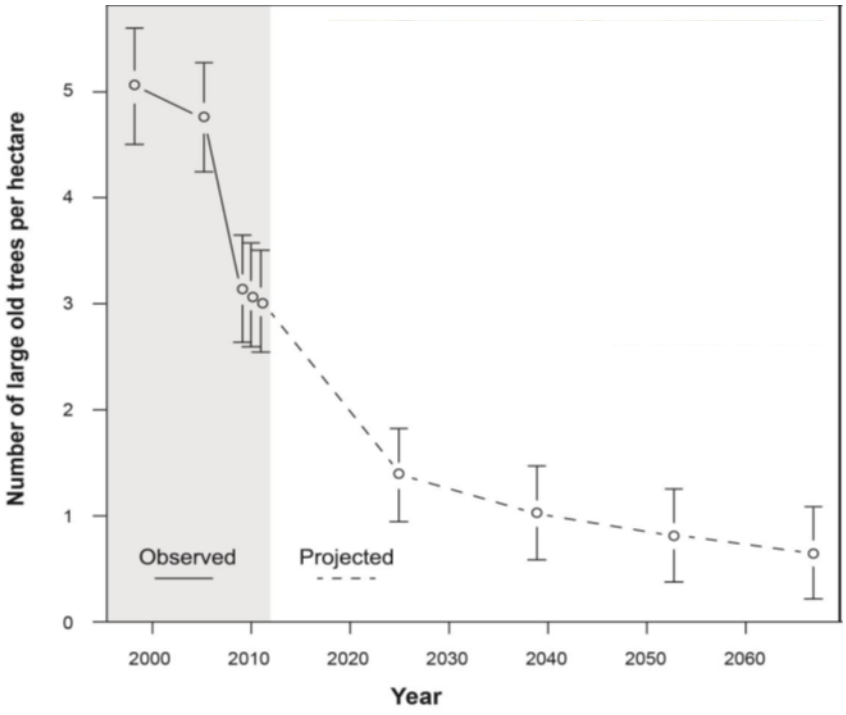
Fire impacts may be exacerbated where salvage logging (the harvesting of fire-impacted trees following bushfire) is practised, as this results in further losses of the critical resource of large hollows (Lindenmayer and Ough 2006; Likens and Lindenmayer 2012; Lindenmayer et al. 2012; Lindenmayer and Laurance 2012; Lindenmayer et al. 2015a; Lindenmayer et al. 2015b). The removal of hazardous trees following bushfires, while important for human safety, can negatively impact the quality of habitat for Leadbeater's possums by reducing the abundance of hollow-bearing trees or creating large openings and breaks in the otherwise dense vegetation structure. Reduced vegetation structure influences the ability of possums to move through continuous midstorey and canopy vegetation, and may increase the risk of predation by owls, cats and foxes due to increased edge effects or possums descending to the ground.

Habitat suitability is also related to some topographic and climate features, with highest incidence of Leadbeater's possum in forests on east and south facing slopes (Lindenmayer et al. 1990a; Lindenmayer et al. 1993c). In a separate habitat modelling study, those montane ash forests considered most likely to be currently occupied by Leadbeater's possums were characterised by lush vegetation in gullies, located in areas that have relatively low summer temperatures and high summer rainfall (Lumsden et al. 2013).

3.4.3 Decline in habitat extent, suitability and connectivity: montane ash forest

The extent, quality and connectivity of Leadbeater's possum habitat in montane ash forest is undergoing severe ongoing decline. This is a consequence of changing fire regimes, habitat loss due to historical timber harvesting, ongoing habitat fragmentation, and interactions among these factors. The extensive 1939 bushfire burnt about 85% of mountain ash forests in the Central Highlands (Burns et al. 2015), but left a landscape legacy of standing dead large hollow-bearing trees that formed suitable denning sites for Leadbeater's possum. However, the abundance of these large hollow-bearing trees has declined substantially, partly due to extensive salvage logging, subsequent bushfires and the natural decay and collapse of the remaining stags and other large old trees (Lindenmayer and Ough 2006).

Figure 4: Observed and projected changes in the average density of large hollow-bearing trees in mountain ash forests in the Central Highlands

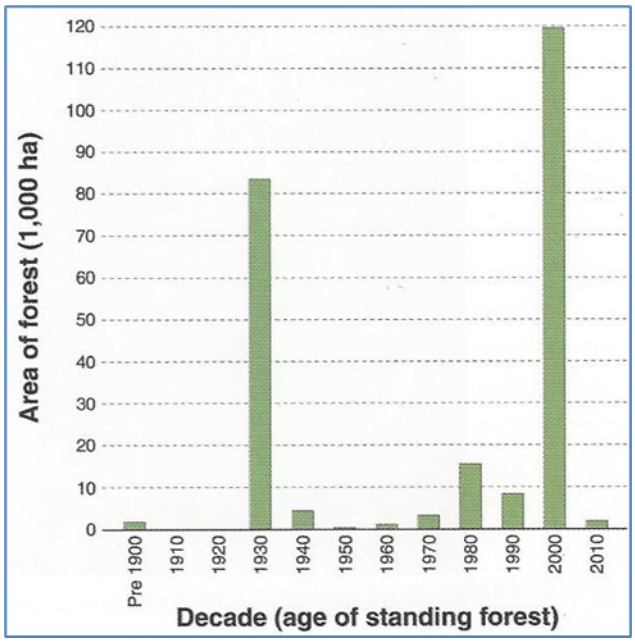


Source: Figure derived from Lindenmayer et al. (2013b), reproduced with permission from David Lindenmayer.

The persistence of large hollow-bearing trees has shown a rapid decline in their abundance across the Central Highlands (Lindenmayer 1996b; Lindenmayer et al. 1997; Lindenmayer 2009; Lindenmayer and Wood 2010; Lindenmayer et al. 2011b; Lindenmayer et al. 2012; Lindenmayer et al. 2015a; Lindenmayer and Sato 2018). The observed and projected rate of decline in the density of large hollow-bearing trees in the Central Highlands (Lindenmayer et al. 2013b; Figure 4) is projected to continue until at least 2065 when new hollow-bearing trees will begin to be recruited (Lindenmayer and Sato 2018).

The 2009 bushfires reduced the abundance of hollow-bearing trees because much of the montane ash forest then burnt was regrowth from the 1939 bushfires or younger forest and thus too small to form hollows. The 2009 bushfires also substantially increased rates of loss of stags that remained after the 1939 fires (Lindenmayer et al. 2012; Lindenmayer et al. 2015a). Currently, the highest proportion of montane ash forest age class now comprises relatively young regrowth (particularly from the 2009 bushfires, but also following timber harvesting in recent decades). Little of the forest is dominated by stands of trees old enough to form hollows suitable for Leadbeater's possum (i.e., trees dating from prior to 1900) (Lindenmayer et al. 2015b; **Error! Reference source not found.**). However, note that some of the forests dominated by younger stands do contain remnant living old trees or dead stags that contain hollows.

Figure 5: The age class of dominant trees in stands of montane ash forests in the Central Highlands



Note: Decade indicates the date at which the trees germinated.
Source: Reproduced with permission from '[Mountain Ash: Fire, Logging and the Future of Victoria's Giant Forests]' by David Lindenmayer, David Blair, Lachlan McBurney and Sam Banks (2015b) and CSIRO Publishing.

Survival of Leadbeater's possum during the projected bottleneck in hollow-bearing trees will depend on protection of refuge habitats, particularly patches of multi-age and old-growth forest, and individual mature and senescent trees, as well as the success of new methods of den provisioning (for example, creation of hollows), translocations or other management actions. Recovery after the bottleneck is expected to depend on the extent of successful fire management and the effects of climate change.

Implications for conservation management

- Management to reduce the likelihood of extensive and severe bushfire will be critical for the long-term persistence of Leadbeater's possum in montane ash forests.
- The 1939 regrowth is, in most areas, the oldest cohort of forest, and hence protection of this age class will be essential for the long-term availability of hollows suitable as breeding sites in the Central Highlands. However, it should also be noted that the *Acacia* midstorey of such forests will have thinned considerably, reducing the quality of the habitat for Leadbeater's possum.
- Hollow-bearing trees are declining in the Central Highlands and will not be naturally replaced for decades. The existing hollow-bearing trees are therefore a critical resource that require full protection.

3.4.4 Sub-alpine (snow gum) woodlands

Leadbeater's possum is now known from several areas (including the Baw Baw Plateau, Mt Bullfight, Mt Useful and Lake Mountain) of sub-alpine woodlands dominated by snow gum (*E. pauciflora*), particularly where there is a dense midstorey of mountain tea tree *Leptospermum grandifolium*

('montane riparian thickets') along drainage lines (Jelinek et al. 1995; Department of Environment and Primary Industries 2014a; Harley 2016) at altitudes of 1300–1500 m. Within the Central Highlands region, such habitat is relatively restricted, with a total area of approximately 8000 ha, most of which occurs on the Baw Baw Plateau (Department of Environment and Primary Industries 2014a). Targeted camera trapping surveys in sub-alpine woodland outside the Central Highlands (for example, Mt Stirling, Tamboritha, Dinner Plain) have to date failed to detect the species (Eyre et al. 2022).

3.4.5 Decline in habitat extent, suitability and connectivity: sub-alpine (snow gum) woodlands

The 2009 bushfires markedly reduced the extent and quality of sub-alpine woodland habitat at Lake Mountain and Mt Bullfight, and caused the loss of many known Leadbeater's possum colonies. At Lake Mountain, more than 95% of the known population was killed by the 2009 fires or failed to persist afterwards (Harley 2016). Post-fire vegetation dynamics are less well known in sub-alpine woodlands than in montane ash forests, but it is likely that it will take several decades for a midstorey layer of mountain tea tree to regenerate in burnt areas and, relative to montane ash forest, vegetation recovery in sub-alpine woodland and as a consequence, possum recolonization rates are far slower (Zoos Victoria, unpublished data). Not all areas of snow gum woodland inhabited by Leadbeater's possum were burnt in the 2009 bushfires, with the Baw Baw Plateau area notably retaining its suitable habitat and Leadbeater's possum populations (Harley 2016).

Implications for conservation management

- Management to reduce the likelihood of extensive and severe bushfire will be critical for the long-term persistence of Leadbeater's possum in sub-alpine woodlands.

3.4.6 Lowland swamp forest

At Yellingbo the isolated Leadbeater's possum subpopulation occurs in lowland (110 m elevation) habitat that contrasts markedly with the habitat in its main range, although there have been recent detections of the possum in similar habitat at Buxton, Murrindindi and Marysville in the Central Highlands (Zoos Victoria, unpublished data). At Yellingbo, it occurs in riparian and seasonally inundated floodplain environments with forest dominated by mountain swamp gum (with canopy height of 15–25 m) with dense thickets of *Melaleuca* (*M. ericifolia* and *M. squarrosa*) and *Leptospermum* (*L. lanigerum*, *L. scoparium* and *L. continentale*) species (Smales 1994; Harley 2002; Harley 2005; Harley et al. 2005; Smith and Harley 2008). The major block of lowland swamp forest at Yellingbo covers an area of approximately 181 ha. However due to habitat degradation less than 20 ha of this currently provides suitable habitat for Leadbeater's possum (Greet et al. 2020). In most parts of this small area, suitable and occupied habitat now occurs only in very narrow (less than 120 m) corridors (Harley et al. 2005). Suitable tree hollows may be limiting in this habitat (Harley 2005; Harley et al. 2005) but have been compensated for through targeted provisioning of nest boxes (Harley 2004b).

It is likely that the earliest historical records of Leadbeater's possum from the Bass River and Koo Wee Rup swamp were also from broadly similar and formerly widespread lowland swamp gum woodlands (dominated by *E. ovata*) and dense thickets of *Melaleuca* and *Leptospermum* (Harley et al. 2005; Greet et al. 2020).

3.4.7 Decline in habitat extent, suitability and connectivity: lowland swamp forest

Most of the swamp gum forests and swampland thickets in the south-western Gippsland to Healesville region have been cleared, with only very small isolates remaining (McMahon and Franklin 1993; Harley et al. 2005; Yugovic and Mitchell 2006; Greet et al. 2020). Based on remnant vegetation, Greet et al. (2020) suggest these habitats once covered extensive areas in southern Victoria.

At Yellingbo, suitable habitat is highly restricted and about half of the Leadbeater's possum territories are considered to have declining habitat quality and have recently been abandoned by the possums (Harley 2015a). This decline in habitat suitability is due to eucalypt dieback arising from altered hydrology, habitat succession towards an older age-class that is more open in structure, and a lack of eucalypt regeneration (Harley 2015a).

A revegetation project to attempt to halt and reverse this decline in habitat quality and extent has been underway for over a decade (Harley 2015a), with potential to more than double the (currently very limited) area of suitable habitat (Harley et al. 2005). The optimal method to promote natural regeneration of this habitat remains a key knowledge gap.

A key risk-spreading strategy to contend with the risk of fire affecting the entire lowland population is to identify suitable lowland release localities beyond Yellingbo where populations could be established through wild-to-wild translocation or the translocation of captive-bred young if there was successful captive breeding (Harley 2016). Zoos Victoria has undertaken extensive surveys across Victoria in an attempt to identify suitable lowland forest for Leadbeater's possum which included several areas outside the possum's current range, such as north-east Victoria, parts of Gippsland and the Otways. While small remnant patches of suitable habitat occur in many areas (for example, near Mansfield, Shelley, Omeo and Bright), none are considered to be of sufficient size or quality to provide significant translocation opportunities. Habitat assessments to identify potential sites for new population establishment are ongoing.

Implications for conservation management

- The current and projected status of the lowland subpopulation is parlous, and this subpopulation is unlikely to persist without significant ongoing management actions.
- Management to reduce the likelihood of severe bushfire will be critical for the long-term persistence of Leadbeater's possum in lowland swamp forests.
- The extent and connectivity of suitable habitat at Yellingbo and other potentially suitable sites nearby should be enhanced through revegetation and techniques to promote natural regeneration, and ongoing use of nest boxes.
- Captive breeding or ranching subadults to establish new pairs, and translocations to suitable habitat in Yellingbo and other areas, will be required as insurance, with care taken in collecting founders from the wild to ensure that taking individuals does not significantly jeopardise the viability of that existing wild population.

3.4.8 Habitat augmentation

In response to the historic, current and projected decline in the extent and quality of habitat across Leadbeater's possum's range, there has been research aimed at augmenting habitat quality.

Nest box provision can provide benefits at localised scale at sites with suitable foraging habitat and vegetation structure but a lack of natural hollows and may be able to increase the likelihood of colonies persisting at such sites (Harley 2004b, 2006b). Nest boxes may also be useful during translocations, and at early post-disturbance successional stages. They can also facilitate the capture of animals for research, such as examination of genetic diversity across the range (Hansen et al. 2009).

There have been variable responses of Leadbeater's possum to the provision of nest boxes. The species has made extensive use of nest boxes in lowland swamp forest at Yellingbo, with more than 75% of the total possum population there making regular use of nest boxes for denning (Harley and Spring 2003; Harley 2004b, 2006b). High occupancy rates for nest boxes have also occurred in sub-alpine (snow gum) woodland, where Leadbeater's possums have constructed nests in 153 of 190 nest boxes (81%) installed in unburnt habitat (Harley 2016).

In contrast, historically there has been less uptake of nest boxes in montane ash forests, and it has been argued that nest boxes are unlikely to provide a significant boost to habitat quality due to the limited longevity of nest-boxes (Lindenmayer et al. 2009), and the impracticality of their application over large areas (Lindenmayer et al. 1991e; McKenney and Lindenmayer 1994). However, recent improvements in design have increased nest box longevity, and some studies have shown an increased use of nest boxes by Leadbeater's possums in montane ash forests (Harley 2016). The vegetation structure in older montane ash forest (for example, 1939 regrowth) makes it more difficult to position nest boxes at heights (of at least 15 m) matching movement pathways for the possum (Harley 2006a), although in younger regrowth they can be positioned lower. Of the nest boxes installed in montane ash forest recently, 30–40% show signs of use by Leadbeater's possum (Harley 2016; D. Harley pers. comm.).

Camera monitoring of nest boxes has revealed the potential for feral cats to sit on top of nest boxes, increasing the risk of predation of animals using the boxes (McComb et al. 2019). This has only been observed at a single site, where a single feral cat was observed at two occupied nest boxes set 3–4 m above the ground in dense regenerating ash forest. Later surveys in this area revealed that the Leadbeater's possum colonies using the cat-targeted boxes persisted, and no further predation attempts have been observed in subsequent more widespread camera monitoring at nest boxes (D. Harley, pers. comm.). It is currently not known how much of a threat feral cat predation is, and the extent to which use of nest boxes increases this risk.

Trials are currently underway to investigate if artificial hollows can be excavated in younger trees to simulate natural hollows used by Leadbeater's possum (LPAG 2014b). Initial results have been encouraging with 62% of the 132 constructed hollows used by Leadbeater's possums, with approximately 43% in use at any one point in time (ARI unpublished data). The uptake of some hollows was rapid, particularly where there was a shortage of natural hollows, with some hollows used within three months of excavation (DELWP 2016). Refinements to the design have been made to reduce the propensity of the tree to heal over the entrance. Further monitoring is required to investigate longer term patterns of use, maintenance requirements and to assess cost-effectiveness of any application to broader scale management programs.

Small-scale thinning, where the density of stems is reduced around focal trees to facilitate increased growth of the focal tree, has also been suggested as a method to accelerate hollow development.

This approach is currently being trialled, with experimental stands showing increased growth rates, with the aim of developing forest management strategies at the stand and landscape scale to accelerate the development of key habitat features for Leadbeater's possum over the longer term (P. Baker, pers. comm.). While thinning may promote accelerated rates of tree growth, the impacts on vegetation structure are also an important consideration.

In some areas, habitat manipulations may be warranted to regenerate eucalypts or midstorey, including wattle or tea tree, to increase food availability in areas where nesting resources are available but foraging habitat is lacking. Such manipulation may facilitate recolonisation of currently unoccupied areas once the midstorey has regenerated sufficiently.

3.4.9 Habitat critical to survival

This species is endemic to Victoria, where it occurs almost entirely on Crown land. Given the current Critically Endangered status of Leadbeater's possum, and its predicted severe ongoing decline, including significant risks of extinction, all current and prospective suitable habitat is critical for its survival, and necessary for its recovery.

Specifically, habitat critical to the survival of Leadbeater's possum comprises four zones: (1) the Baw Baw and Toorongo plateaus (including their slopes), (2) Paradise Plains near Marysville, (3) Yellingbo Nature Conservation Area, and (4) the combined Snobs Creek/Mt Bullfight/Rubicon areas. Areas surrounding these zones provide for potential range extension (through recovery or translocation). Fire impacts on populations and habitat and the pattern of post-fire recolonisation mean that there are likely to be additional parts of the species' range supporting significant local populations. Habitat critical to the survival of the species should not be destroyed or modified and be appropriately managed to support long-term recovery of the species. Actions that have indirect impacts on habitat critical to survival should be avoided, as should any actions that compromise the species' survival across all life stages.

3.5 Diet

3.5.1 Foraging and diet

Leadbeater's possums mostly forage on the trunks and major branches of eucalypts and midstorey (or sub-canopy) shrubs. The majority of the diet comprises exudates. These include carbohydrate-rich secretions (lerp and honeydew) produced by hemipteran insects, and manna, gum and sap exuded by some species of trees (mostly smooth-barked eucalypts) and shrubs (including *Acacia*, *Leptospermum* and *Melaleuca*), sometimes from and due to incisions made by the possums themselves in trunks and branches (Smith 1980; Harley 2005). The nutritional value of plant exudates may vary significantly between different plant species and tree ages, and between different forest types, suggesting that food resource availability may be highly heterogeneous in these forest ecosystems (Lindenmayer et al. 1994a). The importance of exudates in the diet indicates that a major factor in determining habitat suitability is the occurrence, abundance and age of particular plant species that provide relatively abundant exudates. Other than exudates, arboreal arthropods (including beetles, spiders and, particularly, large tree crickets) comprise a significant component of the diet, and make up much of the protein intake (Smith 1980; Smith 1984a; Harley 2005). Eucalypt nectar and pollen are also taken occasionally (Smith 1984a).

Leadbeater's possums typically forage singly and diffusely around communally-shared den sites (a 'central place forager') (Smith 1980; Harley 2005). Energetic costs of foraging may be high (Smith et al. 1982), such that linear strips of habitat may be unsuitable because individuals would have to forage over longer distances than in home ranges of a similar area in continuous habitat in montane ash forest (Lindenmayer et al. 1993b). Energetic costs of foraging are probably reduced where there is a near continuous cover of foliage in tall midstorey shrubs or eucalypt regrowth, allowing economical travel across this vegetation layer for this non-gliding species.

3.5.2 Food supplementation

Supplementary food has successfully been provided to Leadbeater's possums as part of management initiatives at Yellingbo, Lake Mountain, Yarra Ranges National Park and translocation sites at Wallaby Creek and Tolmie. The majority of supplementary feeding has been associated with translocations of the species to unoccupied habitat. Healesville Sanctuary have prepared the supplementary food in these studies, based on the composition of the captive diet for this species.

Leadbeater's possum readily uses artificially supplied foods but food availability is not considered generally to be a key limiting factor (LPAG 2014b). Supplementation is unlikely to have any appreciable benefit other than at a local level in association with specific management actions.

Implications for conservation management

- The energetic costs of foraging relative to the dispersion and nutritive value of available food resources indicate that small fragments and linear strips are less suitable habitat than larger blocks of continuous habitat.
- Food availability may be a limiting factor after major disturbance. There may be some scope for increasing the likelihood of retaining or increasing colony persistence or increasing productivity, or increasing the likelihood of translocation success, using food supplementation. However, this is likely to be practical and applicable only at local scale and for particularly susceptible or important colonies.

Priority research needs to enhance management

- Further research would be useful to evaluate where habitat manipulation could be used to increase future food resources, and to assess its cost-effectiveness.
- Apply new approaches to improve our understanding of the composition of Leadbeater's possum diet in particular forest types, age classes and across seasons.

3.6 Social structure

Leadbeater's possums live in small matriarchal communal social groups ('colonies') of 2–12 (but currently more typically 3–4) individuals, with colonies normally including only one reproductively active female and male plus young or sub-adult and adult offspring (Smith 1984b; Lindenmayer and Meggs 1996; Harley 2005; Harley and Lill 2007). In high quality habitat, colonies occupy actively defended territories of 1–3 ha (Smith 1984b; Harley 2005), that contain multiple den sites (Lindenmayer and Meggs 1996; Harley 2004b). A radio tracking study in 1990 to 1991 recorded individuals moving on average 135 m between den sites, with one long distance movement between dens of 600 m recorded (Lindenmayer and Meggs 1996; Lindenmayer et al. 2017). In the absence of disturbance, colonies have long-term site fidelity (Lindenmayer et al. 2013b; D. Harley, unpublished

data). Social structures and home range characteristics are less well known for colonies in spatially heterogeneous landscapes, notably where contrasting nesting and foraging habitats abut.

In montane ash forests, limited data suggest female dispersal is greater than male dispersal (Smith 1984b) and females (and probably any dispersing individuals) are subject to higher rates of mortality. In lowland swamp forest, males and females disperse similar distances (females – mean 407 m, range 125–1080 m, n = 23; males – mean 495 m, range 105–1460 m, n = 33) (Harley 2005). Dispersal into established colonies is more common than new colony formation in unoccupied habitat (Harley 2005). Dispersal is strongly tied to the onset of reproduction, and hence animals are likely to be searching for breeding opportunities when dispersing (Harley 2005; Harley et al. 2005). There is a biased adult sex ratio, of about three males per female in montane ash forest (Smith 1984b; Lindenmayer 1996b), whereas the adult sex ratio is more variable in lowland swamp forest (Harley 2005).

3.7 Demography and breeding biology

3.7.1 Demography and reproduction

Longevity is 5–8 years in the wild, with the maximum age recorded being ten years (Smith 1984b; Lindenmayer and McCarthy 2006; D. Harley, unpublished data). Age at first breeding is two years (Smith 1980; Lindenmayer et al. 1993d; Lindenmayer and Possingham 1995a, 1995c; Harley and Lill 2007).

Some demographic characteristics vary among subpopulations in different habitats: for example, the mean reproductive life in adult females in a montane ash forest site was reported to be 1.6 years, but at least 3.3 years at Yellingbo (Smith 1984b; Harley 2005; Smith and Harley 2008).

The reproductive rate is relatively low, with a litter size of 1–2 young per breeding female (and hence per colony) with two litters per year (Harley and Lill 2007). Reproductive success is probably related to food supply (Smith 1984b). Breeding is seasonal in montane ash forests, with most births occurring in distinct peaks in May and November (Smith 1984b), but breeding at Yellingbo occurs year-round (Harley 2005; Harley and Lill 2007; Smith and Harley 2008). Young remain in the pouch for 80–93 days (Smith 1980; Harley 2005; Smith and Harley 2008), emerge from the nest at about 111 days, and remain in the natal territory for 7–14 months (females) and 11–26 months (males) (Smith 1980, 1984b; Menkhorst and Lumsden 1995). In lowland swamp forest, some young have been recorded remaining in their natal territories for far longer periods (D. Harley, unpublished data). Only about 20% of young at Yellingbo survived to acquire breeding status within established groups with most animals dispersing at 20–36 months of age (Harley 2005; Harley et al. 2005).

3.7.2 Captive breeding

The first captive breeding of Leadbeater's possums was undertaken by Des Hackett in the early 1970s from animals captured in the Central Highlands (Preuss 2006). Several zoos around the world subsequently bred the species but this program was not integrated into any broader conservation management strategy. With no designated outlet for young bred in captivity, adults were segregated to reduce breeding and the captive population ultimately aged and declined (Harley and Lowry 2013; Steventon et al. In review).

In 2012, Zoos Victoria, initiated a new captive breeding program for Leadbeater's possum to provide insurance against the extinction of the last lowland population, and a future source of animals to re-populate restored habitat in Yellingbo and at least two additional populations. To minimise impacts on the wild population, the collection of founders for captive-breeding was restricted to 3–6 individuals per year (Harley 2015a). The initial target for the size of the captive-breeding program for lowland Leadbeater's possum was 12 pairs, and 21 founders were collected. None of these founders successfully produced young, prompting several reviews of captive husbandry and diet. The causes for the failure are unclear, however male infertility has been considered a likely cause. The captive diet is likely to be a contributing factor, and in 2018 and 2019, the captive diet at Healesville Sanctuary was refined under the guidance of Dr Michelle Shaw, Wildlife Nutritionist at Taronga Zoo. Given that highland Leadbeater's possums have previously bred in captivity at many institutions, in 2019 two highland colonies were brought into captivity to test the new diet and husbandry regime. To date, three litters have been produced by these highland colonies, however the rate of production remains lower than would be expected (D. Harley, pers. comm.). Healesville Sanctuary have also housed several mixed highland-lowland pairings to examine compatibility as part of the genetic rescue programme aiming to alleviate inbreeding in the lowland population (Zilko et al. 2021). No outbred young have been produced to date.

In 2023, the captive population at Healesville Sanctuary contains 6 lowland and 11 highland Leadbeater's possums. Current priorities for the captive-breeding programme include 'ranching' or temporary holding in captivity of lowland subadults sourced from the wild from Yellingbo in order to establish new pairs for translocation, and further examination of the compatibility of mixed highland-lowland pairings to support gene-pool mixing (D. Harley, pers. comm.).

A major investigation of Leadbeater's possum health, predominantly focused on the captive population, has recently been completed by Dr Chloe Steventon. This study collated data for highland and lowland possums held in captivity between 1970 and 2021 (Steventon et al. 2022, In review). Of highland possums 39% of females and 37% of males bred successfully. Reproductive contributions were highly skewed, with 11 females and 12 males producing 75% and 80% of all offspring, respectively (Steventon et al. In review). The median longevity of possums held in captivity was 5.01 years for highland individuals and 5.61 years for lowland individuals. In addition to this study, veterinary and conservation teams at Zoos Victoria are collaborating with several research groups to analyse hormones and investigate the reproductive health of Leadbeater's possums held in captivity (for example, ultrasounds have been performed on females held in captivity).

Translocation

There have been numerous attempts to translocate Leadbeater's possums, the majority involving lowland individuals as part of recovery actions being implemented by Zoos Victoria since 2017. In 1987, there was an unsuccessful attempt to establish captive-bred highland Leadbeater's possums in montane ash forest (Macfarlane and Seebeck 1991). In 2002, a lowland female of dispersal age was successfully translocated to an outlying site at Yellingbo supporting an unpaired male (Harley 2002), resulting in a new breeding territory and production of three young prior to the loss of the adult female. This success prompted the wild-to-wild translocation of a further five lowland individuals, for which post-release site fidelity was low and predation rates high. Translocation is more likely to succeed if established social groups are moved into unoccupied habitat, or if individuals are translocated into the territories of unpaired individuals (D. Harley, pers. comm.). Techniques to

promote post-release site fidelity (for example, supplementary feeding, nest box provisioning) are important to improve translocation success, as this may avoid elevated predation risk associated with animals attempting to disperse through unfamiliar habitat (D. Harley, pers. comm.).

Extensive translocation work with this species since 2017 has refined release methods such that entire colonies can now be successfully translocated to new locations with a high likelihood of site fidelity following release. Similarly, there has been recent success in translocating individuals to territories containing an unpaired possum of the opposite sex, whereby new breeding pairs may be established. Nest box provisioning, supplementary feeding, and monitoring via camera traps and radio-tracking are key components of the current translocation protocol.

Monitoring cat and fox activity is key at translocation sites. Two translocations intended to establish colonies outside the current range, of 11 possums in 2020 and 13 in 2022 to 2023 were terminated following high rates of predation, particularly by feral cats. Attempts to reduce cat densities through trapping at each location were ineffective.

Extensive work has been undertaken by Zoos Victoria in an attempt to identify habitat suitable for the translocation of lowland individuals, both within and outside the species' historic range. To date, no large, intact areas of suitable swamp forest have been identified, limiting translocation options. These habitat assessments have also included evaluation of potential habitat for highland Leadbeater's possums in north-east Victoria, and indicate suitable habitat may be limited in area and highly fragmented (Eyre et al. 2022). Further assessments are required for parts of Gippsland, with bushfire risk and climate change modelling integral components of assessing the suitability of potential translocation areas.

Implications for conservation management

- Translocation may be an important component of an overall conservation management program into the future. Objectives include (1) bolstering the occupancy and persistence in habitat fragments for the lowland population, and establishment of new lowland populations beyond Yellingbo; (2) maintaining or enhancing genetic heterogeneity of isolated subpopulations; (3) assisting the recolonisation of suitable but unoccupied habitat within the Central Highlands (such as regenerated fire-affected areas), and (4) (subject to appropriate risk and cost-benefit assessment) extending the range to suitable habitat beyond the current distribution.
- Given ongoing habitat decline at Yellingbo, translocating lowland individuals to new locations is a high priority. Given the high predation rates documented during translocation trials at Wallaby Creek and Toombullup State Forest, cat exclusion should be undertaken at one or more of these translocation sites.
- The small size of the lowland population (fewer than 30 individuals) constrains translocation opportunities. Ranching subadults from Yellingbo in captivity to establish new pairs will provide a key method of increasing the availability of animals for translocation.

Priority research needs to enhance management

- Further research is required to identify and overcome the barriers to captive breeding of lowland Leadbeater's possums.

- Identify suitable translocation habitat for lowland and highland populations of Leadbeater's possum, including regions within and outside the species' historic range. These assessments should consider bushfire risk and climate change.

3.7.3 Causes of mortality

There is little available information on causes of mortality, but occurrence in sub-fossils deposited by sooty owls (Bilney et al. 2006; Bilney et al. 2010; Bilney 2014) demonstrates that owls prey on the species, and predation by cats has impacted several translocation attempts (Zoos Victoria, unpublished data).

No data are available on the frequency or extent of mortality due to predation by introduced predators (cats, foxes) in the montane ash forest. Leadbeater's possum remains were recorded in the stomachs of two feral cats (from seven sampled) in forests north of Powelltown (McComb et al. 2019). It is unclear whether habitat disturbance, fragmentation and road construction alter predation risk in the Central Highlands, however it is conceivable that they increase predation risk.

Disturbance events that dramatically alter the environment can result in direct mortality of individuals. For example, the 2009 bushfire resulted in greater than 95% mortality for Leadbeater's possums on the Lake Mountain plateau (Harley 2016).

Predation has not been a major cause of adult mortality for the Yellingbo subpopulation (Harley 2015a). Of a large number of individuals radio-tracked at Yellingbo, there were only three adult mortality events. All coincided with the dispersal of new animals into established colonies: one was from female-female aggression; another attributable to predation by a powerful owl (*Ninox strenua*), and; the third from predation by either a cat or fox (Harley 2005). Some juvenile mortality at Yellingbo (0.5 in the first 12 months) may be attributable to predation but the population decline there is principally due to severe decline in habitat conditions (Harley 2015a).

The main ultimate cause of mortality across the possum's range is episodic habitat loss or gradual reduction in habitat quality associated with disturbance events (Harley 2023). These are discussed in more detail in the Threats section below.

4 Threats

The major threat to the Leadbeater's possum is the ongoing reduction in the extent, quality and connectivity of suitable habitat (especially large or hollow-bearing trees), with this threat in part a historical legacy, in part a consequence of ongoing actions, and in part a future expectation based mostly on factors which are difficult to control (bushfire).

4.1 Historical causes of decline

Fossil, sub-fossil and historical records demonstrate that the species was formerly more widely distributed (Lindenmayer et al. 1991d; Lindenmayer et al. 1993d; Harley 2004c; Bilney et al. 2010), however the pattern and timing of historical decline is poorly resolved. Some decline probably occurred prior to European settlement, due to changes in climate and hence fire regimes and habitat extent, but the rate of decline has most likely accelerated since European settlement.

Extensive clearing and landscape modification (including draining of wetlands) – mostly in the decades from the late nineteenth to early twentieth century – removed almost all suitable habitat from the type locality and across the species' lowland range (Brazenor 1950; Macfarlane et al. 1997; Harley 2004c; Harley et al. 2005; Greet et al. 2020).

The extent of suitable montane ash forest has varied markedly over time in response to variation in climate and fire regimes (McKenzie 2002; Worth et al. 2014). Since European colonisation fire management practices (and hence fire regimes) have changed, including in montane ash forests, and along with cumulative impacts of timber harvesting have led to decline in the extent, quality and connectivity of montane ash habitat suitable for Leadbeater's possum (Lindenmayer et al. 2008; Lindenmayer et al. 2011a; Burns et al. 2015; Taylor and Lindenmayer 2020).

4.2 Current threatening processes

The ongoing reduction in the extent, quality and connectivity of suitable habitat has resulted in, and is projected to continue to cause, ongoing decline in population size and conservation status (TSSC 2019). This has occurred, and continues to occur, through a range of drivers:

- impacts of severe fire and changes in fire regime;
- timber harvesting over many decades – noting that timber harvesting by the Victorian government on state land will cease 1 January 2024. Coverage in this plan is restricted to the legacy impacts of historical harvesting;
- reduction in the abundance of hollow-bearing trees;
- eucalypt dieback and altered hydrology (for the lowland subpopulation); and
- lack of genetic diversity (for the lowland swamp subpopulation).

In turn, ongoing habitat loss has resulted in, and will continue to cause, some fragmentation (and thus reduced genetic diversity and viability) of subpopulations in the Central Highlands.

Current and projected climate change is likely to exacerbate the ongoing reduction in habitat extent and quality, particularly through its impacts on the severity and frequency of bushfires (Lindenmayer

et al. 1991d; Williams et al. 2009; Keenan and Nitschke 2016), and hence on forest structure, tree age distribution and hollow availability (Keenan and Nitschke 2016). Leadbeater's possum occurs in a cool-climate region and is likely to be susceptible to increasing temperatures and extreme heat events.

The impact of predation by cats and foxes on population condition, particularly in disturbed habitat (for example, following bushfire), is poorly understood, but potentially problematic.

4.2.1 Impacts of severe fire and changes in fire regime

Fire is a direct and indirect threat to Leadbeater's possum. Few if any Leadbeater's possums survived in areas burnt by bushfires in 2009, regardless of fire severity (Lindenmayer et al. 2013c; Lumsden et al. 2013). Marked loss was also reported for Leadbeater's possum in snow gum woodlands (Harley 2016). Possums were also less abundant on unburned sites where the surrounding landscape has been burned (Lindenmayer et al. 2013c; Lindenmayer et al. 2015b). However, about 8–10 years post-fire some of the areas burnt in 2009 have been recolonised, coinciding with development of a dense cover of wattle and other small trees. This re-establishment is likely to be contingent on some hollow-bearing trees remaining in the burnt landscape, or being in close proximity to burnt areas. The rate of habitat and population recovery following bushfire in sub-alpine woodland is far slower than in montane ash forest (Zoos Victoria, unpublished data).

Fire is the primary form of natural disturbance in montane ash forest, and the dynamics of post-fire vegetation succession critically influences habitat suitability for Leadbeater's possum. However, fire regimes have changed with bushfires now likely to be more frequent than prior to European settlement (Lindenmayer et al. 2013c). The current pattern of severity and frequency of bushfires is resulting in ongoing diminution in the extent and quality of habitat for Leadbeater's possum.

The impacts of changed fire regime are particularly evident in the reduced extent and increased fragmentation of old-growth forest (that is, where dominant trees are more than 120 years old). At around the onset of European settlement, old-growth forest comprised at least 30% and possibly up to 60–80% of the mountain ash forest in the Central Highlands (Lindenmayer 2009). Its proportional extent now has been estimated to be only about 1.1% (Lindenmayer et al. 2012; Lindenmayer et al. 2013a; Lindenmayer et al. 2015b).

The most extensive fire affecting Leadbeater's possum habitat in recorded history was in 1939, burning about 85% of mountain ash forests in the Central Highlands (Burns et al. 2015). In 1983, sections of forest within the southern part of the species' range were burnt in a severe bushfire. Regeneration from this fire now provides important habitat for the species, with the combination of large stags providing nest sites and the regeneration providing foraging habitat. The next extensive bushfire was in 2009, with this fire burning about 68,000 ha of montane ash forest and sub-alpine (snow gum) woodlands considered to be potential habitat of Leadbeater's possum, including 45% of the Leadbeater's possum reserve (LPAG 2014b).

The impacts of fire vary according to the age and structure of the forest at the time at which it is burnt, the severity of the fire, and the fire's landscape context (mainly the amount and connectivity of unburnt patches). In montane ash forests, a severe fire kills most midstorey vegetation and canopy trees (but releases their seed, allowing for a regeneration cohort), and consumes most previously dead trees, rendering the habitat unsuitable for Leadbeater's possum in the short term. However,

fire may promote the capacity for older trees to form hollows from fire scarring. If large live trees were present prior to the fire, many of those killed will remain as stags (or in some cases, as fire-scarred old live trees), providing suitable hollows for Leadbeater's possum. In the period after fire, the abundance of this resource gradually (over decades) diminishes, as the stags collapse.

While some hollows may be retained in burnt areas, it takes 7–10 years before the midstorey develops sufficiently to provide suitable foraging habitat. In the absence of other disturbance, by about 50 years after fire, the dense tall wattle midstorey senesces and thins out, reducing habitat quality again, so more frequent, but lower intensity, fire may be needed to maintain the extent and cover of the wattle understorey component of Leadbeater's possum habitat. The cohort of post-fire regeneration eucalypts takes more than 120 years to mature sufficiently to start forming hollows suitable for Leadbeater's possum, but – if undisturbed for this period – this cohort ultimately provides the hollows required for future suitable habitat.

If severe fire recurs at shorter intervals than the period required for hollow formation, the more recent fire will have more substantial consequences for habitat quality, as it will eliminate many of the stags that persisted after the earlier fire (Lindenmayer et al. 2011a; Lindenmayer et al. 2015b). Furthermore, young trees generally do not stand long after they are burned (Lindenmayer et al. 2013c), and areas repeatedly burnt by severe fire will not provide current or future hollow-bearing habitat for Leadbeater's possum. Indeed, if the inter-fire interval is shorter than the time taken for mountain ash trees to reach reproductive age (approximately 15–20 years), they will be lost entirely from stands and be replaced with other species with shorter reproductive periods, such as wattles (Lindenmayer et al. 2011a).

While the most acute fire-related detrimental impacts to Leadbeater's possum are due to severe bushfire, some pre-emption, prevention, suppression and recovery fire management measures may also pose some risks to Leadbeater's possum and its habitat. Such actions may include the establishment of networks of fire breaks, and the felling of 'hazardous' large dead trees after fire. There is scope to refine on-ground fire management activities to maximise as much as possible the positive benefits for this species and those for people and community safety. (see Section 7.2.2 Objectives, actions, outcomes and performance criteria).

4.2.2 Historical timber harvesting

Note that timber harvesting on state land by the Victorian government will cease 1 January 2024. Coverage is now restricted to past and legacy impacts of historical harvesting.

Timber harvesting has reduced habitat suitability, extent and connectivity in Leadbeater's possum's montane ash forest environments, but does not occur in the far smaller areas of sub-alpine (snow gum) woodland or lowland swamp forest habitat.

A total of approximately 38,000 ha of montane ash forest was harvested in the Central Highlands from 1978 to 2016, when clear-felling became the predominant form of harvesting. Clear-felling is a method of harvesting in which all merchantable trees, apart from those to be retained for wildlife habitat or other values (for example, water quality), in a defined coupe area are removed in a single operation (Department of Environment and Primary Industries 2014a).

The remaining debris was burnt to provide a seedbed to regenerate the new stand of trees. This creates an even-aged area of forest with few or no hollow-bearing trees within the harvested part of the coupe. Leadbeater's possums do not occur in recently clear-felled areas (Lindenmayer et al. 2015b), and are unlikely to occur in these areas for approximately 10 years after harvesting. As the habitat regenerates, Leadbeater's possums can use this harvesting regrowth as foraging habitat (Smith and Lindenmayer 1992; Nelson et al. 2015; Keith et al. 2016; Nelson et al. 2017) if there are suitable nesting sites nearby.

Since 2014, VicForests undertook 'regrowth retention harvesting' (VicForests 2019), which aimed to increase the amount of retained habitat within the coupe by retaining clusters of trees as habitat islands or peninsulas, and was designed to retain stands of trees able to continue to grow on and in time form hollows and Leadbeater's possum habitat.

Not all areas were harvested, with on average approximately 32% of the coupe left unharvested (data from VicForests in 2014 to 2015), due to a range of features, including streamside reserves, steep areas, Leadbeater's possum Zone 1 habitat and aggregated retention areas. These areas retain some older forest, and can allow younger forest to mature. Post-harvesting regeneration that was surrounded by sufficient retained (older) habitat to support colonies could then form a landscape-scale spatial mosaic of age classes providing older forest for nesting and dense young forest for foraging.

The majority of the recent timber harvesting in Central Highland ash forests occurred in areas that regenerated after the 1939 bushfires, with small amounts from stands resulting from fires between 1900 and 1938. These forests are classified as regrowth forests and regenerating trees in them have typically not yet formed hollows.

Thinning of younger regrowth forests (typically 18–30 years old) occurred in some areas, with the aim of increasing the growth rate of the remaining trees. Although not all trees are harvested, thinning opens up the stand, removing the dense midstorey connectivity needed by Leadbeater's possum for movement and foraging. Thinning can accelerate the growth of trees and potentially the formation of hollows (P. Baker, University of Melbourne, unpublished) but may concurrently adversely affect vegetation structure for the Leadbeater's possum.

In addition to the direct impacts that timber harvesting had on habitat availability for Leadbeater's possum, harvesting may have ongoing indirect impacts, although the severity of such impact is not well resolved. Proliferation of the track network associated with harvesting may isolate some Leadbeater's possum subpopulations and reduce dispersal.

4.2.3 Reduction in the abundance of hollow-bearing trees

This factor can be considered to be a consequence of other threats or as a threat itself, but it is included specifically here as a threat as it is such an important consideration for the future of this species. The quality of the montane ash habitat for Leadbeater's possum has declined in recent decades due to a significant loss of hollow-bearing trees. Long-term monitoring over the last 30 years in the Central Highlands has shown that within unburnt areas, approximately 3.5% of dead trees collapsed per year during that period and approximately 1.5% of large, live hollow-bearing trees died per year (Lindenmayer et al. 2012). This severe rate of loss of dead and live hollow-bearing trees is predicted to continue into the future (Lindenmayer and Sato 2018). There is currently negligible

natural development of new hollow-bearing trees, as 1939 regrowth trees are yet to form hollows. The combination of the loss of existing hollow-bearing trees and a current lack of development of new hollow-bearing trees is predicted to lead to an increasingly severe shortage of these trees in the next 30–70 years (Lindenmayer et al. 1990b; Lindenmayer et al. 2012; Lindenmayer and Sato 2018).

4.2.4 Eucalypt dieback and altered hydrology (for lowland subpopulation)

Lowland swamp forest habitat at Yellingbo and in nearby areas is experiencing ongoing decline in habitat quality due to eucalypt dieback and reduced regeneration, resulting in an altered, more open forest structure. Largely due to such ongoing habitat deterioration, only about 10% of the 180 ha of lowland swamp forest in the Cockatoo Creek section of Yellingbo Nature Conservation Area now supports high-quality habitat, and the subpopulation of Leadbeater's possum in the reserve has declined severely across the monitored period of 2001 to 2022 (Harley 2016, 2023). This reduction in habitat quality is due to severe eucalypt dieback caused by altered hydrology of the Cockatoo Creek floodplain and lack of appropriate disturbance regime to promote natural regeneration of eucalypts and *Melaleuca* and *Leptospermum* midstorey (Harley 2016; Greet et al. 2020). Browsing by swamp wallabies (*Wallabia bicolor*), sambar deer (*Cervus unicolor*) and potentially fallow deer (*Dama dama*) is also likely to compound the effects of dieback and impact recruitment of seedlings necessary to maintain dense vegetation structure (D. Harley pers. comm.).

4.2.5 Population fragmentation

An ongoing reduction in the extent of suitable habitat is likely to lead to increased fragmentation of the population into a series of variably-sized subpopulations. Subpopulation structuring has recently been examined in the Central Highlands (Zilko 2021) and revealed four distinct genetic groups in the highlands: Northern (encompassing Snob's Creek, Mt Bullfight, Lake Mountain, Arnold Gap, and Marysville), Central (Warburton, Donna Buang, and Ben Cairn), Southern (Powelltown), and Eastern (Baw Baw National Park and Toorongo Plateau). This suggests contemporary isolation of the four groups, highlighting the need to reconnect populations to avoid further erosion of genetic diversity and fitness decline (as has been documented for the lowland population). The southern genetic group (Powelltown population) appears to be most vulnerable based on its size, it also was inferred to have had the most recent gene flow with the extinct Bass River population, which in turn shared genes with the lowland population (Hansen et al 2009). This suggests mixing lowland possums with those of the southern groups should replicate past gene flow and thus be of low risk of outbreeding depression (Ralls et al. 2020). Molecular analyses for the Yellingbo subpopulation indicate that population fragmentation can occur over very small spatial scales, even where continuous vegetation cover exists, suggesting the species is highly sensitive to habitat quality (Hansen 2008; Hansen and Taylor 2008; Zilko et al. 2020).

4.2.6 Climate change

The climate of the Central Highlands is likely to change significantly in future decades, with high-confidence predictions of higher temperatures, a higher frequency of days of extreme heat, increased incidence and longevity of meteorological drought, and harsher fire-weather climate (Grose et al. 2015). These projections largely maintain or accelerate climate trends evident over recent decades, which have contributed to ongoing reduction in the quality and extent of habitat suitable for Leadbeater's possum. Zoos Victoria and Deakin University have recently modelled the impacts of increasing temperatures on the suitable climate space for Leadbeater's possum for four future emission scenarios: RCP 2.6-SSP1, RCP 4.5-SSP2, RCP 7.0-SSP3 and RCP 8.5-SSP5, with the

results indicating significant reductions in the habitable area within the Central Highlands by 2090 with greater emissions (Archibald et al. 2023). Under these scenarios, a subset of forest patches could be abandoned by Leadbeater's possum due to increased mean annual temperatures. Some sites, most likely towards the periphery of the range, may cross a tipping point whereby they would be no longer cold enough for this species.

Ongoing increases in the incidence of drought and high temperatures are likely to lead to further marked increase in the frequency and intensity of bushfires (Williams et al. 2009; Dutta et al. 2016), and hence to more frequent acute episodes of high mortality of possums (including direct mortality during extreme heat events), and chronic marked reductions in the landscape-scale abundance of hollow-bearing trees.

Regardless of the associated increased risks of severe bushfire, a higher incidence of drought and of extremely hot days is also likely to lead to high rates of mortality of large trees. For example, elevated rates of tree mortality were reported for the period 2004 to 2011 (during which 23% of large living trees died on unburned sites), associated with drought conditions (Lindenmayer et al. 2012; Lindenmayer et al. 2013a). While such drought-killed trees may stand as stags in the landscape, they are more susceptible to collapse during and after severe bushfire than are large living trees (Lindenmayer et al. 2012), so an increased incidence of severe drought in the future will result in further reductions in the abundance of hollow-bearing trees. Ecological thinning of some forests should be investigated. Retention of suitable (dense) vegetation structure in aging forests is challenging, and thinning can contribute to loss of structure where midstorey recruitment is not occurring, such as at Arnold Gap (at Lake Mountain) and elsewhere (D. Harley, pers. comm.).

Because mountain ash and alpine ash have moderately narrow limits of climatic suitability climate change will lead to a reduction in the distributional extent of these two tree species (Wang et al. 2016). There is expected to be a severe impact on the regeneration of mountain ash, reducing the total area suitable for natural regeneration by more than 80% by 2080 (Baker et al. 2017). Mountain ash stand density and volume will also be reduced by about 15% (Baker et al. 2017). The impact of increased incidence of severe fire will be especially profound where future fires recur at intervals shorter than the time taken for ash trees to mature, leading to forests dominated by species such as *Acacia*. Habitat condition will be reduced due to vegetation dieback during drought conditions.

Climate change may also affect food availability for Leadbeater's possum, through changes in the abundance and diversity of invertebrates, the production and persistence of exudates, and the frequency and productivity of flowering events. There is only limited information to specifically link these factors to climate characteristics in montane ash systems or to predict the impacts of climate change on food resource availability, however climate conditions have been shown to cause a major reduction in the availability of some types of food for Leadbeater's possum (Smith 1980; Smith 1984a; Lindenmayer and Possingham 1995c), and breeding success in Leadbeater's possum is 'closely related' to the abundance of some food resources (Smith 1980; Lindenmayer and Possingham 1995c).

It is possible that an increased incidence of days of extreme heat may narrow the range of hollows that are suitable as den and breeding sites for Leadbeater's possum, but there is insufficient evidence to assess the likelihood of such change.

Recent modelling has identified areas of Leadbeater's possum habitat that are likely to remain relatively stable under a climate change scenario of increase in 2˚C, and other areas that will become transient, with some losing suitable habitat while other areas may gain suitable habitat (Nitschke et al. 2020). This modelling will be useful to incorporate into future reserve design considerations.

5 Legislative, policy and planning context

This Recovery Plan is informed and guided by relevant Commonwealth and State legislation and policies as well as Australia's obligations under various international agreements.

5.1 International agreements and obligations

Australia is a signatory to a number of international agreements relevant to the conservation of Leadbeater's possum. This plan is consistent with and is guided by Australia's international responsibilities under these agreements, and the plan's implementation will support meeting these obligations. These include:

- United Nations 2015 sustainable development goals which include to 'take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species' (Goal 15.5).
- Parties to the Convention on Biological Diversity (CBD) adopted the Kunming-Montreal Global Biodiversity Framework in December 2022. The newly adopted framework will now set the global biodiversity action agenda for the next decade, including to halt extinction of known threatened species and significantly reduce extinction risk.
- Montreal Process (Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests) requires the Australian government to report regularly on the number and status of forest species at risk or in serious decline, and also on management actions taken to attempt to safeguard such species. Five yearly reporting is via State of the Forests Reports.

This Recovery Plan considers some ex situ and translocation management actions. Although not binding, it is appropriate that such actions for Leadbeater's possum should be consistent with international standards and protocols for ex situ conservation and translocation (IUCN/SSC 2013, 2014) as well as relevant Australian and Victorian government legislation and policy.

5.2 National threatened species policy

The Australian Government's Threatened Species Action Plan 2022-2032 was released in October 2022. It maps a pathway to protect, manage and restore Australia's threatened species and important natural places. The Plan is a key policy to guide proactive recovery of threatened species and will be complimented by regulatory reforms to protect species. A key objective is that the risk of extinction is reduced for all priority species; Leadbeater's possum is one of the 110 species identified for focussed and targeted effort.

5.3 National forest policy

The management of Australia's forests is guided by the 1992 National Forest Policy Statement (NFPS) (Anon 1992). As signatories to the NFPS, the Australian, state and territory governments are committed to the sustainable management of all Australian forests, whether the forest is on public or private land, or reserved or available for production.

In developing the NFPS, governments were mindful of the important conservation values of Australia's forests and of the contribution that forest activities make to the national economy and rural and regional communities. This is reflected in the Regional Forest Agreements (RFAs), which were a key outcome of the NFPS.

RFAs are long-term agreements between the Australian and state governments with an objective to balance environmental, social and economic outcomes in the management of Australia's native forests. Within RFA areas, forestry operations carried out in accordance with the RFA are exempt from the provisions of the EPBC Act, except where they are likely to have significant impact on World Heritage or Ramsar wetland sites.

On 30 March 2020, the Australian and Victorian Governments modernised and extended all Victorian RFAs until 30 June 2030. All five RFAs provide mechanisms to enhance protection of threatened species, including commitments to:

- maintain a Forest Management System that provides for the protection and management of Matters of National Environmental Significance (MNES) that will take into account relevant Commonwealth principles, policies and statutory plans.
- continue to improve, where necessary, the research, monitoring, management, reporting, evaluation and communication mechanisms as part of its adaptive Forest Management System.

The modernised RFAs also have new commitments to work together with Traditional Owners to protect Country.

5.4 Victorian state policy and planning

Victoria has approximately 8.2 million ha of forests, including native forest and plantations on public and private land. Of this, 6.2 million ha is in the five Victorian RFA regions, with 5.6 million ha of native forest, 0.41 million ha of commercial plantation and 0.13 million ha of other forest. Approximately 81% of Victoria's forested land is Crown land – including around 3 million ha in forested parks and conservation reserves and around 3 million ha in State forests. In addition, private landholders manage 1.45 million ha of forest of which around 422,000 ha are plantations.

The Leadbeater's possum is protected under Victoria's state policy and planning framework. Although protection applies to both public and private land, the possum is found almost exclusively on public land, with around 3% of modelled habitat occurring on private land.

Within the formal reserve system (national parks and conservation reserves), current land planning documents prepared by Parks Victoria under the *National Parks Act 1975* (Vic) include the Yellingbo Liwik Barring Landscape Conservation Area 10 year plan 2021, the Baw Baw National Park Management Plan 2005 and the Yarra Ranges National Park Management Plan 2002.

The Leadbeater's possum's range (about 93%) is almost entirely within the Central Highlands RFA area, with the remainder in the Gippsland RFA and the North East RFA. The current forest management plan prepared under the *Forests Act 1958* (Vic) for the Central Highlands is over 20 years old (Department of Natural Resources and Environment 1998). As agreed under the modernised RFAs, a new forest management plan for the area is currently under preparation. For

more detail on Victoria's forest management system, including forest zones, see Overview of Victoria's Forest Management System on DEECA's website.

The Department of Energy, Environment and Climate Action undertakes risk assessments for species and communities that have been listed as threatened under Victoria's FFG Act or the Commonwealth EPBC Act and are potentially impacted by forestry operations across Victoria's five RFA regions. This became a new requirement in the modernised RFAs. Leadbeater's possum was assessed in March 2020 in Tranche 1, see Threatened Species and Communities Risk Assessment on DEECA's website.

In November 2019, the Victorian Government announced its decision to phase out all timber harvesting in native forests and transition Victoria's timber industry fully to plantations by 30 June 2030. Under the Victorian Forestry Plan, harvest levels in State forests were to be progressively stepped down over the next 10 years.

In May 2023, the Victorian Government announced the early cessation of native forest timber harvesting by January 1, 2024, Delivering Certainty For Timber Workers. This was in response to timber supply constraints arising from increasingly severe bushfires, prolonged legal action and court decisions.

6 Conservation and management history

Leadbeater's possum has been the subject of much conservation management activity extending for more than three decades. Initially, much of this activity was framed by the previous Recovery Plan (Macfarlane et al. 1997) and overseen by a Leadbeater's possum recovery team. That conservation effort built a substantial legacy and foundation for current conservation activity. Available on the Commonwealth Department of Climate Change, Energy, the Environment and Water's (DCCEEW) website, the Review of the 1997 Recovery Plan for Leadbeater's Possum summarised that research and management effort, and the extent to which each action was implemented.

In June 2013, the Victorian Government focused a major conservation management effort through the establishment of the Leadbeater's Possum Advisory Group (LPAG). LPAG was established to provide recommendations aimed at 'supporting the recovery of the possum while maintaining a sustainable timber industry' in the Central Highlands. LPAG recommended a package of actions to slow the projected decline in population in the Central Highlands, by: providing protection to known colonies; protecting current high quality habitat; expanding future old-growth forest and possum habitat; proactively increasing the availability of nest sites at selected locations (via nest boxes and artificial hollows), and; improving knowledge to more effectively implement management actions (LPAG 2014a). LPAG only examined management options for highland Leadbeater's possum populations given the overlap with timber harvesting.

In April 2014, the Victorian Government accepted all 13 recommendations and announced that it would invest $11 million to implement these over the following five years. The LPAG recommendations were incorporated into a revised Victorian Action Statement in 2014 which outlined the conservation measures in place for Leadbeater's possum (Department of Environment and Primary Industries 2014a). Further measures were introduced in 2015, including: (1) accelerating the LPAG targeted survey program to more quickly locate and protect Leadbeater's possum colonies, (2) applying remote sensing techniques to map key habitat features, and (3) introducing a risk-based pre-timber harvesting survey program deploying new survey methodologies.

Approximately two thirds of the potential habitat within the distribution of Leadbeater's possum is now in the comprehensive, adequate, and representative (CAR) reserve system The largest area of reserved ash forest is in the Yarra Ranges National Park, which includes three extensive water catchments. The major sub-alpine (snow gum) woodland sites inhabited by Leadbeater's possum are protected within the Yarra Ranges National Park (Lake Mountain), Mount Bullfight Nature Conservation Reserve and Baw Baw National Park. The lowland swamp forest occupied by Leadbeater's possum is fully protected within the Yellingbo Nature Conservation Area (Department of Environment and Primary Industries 2014a).

A significant measure that added habitat to the reserve system was to establish a 200 m radius exclusion zone around all Leadbeater's possum records within State forests. This included all records since 1998, except those burnt in 2009, as well as around all new records. Given that DEECA, community members and other organisations have conducted extensive targeted surveys since 2014,

using effective new methods, several hundred such zones were established prior to the announcement that timber harvesting would cease in 2024.

Intensive, widespread bushfires are a significant threat to the ongoing persistence of Leadbeater's possum. LPAG recommended actions aimed at increasing the protection of Leadbeater's possum colonies and habitat through intensified fire planning and management. Where possible and appropriate, active fire management activities are to be used to protect identified colonies and high-quality habitat from bushfire, taking into consideration the requirements of other threatened species (LPAG 2014a). This includes suppression activities and fuel management in adjacent drier forest types. Strategic fuel breaks have been constructed with the aim of protecting Melbourne's water supply from fire. To reduce the risk of these breaks fragmenting Leadbeater's possum habitat, bands of wattle and ash forest are retained at 100 m intervals in some areas, and removal of hollow-bearing trees is restricted (Department of Sustainability and Environment 2008b).

Fire recovery protocols have been developed to assist in decision making and timely emergency management responses following bushfires. These protocols provide guidance on when intervention – such as providing additional nesting resources, supplementary food, artificial connectivity or translocation – is warranted. Following the severe impacts of the 2009 bushfires at Lake Mountain, additional den sites (nesting boxes) were provided and a supplementary feeding program was undertaken over winter for three years following the fire. This was coordinated by Parks Victoria, with extensive volunteer participation from the Friends of Leadbeater's Possum group. The few remaining animals made extensive use of the supplementary food provided (J. Antrobus and D. Harley, pers. comm.).

The establishment and regular checking of nest boxes as a survey, research and monitoring tool has been maintained, with particular applicability in sub-alpine woodland and lowland swamp forest habitat and with varying success in montane forests (Harley 2016). Project Possum is a collaborative project between Zoos Victoria, Parks Victoria and the Friends of Leadbeater's Possum that aims to provide long-lasting nest boxes at strategic locations within Leadbeater's possum's range in the Central Highlands. As at May 2023, 823 nest boxes have been installed (347 in sub-alpine woodland, 396 in montane ash forest and 80 in lowland forest; 511 in parks and reserves, 312 in State Forest) (D. Harley, pers. comm.). A further 100 nest boxes are maintained by Zoos Victoria in Yellingbo Nature Conservation Area.

The Arthur Rylah Institute is conducting complementary work on artificial hollows cut with chainsaws. Of the 132 established to date Leadbeater's possum currently occupy 43%, with 62% having been used at some time since they were installed in 2015 and 2017. Although some hollows were occupied very soon after construction, others that had not previously been used by Leadbeater's possums in 6 years were occupied this year. This highlights the benefit of long-term monitoring of the hollows as patterns change over time.

Since 2012, two different conservation strategies have been applied to the lowland population at Yellingbo. The first, applied from 2012 to 2017, focused on captive-breeding and habitat restoration. Unfortunately, no lowland young have yet been produced by captive breeding. The captive-breeding program is linked with a major habitat protection and restoration program underway for both Leadbeater's possum and the helmeted honeyeater. This has included targeted revegetation to compensate for loss of vegetation structure and lack of natural regeneration. DEECA and Parks

Victoria is working with adjacent landowners to fence off stream frontages and phase out grazing over a significant area in the Yarra Valley to improve water quality and protect riparian habitats (DELWP 2015a). A 5 km habitat protection fence, encompassing 44 ha of the most critical remaining habitat for the lowland Leadbeater's possum has been built at Yellingbo to reduce browsing impacts of deer and wallabies on vegetation and seedling recruitment. It is likely that restored habitat will be dispersed across a collection of sites 30–80 ha in size, and thus ongoing genetic management through periodic transfer of individuals among translocated possum populations will be necessary.

The most significant habitat restoration to date is ~28 ha of revegetated swamp forest at Haining Farm, 9 km from Yellingbo. Predator exclusion fencing is being planned for this site in order to remove cat and foxes ahead of the release of lowland Leadbeater's possums.

In 2017 to 2018, given ongoing population declines and challenges with captive breeding and habitat restoration, a revised recovery model was developed based upon wild-to-wild translocation to intact suitable habitat. Expert elicitation indicated that new translocation sites had higher probability of success than focusing recovery measures at Yellingbo. However, there was high uncertainty regarding the likelihood of translocation success. Despite extensive searches, based on habitat modelling and expert advice, to identify potential translocation sites no large patches of intact, high quality lowland swamp forest suitable for translocation were identified.

Section 3 Background information informing recovery action summarises a very substantial evidence base resulting from decades of intensive research on Leadbeater's possum and its environment. This research effort has been, and will continue to be, a crucial component of conservation management for this species. The historic and ongoing research effort is not reviewed here (see instead, for example, Smith et al. (1985); Lindenmayer (1996a, 2009); Harley (2016)), but this section briefly notes some recent research activity that targets key knowledge gaps that, if filled, may substantially increase conservation management effectiveness. This includes:

- a substantial survey effort across the known range of the species to help assess patterns of habitat use and abundance (DEECA, Zoos Victoria);
- an assessment of colonisation rates of nest boxes and artificially excavated hollows;
- extensive and substantial survey effort to assess the extent of suitable habitat and occurrence of Leadbeater's possum in Victorian areas beyond the known range, in part to identify options for future translocations (Zoos Victoria, University of Melbourne, DEECA);
- an assessment of the extent to which predation by cats may be a significant threat to the species (following on from the work of McComb et al. 2019);
- high resolution aerial photography and remote sensing technology (including LiDAR) is being used for the fine-scale detection and dynamic modelling of particular critical habitat features, notably hollow-bearing trees and midstorey density, across the Central Highlands range, to allow high resolution mapping of habitat suitability and improve spatial habitat models (University of Melbourne, DEECA);
- a radio-tracking study to quantify nest tree use, home range size, spatial habitat use and the habitat requirements of Leadbeater's possum in a regrowth dominated landscape, including

how the use of regrowth habitat for foraging may depend upon the proximity of contrasting habitat that provides hollows (research by ANU);

- ongoing genetic analyses of highland and lowland subpopulations, including work investigating future genetic management options for the lowland population (Monash University, Zoos Victoria);
- analysis of radio-tracking data examining the spatial ecology of the lowland population at Yellingbo prior to the decline of this population (Zoos Victoria, Deakin University);
- climate suitability modelling for Leadbeater's possum under various climate change scenarios (Deakin University, Zoos Victoria);
- stand and landscape forest growth models are being developed to better understand the implications of management actions on spatial and temporal changes to forest structure (University of Melbourne, DEECA);
- identifying areas of stable or transient Leadbeater's possum habitat in dynamic landscapes under a range of management and climate scenarios, using a spatially explicit landscape simulation model, plus habitat suitability and patch modelling (University of Melbourne);
- a review and refinement of a PVA for the species was done in 2021 with further refinement due Dec 2023 (University of Melbourne, DEECA); and
- research by ARI into persistence of colonies within 200 m buffers; findings expected late 2023.

7 Recovery objectives and actions

7.1 Context

The recovery objectives and actions proposed here are informed by a set of general principles and requirements. These include:

1) that the pre-eminent purpose of this Recovery Plan is to stop the decline and support the recovery of Leadbeater's possum so that its chances of long-term survival in nature are maximised, as required under the EPBC Act;

2) that decades of research and management activity have provided a robust evidence base for recovery, and such evidence has formed the basis of a considered assessment of the likely efficacy of possible recovery actions (LPAG 2014b). Recovery objectives and actions delineated here have been informed by this evidence base and will incorporate findings that arise from new and ongoing research;

3) that while existing recovery actions have contributed to some conservation advances, they have been, and are likely to continue to be, insufficient to recover the species, hence a substantially new or more committed management response is required;

4) that the overwhelming majority of the known population of Leadbeater's possum is confined to the Central Highlands montane ash forest, and that the development of effective conservation management actions for this species in this region is most critical to the species' likelihood of recovery;

5) but that, on current trends, there is a high risk of extinction for the species in this region, especially through extensive and severe bushfire, and hence there is value in considering options to try to spread this risk through attempts to secure or establish subpopulations of the species in the most suitable habitat outside this region;

6) that conservation effort also needs to attempt to retain and recover the lowland swamp forest subpopulation (an ESU), with this subpopulation particularly at risk of imminent extinction;

7) that conservation success will not be achieved by management actions alone, but will depend also upon enhancing existing and future planning and policy settings, such that these contribute appropriately to the long-term survival of Leadbeater's possum in nature;

8) that there remain important uncertainties about some conservation management actions (such as translocation, effective fire mitigation options, accelerated hollow development, climate change responses), so this Recovery Plan should address these knowledge gaps and be flexible, responsive to new information, and capable of adaptive management; and

9) that as the Victorian government transitions out of native forest harvesting, the Recovery Plan, while forward looking in identifying objectives to support Leadbeater's possum recovery beyond native forest harvesting, recognises the legacy of timber harvesting with respect to the ongoing decline of large hollow-bearing trees and other residual effects, and responds accordingly.

7.2 Recovery objectives, actions and performance measures

7.2.1 Long-term recovery objective

The extent, quality and connectivity of current and future suitable habitat, and its occupancy by Leadbeater's possum is increased, such that its probability of extinction over a 100-year period is less than 1%.

Rationale

Conservation planning for Leadbeater's possum is a long-term proposition and commitment. Actions taken now to enhance its conservation status are unlikely to reverse the current decline in the extent of its suitable habitat or of its population over the 10-year period of this plan, but they will help to slow this rate of decline. These actions will provide a basis for promoting recovery and managing the species over the medium to long term, and importantly, actions taken or not taken now will affect its likelihood of extinction over a 50–100-year timeframe. Furthermore, the extent and location of suitable habitat for Leadbeater's possum will vary substantially over time, depending upon the type and extent of disturbance and successional processes in its habitat.

Given some still existing substantial uncertainties about population size, the scale and impact of future threats and the likely benefits and practicality of potential actions, it is challenging at this stage to prescribe 'acceptable' and plausible target levels for the probability of long-term persistence of Leadbeater's possum. No matter what set of conservation actions are taken, it is unlikely that its long-term fate can be guaranteed (i.e., that those actions would result in a 0% probability of functional extinction over the next 100 years). A reasonable and realistic long-term target to help frame the short-term objectives in this Plan is that those actions should collectively benefit this species so that its probability of extinction over a 100-year period becomes less than 1%.

Performance criteria are listed in the section below for a set of objectives operating over the lifetime of this Plan. It is less meaningful to attempt to provide comparable criteria for the period beyond this plan, but the long-term objective described above would require the following outcomes:

- the total population size of Leadbeater's possum stabilises and then increases over the next 20–50 years;
- risks to Leadbeater's possum from catastrophe (notably extensive, severe bushfire) are managed effectively through securing viable subpopulations across an area that is at least as extensive as its distribution immediately prior to the 2009 bushfires;
- the extent and continuity of suitable habitat is increased or at least maintained across the Central Highlands;
- landscape planning ensures climate modelling (1) informs identification and protection of climate refugia, and (2) is integrated with other modelling approaches such as PVA and connectivity analysis to determine the overall extinction risk for Leadbeater's possum;
- there is an ongoing commitment, with appropriate resourcing, to effective and enduring management of threats to this species, including effective management that results in a pattern of bushfire frequency and severity that is less detrimental to this species (and its forest environment);

- the subpopulation in the lowland swamp forest is retained and its population size and the extent and suitability of its habitat are substantially greater than at present.

7.2.2 Objectives, actions, outcomes and performance criteria

The objectives and actions proposed in this section should be considered as an integrated and coherent package. These objectives and actions span a broad gamut of policy, management, research, monitoring, governance and other components, recognising the high profile but complex conservation context for this species. The set of objectives and actions described here includes all, or components of, conservation actions developed through the LPAG process and implemented through the Victorian Action Statement for this species (Department of Environment and Primary Industries 2014a), but also significantly extends these actions and includes new actions. This set of actions does not necessarily include all actions recommended outside the LPAG process (such as those described in Section 7.2 Recovery objectives, actions and performance measures), but includes components of these and encompasses those components within a broader package that should collectively secure the conservation future for this species. Noting that actions under the 2019 Conservation Advice predated the Victorian Government announcement to cease native forest harvesting, the actions described in this Recovery Plan build upon only those relevant actions in the 2019 Conservation Advice (TSSC 2019).

All objectives and actions in this Plan will contribute significantly to the conservation of Leadbeater's possum, and all individual actions are of high priority and need to be implemented. However, to assist in the orderliness of this implementation, actions are prioritised (see Section 8.1 Implementation schedule and costs).

The objectives also vary in complexity and magnitude. In particular, Objective 2 includes a large set of substantial and inter-dependent actions that focus on the conservation and management of current and future habitat. There are some interrelated activities across some objectives, for example although there are translocation components within Objective 3 and Objective 4, they have a different purpose with Objective 3 developing translocation protocols and, subject to appropriate assessment of risks and benefits, moving animals to currently unoccupied, but suitable, habitat within their known range, while Objective 4 includes translocation as a subsidiary action within a broader program focusing on spreading the risk, searching for new populations or potential habitat outside of the current known range.

Objective 1

All relevant existing and future planning and policy settings are reviewed, and where required, refined and implemented in a manner that contributes appropriately to maximising the chances of long-term survival of Leadbeater's possum in nature.

Rationale

Management actions alone will not be sufficient to recover the Leadbeater's possum: that objective also needs harmonisation of existing and future planning and policy settings such that they collectively and coherently contribute appropriately to maximising the chances of long-term survival of Leadbeater's possum in nature. The current policy setting that most influences the likelihood of conservation success for Leadbeater's possum is the Victorian Government's decision to end native timber logging on public land 1 January 2024 and the subsequent planning and policy decisions relating to forest management. The Recovery Plan represents an opportunity to inform that process,

as the Victorian Government considers those forest areas that qualify for protection as National Parks, or those suitable for recreation opportunities and opportunities for management of public land by Traditional Owners. Ensure that high quality, unburnt habitat (for example, Toorongo, Baw Baw) and habitat impacted by fire but still with HBTs (for example, Paradise Plains) are included in fire management planning.

Action 1.1 – Priority: Urgent
Review and, where required, revise existing relevant planning and policy settings, including fire management plans, to ensure that they provide for maximising the chances of long-term survival of Leadbeater's possum.

Action 1.2 – Priority: Urgent
Ensure that future relevant planning and policy settings provide for maximising the chances of long-term survival of Leadbeater's possum.

Performance criteria

1) All relevant plans and policy are compatible and coordinated with, and contribute more effectively to, the objective of maximising the likelihood of long-term survival of Leadbeater's possum.

Table 1: Objective 1 deliverables

Timing	Outcome
By end of 1st year	• All key relevant policies and plans are assessed to identify settings or practice that may contribute significantly to, or may be inconsistent with, the successful implementation of this Recovery Plan (Action 1.1 – Priority: Urgent). [a] • Any new key relevant policies and plans that are informed by, take account of, are consistent with, and contribute significantly to the implementation of this Recovery Plan (Action 1.2 – Priority: Urgent).
By end of 2nd year	• Settings in all key relevant policies and plans are refined to ensure alignment with this Recovery Plan, and effective coordination across plans and policies to achieve the Recovery Plan's objectives (Action 1.1 – Priority: Urgent). [a]

Note: [a] Action is ongoing thereafter.

Objective 2
A whole of landscape management regime is in place ensuring that all current and future suitable habitat across the species' known range is maintained, enhanced and effectively managed to maximise its suitability for Leadbeater's possum.

Rationale
The key conservation concern for Leadbeater's possum is the limited and declining extent, quality and connectivity of suitable habitat (defined as areas of montane ash forests or snow gum woodlands within the range of the species). This objective seeks to focus explicitly on the maintenance and management of habitat that is currently suitable, and habitat that will become suitable in the future. Retention of habitat should largely be through an increase in the dedicated reserve system to improve that system's adequacy, supported by complementary actions across other tenures. A whole of landscape management planning approach is needed to identify, protect and effectively manage habitat as well as mitigating landscape and other threats, including capacity to respond to emergency events such as severe extensive fire.

Balancing appropriate levels of fire management and on-ground actions will be complex and require detailed planning. On-ground activities will need to both suppress some aspects of fire and promote others. Desirable landscape-scale fire patterns will be necessary to mitigate the threat from inappropriate fire regimes and increased intensity, extent and frequency of bushfires under climate change scenarios. A suite of coincident actions will also be necessary that most closely resemble 'natural' fire disturbance in montane ash forest and enhance habitat suitability for Leadbeater's possum. Achieving optimal landscape-scale outcomes, including those for this species, will likely require the application of fire and other fire management interventions within areas of potential habitat (for example, refugia protection and maintenance as well as maintenance of key populations). 'Fire regimes that support healthy and resilient ecosystems and nature conservation' is an aim of 'Victoria's bushfire management strategy' draft (DEECA 2023).

This objective relates to the nub of the conservation challenge for Leadbeater's possum: in a highly dynamic landscape and with some substantial uncertainties, how to define, retain and manage sufficient areas of suitable habitat over periods of many decades to provide for the conservation security for the species. The approach adopted here to address this problem is to maintain or enhance existing protective mechanisms, and to complement it with the implementation of a dynamic land-use planning exercise that pivots explicitly on the requirement that sufficient habitat is retained and managed to provide a high level (99%) of confidence that the species will persist in nature over at least a 100 year period.

Actions under Objective 1, and the timing of those, will be crucial in informing actions under this objective, as the Recovery Plan informs, or is informed by the subsequent planning and policy decisions in response to the Victorian Government's decision to end native timber logging on public land from 1 January 2024.

Note that, except where stipulated otherwise, all actions contributing to this objective relate to the Central Highlands.

Action 2.1 – Priority: Urgent
Ensure that predicted impacts from climate change on Leadbeater's possum and habitat are assessed and ameliorated to the extent possible. Continue to use and update dynamic modelling for fine scale detection of particular critical habitat features, especially availability of tree hollows, and likelihood of tree death. Conduct these actions under several climate change scenarios and timescales (for example, 5, 10, 20+ years) for better forecasting ability.

Action 2.2 – Priority: Urgent
Ensure that modelling under Action 2.1 – Priority: Urgent is used to inform and adaptively update planning for all relevant in situ and ex situ management responses (see Action 1.1 – Priority: Urgent and Action 1.2 – Priority: Urgent). Outcomes of modelling should inform delineation of suitable habitat under a variety of climate change scenarios for possible future emergency translocations (for example, in the event of bushfires) or protection and management of climate refugia. Work with DEECA to refine on-ground fire management activities to maximise the positive benefits for this species while ensuring community safety.

Action 2.3 – Priority: Urgent
Continue to refine and update occupancy and other relevant distributional and population viability modelling, in all land tenures across the full range of the species, with the aim of providing maximum protection of habitat critical, and responding to a dynamic environment and climate. Such refinements should incorporate new distributional data and finer-scale mapping of key habitat attributes, such as large hollow-bearing trees and midstorey density (see Objective 4 and Objective 5), and should consider future changes in habitat availability and population size across a range of plausible future disturbance episodes.

This is the foundation for a proactive land-use (conservation) planning process at a landscape scale. It will require (1) consolidating, verifying and refining spatial habitat models across the full range of the species (including the recent developments of forest mapping through LiDAR imagery (Baker et al. 2017), (2) incorporating new information arising from the recent and ongoing substantial survey effort; (3) future changes in habitat suitability as described by forest growth models under development by the University of Melbourne (Baker et al. 2017); and (4) testing these refined models through additional structured surveys across all land tenures.

Following refinement (and testing) of these distributional models, they then need to be linked to updated population viability and other dynamic modelling, to project, predict and map the distributional extent of suitable habitat and possum occurrence and population size under a range of disturbance regimes over at least a 100-year period.

Action 2.4 – Priority: Urgent
Based on models developed in Action 2.3 – Priority: Urgent, undertake landscape scale land-use planning that aims to provide maximum protection of habitat critical, and responds to a dynamic environment and climate, providing options for conservation of suitable habitat now and in the future to ensure an acceptably high likelihood of persistence (such as at least 99% over 100-year period) for Leadbeater's possum.

This action will enable a landscape-scale approach to determine appropriate protection, in addition to the location and protection of known Leadbeater's possum colonies. Given the distributional and population viability models developed in Action 2.1 – Priority: Urgent, this action seeks to determine options to achieve the appropriate mix of additional dedicated reserves, informal reserves and values protected through prescriptions in the remaining areas of state forest that will be required to meet the long-term objective of being at least 99% confident that the species will persist in the wild for at least 100 years. That objective should be the numerical target of this planning, but a subsidiary objective is to strategically develop and maintain a substantial increase in the extent of large and hollow-bearing trees and habitats that will be likely to provide these in the future. This planning should also consider the requirements of, or any potential negative impacts on, other threatened species.

Action 2.5 – Priority: Urgent
Expand the dedicated reserve system with the aim of providing maximum protection of habitat critical, and responding to a dynamic environment and climate, incorporating sufficient areas of current and future suitable habitat to ensure that it is adequate to maintain and enhance the long-term population viability of Leadbeater's possum.

The conservation future of Leadbeater's possum will depend upon a complementary mix of dedicated reserves, informal reserves and protection of values through management prescriptions. However, dedicated reserves are likely to provide greater conservation security and more confidence in conservation outcomes than unreserved lands that may be subject to other uses. Todd et al. (2016) and Taylor et al. (2017) used projective population modelling to demonstrate that the current reserve system alone is inadequate for the long-term conservation of Leadbeater's possum, and especially so when incorporating the likelihood of future extensive bushfires. Accordingly, there is need for substantial enhancement of the existing dedicated reserve system, to recognise its primary role in providing for the long-term persistence of the species. Implementation of a substantial expansion of the current reserve system, informed by Action 2.6 – Priority: Urgent and Action 2.7 – Priority: Essential, should seek to encompass all areas of high likelihood of occurrence of the species (currently and in the future). It should also include areas of current and projected old-growth forests; and such expansion should increase the connectivity of the reserve system, as well as protecting a range of other values.

Action 2.6 – Priority: Urgent
Assess the feasibility, risks and cost-effectiveness of fire management options that seek to deliver long-term, strategic and landscape scale enhancement of the extent, and quality of current and future suitable habitat. Develop and implement fire management that effectively secures and promotes long-term, strategic and effective protection of known colonies and suitable habitat.

This action relates to populations across the entire range, including the sub-alpine (snow gum) woodlands and lowland swamp gum forest habitats. It addresses the primary pervasive threat to the possum and its habitat. This action will build on the East Central Bushfire Risk Landscape management plan (Department of Environment and Primary Industries 2014d), which encompasses all of the Leadbeater's possum range. This plan assessed the bushfire risk to known Leadbeater's possum colonies and high-quality habitat, and modelled the extent to which fuel management in adjacent areas reduced this risk.

In implementing this action, management needs to evaluate options relating to short- and long-term planning, local and landscape scales, cost-effectiveness, and risks. It needs to consider pre-emptive fire management actions, responses to bushfires, and post-fire remediation, within the context of the objectives of the Code of Practice for Bushfire Management on Public Land (Department of Sustainability and Environment 2012).

Action 2.7 – Priority: Essential
Develop a suite of priority responsive actions designed to maintain or recover populations as rapidly as possible after extensive bushfire. These actions may include rapid survey to locate and assess the viability of any colonies surviving in small unburnt patches, targeted provision of nest boxes or food supplementation, as appropriate.

This action recognises that extensive bushfires will likely occur during the life of this Plan, or in coming decades, and that such fires will pose a significant risk to the viability of the species. Such fires will also likely be hazardous to people. Rapid and strategic responses following bushfire are required to maximise the retention of Leadbeater's possums surviving within the burnt landscape, and to recover populations as quickly as possible in formerly occupied, but now burnt, habitat. These post-fire recovery guidelines will be substantially informed by research Action 5.3 – Priority:

Essential. It is also recognised that a rapid response may not be possible in situations that present risks to people, property and infrastructure. Predation by cats and foxes could become a more significant issue following major fires, given these predators may target recently burned sites.

Action 2.8 – Priority: Essential
Where research on habitat augmentation (Action 5.4 – Priority: Essential) (including the provision of nest boxes, artificially excavated hollows, and manipulation of midstorey) demonstrates that benefits can be obtained effectively, strategically implement these mechanisms to enhance the current and future extent of suitable habitat in the Central Highlands.

This action relates to all land tenures in the Central Highlands and is based on the premise that the current and projected extent and quality of suitable habitat is a major limiting factor, and that active management may be able to support the persistence of colonies where den sites are declining and provide some increase in the extent of suitable habitat. Note that this action should be recognised as complementary to, and not a substitute for, the protection of existing habitat, especially hollow-bearing trees. This management is a short- to medium-term bridging action to enhance the availability of suitable habitat (particularly hollows) over the future decades in which shortage of natural hollows is predicted to be a major factor limiting population size and recovery. Maintaining den availability through the provision of nest boxes and artificially excavated hollows in recently burnt forest, where suitable foraging conditions exist but hollow-bearing trees may be limiting, may provide an important component to maintaining population size.

The manipulation of vegetation structure to enhance a dense midstorey layer to improve foraging and movement habitat may be beneficial in some situations (for example, 1939 regrowth or older forests). However, there are currently extensive areas with a dense midstorey in fire and timber harvesting regrowth, therefore this approach is considered a lower priority than enhancing hollows. In addition, any action to increase midstorey density would need to consider the habitat requirements of co-occurring species.

Note that this action links also to research Action 5.5 – Priority: Essential, that seeks to assess the benefit, practicality and cost-effectiveness of such habitat augmentation measures.

Action 2.9 – Priority: Urgent
Maintain the current and continuing supply of denning habitat for Leadbeater's possum as much as possible by retaining all live and dead trees that are either large (over 150 cm DBH) or hollow-bearing (where over 80 cm DBH) in montane ash forests within the distribution of Leadbeater's possum.

Large hollow-bearing trees (live or dead) are a fundamental defining feature of suitable habitat for Leadbeater's possum, but are a rapidly declining resource (Lindenmayer et al. 2012). At present, old, live trees (pre-1900) and all live trees greater than 2.5 m DBH are offered some, but not necessarily effective, protection under timber harvesting prescriptions (Department of Environment and Primary Industries 2014c). However, other hollow-bearing trees fall outside this definition and are not protected, as well as some larger trees that may not yet have hollows but will be the hollow-bearing trees of the future (approximately 30% of mountain ash with a DBH of 150 cm have not yet formed hollows (Fox et al. 2008)). More recent analyses of the relationship between tree diameter and hollow abundance show a steep increase across the range of tree diameters from 100 cm to 200 cm in the likelihood of a tree providing hollows, with trees of 150 cm DBH having a probability of about

50% of having at least one hollow, rendering this diameter an appropriate threshold for protection (P. Baker pers. comm), although it is notable also that a proportion of trees with smaller diameter also have hollows.

Given their importance for provision of hollows, all large (greater than 150 cm DBH) live and dead trees need to be protected irrespective of whether or not they currently have visible hollows. In addition, all smaller trees (dead or live), greater than 80 cm DBH, that contain obvious hollows should be retained, as such trees will provide critical resources for Leadbeater's possum now. This protection applies to all tree species in montane ash forests within the distributional range of Leadbeater's possum (including non-ash species if within a predominantly ash stand), and independent of any future land tenure and associated management regimes. Consideration should be given to how this action might be applied when implementing the Victorian Government's policy of hazardous tree removal post fire.

Action 2.10 – Priority: Urgent
Enhance current and future habitat suitability and extent of swamp forest habitat for the lowland subpopulation.

Currently, there is limited eucalypt regeneration in the floodplain at Yellingbo, and habitat management and restoration is required to increase the amount of structurally dense forest to provide additional foraging habitat and connectivity at Yellingbo and in other potentially suitable sites. This includes hydrological restoration in the floodplains of the Cockatoo and Macclesfield Creeks and the development and application of a disturbance regime to promote the regeneration of dense stands of canopy and midstorey species on the floodplain and terraces immediately adjacent to the floodplain. Until appropriate broad-scale disturbance mechanisms are developed, manual revegetation should be undertaken in priority sites, notably those currently supporting Leadbeater's possum colonies, at Yellingbo and sites with suitable hydrology elsewhere in the Yarra Valley (for example, Haining Farm). The long-term target is to provide at least 220 ha of suitable foraging habitat for lowland Leadbeater's possum, and hence to reverse the current decline of the subpopulation in lowland swamp forest.

Performance criteria

1) Enhanced spatial distribution models, and a dynamic spatially explicit population viability model, are developed and form a robust basis for current and future conservation planning.
2) Areas that can provide suitable habitat now, and over the next 50 years, are modelled and mapped including identification of climate refugia.
3) Sufficient additional areas of current and future suitable habitat are incorporated in an expanded dedicated and informal reserve system to ensure that the system maximises the likelihood of persistence of Leadbeater's possum, over at least a 100-year period.
4) Options for fire management are better evaluated for impacts on Leadbeater's possum. Fire management policy, planning and actions are implemented in a manner that minimises risks to the viability of Leadbeater's possum and reduces the likelihood of extensive and severe bushfires.
5) A suite of priority actions to enhance recovery of Leadbeater's possum after extensive bushfire is developed, and implemented should such fires occur.

6) The effectiveness of nest boxes, artificially excavated hollows and manipulation of midstorey is understood and these management actions are implemented where appropriate.

7) All live and dead trees that are either large (over 1.5 m DBH) or hollow-bearing (over 80 cm DBH) are protected as much as possible, including during forest management activities such as removal of hazardous trees.

8) Active habitat management and restoration at Yellingbo and designated sites throughout the Yarra Valley to provide increased habitat extent and suitability for the lowland swamp forest subpopulation.

Table 2: Objective 2 deliverables

Timing	Outcome
By end of 1st year	• Improved distributional models are developed that combine distribution and habitat models developed by Victorian government and other researchers, and incorporate substantial new data from recent surveys and mapping of additional habitat features (Action 2.1 – Priority: Urgent). • The risks, consequences and effectiveness for Leadbeater's possum viability of fire management options are evaluated (Action 2.4 – Priority: Urgent). • A management regime is in place to ensure that all large, live and dead trees, and hollow-bearing trees, are progressively identified and effectively protected (Action 2.7 – Priority: Essential).
By end of 2nd year	• Dynamic population viability modelling is refined such that likelihood of extinction can be calculated robustly across a range of reservation and management options, and across a range of plausible future disturbance episodes. This modelling is then linked to distributional modelling to identify reservation and management scenarios that provide an acceptably low risk of extinction (less than 1% probability) over a 100-year period (Action 2.1 – Priority: Urgent). • The reserve system is expanded consistent with distribution and population viability models, and land-use planning, to a level that provides confidence that long-term risks of extinction are acceptably low (Action 2.2 – Priority: Urgent and Action 2.3 – Priority: Urgent). • A long-term strategic fire management plan for the Central Highlands is developed or refined that identifies key risks, key biodiversity assets for protection, effective management to reduce likelihood of extensive high intensity fire and effective responses to asset protection during high intensity fire (Action 2.4 – Priority: Urgent). • A suite of priority responses is developed that will provide for rapid, strategic and targeted responses following bushfire (Action 2.5 – Priority: Urgent). • Based on evidence from research (1) the effectiveness of habitat augmentation measures is assessed, (2) sites are identified where augmentation can contribute most significantly to the long-term persistence of Leadbeater's possum, and (3) a long-term strategic program of habitat augmentation is implemented, such that this contributes most effectively to persistence (Action 2.6 – Priority: Urgent).
By end of 5th year	• Active restoration and related activities provide the basis for long-term increase in the extent of suitable habitat for Leadbeater's possum at Yellingbo and similar nearby areas (Action 2.8 – Priority: Essential).
By end of 10th year	• Enhanced reservation and effective management of adequate areas of unreserved habitat provides an acceptably low risk of extinction (for example, less than 1% probability) over a 100-year period (Multiple actions).

Objective 3

A range of ex-situ conservation strategies to support within range recovery are assessed, and where deemed there is a net long-term benefit (such as, likelihood of increase in overall population viability), implemented and evaluated.

Rationale

The distribution of Leadbeater's possum is fragmented, and probably increasingly so. Some small and isolated subpopulations are likely to have especially high probabilities of local extinction. The frequency of effective natural dispersal of individuals of this species over distances of more than 5 km is unknown. In addition, because of past events, some currently suitable habitat may now be unoccupied, or areas will become suitable in the near future (for example, parts of the area burnt in the 2009 fires). Strategic translocations within the known range may decrease population fragmentation, and increase subpopulation viability and occupancy of suitable habitat. It is prudent to carefully trial any such translocations early in the plan, given the possibility of even more urgent need for such actions in the future following catastrophic bushfire, and as the population size declines and becomes increasingly fragmented.

Criteria used to assess translocation site suitability include: (1) Traditional Owner support, (2) suitable floristics to support Leadbeater's possum foraging, (3) suitable structure to facilitate possum movement, (4) patch size and carrying capacity, (5) operational logistics of conducting translocations at that locality. Hollow-bearing tree abundance is noted; however, nest boxes or chainsaw hollows can be provided should suitable foraging habitat lack tree hollows. The abundance of cats is an important consideration, although predation risk is likely to vary among locations. Modelling should be used to examine fire-risk and whether sites will remain climatically suitable for Leadbeater's Possum under climate change. Particularly important criteria for translocation site selection include carrying capacity and whether sites may constitute climate refugia.

The lowland swamp forest subpopulation is particularly precarious, should the barriers to breeding lowland Leadbeater's possums in captivity be overcome, this captive population has the potential to provide important insurance against the loss of this unique subpopulation in the wild. However, as captive-breeding has not yet been successful with lowland individuals and is unlikely to provide benefits in the necessary timeframe, ex situ priorities now relate to (1) pair wild-born subadults (approaching sexual maturity) in captivity ahead of re-release to the wild to establish additional breeding territories, and (2) establish and maintain mixed highland-lowland pairings as part of the genetic rescue strategy being applied for the lowland population.

As climate change advances, it will be important to identify possible genetic adaption responses for both subpopulations. For example, a genetic rescue strategy is being implemented for Yellingbo based around managed levels of gene-pool mixing between lowland and highland. While the priority is to introduce highland genes into the lowland population to mitigate inbreeding (and therefore increase genetic diversity), the opposite might also be applied; that is, incorporating lowland genes into the highland population may support adaptation to warming temperatures. The lowland population represents the trailing end of the climate distribution and thus the lowland population may have unique genetic variation for adaptation to warmer environments.

Action 3.1 – Priority: Essential

Use the outcomes of dynamic modelling in Action 2.1 – Priority: Urgent to identify priority areas within the known range to which translocations may provide benefit to the possum's population viability. Assess the risks, potential impacts upon existing subpopulations, benefits, likelihood of success, and cost-effectiveness of translocation options. Develop appropriate protocols for use and implementation of translocation as informed by Action 5.2 – Priority: Essential (most likely 'wild-to-wild' introductions for the Central Highlands subpopulations). Ensure that translocation management

actions are consistent with international standards and protocols for ex situ conservation and translocation (IUCN/SSC 2013, 2014) as well as relevant Australian and Victorian government legislation and policy.

Action 3.2 – Priority: Essential
Continue with genetic sequencing to help inform analyses of selection and climate adaptation among the different Leadbeater's possum populations. Assess the risks, benefits, practicality, cost-effectiveness and consequences of 'gene pool mixing' to increase the viability of both the highland and lowland subpopulations.

Action 3.3 – Priority: Essential
Where Action 3.1 – Priority: Essential and Action 3.2 – Priority: Essential indicate likelihood of net benefit, undertake carefully monitored trial translocations, and – if successful – extend translocations to other priority areas.

Action 3.4 – Priority: Highly beneficial
Apply ex situ strategies where appropriate, including trials with highland animals, to aid the management options for the lowland swamp forest subpopulation.

Priority criteria

1) Surveys, monitoring and assessments are completed that identify where translocation may be valuable within the known range, and evaluates risks, costs, and benefits of translocation options.
2) 'New' colonies or subpopulations within the known range are established, as required, through translocation.
3) Captive management of lowland Leadbeater's possums continues with the objective of maximising the number of lowland pairs (that is, reproductive potential).
4) Gene-pool mixing reduces inbreeding coefficients in the lowland population.

Table 3: Objective 3 deliverables

Timing	Outcome
By end of 1st year	• Protocols and guidelines (that describe the feasibility, risk assessments, evaluation of costs and benefits, and recommended procedures) for translocation are developed and potential source populations identified (Action 3.1 – Priority: Essential). • Maintain an ex situ program including testing captive protocols with highland animals (Action 3.4 – Priority: Highly beneficial).
By end of 2nd year	• Where net benefit is expected, priority sites for translocation within and adjacent to the Central Highlands are identified (Action 3.1 – Priority: Essential). • Gene pool mixing (strategic and adaptive introduction of genes from highland animals into the lowland population) is undertaken to contribute to the long-term viability of the lowland population (Action 3.2 – Priority: Essential).
By end of 5th year	• Where net benefit is expected, at least two trial translocation projects within or near to the current range are undertaken and the outcomes monitored (Action 3.3 – Priority: Essential).
By end of 10th year	• Translocated populations are effectively established and contribute significantly to overall long-term population viability (Action 3.3 – Priority: Essential). • The number of lowland breeding pairs (territories) is increased, in part with support from captivity, such that the lowland subpopulation is sustainable (Action 3.4 – Priority: Highly beneficial).

Objective 4
Additional populations outside the core range of the Central Highlands are located, established, and protected.

Rationale
Although earlier (Lindenmayer et al. 1991d) and more recent surveys (Eyre et al. 2022) have not located Leadbeater's possum in montane ash forests and sub-alpine woodlands outside the Central Highlands, except for the recent 15 km extensions to the east (McBride et al. 2019; ARI unpublished data), additional searches are warranted using the current broad-scale survey techniques and predictive models to ensure any existing populations outside the known range are located and protected. This should include further surveys in suitable habitat within the vicinity of records a century ago at Mt Wills and Mitchell River in eastern Victoria (see Figure 2) and forested areas with potential habitat between these locations and the Central Highlands population. While some areas have been surveyed, other areas are yet to be surveyed (for example, the vicinity of Dartmouth Dam). The species' overall conservation outlook is likely to be improved by seeking to spread extinction risks by establishing additional populations outside this known range (as long as there is reasonable likelihood of success), while the current population size may still allow for such translocation. Over recent decades, translocations have provided very significant conservation gains for many highly threatened Australian mammal species, and robust translocation protocols are well established (Armstrong et al. 2015). Translocation success is maximised if planned for and undertaken early, in anticipation of greater need in the future.

Action 4.1 – Priority: Essential
Use the outcomes of dynamic modelling in Action 2.1 – Priority: Urgent and continue to use recently developed survey approaches and expansion of recent surveys of potentially suitable areas outside the currently known range, including in areas predicted by habitat modelling to provide suitable habitat or where there are previous verified and plausible unverified records.

Action 4.2 – Priority: Essential
If such surveys locate 'new' existing populations (beyond the Central Highlands), assess their status, population size, genetic affinities, habitat relationships, extent of suitable and future habitat and management requirements; and implement appropriate management actions and prescriptions.

Action 4.3 – Priority: Highly beneficial
If such surveys fail to locate existing populations, identify the most suitable candidate areas for potential translocation (considering that climate change and fire risk will cause future shifts in suitable habitat).

Action 4.4 – Priority: Highly beneficial
Assess the welfare risks, likelihood of success, cost-effectiveness, and potential impacts upon existing populations of translocations to those areas outside the current range considered most practical and likely to result in the establishment of new viable subpopulations. If considered to have significant benefits, implement such translocations.

Note that this action links to Action 3.1 – Priority: Essential and Action 3.3 – Priority: Essential. Any translocation should be consistent with relevant legislation and IUCN guidelines (IUCN/SSC 2013), and consistent with trial translocation protocols developed under Action 3.1 – Priority: Essential.

Performance criteria

1) The areas that are most likely to have Leadbeater's possum outside the Central Highlands are identified and surveyed with appropriate methods.
2) Any 'new' populations located outside the known range are appropriately protected and managed.
3) Assessment of the likely benefits, risks and feasibility of translocation to new areas assists with decision-making processes.
4) 'New' subpopulations are established through translocation to suitable habitat, where considered beneficial.

Table 4: Objective 4 deliverables

Timing	Outcome
By end of 1st year	• At least 5 priority areas considered most likely to contain populations of Leadbeater's possum outside the current known range are identified, and surveyed adequately using appropriate protocols (Action 4.1 – Priority: Essential).
By end of 2nd year	• A further 10+ priority areas considered most likely to contain populations of Leadbeater's possum outside the current known range are identified, and surveyed adequately using appropriate protocols (Action 4.1 – Priority: Essential). • If Action 4.1 – Priority: Essential results in location of 'new' populations outside known range, the status (including abundance, habitat requirements, range extent, threats) is assessed, and appropriate conservation management responses are developed and implemented (Action 4.2 – Priority: Essential). • If Action 4.1 – Priority: Essential fails to locate 'new' populations outside known range, using habitat suitability modelling, preliminary survey and risk spreading principles, at least five sites (outside the current known range) with highest potential for translocation are identified; and translocations options for these sites are assessed, factoring in bushfire risk and climate change. (Action 4.3 – Priority: Highly beneficial).
By end of 4th year	• At least two trial translocation projects are undertaken and monitored, assuming suitable habitat has been located and significant benefits are likely (Action 4.4 – Priority: Highly beneficial).
By end of 10th year	• Translocated populations are effectively established, and contribute significantly to overall long-term population viability (Action 4.4 – Priority: Highly beneficial).

Objective 5

Targeted research addresses key knowledge gaps such that management options are better informed and management actions more effective.

Rationale

Notwithstanding several decades of intensive research resulting in extensive understanding of the ecology of the species and the functioning of the ecosystem, there remain some key knowledge gaps that constrain conservation management effectiveness. In some cases, where that research closely relates to other management objectives, the research actions are (also) described within those

objectives. Note that the actions described here should not be seen to limit research options. Other currently established or proposed research actions will also contribute to the objectives of this Plan.

Action 5.1 – Priority: Urgent
Establish an ongoing research forum to enhance existing collaboration among researchers, and between researchers, managers and other interested parties, to make the most effective use of research actions and to identify and address any further key knowledge gaps.

Action 5.2 – Priority: Essential
Conduct an analysis of critical research gaps and undertake research to fill these gaps; in particular, providing more robust knowledge of key demographic and other ecological characteristics of Leadbeater's possum relevant to conservation management, specifically including population size, subpopulation structuring, predation (for example, cats and foxes), dispersal characteristics, diet, social systems, and home range size. This should include research aimed at increasing the likelihood of success of translocations, in order to establish the number, age, provenance (for example, wild-caught or captive-bred) and social relationships of animals that can be used to maximise success and enhance site fidelity post-release in order to reduce dispersal-related mortality.

Action 5.3 – Priority: Essential
Investigate key aspects of the post-fire ecology of Leadbeater's possum especially in relation to the 2009 bushfires, in part to inform responses to future bushfire events. This research should include at least: (1) assessment of current hollow availability and the importance of large dead and any live hollow-bearing trees in the burnt landscape; (2) investigation of hollow development within trees that were 1939 regrowth before being burnt, to determine their potential to provide denning sites into the future; (3) investigation of the persistence of colonies within fire refuges surrounded by burnt areas; (4) monitoring of rates and pattern of natural recolonisation of forest regrowing after fire; and (5) investigation of the role of firstly augmenting sites with additional hollows then translocating possums to these sites. This may become most critical to mitigate impacts of multiple, short-interval fires.

Action 5.4 – Priority: Essential
Continue to assess the practicality and effectiveness of habitat augmentation actions including the provision of nest boxes, artificially excavated hollows, and manipulation of midstorey to accelerate the development of key habitat features.

Action 5.5 – Priority: Essential
Design and undertake research to determine the (1) demography, movement patterns, denning behaviour and foraging activity of possums in areas regenerating after timber harvesting, and (2) interplay between midstorey *Acacia* senescence and hollow development.

Action 5.6 – Priority: Essential
Evaluate the collateral benefits and detriments of management actions proposed in this Plan to other threatened species in this landscape.

Performance criteria

1) Critical knowledge gaps are identified and filled, and management applies this knowledge and is demonstrably more effective.

Table 5: Objective 5 deliverables

Timing	Outcome
By end of 1st year	• A regular research forum is established for all key researchers and stakeholders to (1) help coordinate research; (2) identify key knowledge gaps; (3) effectively disseminate new information from research; (4) guide effective uptake of knowledge to management; and (5) help resolve contested research findings or implications (Action 5.1 – Priority: Urgent).
By end of 2nd year	• The pattern and rate of recolonisation of Leadbeater's possum in areas regrowing after the 2009 bushfires has been assessed (Action 5.3 – Priority: Essential). • The cost effectiveness of habitat augmentation options are understood (Action 5.5 – Priority: Essential).
By end of 5th year	• The size of the total population and individual subpopulations is reliably estimated, and used with PVA to help guide management responses (Action 5.2 – Priority: Essential). • Habitat burnt in 2009 has been assessed to determine natural recolonisation rates and extent of occurrence throughout forest burnt in 2009 (Action 5.3 – Priority: Essential).
By end of 10th year	• The beneficial and detrimental impacts of planning and management options on other threatened species in this landscape are evaluated and appropriately considered in decision-making (Action 5.6 – Priority: Essential).

Objective 6

An integrated monitoring program is effectively implemented (and maintained) that publicly reports in a timely manner on possum status, existing and future habitat extent, quality and connectivity, and effectiveness of management and research activities.

Rationale

Current monitoring programs have been instrumental in charting trends in the abundance and incidence of Leadbeater's possum and in key habitat attributes, including the responses of these features to a range of disturbance events. Information resulting from such monitoring is pivotal for the assessment of the conservation status of this species. Such monitoring information also provides a critical foundation to prioritise management responses, and to measure the extent of management success, and hence to continually review and, where necessary, refine such management. Ideally, monitoring programs should assess, in an unbiased manner, a range of key variables comprehensively across the distribution and ecological settings of the species.

Action 6.1 – Priority: Essential

Maintain, enhance or develop new monitoring programs to ensure an integrated monitoring and survey program across all tenures and management zones and develop effective public reporting of monitoring results. Collate existing monitoring data and programs that assess trends in abundance and incidence of Leadbeater's possum, extent and suitability of habitat (including key habitat attributes, such as the abundance of hollow-bearing trees and *Acacia* midstorey), and management effectiveness. This monitoring should also include ongoing assessment of forest dynamics across the total extent of possum habitat, in a manner that can readily identify priority areas or times for management inputs that will optimise the current and future extent of suitable habitat.

Action 6.2 – Priority: Essential

Identify key trigger events (for example, future widespread fires) or thresholds in monitoring results that would catalyse priority emergency response (and identify such emergency response options).

Action 6.3 – Priority: Essential
Where translocations are proposed (see Action 3.3 – Priority: Essential and Action 4.4 – Priority: Highly beneficial), design translocation trials in a manner that allows for reporting on success or failure, and those factors that contribute to this fate. Monitor those trials, and use results to refine the efficacy of translocation protocols, or to assess critically whether they are of net benefit.

Action 6.4 – Priority: Essential
Monitor the extent of success, including cost-effectiveness and collateral benefits, of management actions individually and collectively (to include the effectiveness of habitat augmentation through the provision of nest boxes and artificially excavated hollows) and use such information as appropriate to refine actions.

Action 6.5 – Priority: Highly beneficial
Where appropriate, include monitoring of other threatened species within the design and implementation of monitoring programs for Leadbeater's possum.

Performance criteria

1) An integrated monitoring program reports effectively, regularly and publicly on key measures, including trends in relative abundance, extent of suitable habitat (and key habitat attributes), and management effectiveness.
2) Management actions are reviewed in response to evidence from monitoring, and revised accordingly.

Table 6: Objective 6 deliverables

Timing	Outcome
By end of 1st year	• An integrated monitoring program is developed (based on coordination or complementarity of existing, enhanced and new monitoring components), with such program including (1) timely public reporting on trends in possum abundance, key habitat features (for example, extent of old-growth forest, abundance of large and hollow-bearing trees) and extent of success of management actions, (2) explicit trigger points for defined emergency responses; and (3) secure commitment over at least the lifetime of this Plan (Action 6.1 – Priority: Essential, Action 6.2 – Priority: Essential and Action 6.5 – Priority: Highly beneficial). • A reporting process is developed, with oversight by a recovery team, and implemented (for example, a website) to regularly provide updates to the public on progress of implementing the actions in this Recovery Plan (Action 6.1 – Priority: Essential).
By end of 2nd year	• Integrated monitoring program is implemented, with appropriate and timely public reporting on trends in possum abundance, key habitat features and extent of success of management actions (ongoing) (Action 6.1 – Priority: Essential, Action 6.2 – Priority: Essential and Action 6.4 – Priority: Essential). • Design completed for experimental translocation and associated monitoring options (Action 6.3 – Priority: Essential).
By end of 5th year	• Monitoring associated with experimental translocation is implemented with appropriate and timely public reporting on success or failure (Action 6.3 – Priority: Essential). • Translocation trials are reviewed for effectiveness (Action 6.3 – Priority: Essential).
By end of 10th year	• The package of actions presented in this plan is evaluated collectively to determine their overall effectiveness (Action 6.4 – Priority: Essential).

Objective 7
Stakeholders support and where relevant are involved in the implementation of the Plan.

Rationale

The fate of Leadbeater's possum has been a major and enduring concern for significant sections of the community, many people value it highly (Jakobsson and Dragun 2001), and its conservation has involved a wide range of people from conservation groups, industries, agencies and others over decades. Its recovery will be dependent upon ongoing engagement, participation and collaboration of a wide range of stakeholders. An active and representative recovery team (or comparable model) will be required to coordinate implementation of the plan and associated reporting, to be established under the Australian Government's Recovery team governance best practice guidelines.

Action 7.1 – Priority: Urgent

Establish (or build from existing mechanisms) and maintain an effective and fit-for-purpose recovery team or similar governance model, with clear, explicit and practical terms of reference to oversee coordination and implementation of the Recovery Plan; and ensure effective and timely operation of such a team.

Action 7.2 – Priority: Essential

Further enhance the community's involvement in Leadbeater's possum recovery.

Action 7.3 – Priority: Essential

Provide enhanced opportunities for the participation of Indigenous groups in research, monitoring, management and other components of this Plan.

Action 7.4 – Priority: Highly beneficial

Raise and monitor the awareness of Leadbeater's possum and its conservation among the general public. Promote and publicise the Recovery Plan and recovery effort.

Performance criteria

1) An inclusive and representative recovery team is established, with effective governance and clarity around roles and responsibilities.
2) Community awareness of, support for, and participation in Leadbeater's possum recovery is increased, and the community finds the management of Leadbeater's possum acceptable.
3) Indigenous groups have the opportunity to play a substantial role in the implementation and oversight of conservation management for Leadbeater's possum.
4) Public information and education materials and programs are developed and implemented, to the satisfaction of all relevant interest groups.

Table 7: Objective 7 deliverables

Timing	Outcome
By end of 1st year	• An effective and representative recovery team or similar governance model is established, and maintained across the life of the Plan (Action 7.1 – Priority: Urgent). • Indigenous groups scope their involvement in implementation of this Plan (Action 7.3 – Priority: Essential). • Multiple actions. A stakeholder forum is established to support community engagement in the Plan's implementation; particularly to (1) identify, establish and coordinate engagement opportunities; (2) coordinate and disseminate information more broadly; (3) monitor and measure success of engagement action; and (4) establish on-going reporting to governance model established (under Action 7.1 – Priority: Urgent). A social survey is undertaken.

Timing	Outcome
By end of 2nd year	• The implementation of this plan appropriately involves Indigenous groups in a manner and to the extent sought by them (Action 7.3 – Priority: Essential).
By end of 5th year	• A stakeholder forum or structured social survey reviews, quantifies and evaluates the extent to which community awareness of, support for, and participation in Leadbeater's possum recovery has increased. This will inform the 5 year Recovery Plan review (Action 8.4 – Priority: Essential) (Multiple actions.).

Objective 8

Effective and adaptive implementation and management oversight of the Plan, including adequate resourcing, is in place.

Action 8.1 – Priority: Urgent

All partners in the Plan coordinate, share information and data and adequately resource implementation to achieve objectives through adaptive management and cost-effective delivery.

Action 8.2 – Priority: Essential

Establish appropriate processes and governance structure to be able to respond to emergency events, such as significant losses of possums to extensive bushfire.

Action 8.3 – Priority: Essential

Monitor and report on the implementation of management actions and associated outcomes.

Action 8.4 – Priority: Essential

Report regularly on performance effectiveness of this Recovery Plan, including a formal review at five years, and adapt as required.

Performance criteria

1) The Plan's progress and success is regularly assessed and reported, explicitly including a five-year review of the Recovery Plan.
2) Resources are adequate to implement the Plan.
3) Managers, researchers and others respond capably and in a timely manner to unforeseen events.

Table 8: Objective 8 deliverables

Timing	Outcome
By end of 1st year	• Resourcing secured for Plan implementation (Action 8.1 – Priority: Urgent). • Appropriate processes and governance structure are established to enable rapid and effective response to emergency events (Action 8.2 – Priority: Essential).
By end of 5th year	• Comprehensive interim review completed of the implementation and success of this Recovery Plan, with recommendations for adaptive changes (Action 8.3 – Priority: Essential and Action 8.4 – Priority: Essential).
By end of 10th year	• Comprehensive review completed of the implementation and success of this Recovery Plan, with this review informing the development and implementation of a new Plan (Action 8.3 – Priority: Essential and Action 8.4 – Priority: Essential).

8 Plan implementation

This Plan describes a coordinated series of objectives and actions designed to secure the conservation future of Leadbeater's possum. However, that future will not be realised unless the Plan is appropriately resourced and effectively and comprehensively implemented. This section describes the process, resource requirements and timing of the Plan's implementation and delivery; indicates those agencies and groups who should take responsibility for, or be involved in, implementation of each action; and prioritisation of actions. Delayed or inadequate implementation of this Plan will further compromise the conservation outlook for this species and render its management increasingly ineffective and risky.

8.1 Implementation schedule and costs

Implementation of this Plan will require commitment and effective coordination and collaboration between key stakeholders and partners. A recovery team or similar governance model (Action 7.1 – Priority: Urgent and Action 8.1 – Priority: Urgent) will be the key mechanism to coordinate recovery effort, ensure appropriate progress in implementation, share and review information, identify funding opportunities and report on progress. Potential implementation partners are identified for every action (Table 9) and broadly include government agencies with statutory responsibilities to protect and manage Leadbeater's possum and its habitat, zoos, forest-based industry groups, community organisations, First Nations communities and research institutions.

Implementation responsibilities and arrangements involving potential partners will be subject to negotiation once the Recovery Plan is in place. A detailed implementation plan is to be developed by agreed implementation partners through which agreement is reached on partner contributions to the implementation of actions. Annual and where possible ongoing budgets should be identified, coordinated and secured by the implementation partners with timing and reporting processes consistent with the proposed timeframes and the priorities identified in Table 9. This implementation plan will identify and commit responsible partners to agreed actions and be facilitated by the recovery team or other governance model.

Potential implementation partners will ensure that any risks associated with implementing actions are identified and managed, and that adaptive management underpins all actions. Adaptive management and prioritisation decisions will be made by the responsible organisations, in consultation with key partners and the recovery team, to ensure any changes are consistent with and progress the Recovery Plan objectives. Because actions are to be implemented adaptively, priority, timing and cost estimates may change during implementation. It is the responsibility of organisations implementing actions to report on implementation through the proposed governance and reporting structure.

Implementing this Plan is subject to budgetary and other resource opportunities and constraints affecting the key stakeholders. The cost of implementing this Plan should, where possible, be incorporated into the core business expenditure of the affected organisations and through additional funds obtained for the explicit purpose of implementing this Recovery Plan. Some actions, or parts of actions, are being implemented through other Leadbeater's possum conservation efforts (see Section 7.1 Context). Additional investment in this Recovery Plan will augment these and ensure

coordination of effort to meet plan objectives. Other proposed actions are new and funding opportunities are yet to be secured.

The implementation costs in Table 9 are indicative only and are based on estimates from comparable actions undertaken or underway as part of the ongoing Leadbeater's possum conservation effort. Costs also draw upon the relative indicative costs identified by the LPAG (2014a). It is not practical at this point to provide meaningful costing figures for actions beyond year five. Significant investment in actions, particularly in the first three years is required to establish the foundation for ongoing conservation effort and will provide more realistic indications of ongoing implementation costs. Indicative costs for actions beyond the fifth year will therefore be developed as these initial actions are implemented and will inform the five year review.

Projected costs are not provided for Action 2.7 – Priority: Essential (expansion of the reserve system) because (1) such costs may be contingent on the extent of that expansion, (2) there is no narrowly-defined acquisition cost per se (given that the land is government owned), and (3) ongoing costs may relate to the intensity of reserved land management actions and the number of new reserve personnel required, Furthermore, for this action and some others (particularly relating to fire management), it is unrealistic to attribute all costs to the recovery of this single species, given that such actions are likely to benefit many more threatened species (see Section 8.3.1 Broader biodiversity benefits).

Projected costs are also not estimated for Action 7.3 – Priority: Essential (First Nations involvement), given that this will depend upon the extent to which First Nations groups seek to be and are engaged in the range of recovery actions.

8.1.1 Priorities

In some conservation scenarios elsewhere, the relative costs and benefits of candidate management actions can be readily compared, with priority then accorded to those actions that bring the greatest return on investment (Carwardine et al. 2011; Carwardine et al. 2014). This Plan does not provide such an evaluation, largely because the relevant evidence base is limited with respect to cost effectiveness, and because it is not straightforward to compare recovery benefits that may arise from, for example, research on mechanisms to reduce fire impacts, or continuation of an enhanced monitoring program, or establishment and maintenance of an effective recovery team: all are important and probably indispensable. Furthermore, the Plan is based on the premise that a very substantial range of complementary actions are required to deliver an effective conservation response.

All proposed actions will collectively contribute to the ongoing recovery needs of Leadbeater's possum and all individual actions are considered priorities for implementation. However, the extent of implementation will be subject to budgetary and other resource constraints. To guide implementation decisions and adaptive responses to any such resource constraints, actions are assigned priorities:

- **urgent** – the conservation future of the species depends upon this action being implemented;
- **essential** – the conservation future of the species will be jeopardised if this action is not implemented;

- **highly beneficial** – this action will contribute to the conservation future of this species.

Table 9: Indicative timeframes, priorities and estimated costs ($000's) of recovery actions over the first five years of implementation

Actions	Priority	Potential implementation partners	Year 1 cost	Year 2 cost	Year 3 cost	Year 4 cost	Year 5 cost	Total
1.1 Review and, where required, revise existing relevant planning and policy settings, to ensure that they provide for maximising the chances of long-term survival of Leadbeater's possum.	Urgent	DEECA, AG	$100	$100	$50	–	–	$250
1.2 Ensure that future relevant planning and policy settings maximise the chances of long-term survival.	Urgent	DEECA, AG	–	$50	$50	$50	$50	$200
2.1 Ensure that predicted impacts from climate change on Leadbeater's possum and habitat are assessed and ameliorated to the extent possible.	Urgent	DEECA, Uni	$50	$50	–	–	–	$100
2.2. Ensure that modelling under Action 2.1 – Priority: Urgent is used to inform and adaptively update planning for all relevant in situ and ex situ management responses. Refine on-ground fire management activities to maximise the positive benefits for this species and those for people and community safety as much as possible.	Urgent	DEECA, AG, Uni	$50	$50	$50	$50	–	$200
2.3 Continue to refine and update occupancy and other relevant distributional and population viability modelling, in all land tenures across the full range of the species.	Urgent	DEECA, Uni	$800	$800	–	–	–	$1600
2.4 Undertake landscape scale land-use planning that provides options for conservation of suitable habitat now and in the future.	Urgent	DEECA, AG, Uni	–	$100	$100	–	–	$200
2.5 Expand the dedicated reserve system to incorporate sufficient areas of current and future suitable habitat to ensure that it is adequate to maintain and enhance the long-term population viability of Leadbeater's possum.	Urgent	DEECA, AG, PV,	–	TBD	TBD	TBD	–	–
2.6 Assess the feasibility, risks and cost-effectiveness of fire management options that seek to deliver long-term, strategic and landscape scale enhancement of the extent, and quality of current and future suitable habitat.	Urgent	DEECA, PV, Melb Water, Uni	$200	$200	$50	$50	$50	$550
2.7 Develop a suite of priority post-fire responses, and implement these following any extensive bushfire.	Essential	DEECA, PV, Zoos Vic	$50	$50	–	–	–	$100

Actions	Priority	Potential implementation partners	Year 1 cost	Year 2 cost	Year 3 cost	Year 4 cost	Year 5 cost	Total
2.8 Undertake strategic habitat augmentation (nest boxes, artificially excavated hollows, manipulation of understorey).	Essential	DEECA, AG, PV, Zoos Vic, Uni, CC	$300	$300	$300	$300	$300	$1500
2.9 Protect and buffer all large (over 150 cm DBH) and hollow-bearing trees (where over 80 cm DBH).	Urgent	DEECA, Uni	$400	–	–	–	–	$400
2.10 Enhance current and future habitat suitability and extent for lowland swamp forest habitat.	Urgent	DEECA, AG, PV, Zoos Vic, CC	$2000	$1100	$100	$100	$100	$3400
3.1 Identify priority areas within the known range to which translocations may provide benefit and develop translocation protocols.	Highly beneficial	DEECA, PV, Zoos Vic	$100	$100	–	–	–	$200
3.2 Continue with genetic sequencing to help inform analyses and assess the risks, benefits, practicality, cost-effectiveness and consequences of 'gene pool mixing' to increase the viability of the lowland subpopulation.	Highly beneficial	DEECA, Uni, PV, Zoos Vic	$50	–	–	–	–	$50
3.3 Where likely benefit, undertake carefully monitored trial translocations.	Urgent	DEECA, PV, Zoos Vic	$500	$500	$500	$500	$500	$2500
3.4 Apply ex situ strategies where appropriate, including trials with highland animals, to aid the management options for the lowland swamp forest subpopulation.	Essential	Zoos Vic	$225	$225	$225	$225	$225	$1125
4.1 Using recently developed survey approaches, survey potentially suitable areas outside the known range.	Urgent	DEECA, PV, Zoos Vic	$500	$500	$500	–	–	$1500
4.2 If such surveys locate 'new' populations, assess their status and management requirements and implement management.	Urgent	DEECA, Uni, PV, Zoos Vic	$700 [a]	$700 [a]	$700 [a]	$700 [a]	–	$2800 [a]
4.3 If such surveys fail to locate existing populations, identify the most suitable candidate areas for translocation.	Urgent	DEECA, Uni, PV, Zoos Vic	–	–	$50	–	–	$50
4.4 If significant benefits, implement translocations to areas considered most likely to result in the establishment of new viable subpopulations.	Urgent	DEECA, Uni, PV, Zoos Vic	–	–	–	$500	$500	$1000
5.1 Establish an ongoing research forum.	Urgent	DEECA, AG, Uni, PV, Zoos Vic, CC	$10	$10	$10	$10	$10	$50

Actions	Priority	Potential implementation partners	Year 1 cost	Year 2 cost	Year 3 cost	Year 4 cost	Year 5 cost	Total
5.2 Conduct an analysis of critical research gaps and undertake research that provides more robust knowledge of key demographic and other ecological characteristics.	Essential	DEECA, Uni, Zoos Vic	$500	$500	$500	$500	$500	$2500
5.3 Investigate key aspects of the post-fire ecology of Leadbeater's possum.	Essential	DEECA, Uni, PV, Zoos Vic	$200	$200	$200	$200	$200	$1000
5.4 Continue to assess the practicality and effectiveness of habitat augmentation.	Essential	DEECA, PV, Zoos Vic, Uni	$200	$200	$200	$200	$200	$1000
5.5 Determine landscape use by possums in areas regenerating after disturbance.	Essential	DEECA, Uni	$300	$300	$300	$300	$300	$1500
5.6 Evaluate benefits and detriments to other threatened species of actions in the Plan.	Essential	DEECA, Uni, Zoos Vic, PV	$100	$100	$100	$100	$100	$500
6.1 Maintain, enhance or develop new monitoring programs across all tenures and management zones.	Essential	DEECA, AG, Uni, PV, Zoos Vic, CC	$300	$300	$300	$300	$300	$1500
6.2 Identify key trigger points or thresholds in monitoring results that would catalyse priority emergency response.	Essential	DEECA, AG, Uni, PV, Zoos Vic, CC	$10	$10	$10	$10	$10	$50
6.3 Where translocations are proposed, design translocation trials in a manner that allows for reporting on success or failure.	Essential	DEECA, Uni, Zoos Vic, PV	–	$20	$20	$20	$20	$80
6.4 Monitor the extent of success of management actions individually and collectively.	Essential	DEECA, AG, Uni, PV	$100	$100	$100	$100	$100	$500
6.5 Include other threatened species within Leadbeater’s possum monitoring programs.	Highly beneficial	DEECA, AG, Uni, PV, Zoos Vic, CC	$100	$100	$100	$100	$100	$500
7.1 Establish and maintain a new and effective recovery team or similar governance model.	Urgent	DEECA, AG, Uni, PV, Zoos Vic, CC	$10	$10	$10	$10	$10	$50
7.2 Involve the community in Leadbeater’s possum recovery.	Essential	DEECA, AG, Uni, PV, Zoos Vic, CC	$50	$50	$50	$50	$50	$250
7.3 Provide enhanced opportunities for the participation of Indigenous groups in research, monitoring and management.	Essential	DEECA, CC PV, Zoos Vic	TBD	TBD	TBD	TBD	TBD	–
7.4 Raise and monitor public awareness and promote the Recovery Plan.	Highly beneficial	DEECA, AG, Uni, PV, Zoos Vic, CC	$50	$20	$20	$20	$50	$160

Actions	Priority	Potential implementation partners	Year 1 cost	Year 2 cost	Year 3 cost	Year 4 cost	Year 5 cost	Total
8.1 All partners in the Plan coordinate and adequately resource implementation.	Urgent	DEECA, AG, Uni, PV, Zoos Vic, CC	–	–	–	–	–	–
8.2 Establish appropriate processes and governance structure to be able to respond to emergency events.	Essential	DEECA, AG, Uni, PV, Zoos Vic, CC	$20	–	–	–	–	$20
8.3 Monitor the extent of implementation of management actions.	Essential	DEECA, AG	–	$10	–	$10	–	$20
8.4 Report regularly on performance effectiveness of this Plan, including a formal review at 5 years.	Essential	DEECA, AG,	$20	$20	$20	$20	$50	$130
Total	–	–	$7,995	$6,775	$4,615	$4,425	$3,725	$27,535

Note: See Section 7.2.2 Objectives, actions, outcomes and performance criteria for full description of Actions; [a] Action (and costing) contingent on outcome of other Action; TBD = Indicative costs yet to be determined; AG = Australian Government; CC = community conservation groups; DEECA = Department of Energy, Environment and Climate Action; Melb Water = Melbourne Water; PV = Parks Victoria; Uni = universities; Zoos Vic = Zoos Victoria.

8.2 Monitoring, evaluation and adaptation of the recovery plan

8.2.1 Monitoring and review

Monitoring of the plan itself will require ongoing assessment of the implementation and success of all actions, with regular reporting to the recovery team or other coordinating group.

A mid-term review (5 years) of the plan will be conducted using a 'Measure of Success' for every action and assessment of progress towards every objective and deliverable. This review will be used to help inform the need for any adaptation required within the plan, to identify and resolve any unexpected impediments, and to re-assess priorities for actions.

The review will be coordinated by relevant Australian and Victorian government agencies, with support of a recovery team and with input sought from key stakeholder groups such as non-governmental organisations, local community groups and research organisations. As per Section 279(2) of the EPBC Act, this 5-year assessment of progress will be reviewed by the Australian Minister for the Environment.

A comprehensive review of the implementation and success of the plan will be undertaken in Year 10 of the Plan as a foundation for the development of a revised 10-year plan. This review will consider, inter alia, trends in the status of the species and its habitat, effectiveness of actions described in this plan, new research findings and emerging issues, policy context, management capability and resourcing, and stakeholder satisfaction with governance and other matters.

8.2.2 Variation and adaptation

This plan recognises a need for some flexibility and adaptation, due to some substantial uncertainties in knowledge of aspects of the species' biology, and about the likelihood of success of some management actions, as well as the likelihood of somewhat unpredictable episodes of acute and severe threat. The 2009 bushfires had a severe impact on the conservation outlook for Leadbeater's possum. Should a comparable extensive bushfire occur over the life of this plan, there may be need for rapid responses in the conservation management of this species. Such response may include adaptation within this Recovery Plan, to re-prioritise some actions, or to establish new actions. Adaptation within the plan should be guided by the regular reporting described above, and should generally fit within the broad framework described in this plan. Any such needed adaptation in this plan should be overseen by the recovery team or other coordinating group.

8.3 Potential benefits and impacts associated with implementation

8.3.1 Broader biodiversity benefits

Actions taken for the recovery of Leadbeater's possum are likely to provide substantial benefits to many other native species and to the ecological communities with which it is associated – montane ash forests, snow gum woodlands and lowland swamp forests.

Management actions, plans and policies that seek to reduce the decline in (and eventually increase) the abundance of hollow-bearing trees across the range of Leadbeater's possum are likely to provide benefits to many other hollow-nesting species, including other possums, gliders, bats, owls, parrots,

cockatoos, treecreepers, owlet-nightjars and kookaburras, for which available hollows may be limiting (Lindenmayer and Sato 2018).

Management actions, plans and policies that seek to reduce the incidence of extensive, high intensity bushfires in montane ash forests, and other habitats used by Leadbeater's possum, will benefit many species that are associated with older-aged forest stands or are likely to suffer substantial mortality due to severe fire and its associated factors (for example, increased predation impacts post-fire). Examples include superb lyrebird (*Menura novaehollandiae*), Bassian thrush (*Zoothera lunulata*), sooty owl, yellow-bellied glider (*Petaurus australis*) and greater glider (southern and central) (Loyn 1985; Macfarlane 1988; Milledge et al. 1991). Two threatened plants (the shiny nematolepis (*Nematolepis wilsonii*) and the tall astelia (*Astelia australiana*)), largely endemic to the Leadbeater's possum Central Highlands range, are highly likely to benefit from improved and strategic management responses to high intensity bushfire. A notable finding was that there are pronounced differences in flea assemblages for highland and lowland populations, with two host-specific flea species, *Stephanocircus domrowi* and *Wurunjerria warnekei* detected on possums in highland habitats, whereas the general marsupial fleas (*Acanthopsylla r. rothschildii* and *Choristopsylla tristis*) were detected on possums in lowland swamp forest at Yellingbo (Steventon et al. 2022).

Enhanced fire management for Leadbeater's possum habitat may also lead to some broader-scale (regional) improved fire regimes for other habitats (those not used by Leadbeater's possum) within and adjacent to the Leadbeater's possum range. The conservation of some threatened aquatic species, such as the barred galaxias (*Galaxias fuscus*) and the Baw Baw frog (*Philoria frosti*), largely restricted to habitat within the range of Leadbeater's possum, will benefit from improved fire management responses within their supporting catchments. Management actions, plans and policies that seek to increase the extent and connectivity of the conservation reserve estate in montane ash forests for Leadbeater's possum will also provide benefit to other species, such as greater glider (southern and central), tall astelia, shiny nematolepis, and barred galaxias.

Management actions, plans and policies that seek to restore the extent, quality and connectivity of lowland swamp forest habitat for Leadbeater's possum will also provide benefit to other species that are associated with this habitat, notably the Critically Endangered helmeted honeyeater, which is now largely restricted to the Yellingbo Nature Conservation Area. Such actions will also benefit the habitat itself, including the State-listed threatened 'Sedge-rich *Eucalyptus camphora* Swamp Community'.

Research actions (including survey, monitoring, fine-scale mapping of habitat features and distributional modelling) for Leadbeater's possum are likely to provide increased information on the distribution of other co-occurring species, particularly other possums and gliders. A broad suite of arboreal mammals are monitored concurrently with Leadbeater's possum in ANU's long-standing monitoring program (Lindenmayer et al. 1991c; Lindenmayer et al. 1994b; Lindenmayer et al. 2003a; Lindenmayer et al. 2011b; Lindenmayer et al. 2013c; Lindenmayer et al. 2014b; Lindenmayer and Sato 2018) and recorded during DELWP's targeted surveys, and such information will help assess population trends for these species. Identifying areas of suitable habitat for other species will benefit from the mapping of Leadbeater's possum habitat features, such as large old trees.

Enhanced reservation and fire management across the core Leadbeater's possum range is likely to benefit the mountain ash forest ecological community generally, for which a recent assessment using IUCN criteria concluded that its conservation status was critically endangered (Burns et al. 2015).

The plan seeks to reduce the incidence of extensive fire, increase the area of montane ash forest in reserves and increase the extent of older-aged ash forest (and older-aged trees). Such outcomes would provide benefits for abatement of greenhouse gas emissions, especially given the very high reported carbon storage in older-aged ash forest (Keith et al. 2009; Keith et al. 2014a, b). In turn, such reduction in greenhouse gas emissions would contribute to global climate change mitigation, and hence provide benefits to biodiversity far more broadly.

It is unlikely that there will be significant detriment to other threatened species arising from the implementation of this plan. One possible detriment may involve actions that lead to increase in the extent of a dense wattle midstorey: such actions will improve a component of the habitat for Leadbeater's possum, but may reduce habitat quality for co-occurring (and rapidly declining) greater gliders, which prefer more open understorey (Smith 2019).

Some plant and animal species associated with drier forests adjacent to known Leadbeater's possum colonies or habitat may be disadvantaged if such habitat is used extensively for pre-emptive management to reduce the likelihood of bushfire in Leadbeater's possum habitat. Some disturbance-favoured species; for example, bush rat (*Rattus fuscipes*), swamp wallaby, agile antechinus (*Antechinus agilis*), superb fairy-wren (*Malurus cyaneus*), flame robin (*Petroica phoenicea*), Australian magpie (*Cracticus tibicen*); Loyn (1985); Macfarlane (1988), may be disadvantaged by the enhanced fire management sought in this plan, but these are generally widespread and non-threatened species and any such detriment is likely to be minor relative to the benefits of this plan for threatened and other species.

Importantly, implementation of this plan will necessitate consideration of conservation and management needs of other threatened species, in particular those identified in Table 10 and for which approved conservation plans are in place, to ensure complementarity of actions. Engagement with these other recovery programs should seek to not only resolve any potential conflicts, particularly as they relate to fire management, but also to identify and realise opportunities for collaboration and any appropriate joint management responses. Examples of this are already occurring through habitat restoration projects at Yellingbo to benefit both the Leadbeater's possum and the helmeted honeyeater.

Table 10: Listed threatened species and ecological communities that occur in areas likely to be affected by this plan

Threatened species or ecological community	EPBC Act status	Victorian FFG Act status	Conservation plan [a]	Likely impact of this plan
Tall astelia (*Astelia australiana*)	Vulnerable	Critically Endangered	Recovery Plan; Action Statement	Consideration of and improved responses to risk of frequent large fires; protection of habitat; improved forest management prescriptions.

Threatened species or ecological community	EPBC Act status	Victorian FFG Act status	Conservation plan [a]	Likely impact of this plan
Shiny nematolepis (*Nematolepis wilsonii*)	Vulnerable	Critically Endangered	Conservation Advice, Recovery Plan; Action Statement	Habitat protection; improved consideration of and responses to risk of frequent large fires.
Barred galaxias (*Galaxias fuscus*)	Endangered	Critically Endangered	Recovery Plan; Action Statement	Habitat protection; improved habitat management – fire management and habitat management – within supporting catchment.
Baw Baw frog (*Philoria frosti*)	Critically Endangered	Critically Endangered	Conservation Advice, Action Statement	Improved habitat management – fire management.
Spotted tree frog (*Litoria spenceri*)	Critically Endangered	Critically Endangered	Conservation Advice, Recovery Plan; Action Statement	Improved habitat management – fire management and habitat management – within supporting catchment.
Alpine tree frog (*Litoria verreauxii alpina*)	Vulnerable	Critically Endangered	Conservation Advice	Improved habitat management – fire management.
Sooty owl (*Tyto tenebricosa*)		Endangered	Action Statement	Habitat protection; increase in abundance of hollow-bearing trees; improved fire management.
Masked owl (*Tyto novaehollandiae*)		Critically Endangered	Action Statement	Habitat protection; increase in abundance of hollow-bearing trees; improved fire management.
Powerful owl (*Ninox strenua*)		Vulnerable	Action Statement	Habitat protection; increase in abundance of hollow-bearing trees; improved fire management.
White-throated needletail (*Hirundapus caudacutus*)	Vulnerable	Vulnerable	Conservation Advice	Habitat protection; improved fire management.
Helmeted honeyeater (*Lichenostomus melanops cassidix*)	Critically Endangered	Critically Endangered	Conservation Advice, Recovery Plan; Action Statement	Habitat restoration at Yellingbo; consideration of and improved fire management responses.
Broad-toothed rat (*Mastacomys fuscus mordicus*)	Vulnerable	Vulnerable	Conservation Advice	Improved fire management; habitat protection.
Spot-tailed quoll (*Dasyurus maculatus maculatus* (SE mainland population))	Endangered	Endangered	Conservation Advice, Recovery Plan; Action Statement	Habitat protection; increase in abundance of hollow-bearing trees; improved fire management.
Greater glider (southern and central) (*Petauroides volans*)	Endangered	Endangered	Conservation Advice	Habitat protection; increase in abundance of hollow-bearing trees; improved fire management. However, greater gliders may be disadvantaged by management that results in increase in density of midstorey.

Threatened species or ecological community	EPBC Act status	Victorian FFG Act status	Conservation plan [a]	Likely impact of this plan
Sedge-rich *Eucalyptus camphora* Swamp Community		Threatened	Action Statement	Habitat restoration at Yellingbo; consideration of and improved fire management responses.

Note: [a] Recovery Plans and Conservation Advices are made under the Commonwealth's EPBC Act; Action statements are made under the Victorian FFG Act.

8.3.2 Social and economic considerations

The pre-eminent purpose of this Recovery Plan is to stop the decline and support the recovery of Leadbeater's possum so that its chances of long-term survival in nature are maximised. In making a recovery plan for a threatened species, the EPBC Act requires, among other things, that regard must be had to minimising any significant adverse social and economic impacts, consistent with the principles of ecologically sustainable development. However, the EPBC Act does not require that Recovery Plans provide a comprehensive assessment or appraisal of the social and economic values of proposed actions. The Recovery Plan is not required to deliver actions based on a cost-benefit analysis. This section presents available information, noting that some of the data and implications are contested. This Plan does not attempt to resolve these contested perspectives.

Actions in this Recovery Plan largely centre on planning for the protection and enhancement of current and future suitable habitat for Leadbeater's possum. Almost all of the known distribution of Leadbeater's possum is on public land variously managed for multiple purposes and therefore subject to various public policy, regulatory and management action with associated costs and benefits to the community.

Actions in the Recovery Plan have potential benefits associated with their implementation. The extent of adverse impacts will be dependent on the specifics of the application of each action, many of which will be determined during the implementation of the Recovery Plan. Section 8.4 Affected interests outlines those existing organisations, and the individuals that they represent, that may be affected by implementation of the actions proposed in this Plan.

The extent of any proposed land use change resulting from actions outlined in the Plan is not yet known. It will be determined by actions under Objective 2 in parallel with future Victorian government policy on the future tenure and management of ex public forestry land, beyond January 2024.

The Central Highlands region has a variety of land uses including plantation timber, water supply, recreation, tourism, and carbon sequestration and storage, and conservation reserves (Dench McClean Carson 2016; Keith et al. 2016). Actions within this Recovery Plan will provide opportunities for enhancement of other values.

Water provisioning

Forests provide vital hydrological services in Victoria in supplying drinking water to many communities (Department of Environment and Primary Industries 2014e). The mountain ash forests are significant catchment areas for Melbourne's water supply. Ash forests cover just under half this catchment area, but yield 80% of the stream flow because they grow on the higher rainfall sites

(Benyon et al. 1996). Approximately 20% of the mountain ash forest of this catchment area is in closed water catchments (Viggers et al. 2013).

The 'value' of water may be considered as a provisioning service (delivery and other functions such as filtering), some of which can be valued as the cost to replace this service with piping, pumping and filtering; as well as a product (quantity/runoff) (Keith et al. 2016). Keith et al. (2016) found that for their study area (of approximately 80 by 80 km^2), 115,149 ha formed part of the water supply catchment for Melbourne and the surrounding regions. They estimated that for 2014 to 2015, water provisioning service for this area was valued at $75 million and water product at $876 million. The contribution to gross domestic product (industry value added) for water in the study area was estimated to be $267 million (or $2,319/ha) for 2014 to 2015.

Climatic conditions, natural disturbances (bushfires) and human activities in these forests all contribute to variation in water yields (Benyon et al. 1996; Creedy and Wurzbacher 2001; Lane et al. 2010). There is a well-documented empirical relationship between forest stand age and water yield for mountain ash catchments in the Central Highlands: catchments dominated by large old trees and old-growth forests yield significantly more water and improved water filtration than catchments comprising primarily young forest (Vertessey et al. 2001; Viggers et al. 2013). Furthermore, while an increased runoff occurs for some years after disturbance events such as high severity bushfire and clear-fell logging (Keith et al. 2016), regrowth ash forests use a greater amount of water than mature ash forests (Benyon et al. 1996). Changes to forest use will affect water yield into catchments, with cessation of timber harvesting likely to result in increased water yields over time.

Carbon storage

Forests are an important component of the global carbon cycle, and maintaining or increasing forest carbon stocks is a key indicator of sustainable forest management (Department of Environment and Primary Industries 2014e). Wet temperate evergreen forests such as those of the Central Highlands are very valuable for carbon storage, being the most "biomass carbon dense" in the world (holding the highest amount of carbon of any forests at 1,900 tonnes per hectare compared to an average of up to 500 tonnes per hectare for tropical forests) (Keith et al. 2009).

Because growth and retention provides carbon storage whereas harvesting and bushfires result in a net storage loss (Keith et al. 2016), management of native forests offers opportunities to change carbon storage capacity and contribute to global climate change mitigation (with the beneficial social and economic flow-on effects from this ecosystem service).

Keith et al. (2016) calculated the potential value of the ecosystem service of carbon sequestration and carbon stock for their study area, based on reported payments used for abatement projects under the Australian Government Emissions Reduction Fund. With carbon priced at $12.25 per tonne in 2015, the total annual value of carbon stock across all land use in the Central Highlands was estimated at $20 million (1.635 million tonnes) (Keith et al. 2016).

Tourism, visitation and recreation

Keith et al. (2016) provide indicative estimates for the contribution of tourism to gross domestic product (industry value added) in their Central Highlands study area at $260 million (or $353/ha) for 2013 to 2014 and noted that this accounted for 3,500 jobs.

Tourism to the Yarra Valley in 2013 to 2014 contributed an estimated $1.1 billion to the region's economy (approximately 13.4% of gross regional product). Dench McClean Carson (2016) noted that parts of the Yarra Ranges municipality hold high environmental assets and currently offer a diverse range of experiences and recreational opportunities. This study estimated that visitors to parks and forests in the area of the Yarra Ranges currently generate more than 2,700 jobs in the local economy and form a significant component of the revenue for the small gateway towns, however there is no information currently available to enable a projection of changed visitation levels to this area beyond that currently experienced, as a result of any changes due to increased forest protection.

Biodiversity and cultural, social, community values and engagement

Consistent with the implementation of many threatened species' recovery programs, there are also potential social benefits for communities engaged in such programs. Leadbeater's possum in particular has high social value. As one of Victoria's two state terrestrial faunal emblems, it has substantial community profile and interest, and is the focus of community conservation action. A long term collaborative effort by the community in working towards the successful recovery of an iconic critically endangered species could have significant positive social benefit and serve as a model to engage communities more broadly in threatened species conservation.

An economic valuation of the importance of Leadbeater's possum to the Victorian community was undertaken in the late 1990s using the contingent valuation method (Jakobsson and Dragun 2001). In a survey of Victorians, people's willingness to pay to protect Leadbeater's possum was estimated to be between $40 million ($29 per household) and $84 million a year, equivalent in value to both water conservation and recreational values at the time of the analysis.

8.4 Affected interests

Listed below are key interested parties that may be involved in the development, implementation and review of the Leadbeater's possum Recovery Plan, or organisations likely to be affected by implementation of the actions proposed in this plan.

Government agencies

- Department of Agriculture, Fisheries and Forestry, Cth
- Department of Climate Change, Energy, the Environment and Water, Cth
- Department of Jobs, Skills, Industry and Regions, Vic
- Department of Energy, Environment and Climate Action, Vic (including the Arthur Rylah Institute for Environmental Research)
- Melbourne Water
- Parks Victoria
- Trust for Nature (Victoria)
- Zoos Victoria

Local councils

- Baw Baw
- Cardinia

- Healesville
- Marysville
- Murrindindi
- Powelltown
- Toolangi
- Warburton
- Yarra Ranges

Indigenous groups

- Wurundjeri Woi Wurrung Cultural Heritage Aboriginal Corporation.
- Taungurung Land and Waters Council
- Gunaikurnai Land and Waters Aboriginal Corporation

Non-government organisations and community groups

- Australian Conservation Foundation
- Field Naturalists' Club of Victoria
- Friends of the Helmeted Honeyeater
- Friends of the Leadbeater's Possum
- Healesville Environment Watch Inc
- MyEnvironment
- Regional tourism businesses
- The Wilderness Society
- Victorian National Parks Association
- Warburton Environment Inc

Universities

- Australian National University
- Monash University
- University of Melbourne

8.4.1 Role and interest of Indigenous groups

Consultation on the development and implementation of the Leadbeater's Possum Recovery Plan has been undertaken with the Wurundjeri, Taungurung and Gunaikurnai Indigenous communities whose traditional lands overlap with the range of the Leadbeater's possum. These traditional owner groups are concerned for the conservation of Leadbeater's possum, and state explicitly:

> "The Wurundjeri, Taungurung and Gunaikurnai people are the traditional custodians of a large portion of the land on which the Leadbeater's possum is found. The Leadbeater's possum's range previously extended across much of Wurundjeri,

Taungurung and Gunaikurnai Country but now, critically endangered, they are only found in small pockets of their former range.

Wurundjeri, Taungurung and Gunaikurnai welcome a Recovery Plan for the Leadbeater's possum, and the Threatened Species Strategy generally as taking a necessary step toward halting the decline in biodiversity. Wurundjeri Council, Taungurung Clans Aboriginal Corporation, and Gunaikurnai Land and Water Aboriginal Corporation welcomes an inclusive plan to care for the land, plants, animals and waterways of Wurundjeri, Taungurung and Gunaikurnai Country.

The Wurundjeri, Taungurung and Gunaikurnai wish to acknowledge the current status and challenges confronting the Leadbeater's possum as representing the greater crisis in which our Wurundjeri, Taungurung and Gunaikurnai landscapes and biodiversity find themselves as we all place pressures on biodiversity through our daily actions.

Wurundjeri, Taungurung and Gunaikurnai Elders welcome a collective approach to setting targets to improve and enhance the habitat of the Leadbeater's possum and that of all species and place strong emphasis on valuing our unique regional environment, to honour the past and for all future generations. We believe this approach will result in positive outcomes for our environment and enhance populations of threatened species such as the critically endangered Leadbeater's possum.

Wurundjeri, Taungurung and Gunaikurnai people have a deep understanding and connection to this land that should be respected and valued. Caring for country was the birth right of Wurundjeri, Taungurung and Gunaikurnai people for tens of thousands of years and we now work to pass on the knowledge and skills developed to help everyone care for this land in similar ways. We encourage all involved to include Wurundjeri, Taungurung and Gunaikurnai people in the future conservation and sustainable management of Leadbeater's possum habitat."

9 Acknowledgements

This plan was compiled by the Department of Climate Change, Energy, the Environment and Water with significant contributions from Professor John Woinarski (Charles Darwin University), Dr Lindy Lumsden (Arthur Rylah Institute for Environmental Research, Department of Energy, Environment and Climate Action), the Wurundjeri, Taungurung and Gunaikurnai people, and Victorian Government, particularly Dr Dan Harley from Zoos Victoria. Substantial advice was also provided by the environment, science and forestry sectors.

10 Acronyms and definitions

10.1 Acronyms

- **ARI** Arthur Rylah Institute for Environmental Research
- **ANU** Australian National University
- **CAR** Comprehensive, Adequate and Representative (for the reserve system)
- **DCCEEW** Department of Climate Change, Energy, the Environment and Water (Cth)
- **DELWP** (the former) Department of Environment, Land, Water and Planning (Vic)
- **DEECA** Department of Energy, Environment and Climate Action (Vic)
- **EPBC Act** *Environment Protection and Biodiversity Conservation Act 1999* (Cth)
- **ESU** Evolutionarily Significant Unit
- **FFG Act** *Flora and Fauna Guarantee Act 1988* (Vic)
- **GMZ** General Management Zone
- **IUCN** International Union for Conservation of Nature
- **LiDAR** Light detection and ranging remote sensing technology
- **LPAG** Leadbeater's Possum Advisory Group
- **MNES** Matters of National Environmental Significance
- **NFPS** National Forest Policy Statement 1992
- **NGO** Non-government organisation
- **PV** Parks Victoria
- **PVA** Population viability analysis
- **RFA** Regional Forest Agreement
- **SMZ** Special Management Zone
- **SPZ** Special Protection Zone
- **TSSC** Threatened Species Scientific Committee (a statutory committee under the EPBC Act)

10.2 Definitions

The following definitions help explain or clarify some technical terms used in the body of this plan. Where appropriate, definition of some of these terms have been sourced from the Leadbeater's Possum Advisory Group Technical Report 2014 (LPAG 2014b).

Buffer area – a circumscribed distance or area around a particular feature, whose protection from a designated threat helps to protect the feature itself.

Bushfire – under the Victorian Code of Practice for Bushfire Management on Public Land, a bushfire is defined as a general term used to describe a fire in any vegetation. Within this plan, the term bushfire is used exclusively for wildfires (that is, those triggered through natural processes, lightning, accidental or deliberate human ignition) and does not encapsulate planned burning activities.

CAR reserve system – "The CAR (comprehensive, adequate and representative) reserve system comprises areas of both public and private land that are reserved specifically for conservation purposes, and where the tenure of the reserved areas is secured by legislation or other methods appropriate for the area concerned…… All reasonable effort should be made to provide for biodiversity and old-growth forest conservation and wilderness in the Dedicated Reserve system on public land. However, where it is demonstrated that it is not possible or practicable to meet the criteria in the Dedicated Reserve system, other approaches will be required" (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997).

Central Highlands – the higher elevation forested area to the north-east of Melbourne broadly encapsulated by the Central Highlands RFA area. In this plan the Central Highlands population of Leadbeater's possum represents the montane ash and snow gum habitat and does not include the lowland population at Yellingbo. The recent findings of Leadbeater's possums to the east of the Central Highlands RFA area has extended the range outside of this area, however for simplicity in this plan and unless otherwise indicated the full range is still called the Central Highlands.

Clearfall / clear-felling – silvicultural method of harvesting a coupe whereby all merchantable trees, apart from those to be retained for wildlife habitat, are removed.

Colony – for Leadbeater's possum, a social group that dens together, comprising a breeding pair and associated non-breeding individuals.

Coupe – as defined in the Victorian Sustainable Forests (Timber) Act 2004 means a specific area of state forest identified for the purposes of a timber harvesting operation in a timber release plan from which timber is harvested in one operation.

Dedicated reserves – "Reserves where the management regime equates to specific protected area management categories defined by the IUCN Commission for National Parks and Protected areas (1994). [Categories I, II, III and IV]. Security of tenure, as demonstrated if Parliamentary action by Commonwealth, State or Territory Governments is required for revocation of the reserve, is fundamental to the establishment and management of formal reserves" (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997).

Dynamic modelling – modelling that includes consideration of changes over time in, for example, habitat availability and suitability, population size and dispersion, and viability, with such changes driven by fire and other disturbance events.

Evolutionarily Significant Unit (ESU) – is a set of populations that are morphologically and genetically distinct from other similar populations, with such distinction arising from a distinct evolutionary history.

Exclusion zone – an area within the general management zone (GMZ) or special management zone (SMZ) where timber harvesting operations are excluded.

Exudate – a sugar-rich substance secreted by plants or by hemipteran insects feeding from plants, important in the diet of Leadbeater's possum.

Fire regimes – the characteristic pattern of frequency, intensity, extent and timing of fires in a given area or habitat.

Forest Protection Survey Program – a Victorian government initiative led by the Department of Energy, Environment and Climate Action that undertakes extensive flora and fauna surveys with the aim of protecting animals and plants that are either threatened or of high conservation value where they occur in areas (or 'coupes') of State forests that are scheduled to be harvested.

Gene pool mixing – the mixing of genetically divergent lineages/populations of a species to rescue and restore genetic variation in populations that have undergone large reductions in genetic diversity and fitness.

General Management Zone (GMZ) – areas within state forest that are managed for a range of uses and values, with the sustainable production of timber and other forest products being a major use. Within the GMZ there are areas that are excluded from harvesting operations due to the requirements of the Code of Practice for Timber Production. These areas include stream buffers and slopes generally steeper than 30°.

Hollow-bearing tree – any tree, dead or alive, that contains a hollow of any shape or size.

In-field prescriptions – harvesting exclusion rules established to protect forest values found in proposed coupes during planning processes and field inspections, which may not result in a zoning amendment.

Informal Reserves – "Reserves that contain and are managed for conservation values which unequivocally contribute to the CAR system. Such reserves have a basis in legislation (for example, management plans required under legislation) with provision of opportunity for public comment on changes to reserve boundaries, and where decisions on their establishment and alteration are politically accountable. In addition, they must be able to be accurately identified (on maps), and of sufficient area and adequate design to contribute to the continued viability of the values they seek to protect" (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997). Special Protection Zones (SPZs) are Informal Reserves.

Leadbeater's Possum Advisory Group – in 2013, the Victorian Government established the Leadbeater's Possum Advisory Group to provide recommendations aimed at supporting the recovery of the possum while maintaining a sustainable timber industry.

Leadbeater's Possum reserve system – an area in the Central Highlands of 30,500 ha set aside in 2008 specifically for Leadbeater's possum conservation, of which 58% is within national parks and 42% reserved in SPZs in state forest. The reserve consists of 127 patches spread across the species' range. Each patch was greater than 50 ha in size and contained predominantly old-growth ash forest, as they were the areas most likely to provide habitat into the future.

LiDAR – Light detection and ranging Remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

Lowland swamp forests – forest dominated by mountain swamp gum (*Eucalyptus camphora*) with dense thickets of *Melaleuca* and *Leptospermum* species.

Montane ash forest – forest dominated by mountain ash (*E. regnans*), alpine ash (*E. delegatensis*) or shining gum (*E. nitens*).

National Park – an area of permanently reserved land or water managed by Parks Victoria under the Victorian *National Parks Act 1975*. The objectives of the Act are the permanent preservation and protection of the natural environment and indigenous flora and fauna, as well as natural, cultural and other features.

Occupancy model – a modelling technique used to predict where a species is likely to occur based on environmental parameters and reflecting the impact of disturbances.

Old-growth forest – forest which contains significant amounts of its oldest growth stage – usually senescent trees – in the upper stratum and the effects of any previous disturbance is now negligible.

Phylogenetically distinctive species – a species that has few close relatives, for example a species that is the only (extant) species in a genus or family.

Population viability – the maintenance of a population in the wild that is sufficiently large to be resilient to disturbance and maintain its long-term evolutionary potential.

Population viability analysis (PVA) – a modelling technique for the estimation of persistence or extinction probability based on threats to survival.

Potential habitat – all areas of montane ash forests or sub-alpine (snow gum) woodlands within the range of Leadbeater's possum in the Central Highlands. This includes approximately 200,000 ha of forest, not all of which will be occupied at any point in time.

Regional Forest Agreement (RFA) – In Victoria, an agreement between the Commonwealth and Victorian state government that establishes the framework for the conservation and sustainable management of forests within each of the five Victorian RFA regions. The main objectives of the Victorian RFAs are to identify a Comprehensive, Adequate and Representative (CAR) reserve system and provide for the conservation of those areas; to provide for the ecologically sustainable

management and use of forests in each RFA region; and to provide for the long-term stability of forests and forest industries.

RFA Modernisation Program – the Victorian Government has embarked on a major program to modernise the state's RFAs and the forest management system they accredit, through comprehensive engagement with Victorian communities and investment in contemporary science. The program aims to deliver: a vision for the future management of forests; a strategy for the management of State forests; renewal and extension of the Victorian RFAs, through negotiation with the Commonwealth of Australia; reform of environmental regulation of timber harvesting operations; and development of new forest management plans across the State, including greater integration across tenures and between forest and fire management.

Relictual distribution – the current (remaining) range of a species that formerly had a substantially larger distribution.

Rotation – means the planned number of years between the regeneration of a forest stand and its subsequent harvesting.

Salvage harvesting – harvesting operations conducted to remove timber following bushfire or other major disturbance that has caused significant tree mortality or damage.

Special Management Zone (SMZ) – areas of state forest that cover a range of natural or cultural values and are managed to conserve specific features. The protection or enhancement of these values requires modification to timber harvesting or other land use practices rather than their exclusion. Timber and other forest produce may be harvested from this zone under certain conditions. Periodic zoning reviews are undertaken to ensure SMZs are in the most appropriate locations, including after significant disturbance events such as bushfires.

Special Protection Zone (SPZ) – areas of state forest managed for conservation designed to complement the dedicated reserve system and categorised as Informal reserves. Larger components of the zone are based on representative examples of vegetation communities and old-growth, as well as localities of key threatened and sensitive flora and fauna species. This zone is managed to minimise disturbances or processes that threaten their respective values, and timber harvesting is excluded. Periodic zoning reviews are undertaken to ensure SPZs are in the most appropriate locations, including after significant disturbance events such as bushfires.

Stag – large hollow-bearing tree killed by fire but remaining standing.

Stag-watching – a sampling and monitoring method which involves a set of observers positioned around large hollow-bearing trees and observing the emergence of animals from tree hollows at dusk.

State forest – as defined in Section 3 of the Victorian *Forests Act 1958*, state forest comprises publicly owned land which is managed for the conservation of flora and fauna; for the protection of water catchments and water quality; for the provision of timber and other forest products on a sustainable basis; for the protection of landscape, archaeological and historical values; and to provide recreational and educational issues.

Sub-alpine (snow gum) woodlands – higher elevation (approximately 1400 m) habitat dominated by snow gum (*E. pauciflora*). Leadbeater's possum occurs in this habitat mostly where there is a dense midstorey (particularly of mountain tea tree (*Leptospermum grandifolium*) along drainage lines.

Subpopulations – geographically or otherwise distinct groups in the population between which there is little demographic or genetic exchange (typically 'one successful migrant individual or gamete per year or less') (IUCN Standards and Petitions Subcommittee 2013). Note that subpopulations may be in close proximity, but interchange of individuals between them may nonetheless be highly constrained because of barriers to dispersal or because dispersal capability is limited. If their isolation is relatively recent, subpopulations may not show substantial genetic distinctiveness.

Suitable habitat – areas of montane ash forests or snow gum woodlands within the range of the species considered to provide habitat that is currently suitable for the species to occupy.

Thinning – the removal of part of a forest stand or crop, with the aims of increasing the growth rate or health of retained trees and, in commercial thinning, obtaining timber from trees that would otherwise eventually die before final harvest.

Timber harvesting – any activities carried out for the purpose of removing timber for sale, including timber felling, regeneration and associated roading. Not including the collection of firewood for domestic use.

Translocation – the human-mediated movement of living organisms from one area, with release in another (IUCN/SSC 2013). In this Plan, translocation relates to moving of Leadbeater's possums to seek to establish a new subpopulation, or to bolster numbers (or genetic diversity) in an established subpopulation.

Values Protected by Prescription – "Where the nature of a forest value that is needed to contribute to the CAR reserve system makes inclusion in either Dedicated or Informal Reserves impractical (for example, very rare values, values with fragmented distributions, or values naturally occurring in linear form such as riparian vegetation), then protection may be prescribed in Codes of Practice or Management Plans and where appropriate, identified on maps. These prescriptions should meet the following principles: there is an opportunity for public comment on proposed changes; they have a sound scientific basis; and they are adequate to maintain the values they seek to protect" (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997).

11 References

Anon (1992) 'National Forest Policy Statement: a new focus for Australia's forests.' (Commonwealth of Australia: Canberra).

Archibald CL, Summers DM, Graham EM, Bryan BA (2023) Habitat suitability maps for Australian flora and fauna under CMIP6 climate scenarios. http://ecoevorxiv.org).

Armstrong DP, Hayward MW, Moro D, Seddon PJ (2015) (Ed.) 'Advances in reintroduction biology of Australian and New Zealand fauna.' (CSIRO Publishing: Clayton South).

Baker PJ, Nitschke C, Trouvé R, Robinson AP (2022) Forest stand dynamics drive a conservation conundrum for the critically endangered Leadbeater's possum. In: Baker, P.J., Larsen, D.R., Saxena, A. (eds) Forests as Complex Social and Ecological Systems. Managing Forest Ecosystems, vol 41. Springer, Cham. https://doi.org/10.1007/978-3-030-88555-7_5.

Baker PJ, Spring D, Nitschke C, Trouvé R (2017). Appendix A: Consultants' report In: Fibre and Wood Supply Assessment Report. Victorian Environmental Assessment Council, Melbourne.

Benyon TJ, Vettessy RA, Hatton RG, Dawes WR (1996) Long-term growth and water balance predictions for a mountain ash (*Eucalyptus regnans*) forest catchment subject to clear-felling and regeneration. *Tree Physiology* **16**, 221–232.

Bilney RJ (2014) Poor historical data drive conservation complacency: the case of mammal decline in south-eastern Australian forests. *Austral Ecology* **39**, 875–886.

Bilney RJ, Cooke R, White J (2006) Change in the diet of sooty owls (*Tyto tenebricosa*) since European settlement: from terrestrial to arboreal prey and increased overlap with powerful owls. *Wildlife Research* **33**, 17–24.

Bilney RJ, Cooke R, White JG (2010) Underestimated and severe: small mammal decline from the forests of south-eastern Australia since European settlement, as revealed by a top-order predator. *Biological Conservation* **143**, 52–59.

Brazenor CW (1932) A re-examination of *Gymnobelideus leadbeateri* McCoy. *Australian Zoologist* **7**, 106–109.

Brazenor CW (1950) 'The mammals of Victoria.' (Brown, Prior & Anderson: Melbourne)

Burgman MA, Lindenmayer DB (1998) 'Conservation biology for the Australian environment.' (Surrey Beatty & Sons: Chipping Norton).

Burns EL, Lindenmayer DB, Stein J, Blanchard W, McBurney L, Blair D, Banks SC (2015) Ecosystem assessment of mountain ash forest in the Central Highlands of Victoria, south-eastern Australia. *Austral Ecology* **40**, 386–399.

Cardillo M, Bininda-Emonds ORP, Boakes E, Purvis A (2004) A species-level phylogenetic supertree of marsupials. *Journal of Zoology* **264**, 11–31.

Carwardine J, O'Connor T, Legge S, Mackey B, Possingham H, Martin TG (2011) 'Priority threat management to protect Kimberley wildlife.' Brisbane.

Carwardine J, Nicol S, Van Leeuwen S, Walters B, Firn J, Reeson A, Martin TG, Chadès I (2014) 'Priority threat management for Pilbara species of conservation significance.' Brisbane.

Creedy J, Wurzbacher AD (2001) The economic value of a forested catchment with timber, water and carbon sequestration benefits. *Ecological Economics* **38**, 71–83.

Dench McClean Carson (2016) 'Assessment of the economic, social and environmental impact of the proposed Great Forest National Park to the Yarra Ranges Municipality.' Report commissioned for the Yarra Ranges Municipal Council.

Department of Energy, Environment and Climate Action (DEECA) (2023) 'Victoria's bushfire management strategy' (draft). Department of Energy, Environment and Climate Action, Melbourne.

Department of Environment and Primary Industries (2014a) 'Action statement no. 62: Leadbeater's Possum *Gymnobelideus leadbeateri*.' Department of Environment and Primary Industries, Melbourne.

Department of Environment and Primary Industries (2014c) 'Management standards and procedures for timber harvesting operations in Victoria's State Forests 2014.' Department of Environment and Primary Industries, Melbourne.

Department of Environment and Primary Industries (2014d) 'Strategic Bushfire Management Plan, East Central Bushfire Risk Landscape.' Department of Environment and Primary Industries, Melbourne.

Department of Environment and Primary Industries (2014e) 'Victoria's State of the Forests Report 2013.' Department of Environment and Primary Industries, Melbourne.

Department of Environment, Land, Water and Planning (DELWP) (2015a) 'Supporting the recovery of the Leadbeater's Possum: Progress report October 2015.' Department of Environment Land Water and Planning, Melbourne.

Department of Environment, Land, Water and Planning (DELWP) (2016) 'Supporting the recovery of the Leadbeater's Possum: Progress report December 2016.' Department of Environment, Land, Water and Planning, Melbourne.

Department of Environment, Land, Water and Planning (DELWP) (2017) A review of the effectiveness and impact of establishing timber harvesting exclusion zones around Leadbeater's Possum colonies. Department of Environment, Land, Water and Planning with contribution from VicForests.

Department of Natural Resources and Environment (1998) 'Forest management plan for the Central Highlands.' Department of Natural Resources and Environment, Melbourne.

Department of Sustainability and Environment (2008b) 'Strategic fuelbreaks: construction and environmental management plan. Work unit: Reefton. February–April 2008.' Department of Sustainability and Environment, East Melbourne.

Department of Sustainability and Environment (2012) 'Code of Practice for Bushfire Management on Public Land 2012.' Department of Sustainability and Environment, Melbourne.

Dutta R, Das A, Aryal J (2016) Big data integration shows Australian bush-fire frequency is increasing significantly. *Royal Society Open Science* **3**, 150241.

Edwards D, Westerman M (1992) DNA-DNA Hybridization and the position of Leadbeater Possum (*Gymnobelideus leadbeateri* McCoy) in the Family Petauridae (Marsupialia, Diprotodontia). *Australian Journal of Zoology* **40**, 563–571.

Eyre AC, Cripps J, Miritis V, Watchorn D, Ashman K, Burns P, Fairman T, Durkin L, Nelson J, Macak P, Lumsden L, Harley D (2020) Surveys for Leadbeater's Possum *Gymnobelideus leadbeateri* at Wallaby Creek, Kinglake National Park. *The Victorian Naturalist* **137**, 36–40.

Eyre AC, Briscoe NJ, Harley DK, Lumsden LF, McComb LB, Lentini PE (2022) Using species distribution models and decision tools to direct surveys and identify potential translocation sites for a critically endangered species. *Diversity and Distributions* **28**, 700–711.

Fox JC, Hamilton F, Ades PK (2008) Models of tree-level hollow incidence in Victorian State forests. *Forest Ecology and Management* **255**, 2846–2857.

Greet, J., Harley, D., Ashman, K., Watchorn, D. and Duncan, D. (2020). The vegetation structure and condition of contracting lowland habitat for Leadbeater's possum (*Gymnobelideus leadbeateri*). Australian Mammalogy 43, 344–353

Grose M, Abbs D, Bhend J, Chiew F, Church J, Ekström M, Kirono D, Lenton A, Lucas C, McInnes K, Moise A, Monselesan D, Mpelasoka F, Webb L, Whetton P (2015) 'Southern Slopes Cluster Report.' CSIRO and Bureau of Meteorology, Canberra.

Hansen BD (2008) 'Population genetic structure of Leadbeater's Possum *Gymnobelideus leadbeateri*, and its implications for species conservation. Ph.D. thesis.' Monash University, Clayton.

Hansen BD, Taylor AC (2008) Isolated remnant or recent introduction? Estimating the provenance of Yellingbo Leadbeater's possums by genetic analysis and bottleneck simulation. *Molecular Ecology* **17**, 4039–4052.

Hansen BD, Sunnucks P, Blacket M, Taylor AC (2005) A set of microsatellite markers for an endangered arboreal marsupial, Leadbeater's possum. *Molecular Ecology Notes* **5**, 796–799.

Hansen BD, Harley DKP, Lindenmayer DB, Taylor AC (2009) Population genetic analysis reveals a long-term decline of a threatened endemic Australian marsupial. *Molecular Ecology* **18**, 3346-3362.

Harley D (2002) The discovery of Leadbeater's possum *Gymnobelideus leadbeateri* along the Woori Yallock Creek, Yellingbo. *Victorian Naturalist* **119**, 233–235.

Harley D (2004a) A survey for Leadbeater's Possum *Gymnobelideus leadbeateri* in lowland swamp forest at Bunyip State Park. *The Victorian Naturalist* **121**, 158–163.

Harley DKP (2004b) Patterns of nest box use by Leadbeater's Possum (*Gymnobelideus leadbeateri*): applications to research and conservation. In 'The biology of Australian possums and gliders'. (Eds R Goldingay and S Jackson) pp. 318–329. (Surrey Beatty and Sons: Chipping Norton).

Harley DKP (2004c) A review of recent records of Leadbeater's Possum (*Gymnobelideus leadbeateri*). In 'The biology of Australian possums and gliders'. (Eds R Goldingay and S Jackson) pp. 330–338. (Surrey Beatty and Sons: Chipping Norton)

Harley DKP (2005) 'The life history and conservation of Leadbeater's Possum (*Gymnobelideus leadbeateri*) in lowland swamp forest. Ph.D. thesis.' Monash University, Clayton.

Harley D (2006a) The Yellingbo population of Leadbeater's Possum - remnant or introduced? *Victorian Naturalist* **123**, 170–173.

Harley DKP (2006b) A role for nest boxes in the conservation of Leadbeater's possum (*Gymnobelideus leadbeateri*). *Wildlife Research* **33**, 385–395.

Harley D (2012) The application of Zoos Victoria's 'Fighting Extinction' commitment to the conservation of Leadbeater's Possum *Gymnobelideus leadbeateri*. *Victorian Naturalist* **129**, 175–180.

Harley D (2015a) 'Translocation plan: establishment of a captive insurance population for the lowland Leadbeater's Possum population at Yellingbo.' Zoos Victoria, Melbourne.

Harley D (2015b) The use of call imitation to establish territory occupancy by Leadbeater's possum (*Gymnobelideus leadbeateri*). *Australian Mammalogy* **37**, 116–119.

Harley D (2016) An overview of actions to conserve Leadbeater's Possum (*Gymnobelideus leadbeateri*). *Victorian Naturalist* **133**, 85–97.

Harley D (2023). Seven urgent actions to prevent the extinction of the critically endangered Leadbeater's possum (Gymnobelideus leadbeateri). *Pacific Conservation Biology*.

Harley, D. and Eyre, A. (In review). Ten years of arboreal camera trapping for the critically endangered Leadbeater's Possum (Gymnobelideus leadbeateri) – insights and applications

Harley DKP, Lill A (2007) Reproduction in a population of the endangered Leadbeater's possum inhabiting lowland swamp forest. *Journal of Zoology* **272**, 451–457.

Harley D, Lowry R (2013) The re-establishment of Zoos Victoria's captive-breeding program for Leadbeater's Possum: a new era of zoo-based conservation to assist wild populations. In 'Leadbeater's Possum - Bred to be Wild. Edition 2'. (Ed. P Preuss).

Harley DKP, Spring DA (2003) Reply to the comment by Lindenmayer *et al*. on "Economics of a nest-box program for the conservation of an endangered species: a re-appraisal". *Canadian Journal of Forest Research* **33**, 752–753.

Harley DKP, Worley MA, Harley TK (2005) The distribution and abundance of Leadbeater's possum *Gymnobelideus leadbeateri* in lowland swamp forest at Yellingbo Nature Conservation Reserve. *Australian Mammalogy* **27**, 7–15.

Harley DKP, Holland GJ, Hradsky BAK, Antrobus JS (2014) The use of camera traps to detect arboreal mammals: lessons from targeted surveys for the cryptic Leadbeater's Possum *Gymnobelideus leadbeateri*. In 'Camera Trapping: Wildlife Management and Research'. (Eds P Meek and P Fleming) pp. 233–244. (CSIRO Publishing: Collingwood)

IUCN Standards and Petitions Subcommittee (2013) 'Guidelines for Using the IUCN Red List Categories and Criteria. Version 10.' Gland, Switzerland.

IUCN/SSC (2013) 'Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0.' Gland, Switzerland.

IUCN/SSC (2014) 'Guidelines on the use of *ex situ* management for species conservation. Version 2.0.' IUCN Species Survival Commission, Gland, Switzerland.

Jakobsson KM, Dragun AK (2001) The worth of a possum: valuing species with the contingent valuation method. *Environmental and Resource Economics* **19**, 211–227.

Jelinek A, Cameron D, Belcher C, Turner L (1995) New perspectives on the ecology of Lake Mountain: the discovery of Leadbeater's Possum *Gymnobelideus leadbeateri* McCoy in sub-alpine woodland. *Victorian Naturalist* **112**, 112–115.

Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee (1997) 'Nationally agreed criteria for the establishment of a comprehensive, adequate and representative reserve system for forests in Australia.' Canberra.

Keenan RJ, Nitschke CJ (2016) Forest management options for adaptation to climate change: a case study of tall, wet eucalypt forests in Victoria's Central Highlands region. *Australian Forestry* **79**, 96–107.

Keith H, Mackey BG, Lindenmayer DB (2009) Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *Proceedings of the National Academy of Sciences* **106**, 11635–11640.

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

Keith H, Lindenmayer DB, Mackey BG, Blair D, Carter L, McBurney L, Okada S, Konishi-Nagano T (2014b) Accounting for biomass carbon stock changes due to wildfire in temperate forest landscapes in Australia. *PLoS ONE* **9**, e107126.

Keith H, Vardon M, Stein J, Stein J, Lindenmayer D (2016) 'Experimental ecosystem accounts for the Central Highlands of Victoria.' Australian National University, Canberra.

Lane PNJ, Feikema PM, Sherwin CB, Peel MC, Freebairn AC (2010) Modelling the long term water yield impact of wildfire and other forest disturbance in Eucalypt forests. *Environmental Modelling & Software* **25**, 467–478.

Leadbeater's Possum Advisory Group (LPAG) (2014a) Leadbeater's Possum Recommendations: Report to the Minister for Environment and Climate Change and the Minister for Agriculture and Food Security.

Leadbeater's Possum Advisory Group (LPAG) (2014b) Leadbeater's Possum Technical Report: Report to the Minister for Environment and Climate Change and the Minister for Agriculture and Food Security.

Likens GE, Lindenmayer DB (2012) Integrating approaches leads to more effective conservation of biodiversity. *Biodiversity and Conservation* **21**, 3323–3341.

Lindenmayer DB (1989) 'The ecology and habitat requirements of Leadbeater's possum. Ph.D. thesis.' Australian National University, Canberra.

Lindenmayer D (1996a) 'Wildlife and woodchips: Leadbeater's possum: a test case for sustainable forestry.' (UNSW Press: Sydney).

Lindenmayer DB (1996b) 'Forest pattern and ecological processes: a synthesis of 25 years of research.' (CSIRO Publishing: Collingwood).

Lindenmayer DB (2000) Factors at multiple scales affecting distribution patterns and their implications for animal conservation – Leadbeater's Possum as a case study. *Biodiversity & Conservation* **9**, 15-35.

Lindenmayer D (2009) 'Forest pattern and ecological process: a synthesis of 25 years of research.' (CSIRO Publishing: Collingwood).

Lindenmayer DB, Cunningham RB (1997) Patterns of co-occurrence among arboreal marsupials in the forests of central Victoria, southeastern Australia. *Australian Journal of Ecology* **22**, 340–346.

Lindenmayer DB, Dixon JM (1992) An additional historical record of Leadbeater's Possum, *Gymnobelideus leadbeateri* McCoy, prior to the 1961 rediscovery of the species. *Victorian Naturalist* **109**, 217–218.

Lindenmayer DB, Lacy RC (1995b) Metapopulation viability of Leadbeater's possum, *Gymnobelideus leadbeateri*, in fragmented old-growth forests. *Ecological Applications* **5**, 164-182.

Lindenmayer DB, Laurance WF (2012) A history of hubris–Cautionary lessons in ecologically sustainable forest management. *Biological Conservation* **151**, 11–16.

Lindenmayer DB, McCarthy MA (2006) Evaluation of PVA models of arboreal marsupials: coupling models with long-term monitoring data. *Biodiversity & Conservation* **15**, 4079–4096.

Lindenmayer DB, Meggs RA (1996) Use of den trees by Leadbeater's Possum (*Gymnobelideus leadbeateri*). *Australian Journal of Zoology* **44**, 625–638.

Lindenmayer DB, Ough K (2006) 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.

Lindenmayer DB, Possingham HP (1995a) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-eastern Australia—VII. Modelling the persistence of Leadbeater's possum in response to modified timber harvesting practices. *Biological Conservation* **73**, 239–257.

Lindenmayer DB, Possingham HP (1995c) Modelling the viability of metapopulations of the endangered Leadbeater's possum in south-eastern Australia. *Biodiversity & Conservation* **4**, 984–1018.

Lindenmayer DB, Sato C (2018). Hidden collapse is driven by fire and logging in a socioecological forest ecosystem. *PNAS* **115**, 5181–5186.

Lindenmayer DB, Wood JT (2010) 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 DB, Smith AP, Craig SA, Lumsden LF (1989) A survey of the distribution of Leadbeater's possum, *Gymnobelideus leadbeateri* McCoy in the Central Highlands of Victoria. *Victorian Naturalist* **106**, 174–178.

Lindenmayer D, Cunningham R, Tanton M, Smith A, Nix H (1990a) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, southeast Australia: I. Factors influencing the occupancy of trees with hollows. *Biological Conservation* **54**, 111–131.

Lindenmayer DB, Cunningham RB, Tanton MT, Smith AP (1990b) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia: II. The loss of trees with hollows and its implications for the conservation of Leadbeater's Possum *Gymnobelideus leadbeateri* McCoy (Marsupialia: Petauridae). *Biological Conservation* **54**, 133–145.

Lindenmayer DB, Norton TW, Tanton MT (1990c) Differences between wildfire and clearfelling on the structure of montane ash forests of Victoria and their implications for fauna dependent on tree hollows. *Australian Forestry* **53**, 61–68.

Lindenmayer DB, Cunningham RB, Nix HA, Tanton MT, Smith AP (1991a) Predicting the abundance of hollow-bearing trees in montane ash forests of south-eastern Australia. *Australian Journal of Ecology* **16**, 91–98.

Lindenmayer DB, Cunningham RB, Tanton MT, Nix HA, Smith AP (1991b) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia: III. The habitat requirements of Leadbeater's Possum *Gymnobelideus leadbeateri* and models of the diversity and abundance of arboreal marsupials. *Biological Conservation* **56**, 295–315.

Lindenmayer DB, Cunningham RB, Tanton MT, Smith AP, Nix HA (1991c) Characteristics of hollow-bearing trees occupied by arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia. *Forest Ecology and Management* **40**, 289–308.

Lindenmayer DB, Nix HA, McMahon JP, Hutchinson MF, Tanton MT (1991d) The conservation of Leadbeater's possum, *Gymnobelideus leadbeateri* (McCoy): a case study of the use of bioclimatic modelling. *Journal of Biogeography* **18**, 371–383.

Lindenmayer DB, Tanton MT, Cunningham RB (1991e) A critique of the use of nest boxes for the conservation of Leadbeater's possum, *Gymnobelideus leadbeateri* McCoy. *Wildlife Research* **18**, 619–623.

Lindenmayer DB, Cunningham RB, Donnelly CF (1993b) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia, IV. The presence and abundance of arboreal marsupials in retained linear habitats (wildlife corridors) within logged forest. *Biological Conservation* **66**, 207–221.

Lindenmayer DB, Cunningham RB, Donnelly CF, Tanton MT, Nix HA (1993c) The abundance and development of cavities in Eucalyptus trees: a case study in the montane forests of Victoria, southeastern Australia. *Forest Ecology and Management* **60**, 77–104.

Lindenmayer DB, Lacy RC, Thomas VC, Clark TW (1993d) Predictions of the impacts of changes in population size and environmental variablitity on Leadbeater's possum, *Gymnobelideus leadbeateri* McCoy (Marsupialia: Petauridae) using population viability analysis: an application of the computer program VORTEX. *Wildlife Research* **20**, 67–85.

Lindenmayer DB, Boyle S, Burgman MA, McDonald D, Tomkins B (1994a) The sugar and nitrogen content of the gums of *Acacia* species in the mountain ash and alpine ash forests of central Victoria and its potential implications for exudivorous arboreal marsupials. *Australian Journal of Ecology* **19**, 169–177.

Lindenmayer DB, Cunningham RB, Donnelly CF (1994b) The conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-eastern Australia, VI. The performance of statistical models of the nest tree and habitat requirements of arboreal marsupials applied to new survey data. *Biological Conservation* **70**, 143–147.

Lindenmayer DB, Cunningham RB, Donnelly CF (1997) Decay and collapse of trees with hollows in eastern Australian forests: impacts on arboreal marsupials. *Ecological Applications* **7**, 625–641.

Lindenmayer DB, Cunningham RB, Donnelly CF, Franklin JF (2000) Structural features of old-growth Australian montane ash forests. *Forest Ecology and Management* **134**, 189–204.

Lindenmayer DB, Cunningham RB, MacGregor C, Incoll RD, Michael D (2003a) A survey design for monitoring the abundance of arboreal marsupials in the Central Highlands of Victoria. *Biological Conservation* **110**, 161–167.

Lindenmayer DB, MacGregor CI, Cunningham RB, Incoll RD, Crane M, Rawlins D, Michael DR (2003b) The use of nest boxes by arboreal marsupials in the forests of the Central Highlands of Victoria. *Wildlife Research* **30**, 259–264.

Lindenmayer DB, Burton PJ, Franklin JF (2008) 'Salvage logging and its ecological consequences.' (Island Press: Washington).

Lindenmayer DB, Welsh A, Donnelly C, Crane M, Michael D, Macgregor C, McBurney L, Montague-Drake R, Gibbons P (2009) Are nest boxes a viable alternative source of cavities for hollow-dependent animals? Long-term monitoring of nest box occupancy, pest use and attrition. *Biological Conservation* **142**, 33–42.

Lindenmayer DB, Hobbs RJ, Likens GE, Krebs CJ, Banks SC (2011a) Newly discovered landscape traps produce regime shifts in wet forests. *Proceedings of the National Academy of Sciences* **108**, 15887–15891.

Lindenmayer DB, Wood JT, McBurney L, Michael D, Crane M, MacGregor C, Montague-Drake R, Gibbons P, Banks SC (2011b) Cross-sectional versus longitudinal research: a case study of trees with hollows and marsupials in Australian forests. *Ecological Monographs* **81**, 557–580.

Lindenmayer DB, Blanchard W, McBurney L, Blair D, Banks S, Likens GE, Franklin JF, Laurance WF, Stein JAR, Gibbons P (2012) Interacting factors driving a major loss of large trees with cavities in a forest ecosystem. *PLoS ONE* **7**, e41864.

Lindenmayer D, Blair D, McBurney L, Banks S, Stein J, Hobbs R, Likens G, Franklin J (2013a) Principles and practices for biodiversity conservation and restoration forestry: a 30 year case study on the Victorian montane ash forests and the critically endangered Leadbeater's Possum. *Australian Zoologist* **36**, 441–460.

Lindenmayer DB, Blair D, McBurney L, Banks S (2013b) 'New restoration forest management prescriptions to conserve Leadbeater's possum and rebuild the cover of ecologically mature forest in the Central Highlands of Victoria.' Fenner School of Environment and Society The Australian National University Canberra.

Lindenmayer DB, Blanchard W, McBurney L, Blair D, Banks SC, Driscoll D, Smith AL, Gill AM (2013c) Fire severity and landscape context effects on arboreal marsupials. *Biological Conservation* **167**, 137–148.

Lindenmayer D, Blair D, McBurney L, Banks S (2014a) Preventing the extinction of an iconic globally endangered species-Leadbeater's Possum (*Gymnobelideus leadbeateri*). *Journal of Biodiversity & Endangered Species* **2**.

Lindenmayer DB, Barton PS, Lane PW, Westgate MJ, McBurney L, Blair D, Gibbons P, Likens GE (2014b) An empirical assessment and comparison of species-based and habitat-based surrogates: a case study of forest vertebrates and large old trees. *PLoS ONE* **9**, e89807.

Lindenmayer DB, Blair D, McBurney L, Banks SC (2015a) 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.

Lindenmayer DB, Blair D, McBurney L, Banks SC (2015b) 'Mountain Ash: fire, logging and the future of Victoria's giant forests.' (CSIRO Publishing: Clayton).

Lindenmayer DB, Blanchard W, Blair D, McBurney L, Banks SC (2016) Environmental and human drivers of large old tree abundance in Australian wet forests. *Forest Ecology and Management* **372**, 226–235.

Lindenmayer DB, McBurney L, Blair D, Banks SC (2017). Inter-den tree movements by Leadbeater's possum. *Australian Zoologist* **39**, 464–468.

Lindenmayer DB, Blanchard W, Blair D, McBurney L, Stein J & Banks SC (2018). Empirical relationships between tree fall and landscape-level amounts of logging and fire. *PLOS One 13*, e0193132.

Loyn RH (1985) Bird populations in successional forests of Mountain Ash *Eucalyptus regnans* in central Victoria. *Emu* **85**, 213–230.

Lumsden LF, Nelson JL, Todd CR, Scroggie MP, McNabb EG, Raadic TA, Smith SJ, Acevedo S, Cheers G, Jemison ML, Nicol MD (2013) 'A new strategic approach to biodiversity management – research component.' Department of Environment and Primary Industries Arthur Rylah Institute for Environmental Research, Heidelberg.

Macfarlane MA (1988) Mammal populations in mountain ash (*Eucalyptus regnans*) forests of various ages in the Central Highlands of Victoria. *Australian Forestry* **51**, 14–27.

Macfarlane MA, Seebeck JH (1991) 'Draft management strategies for the conservation of Leadbeater's Possum *Gymnobelideus leadbeateri*, in Victoria.' Department of Conservation and Environment, 111, Melbourne.

Macfarlane M, Smith J, Lowe K (1997) 'Leadbeater's Possum (*Gymnobelideus leadbeateri*) Recovery Plan.' (Department of Natural Resources and Environment: Melbourne).

McBride TC, Organ A, Pryde E (2019). Range extension of Leadbeater's possum *Gymnobelideus leadbeateri*, McCoy. *Australian Mammalogy* doi:10.1071/AM18025.

McCarthy MA, Lindenmayer DB (2000) Spatially-correlated extinction in a metapopulation model of Leadbeater's Possum. *Biodiversity & Conservation* **9**, 47–63.

McComb LB, Lentini PE, Harley DKP, Lumsden LF, Antrobus JS, Eyre AC, Briscoe NJ (2019) Feral cat predation on Leadbeater's possum (*Gymnobelideus leadbeateri*) and observations of arboreal hunting at nest boxes. *Australian Mammalogy* doi: 10.1071/AM18010.

McKenney DW, Lindenmayer DB (1994) An economic assessment of a nest-box strategy for the conservation of an endangered species. *Canadian Journal of Forest Research* **24**, 2012–2019.

McKenzie GM (2002) The late Quaternary vegetation history of the south-central highlands of Victoria, Australia. II. Sites below 900 m. *Austral Ecology* **27**, 32–54.

McMahon ARG, Franklin DC (1993) The significance of Mountain Swamp Gum for Helmeted Honeyeater populations in the Yarra Valley. *The Victorian Naturalist* **110**, 230–237.

Menkhorst P (2008) *Gymnobelideus leadbeateri*. *Gymnobelideus leadbeateri* (Leadbeater's Possum) (iucnredlist.org).

Menkhorst PW, Lumsden LF (1995) Leadbeater's Possum *Gymnobelideus leadbeateri*. In 'Mammals of Victoria: distribution, ecology and conservation'. (Ed. PW Menkhorst) pp. 104–107. (Oxford University Press: Melbourne).

Milledge DR, Palmer CL, Nelson JL (1991) "Barometers of change": the distribution of large owls and gliders in Mountain Ash forests of the Victorian Central Highlands and their potential as management

indicators. In 'Conservation of Australia's forest fauna'. (Ed. D Lunney) pp. 53–65. (Royal Zoological Society of NSW: Mosman).

Myroniuk PO, Seebeck JH (1992) ln situ and ex situ conservation of Leadbeater's possum *Gymnobelideus leadbeateri*. *International Zoo Yearbook* **31**, 82–90.

Nelson JL, Lumsden LF, Durkin LK, Bryant DB, Macak PV, Cripps JK, Smith SJ, Scroggie MP, Cashmore MP (2015) 'Targeted surveys for Leadbeater's Possum in 2014-2015. Report for the Leadbeater's Possum Implementation Committee.' Arthur Rylah Institute for Environmental Research Department of Environment, Land Water and Planning Victoria, Heidelberg.

Nelson JL, Durkin LK, Cripps JK, Scroggie MP, Bryant DB, Macak PV, Lumsden LF (2017) 'Targeted surveys to improve Leadbeater's Possum conservation'. Arthur Rylah Institute for Environmental Research Technical Report Series No. 278. Department of Environment, Land Water and Planning Victoria, Heidelberg.

Nitschke CR, Trouve R, Lumsden LF, Bennett LT, Fedrigo M, Robinson AP, Baker PJ (2020) Spatial and temporal dynamics of habitat availability and stability for a critically endangered arboreal marsupial: implications for conservation planning in a fire-prone landscape. Landscape Ecology 35, 1553–1570.

Osborne MJ, Christidis L (2001) Molecular phylogenetics of Australo–Papuan possums and gliders (family Petauridae). *Molecular Phylogenetics and Evolution* **20**, 211–224.

Preuss P (2006) 'Leadbeater's Possum: born to be wild.' (Trafford Publishing: Victoria).

Ralls K, Sunnucks P, Lacy RC, Frankham R (2020) Genetic rescue: a critique of the evidence supports maximising genetic diversity rather than minimising the introduction of putatively harmful genetic variation. Biological Conservation 251, 108784.

Seebeck JH, Suckling GC, Macfarlane MA (1983) Leadbeater's Possum - survey by stagwatching. *Victorian Naturalist* **103**, 19–25.

Smales IJ (1994) The discovery of Leadbeater's possum, *Gymnobelideus leadbeateri* McCoy, resident in a lowland swamp woodland. *Victorian Naturalist* **111**, 178–182.

Smith AP (1980) 'The diet and ecology of Leadbeater's possum and the sugar glider. Ph.D. thesis.' Monash University, Clayton.

Smith A (1984a) Diet of Leadbeaters Possum, *Gymnobelideus leadbeateri* (Marsupialia). *Wildlife Research* **11**, 265–273.

Smith AP (1984b) Demographic consequences of reproduction, dispersal and social interaction in a population of Leadbeater's Possum (*Gymnobelideus leadbeateri*). In 'Possums and gliders'. (Eds A Smith and I Hume) pp. 359–373. (Surrey Beatty & Sons: Chipping Norton).

Smith AP (2019) Effects of past and proposed logging on 58 coupes located in the Central Highlands regional forest agreement area in Victoria on the greater glider (*Petauroides volans*). A report to the Federal Court of Australia. Proceeding VID 1228/2017. (Austeco Environmental Consultants, Elanora.).

Smith AP, Harley DKP (2008) Leadbeater's Possum *Gymnobelideus leadbeateri*. In 'The mammals of Australia'. (Eds S Van Dyck and R Strahan) pp. 226–228. (Reed New Holland: Sydney).

Smith AP, Lindenmayer D (1988) Tree hollow requirements of Leadbeater's possum and other possums and gliders in timber production ash forests of the Victorian Central Highlands. *Wildlife Research* **15**, 347–362.

Smith AP, Lindenmayer DB (1992) Forest succession and habitat management for Leadbeater's possum in the state of Victoria, Australia. *Forest Ecology and Management* **49**, 311–332.

Smith AP, Nagy KA, Fleming MR, Green B (1982) Energy requirements and water turnover in free-living Leadbeater's Possums, *Gymnobelideus leadbeateri* (Marsupialia: Petauridae). *Australian Journal of Zoology* **30**, 737–750.

Smith AP, Lindenmayer D, Suckling G (1985) 'The Ecology and Management of Leadbeaters Possum.' (University of New England: Armidale).

Smith AP, Lindenmayer D, Begg RJ, Macfarlane MA, Seebeck JH, Suckling GC (1989) Evaluation of the stag-watching technique for census of possums and gliders in tall open forest. *Wildlife Research* **16**, 575–580.

Steventon C, Harley D, Wicker L, Legione AR, Devlin JM, Hufschmid J (2022) An assessment of ectoparasites across highland and lowland populations of Leadbeater's possum (*Gymnobelideus leadbeateri*): implications for genetic rescue translocations. *International Journal of Parasitology, Parasites and Wildlife* **18**, 152–156.

Steventon C, Wicker L, Dobson E, Legione AR, Devlin, JM, Harley D. (In Review). Management lessons from a long-term captive-breeding programme for a critically endangered species: Leadbeater's possum, *Gymnobelideus leadbeateri*, from 1970–2021.

Taylor C, Lindenmayer DB (2020) Temporal fragmentation of a critically endangered forest ecosystem. *Austral ecology* **45**, 340–354.

Taylor C, Cadenhead N, Lindenmayer DB, Wintle BA (2017) Improving the design of a conservation reserve for a critically endangered species. *PLoS ONE* **12**(1), e0169629. doi:10.1371.

Threatened Species Scientific Committee (TSSC) (2015) 'Conservation advice: *Gymnobelideus leadbeateri*' (PDF: 0.7 MB).

Threatened Species Scientific Committee (TSSC) (2019) 'Conservation advice: *Gymnobelideus leadbeateri*' (PDF: 0.5 MB).

Todd CR, Lindenmayer DB, Stamation K, Acevedo–Cattaneo S, Smith S, Lumsden LF (2016) Assessing reserve effectiveness: application to a threatened species in a dynamic fire prone forest landscape. *Ecological Modelling* **338**, 90–100.

Trouvé R, Nitschke CR, Andrieux L, Willersdorf T, Robinson AP, Baker PJ (2019). Competition drives the decline of a dominant midstorey tree species. Habitat implications for an endangered marsupial. Forest Ecology and Management **447**, 26–34.

Vertessey RA, Watson FG, O'Sullivan SK (2001) Factors determining relations between stand age and catchment water balance in Mountain Ash forests. *Forest Ecology and Management* **143**, 13–26.

VicForests (2019). 'Harvesting and regenration systems'. VicForests, Melbourne.

Viggers JI, Weaver HJ, Lindenmayer DB (2013) 'Melbourne's water catchments. perspectives on a world-class water supply.' (CSIRO Publishing: Melbourne).

Wang T, Wang G, Innes J, Nitschke C, Kang H (2016) Climatic niche models and their consensus projections for future climates for four major forest tree species in the Asia–Pacific region. *Forest Ecology and Management* **360**, 357–366.

Williams RJ, Bradstock RA, Cary GJ, Enright NJ, Gill AM, Liedloff AC, Lucas C, Whelan RJ, Andersen AN, Bowman DMJS, Clarke PJ, Cook GD, Hennessy KJ, York A (2009) 'Interactions between climate change, fire regimes and biodiversity in Australia – a preliminary assessment.' Report to the Department of Climate Change and Department of the Environment, Water, Heritage and the Arts, Canberra, Darwin.

Worth JRP, Williamson GJ, Sakaguchi S, Nevill PG, Jordan GJ (2014) Environmental niche modelling fails to predict Last Glacial Maximum refugia: niche shifts, microrefugia or incorrect palaeoclimate estimates? *Global Ecology and Biogeography* **23**, 1186–1197.

Yugovic J, Mitchell S (2006) Ecological review of the Koo-Wee-Rup Swamp and associated grasslands. *The Victorian Naturalist* **123**, 323–334.

Zilko JP, Harley D, Hansen B, Pavlova A, Sunnucks P (2020) Accounting for cryptic population substructure enhances detection of inbreeding depression with genomic inbreeding coefficients: an example from a critically endangered marsupial. *Molecular Ecology* **29**, 2978–2993.

Zilko, JP (2021) Assessing the Scope of Genetic Rescue for Leadbeater's Possum (Gymnobelideus leadbeateri). Unpublished PhD Thesis. Monash University, Clayton.

Zilko JP, Harley D, Pavlova A, Sunnucks P (2021) Applying Population Viability Analysis to Inform Genetic Rescue That Preserves Locally Unique Genetic Variation in a Critically Endangered Mammal. *Diversity* **13,** 382.